CFL3D and FUN3D Analysis of HiLiftPW-2 Workshop Cases

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CFD Code Descriptions

- CFL3D Structured-Grid Code
  - Parallel 3D compressible cell-centered finite-volume RANS
  - Full Navier-Stokes equations
  - Upwind Roe flux-difference splitting for inviscid fluxes
  - Spalart-Allmaras and SST turbulence models, fully-turbulent
  - SST-Gamma-Re-Theta (GRET), transition
  - Implicit local time-stepping using AF relaxation for linear system
  - Restart computations from lower angles of attack
- FUN3D Unstructured-Grid Code
  - Parallel 3D compressible finite-volume RANS for mixed-element meshes
  - Full Navier-Stokes equations-node centered
  - UMUSCL 0.5 scheme (Averaging + Upwind) for inviscid fluxes
  - Spalart-Allmaras turbulence model, fully-turbulent
  - Implicit local time-stepping using multi-color point Gauss-Seidel relaxation for linear system
  - Restart computations from lower angles of attack

Cases and Grids

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

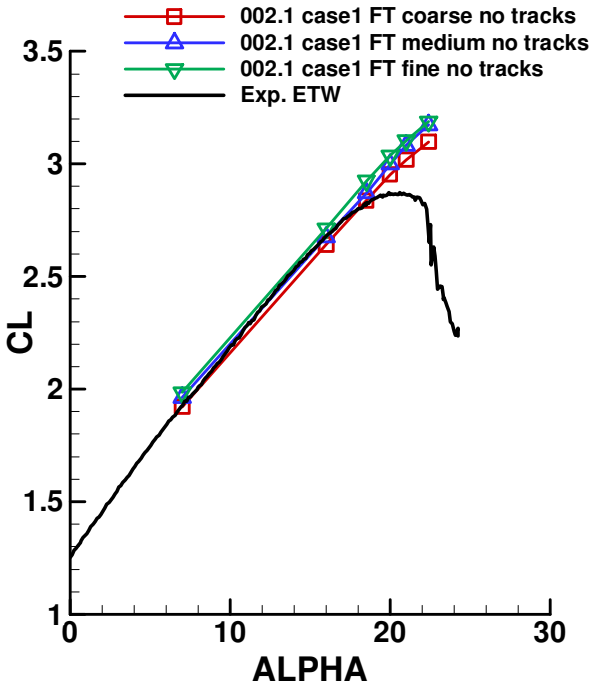
	Struct. 1 to 1 – A (Boeing)	**Unst. Nodal - D (UWYO/Cessna)**
FUN3D		SA (Mixed)
CFL3D (Case 1 only)	SA SST (incomplete) GRET (incomplete)	

Comparison of Grid Sizes

	Coarse	Medium	Fine
Struct. 1-to-1 A Boeing	11M	34M	105M
Mixed ver. Unst. D UWYO/Cessna	10M	31M	76M

Case 1 – FUN3D Grid Convergence, SA

Lift



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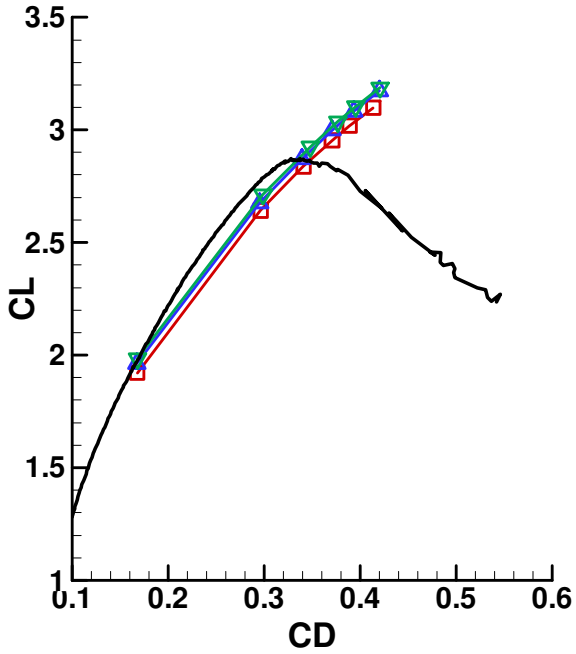
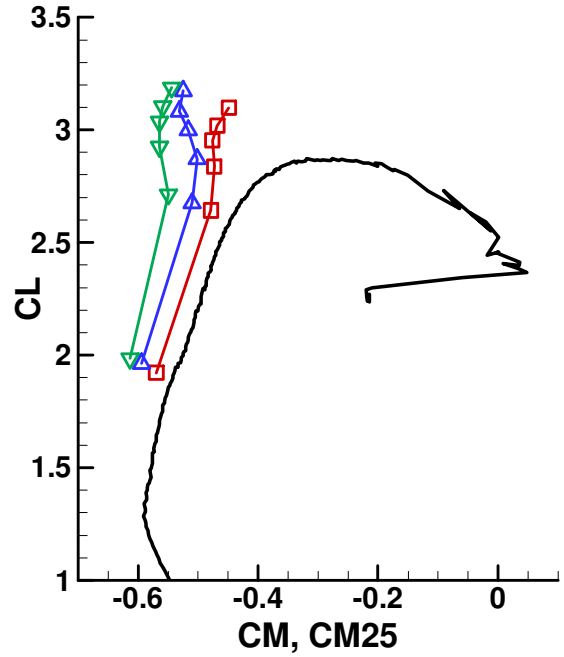
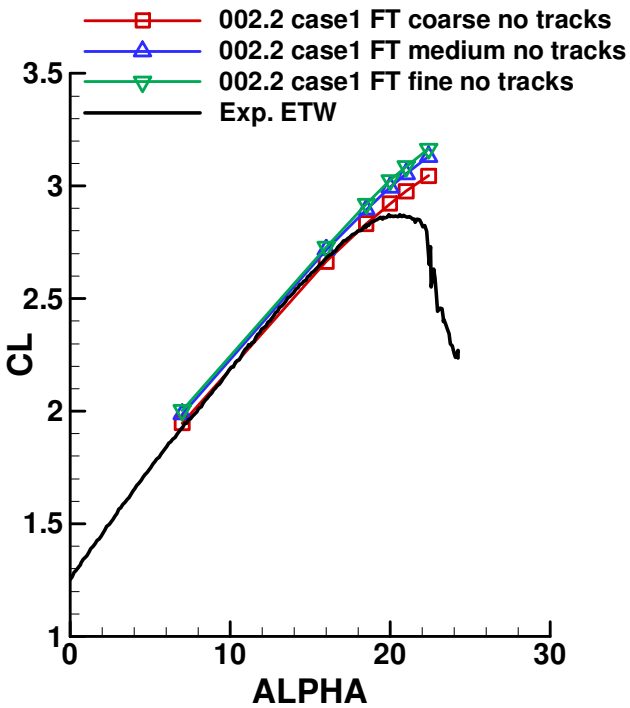


Pitching Moment



Case 1 – CFL3D Grid Convergence, SA

Lift



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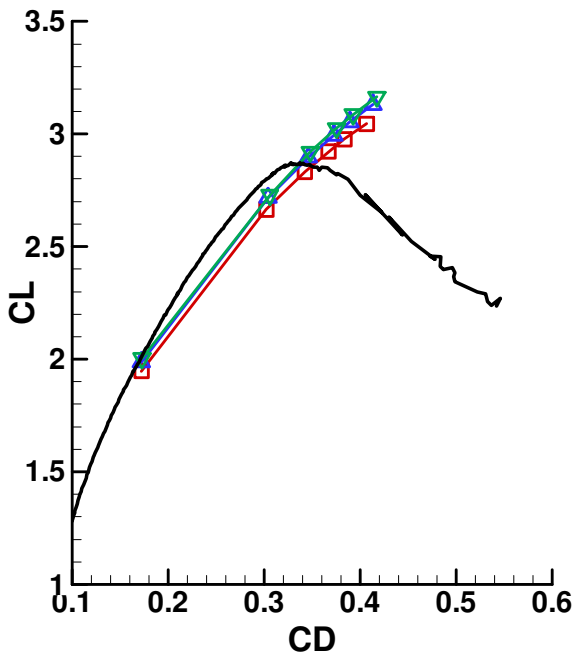
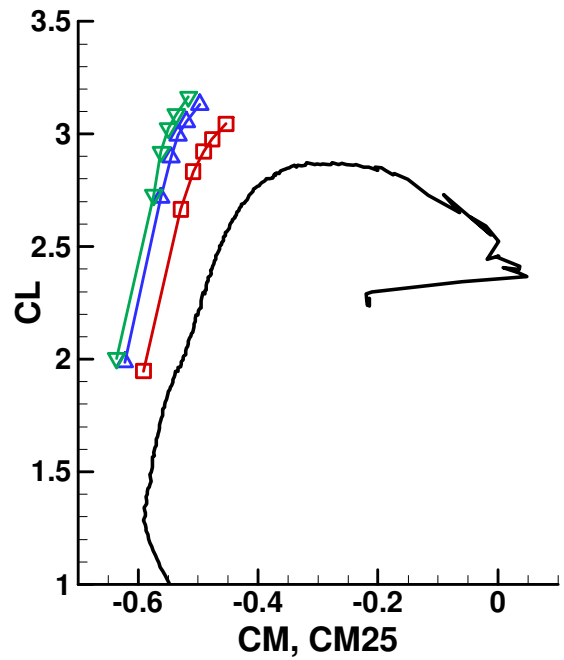


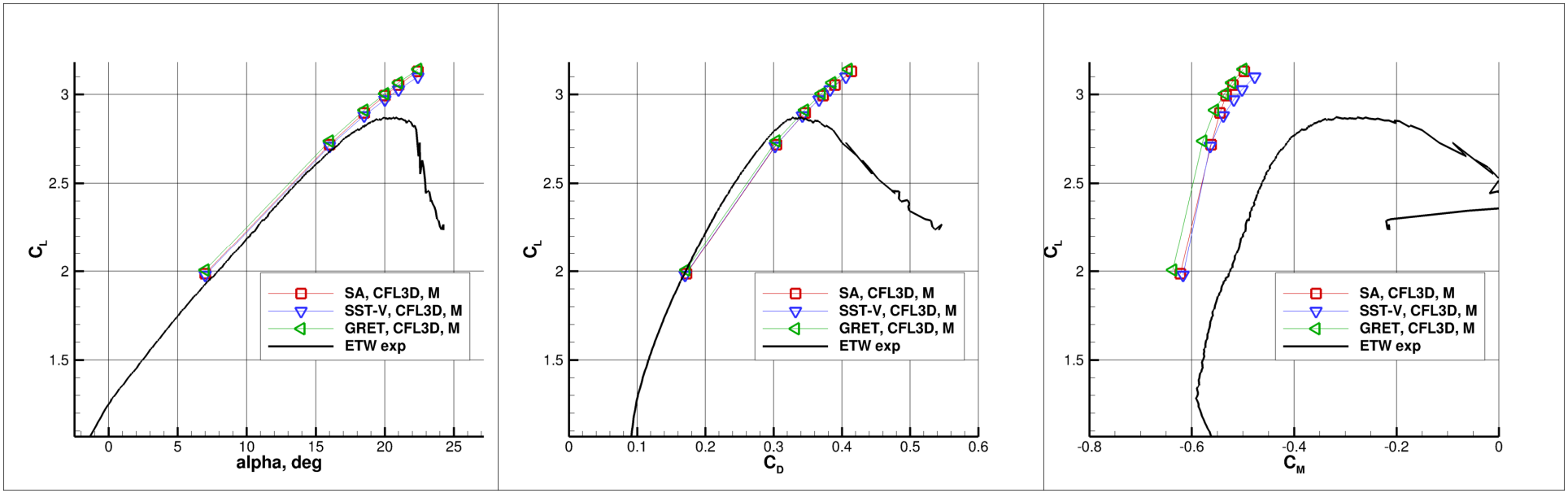
Pitching Moment



Case 1 – CFL3D results, other models

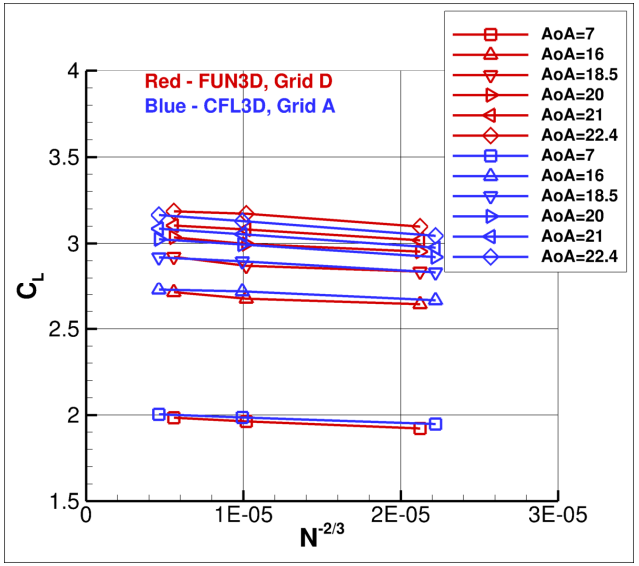
Medium Grids

Lift | Drag | Pitching Moment



Case 1 – Grid Convergence, SA

Lift



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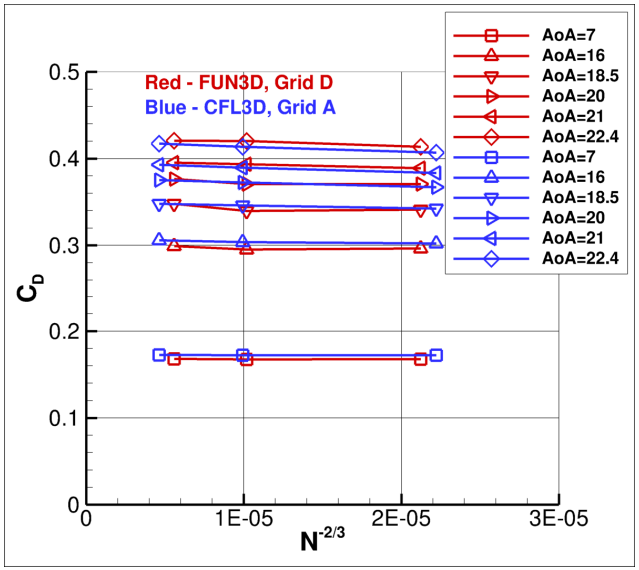

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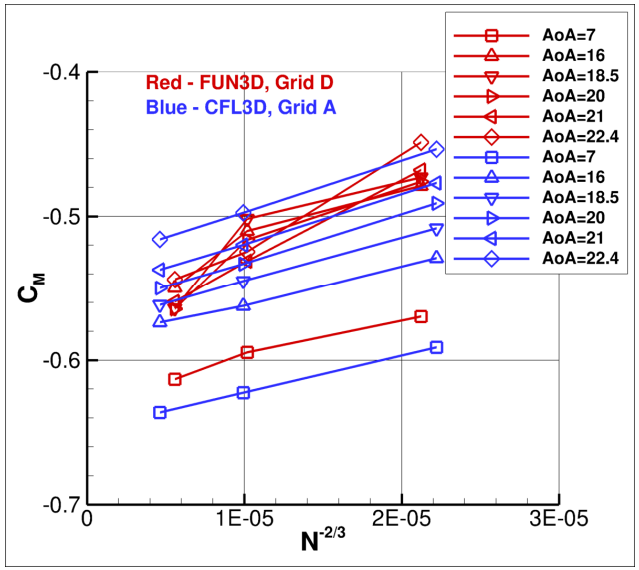
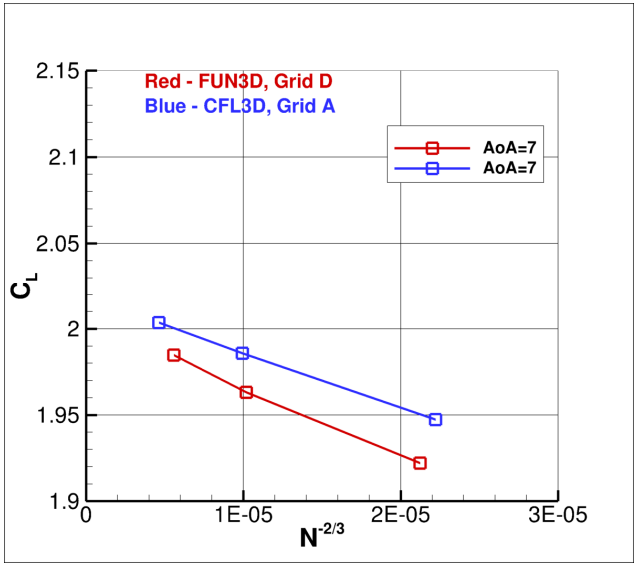


Case 1 – Grid Convergence, AoA=7

Lift



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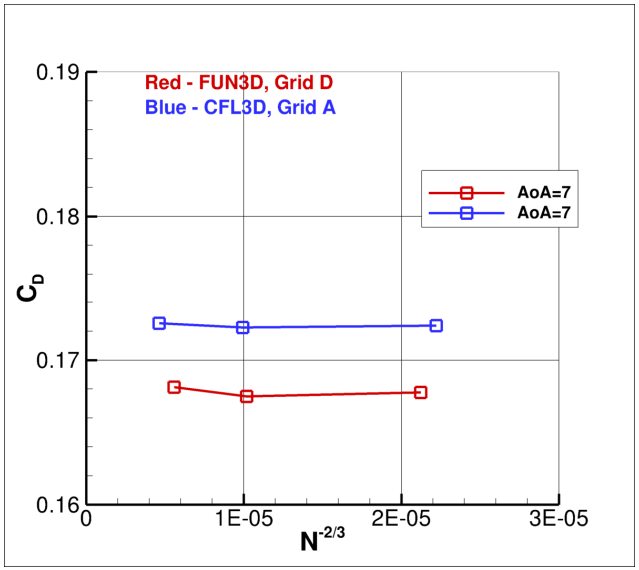
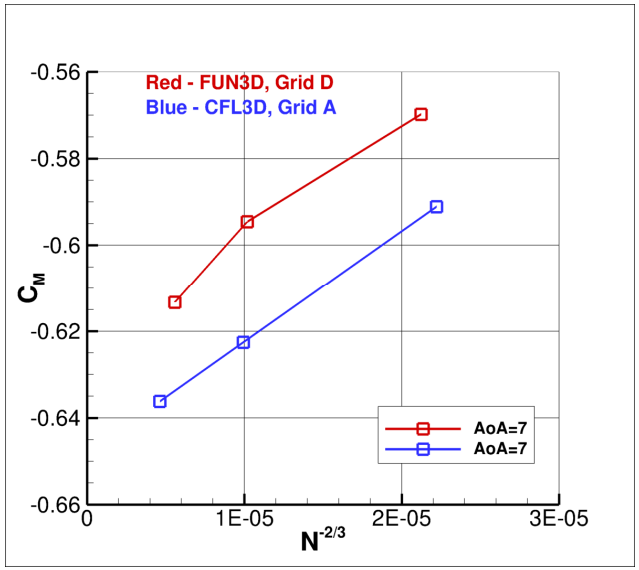


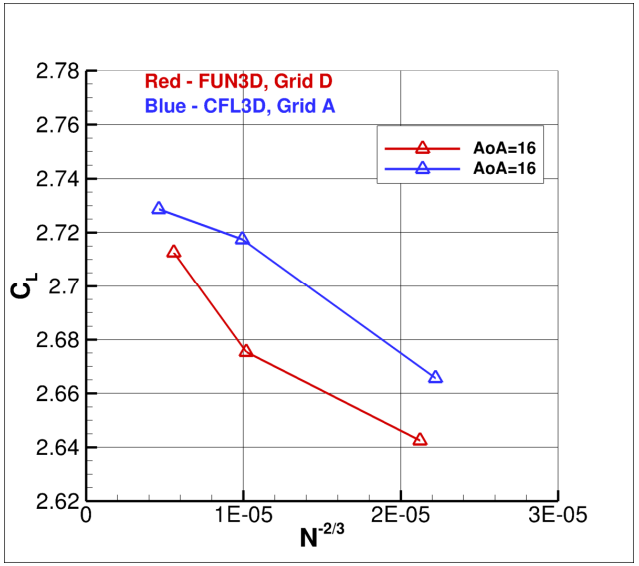
Pitching Moment



Note: Grid D (fine) was discovered to have incorrect min spacing – so not of similar family to C and M.

Case 1 – Grid Convergence, AoA=16

Lift



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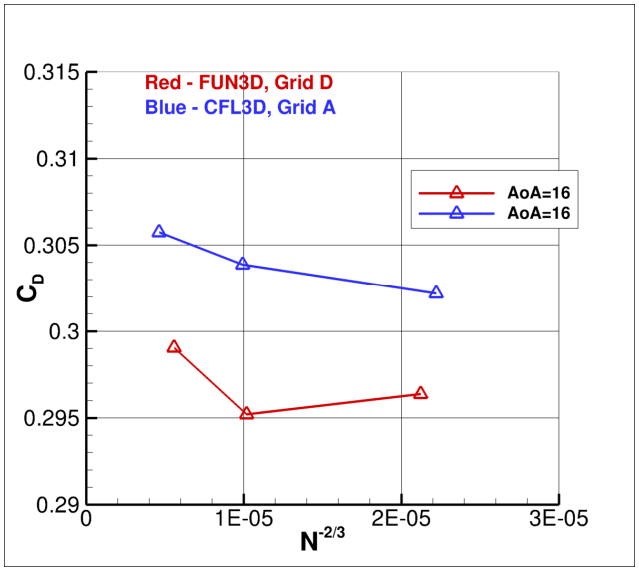
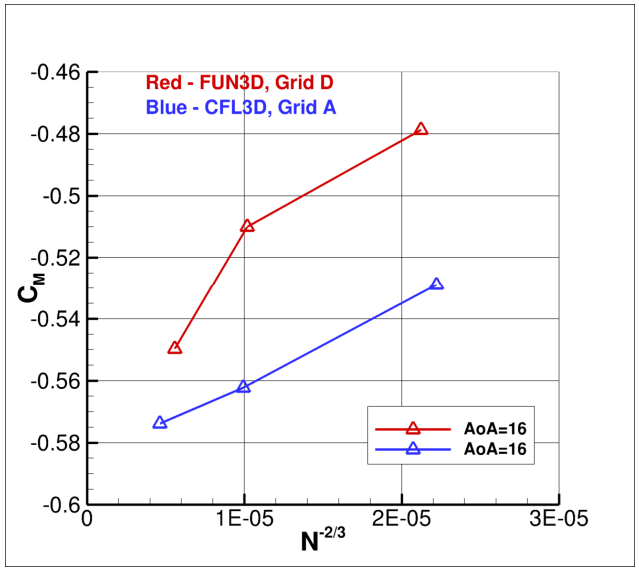


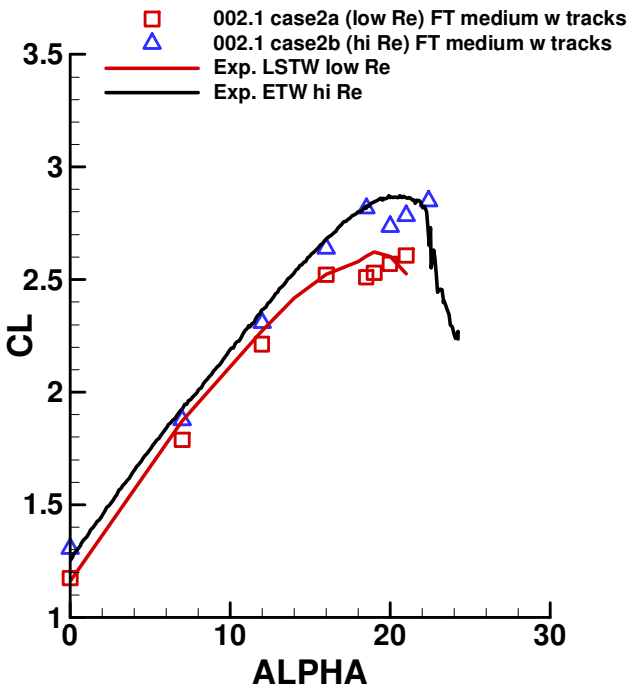
Pitching Moment



Note: Grid D (fine) was discovered to have incorrect min spacing – so not of similar family to C and M.

Case2 – Reynolds Number Study

Lift



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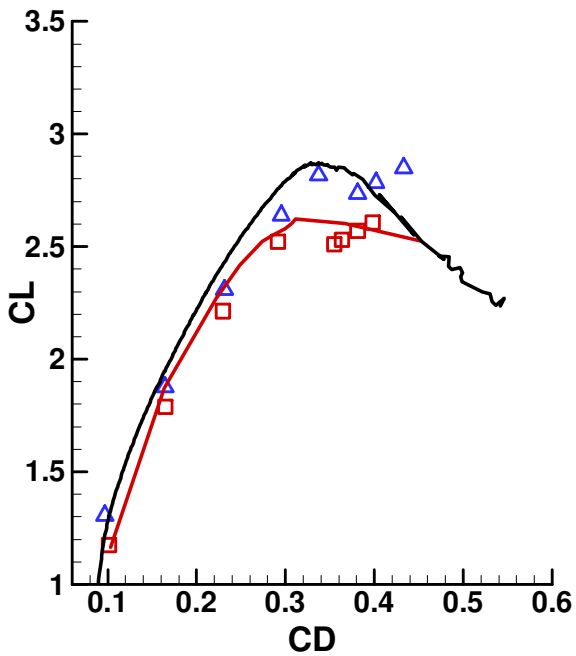

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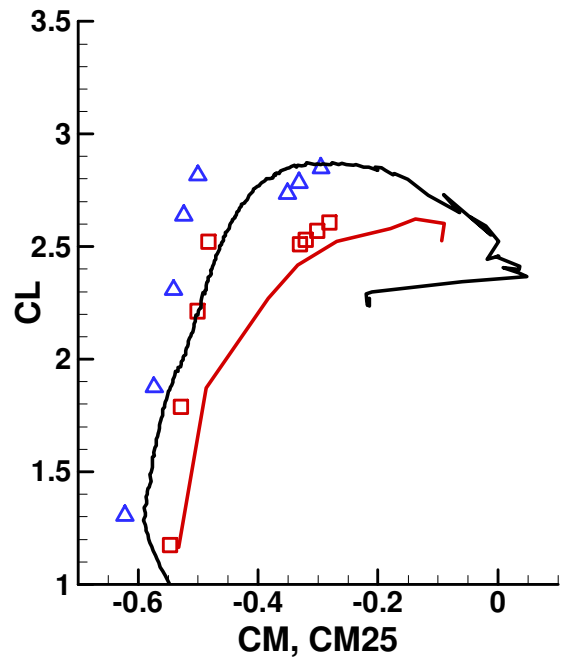
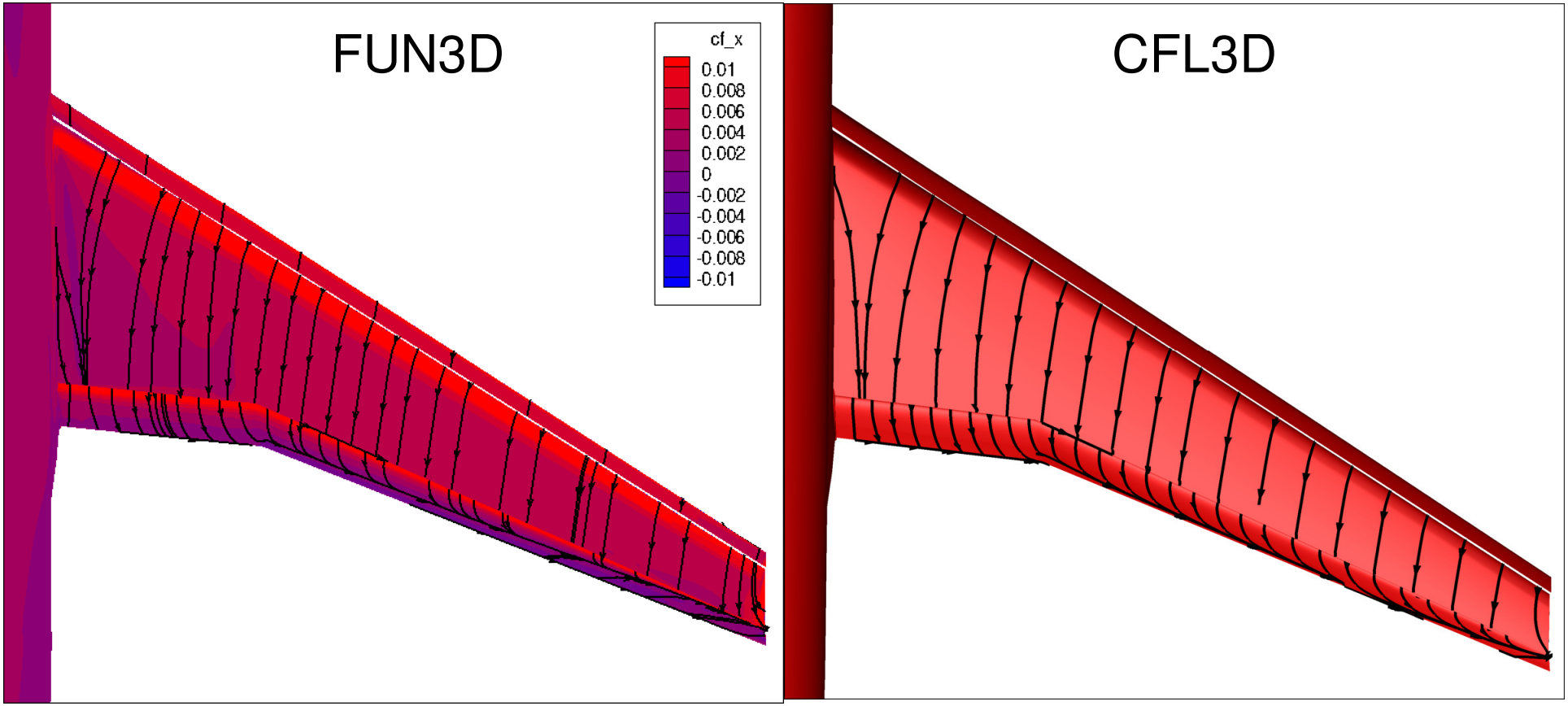


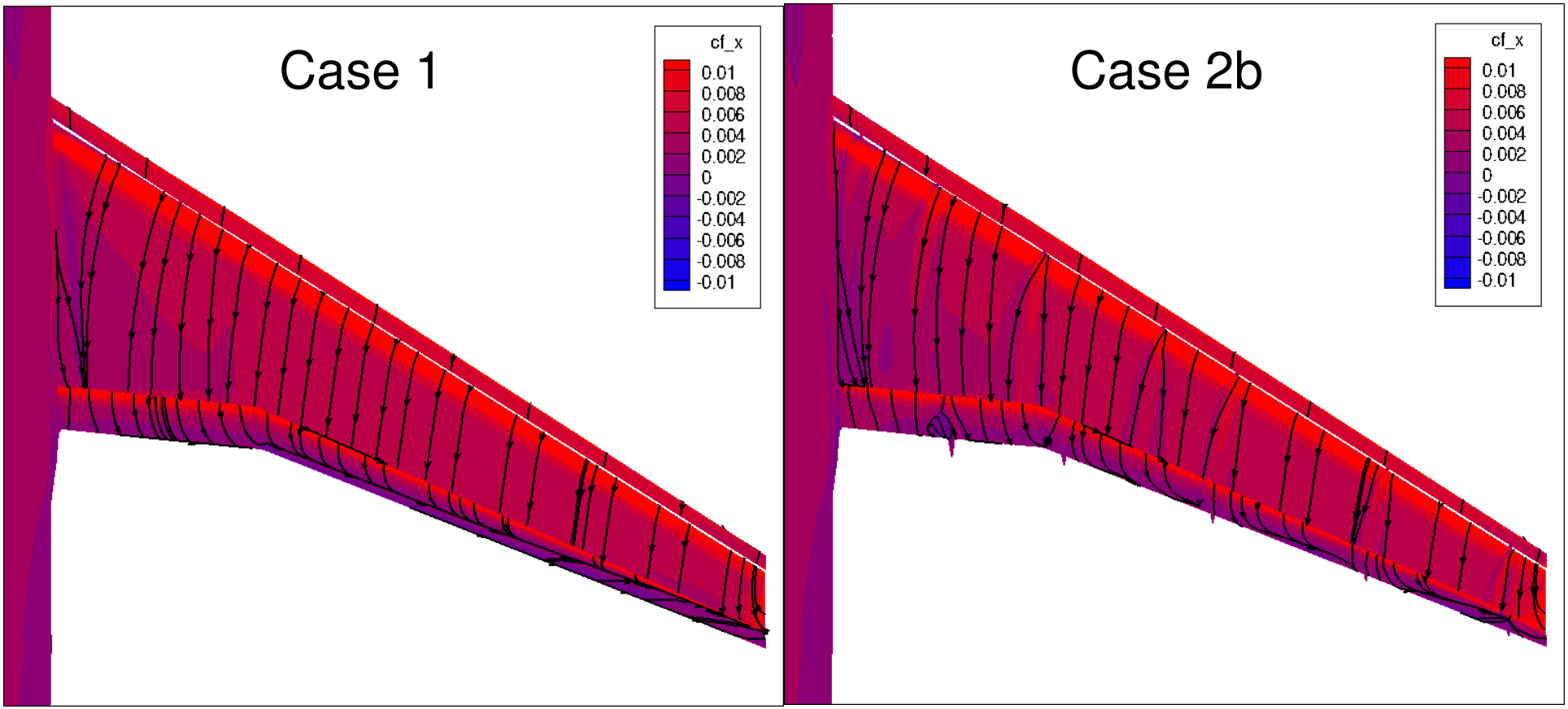
Case 1 Surface Restricted Streamlines

AOA 16deg
Medium Grids



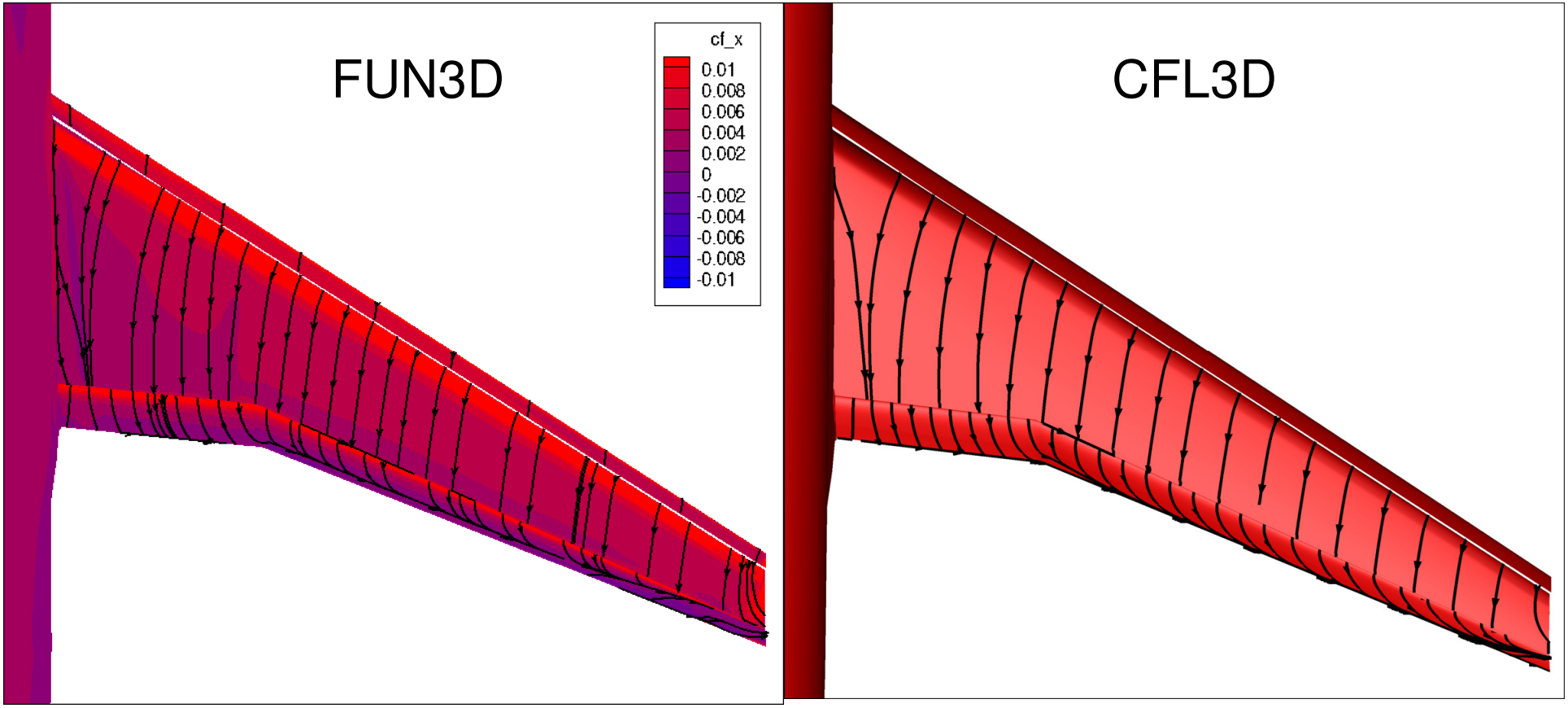
FUN3D Surface Restricted Streamlines

AOA 16deg
Medium Grid



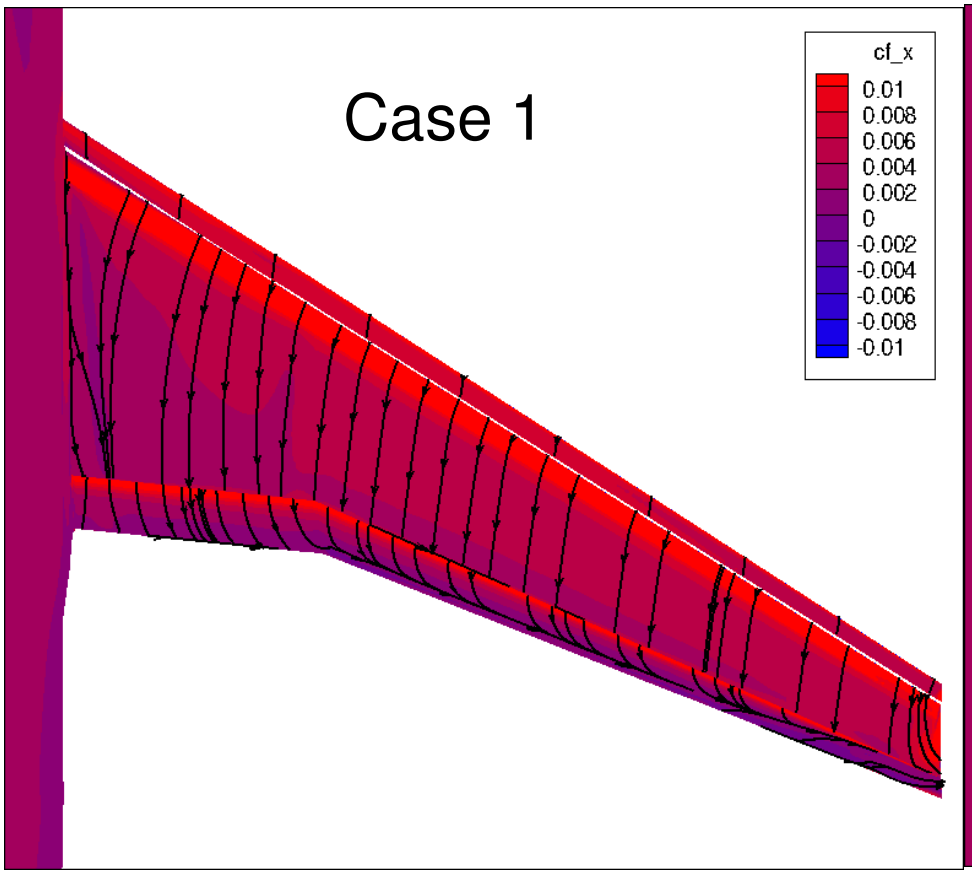
Case 1 Surface Restricted Streamlines

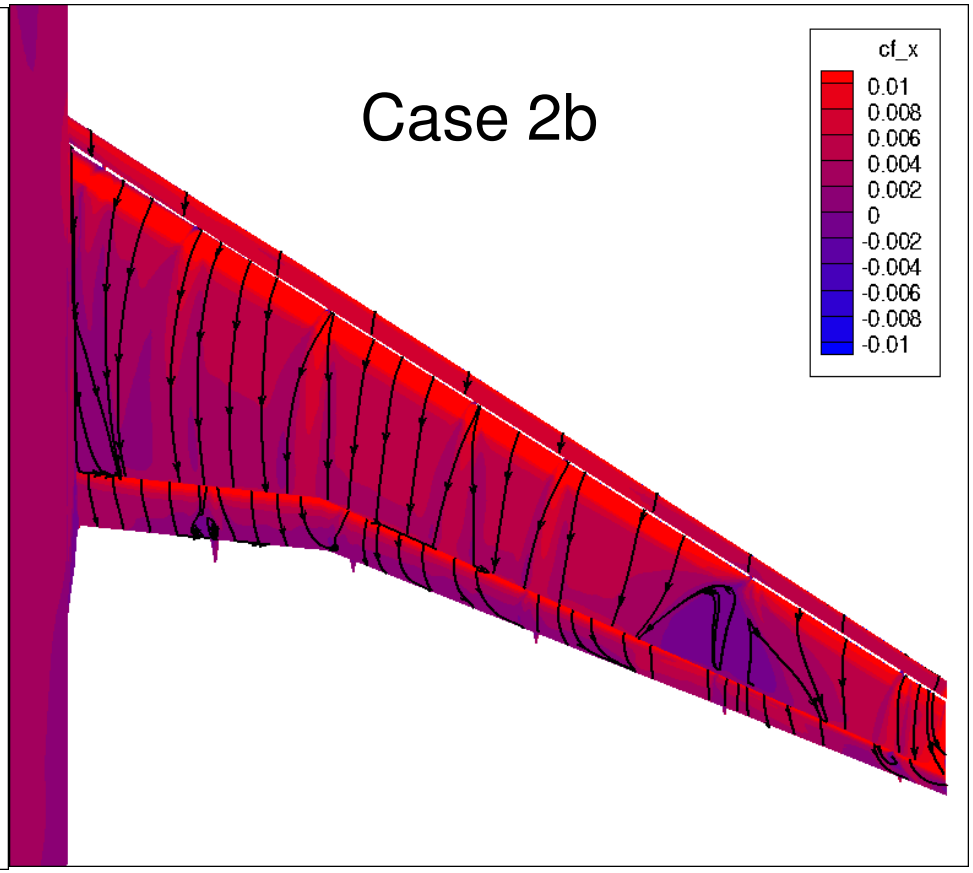
AOA 20deg
Medium Grids



FUN3D Surface Restricted Streamlines

AOA 20deg
Medium Grid

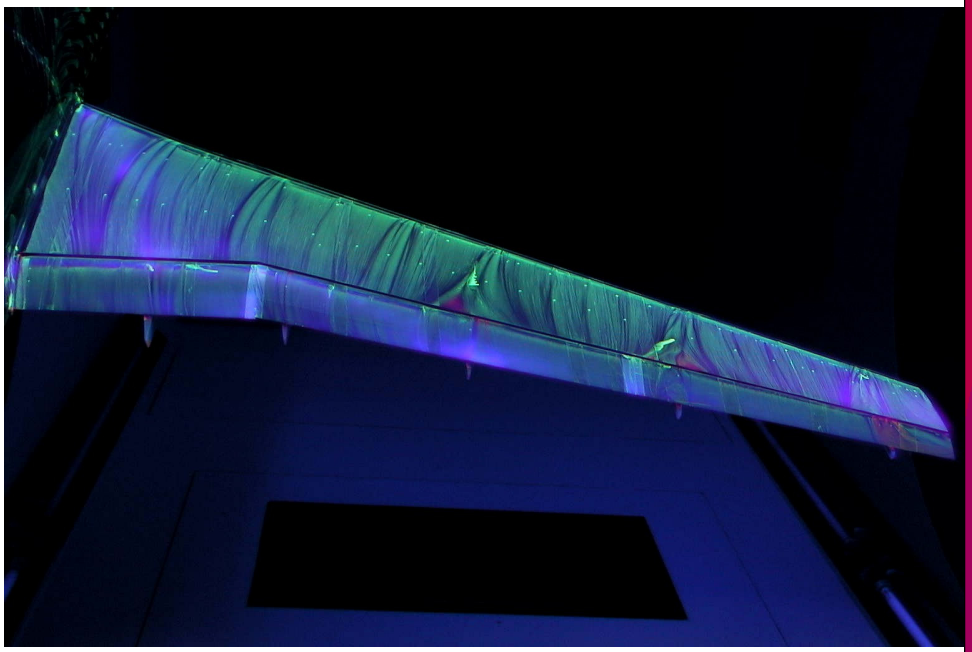


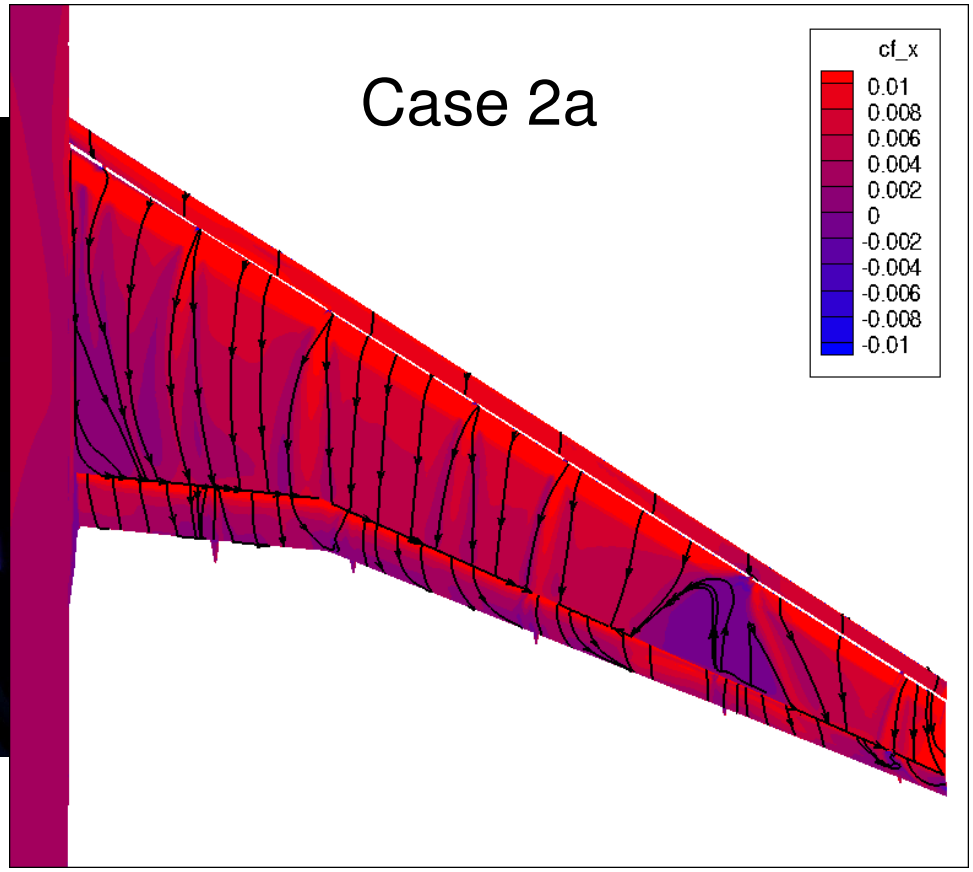


FUN3D Surface Restricted Streamlines

AOA 18.5deg
Medium Grid

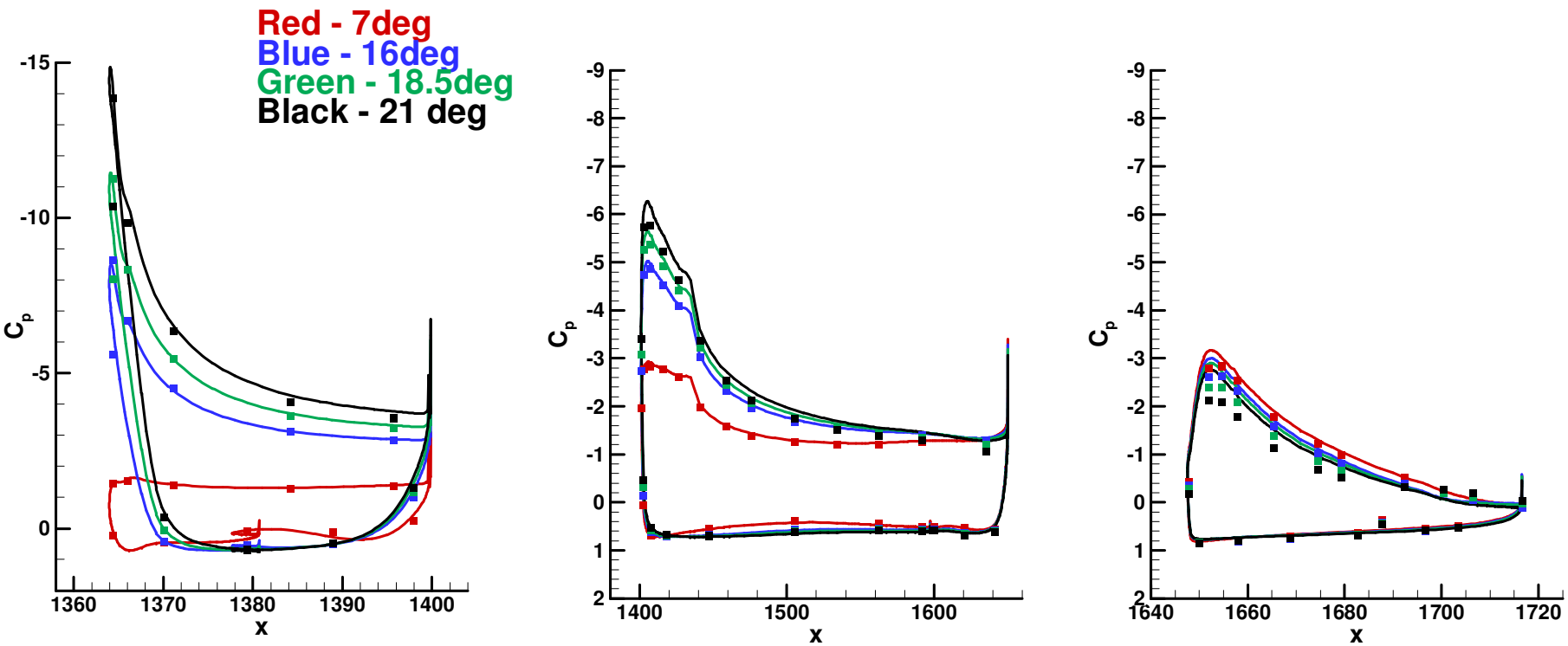
Exp. Oil Flow





FUN3D Pressure Distributions

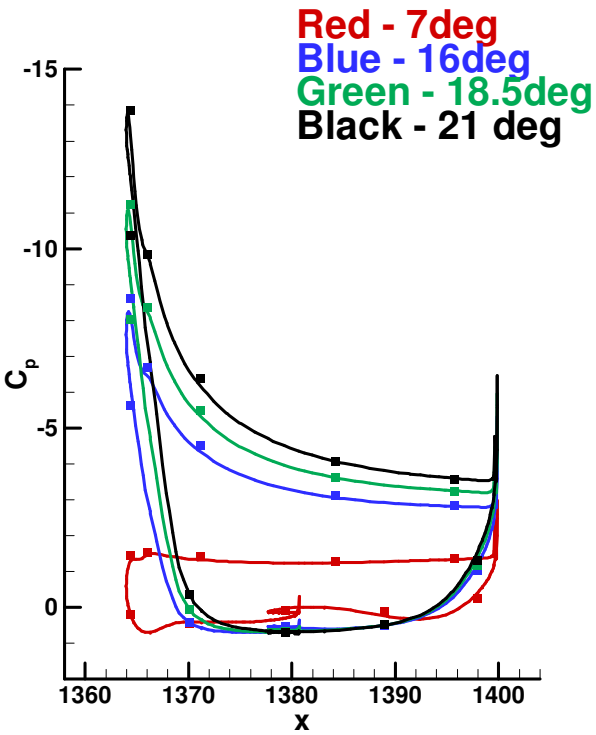
Case 1 Medium Grid
Eta = 0.45



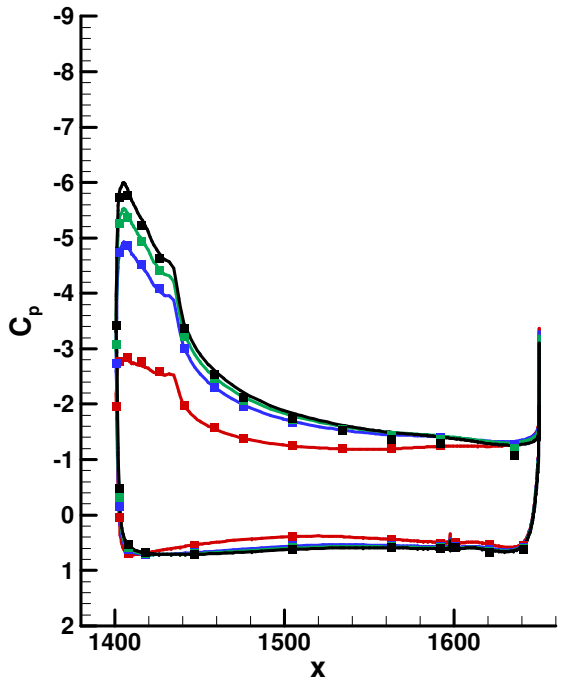
Slat Main Flap

FUN3D Pressure Distributions

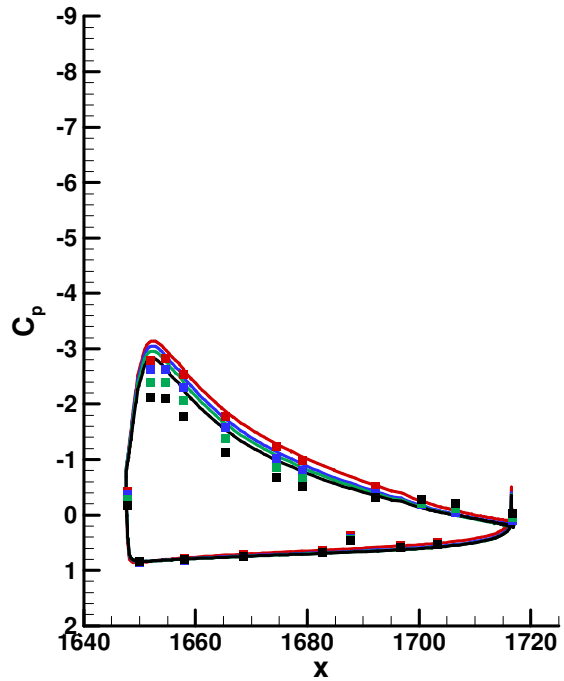
Case 2b
Eta = 0.45



Slat



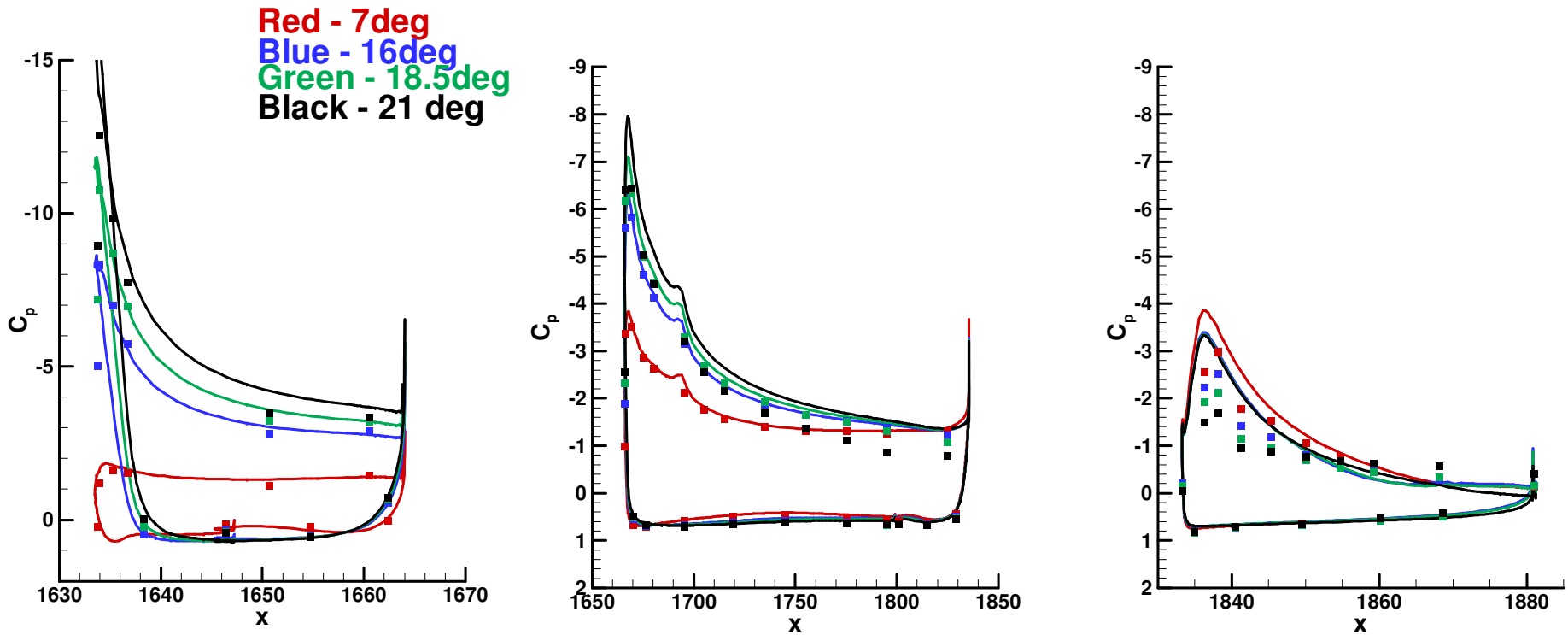
Main



Flap

FUN3D Pressure Distributions

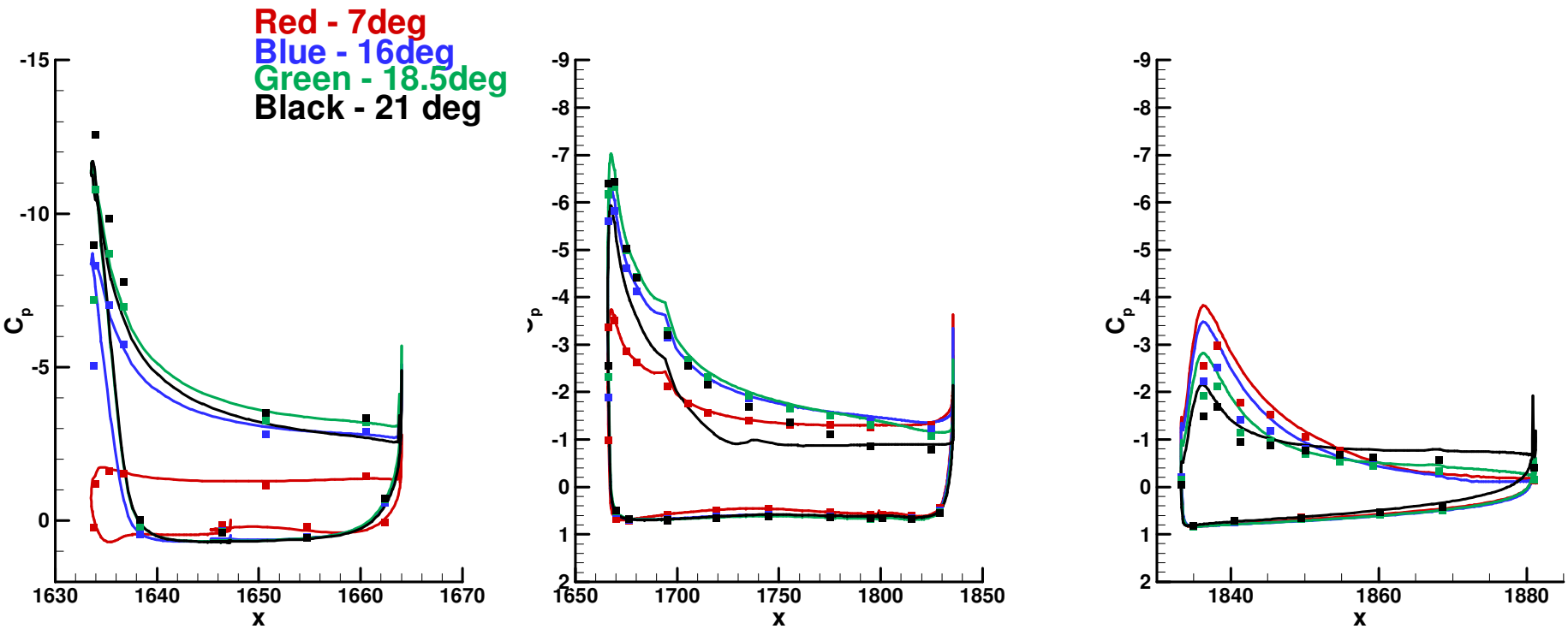
Case 1 Medium Grid
Eta = 0.75



Slat Main Flap

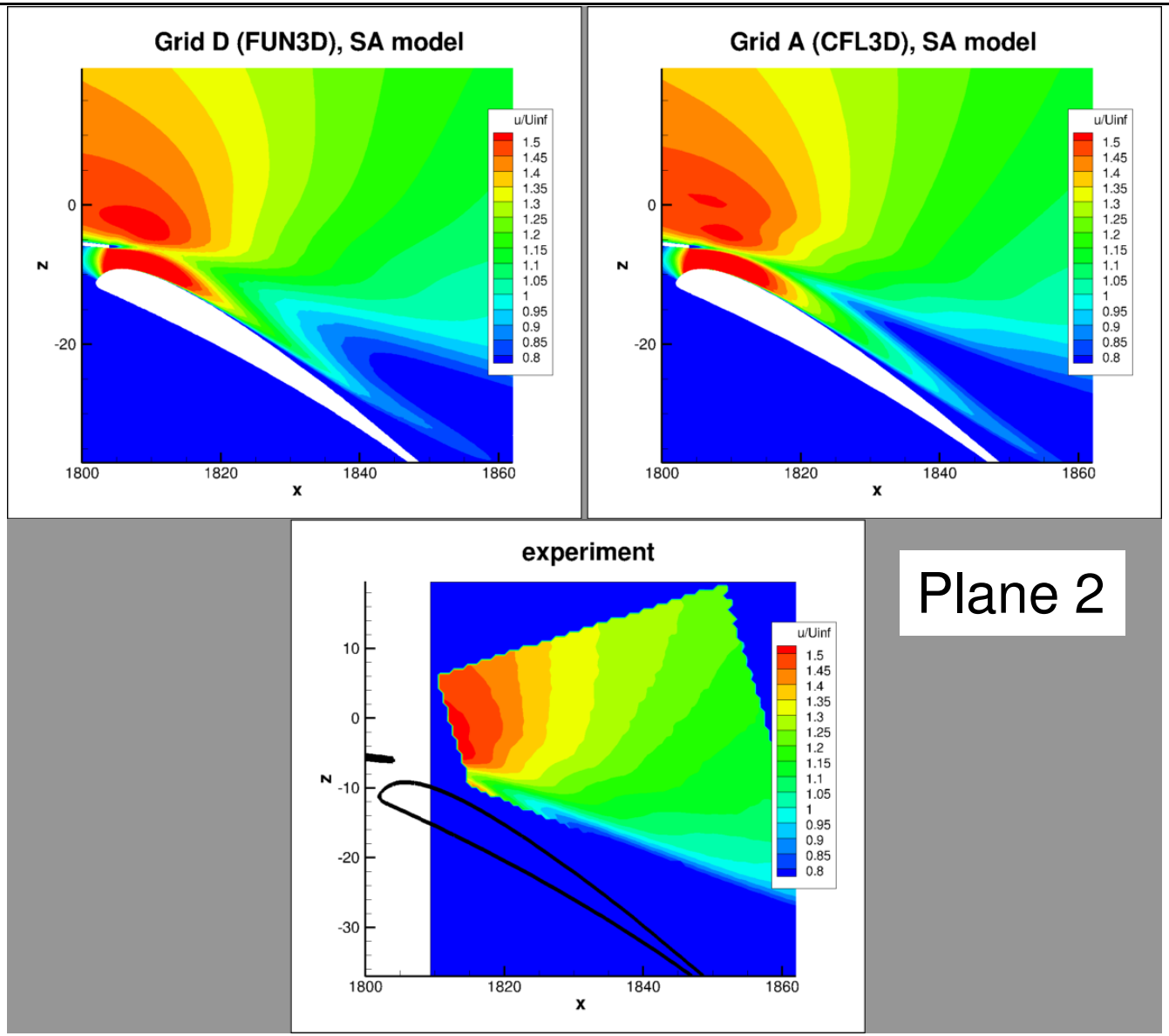
FUN3D Pressure Distributions

Case 2b
Eta = 0.75



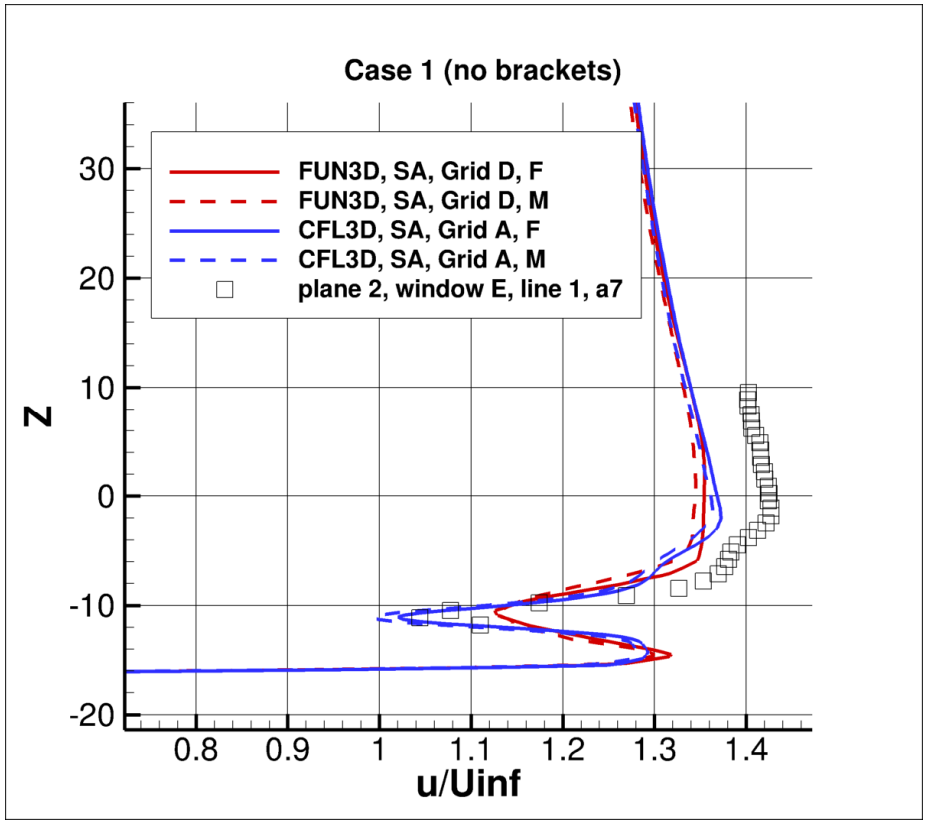
Slat Main Flap

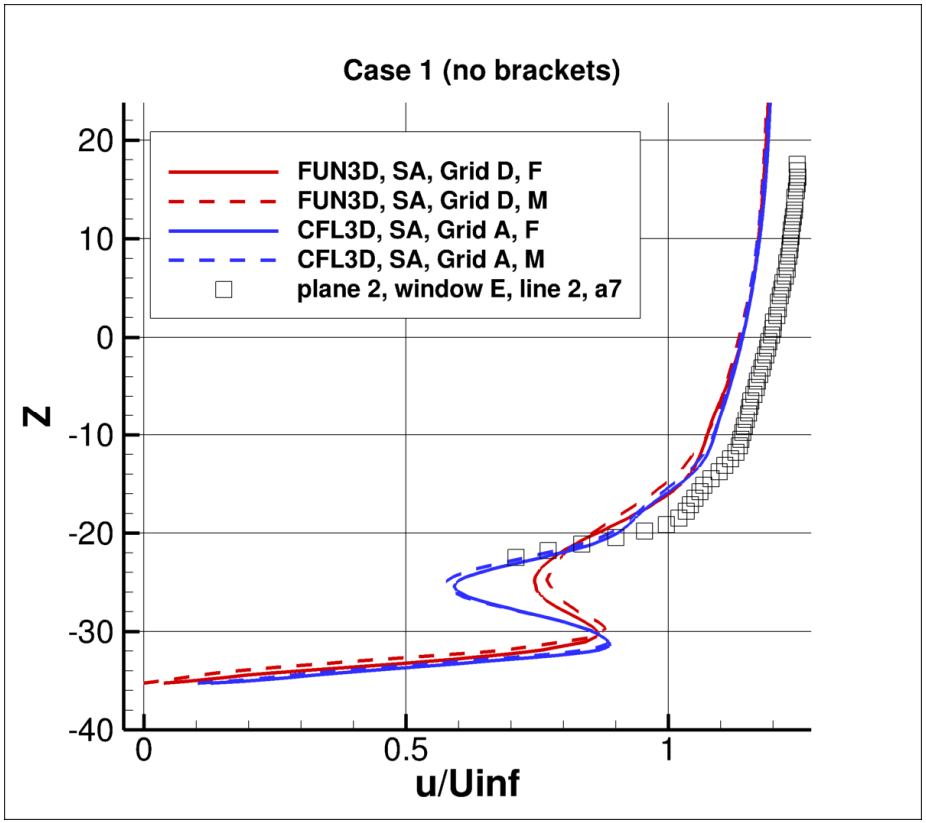
Velocity contours over flap, AoA=7



Velocity profiles over flap, AoA=7

Plane 2
Case 1 Medium/Fine Grids

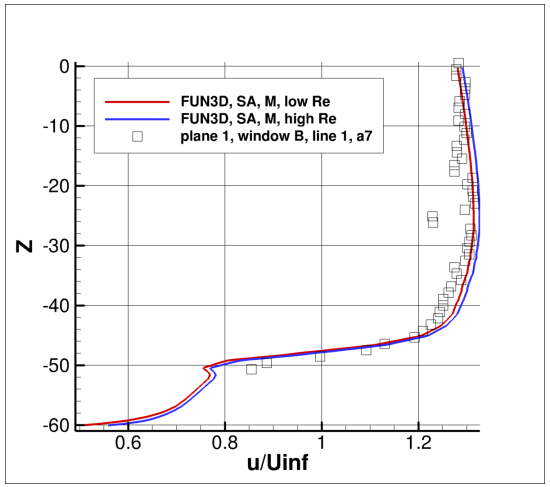




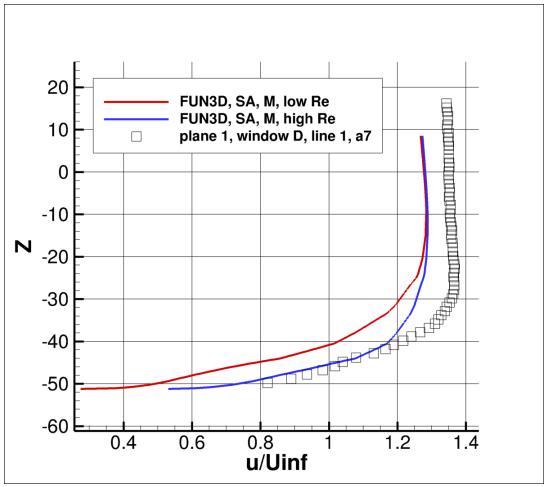
Note: exp data at low Re, shown for reference only

Effect of Re on velocity profiles, AoA=7

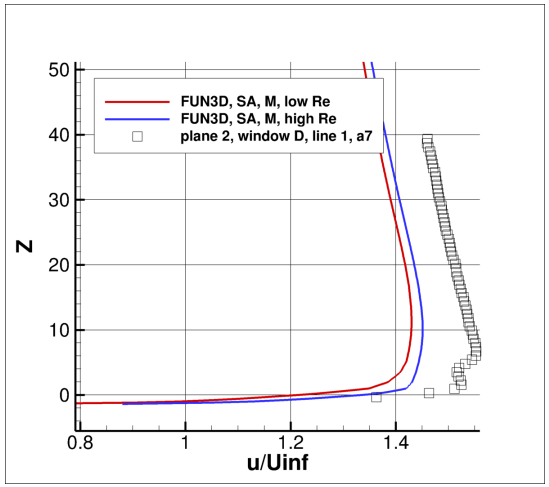
Plane 1-window B



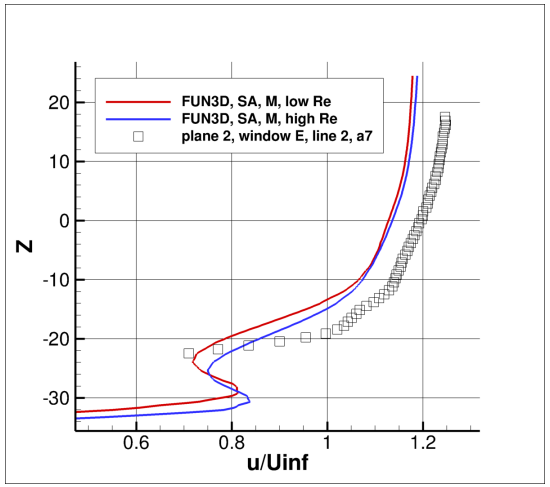
Plane 1-window D



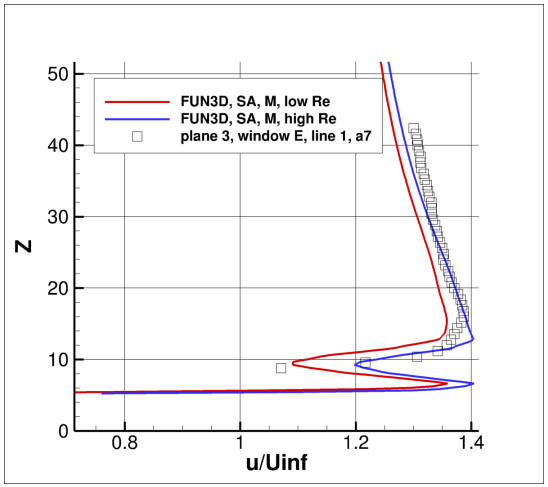
Plane 2-window D



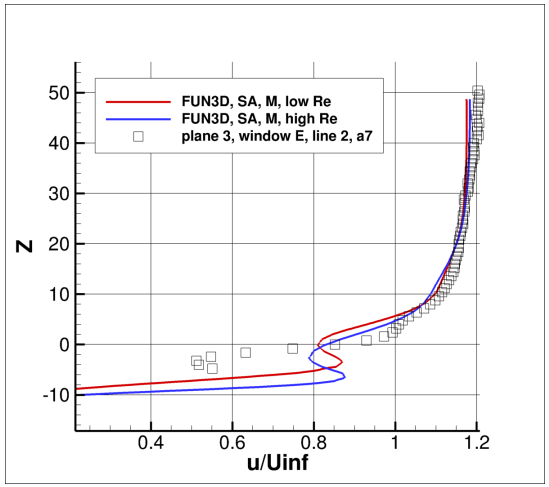
Plane 2-window E



Plane 3-window E



Plane 3-window E



Summary (1)

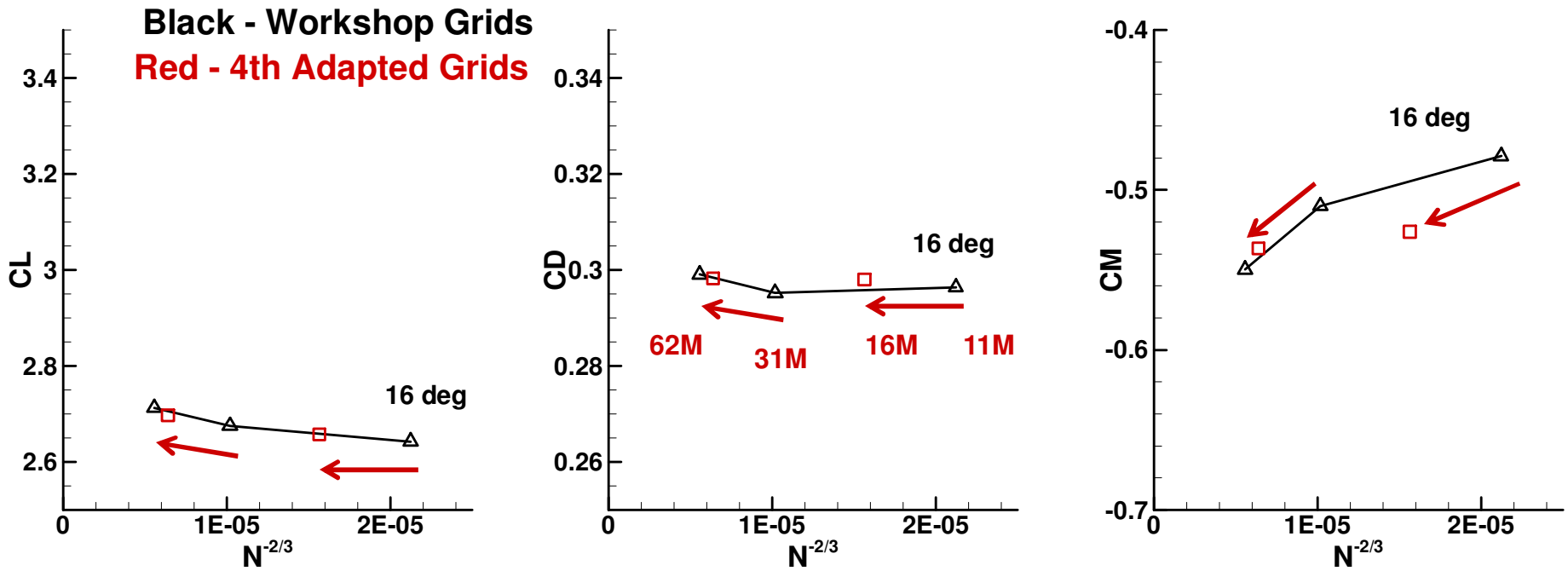
- Grid convergence study (no brackets)
  - Structured grid and unstructured grid results with same turbulence model (SA) compare reasonably well in forces/moments
  - There is flap separation at all AoAs
    - FUN3D on unstructured D grid shows more separation than CFL3D on structured A grid
  - Maximum lift coefficient is over-predicted
  - At higher alphas, there are larger differences between codes (esp. in the moment coefficient)
  - CFL3D on structured A grid series captures wake profiles better than FUN3D on unstructured D grid series

Summary (2)

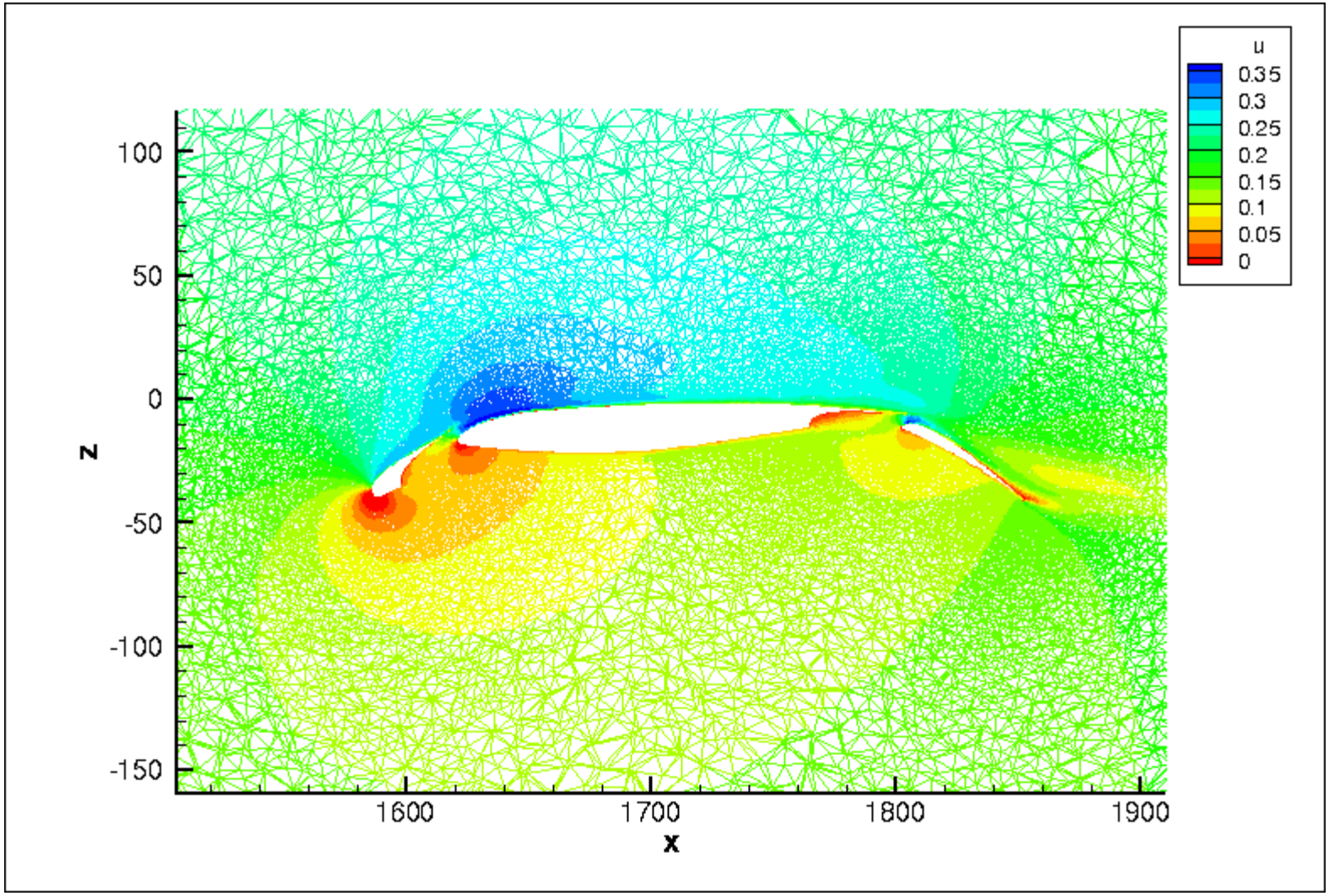
- Bracket study
  - Including brackets improves results (forces, moments, surface pressures)
  - General trends captured
  - $C_{L,max}$ not predicted well due to early main wing separation
  - Slat wakes not resolved on D grids
- Reynolds number study
  - General trends captured, but $C_{L,max}$ not predicted well
  - Velocity profiles compare with experiment only qualitatively

Next Steps

- Adjoint-based adaption : output functional L/D
  - Off-body adaption
  - C1 coarse and medium grids (SA model)
  - AOA 16deg
  - Four adaption cycles (4 additional adjoint and flow solutions)

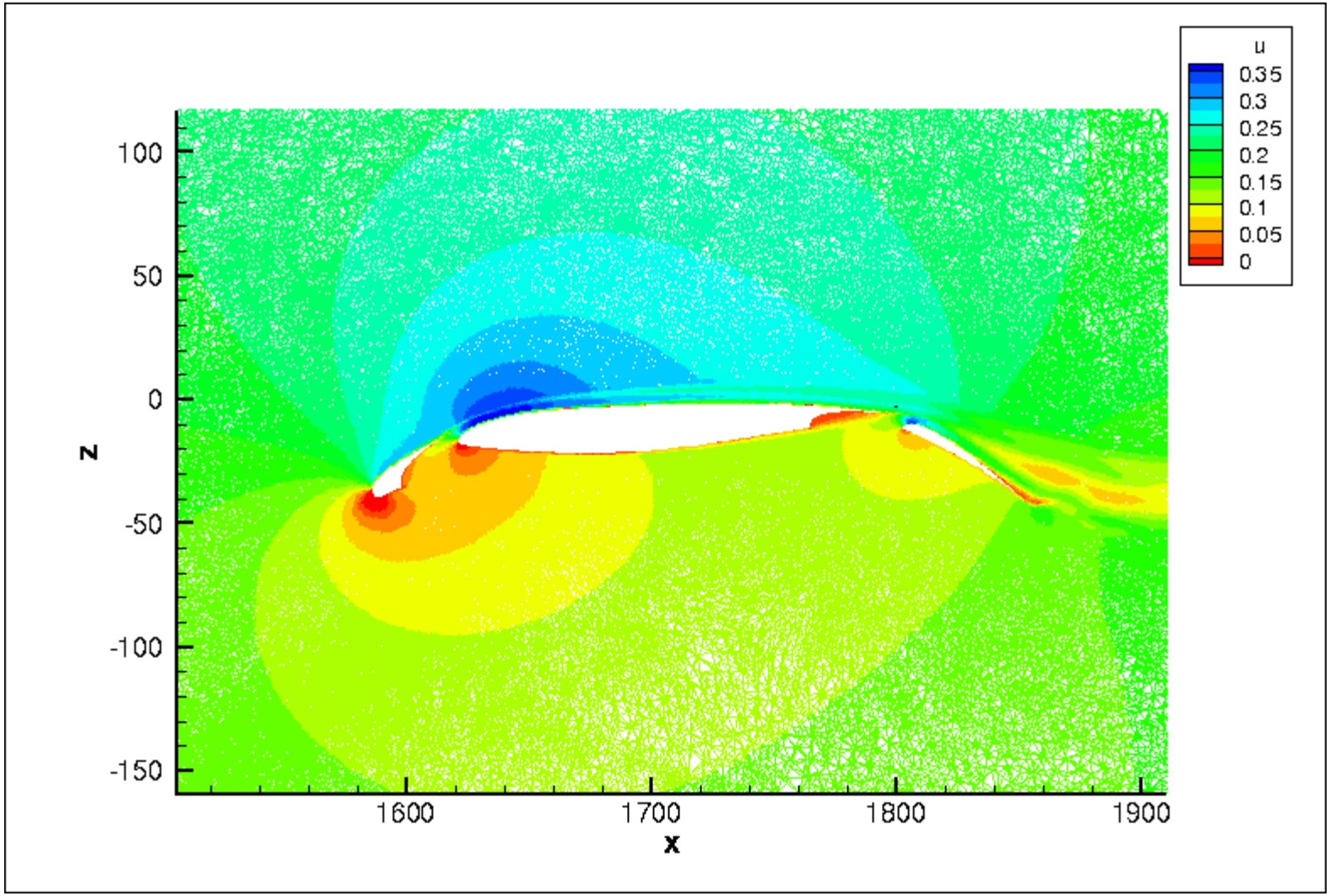


C1 Medium Grid Adaption η=70%



Original Grid – 31M nodes

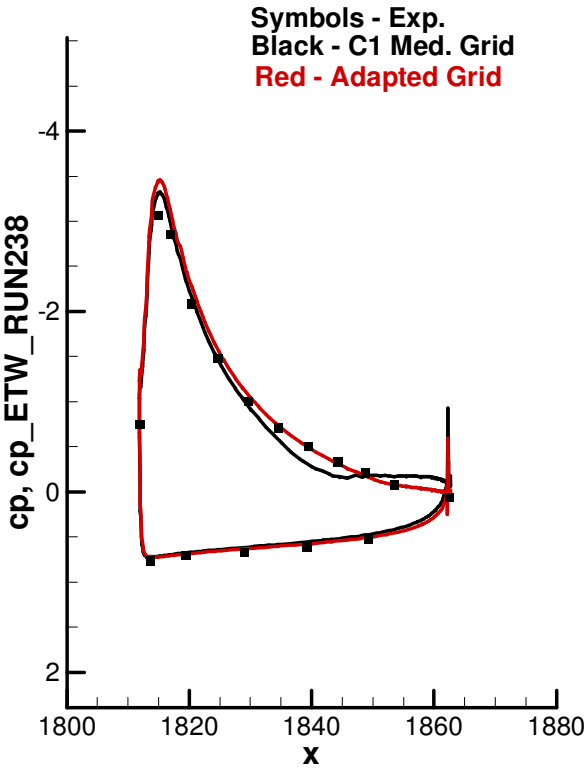
C1 Medium Grid Adaption η=70%



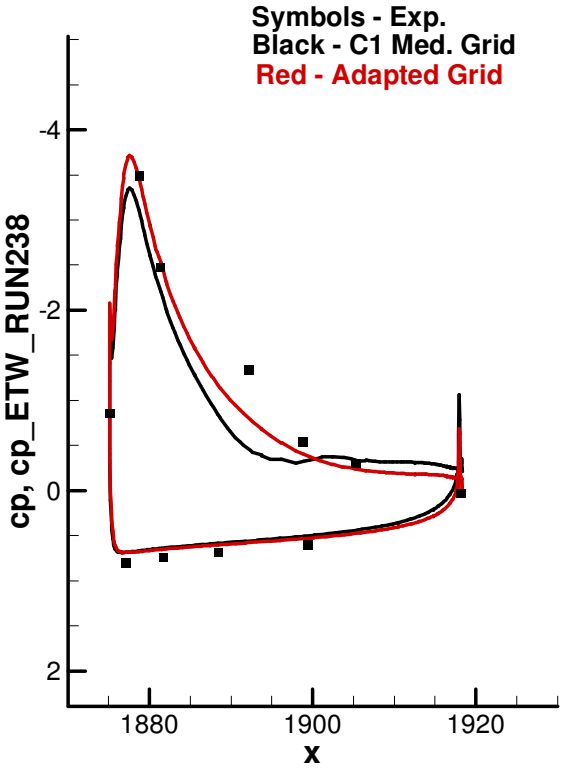
Adapted 4 – 62M nodes

C1 Medium Grid Adaption Flap Cp

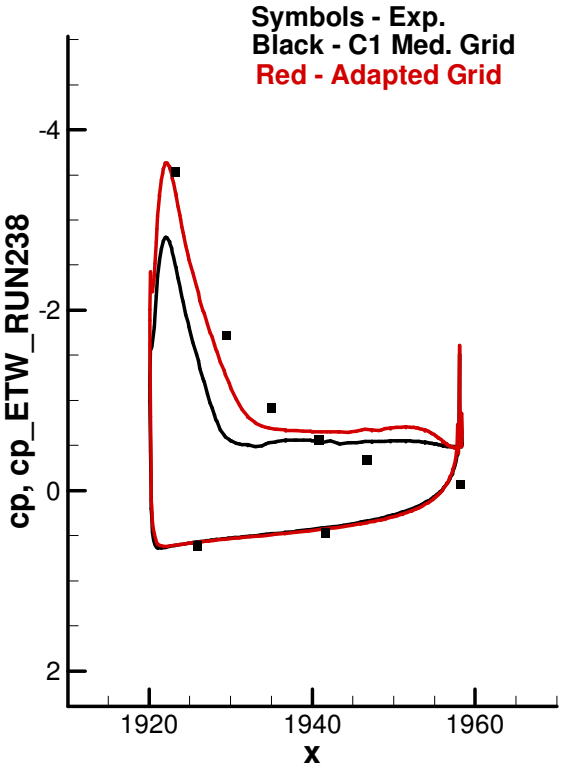
η=72%



η=82%



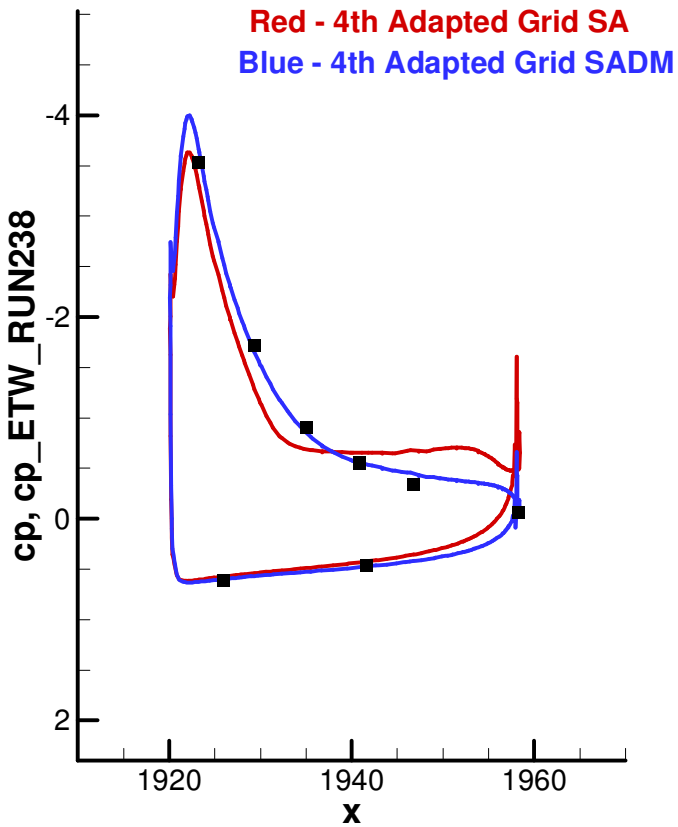
η=89%



Orig. Grid – 31M nodes : Adapted 4 – 62M nodes

Effect of Turb. Model on Flap Cp

η=89%

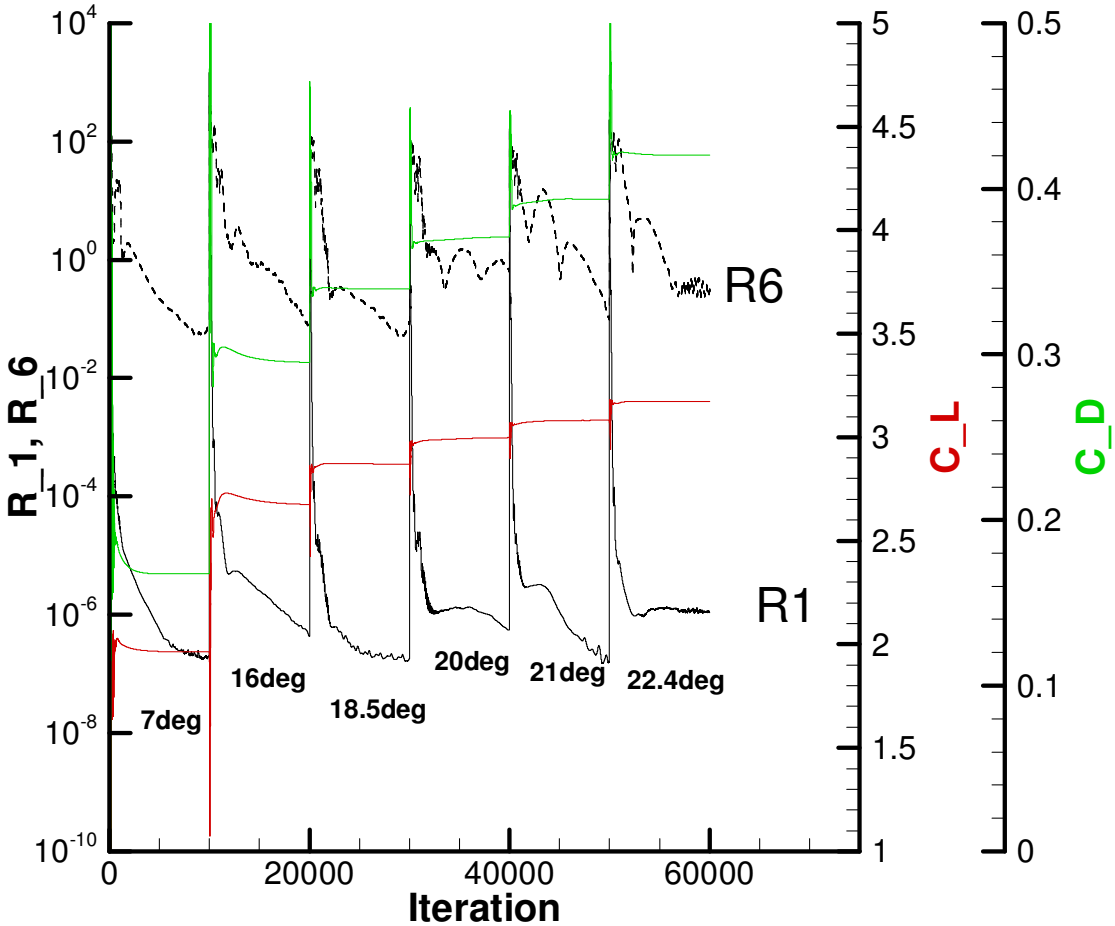


SADM – SA model with Dacles-Mariani correction

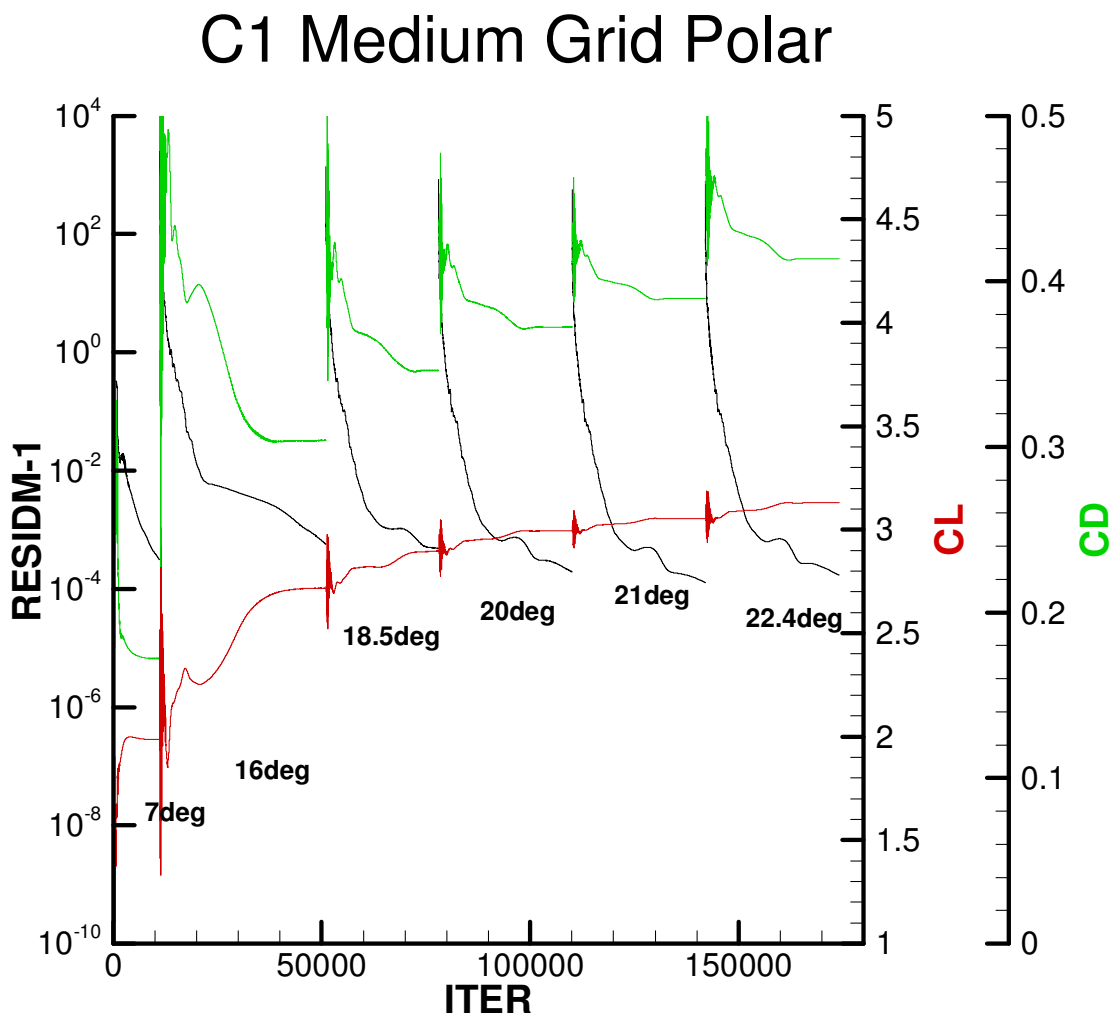
Backup Slides

FUN3D Residual Convergence

C1 Medium Grid Polar



CFL3D Residual Convergence



HiLiftPW-2 - Rehearsal Background

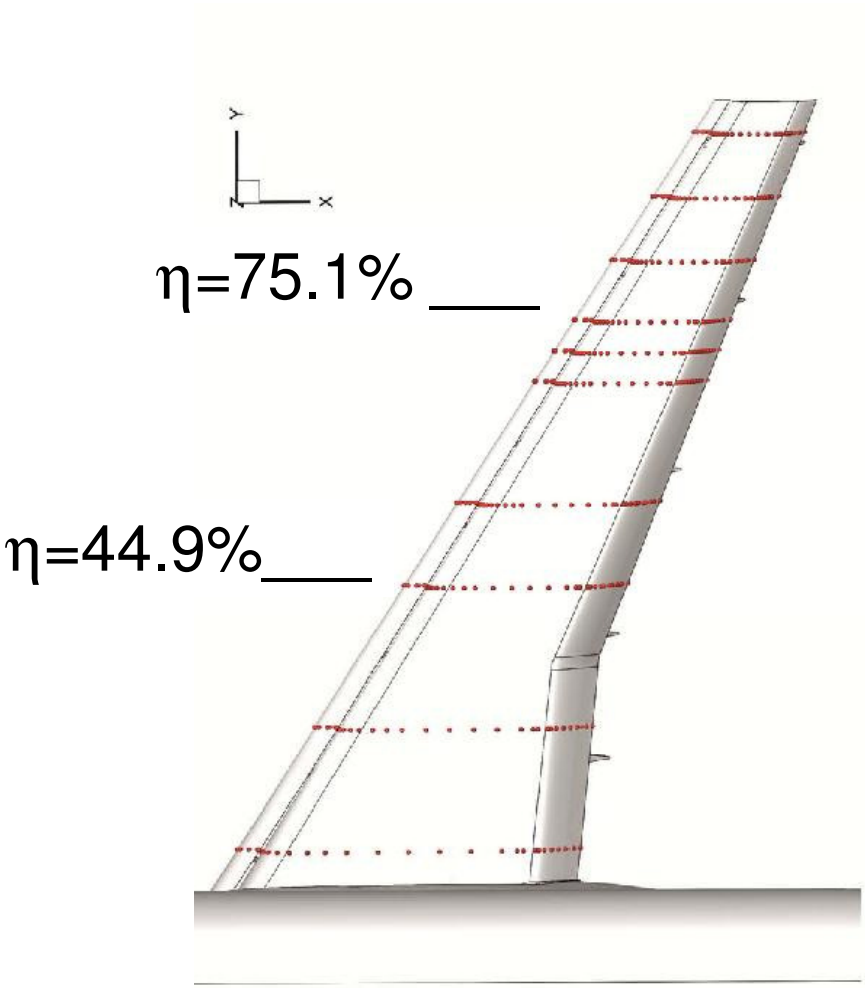
Objectives

- Assess the numerical prediction capability (meshing, numerics, turbulence modeling, high-performance computing requirements, etc.) of current-generation CFD technology/codes for swept, medium-to-high-aspect ratio wings for landing/take-off (high-lift) configurations.
- Develop practical modeling guidelines for CFD prediction of high-lift flow fields.
- Determine the elements of high-lift flow physics that are critical for modeling to enable the development of more accurate prediction methods and tools.
- Enhance CFD prediction capability for practical high-lift aerodynamic design and optimization.

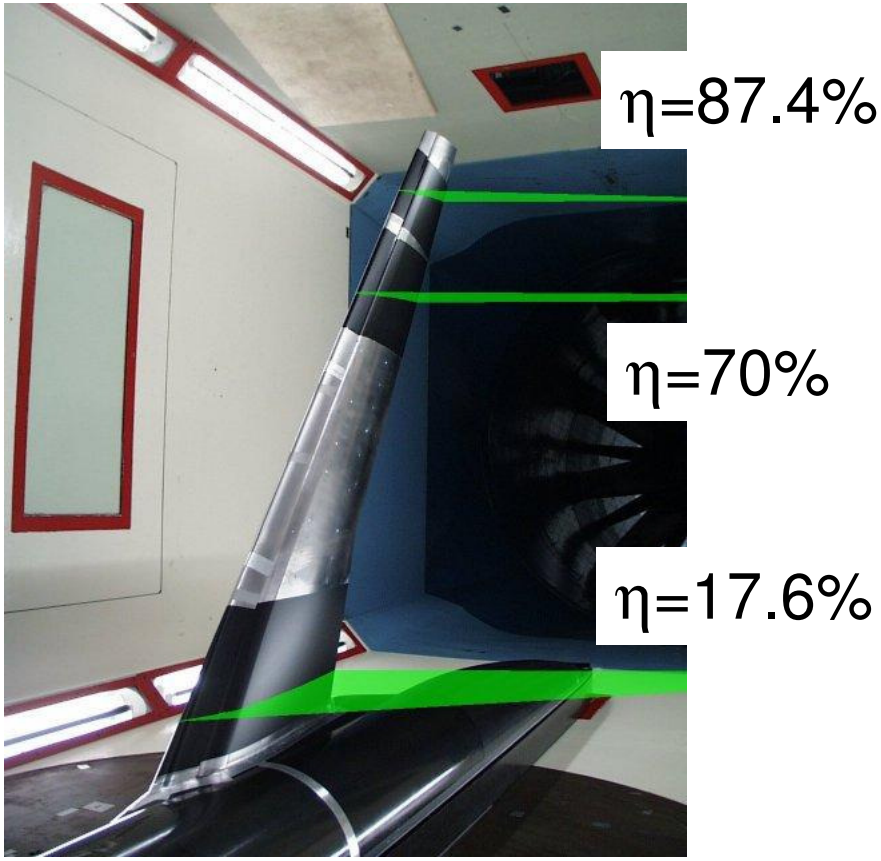
Focus

- The HiLiftPW-2 test cases are based on the European High Lift Programme (EUROLIFT) DLR F11 high-lift configuration.
  - Representative of a commercial wide-body twin-jet high-lift configuration
  - 3 elements : full-span slat, main and full-span flap
  - Landing configuration : slat 26.5 degs and flap 32 degs
- A significant amount of high-quality surface and flow field data are available, including data for an assessment of Reynolds number scale effects.
  - Force and moment (ETW and B-LSWT)
  - Surface pressures (ETW and B-LSWT)
  - PIV and oil flow (B-LSWT)

HiLiftPW-2 – DLR F11



Pressure Tap Stations



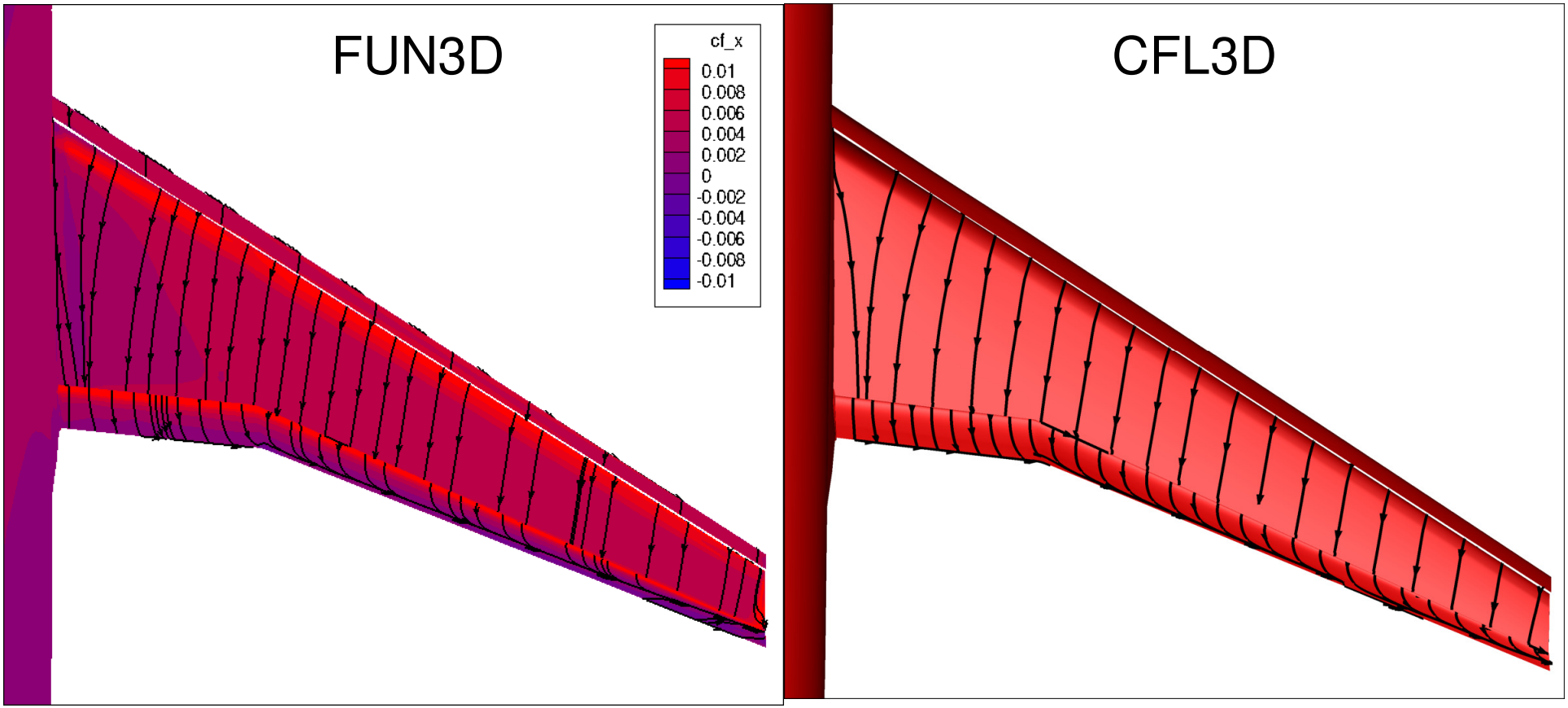
PIV Planes

HiLiftPW-2 - Rehearsal Background

- Case 1 : Grid convergence study (required)
  - Mach = 0.175, free-air
  - Angles-of-attack to be computed (deg) = 7 and 16 (18.5, 20, 21 and 22.4)
  - Re_{MAC} = 15.1 M, fully turbulent
  - DLR F11 "Config 2" - Slat 26.5 deg, Flap 32 deg (Wing/Body/HL system + SOB Flap Seal)
  - Coarse, medium, fine and extra-fine
- Case 2a and 2b: Reynolds number study (required)
  - Mach = 0.175, free-air
  - Angles-of-attack to be computed (deg) = 0, 7, 12, 16, 18.5, 19, 20 and 21
  - Re_{MAC} = 1.35M (Case2a) and 15.1 M(Case2b), fully turbulent
  - Medium density mesh from Grid Convergence Study
  - DLR F11 "Config 4" - Slat 26.5 deg, Flap 32 deg (Config 2 + Slat Tracks and Flap Track Fairings)
- Case 2c (OPTIONAL) - Low Reynolds Number Condition with Transition
- Case 3 (OPTIONAL) - Full Configuration Study
- Case 4 (OPTIONAL) - Turbulence Model Grid-Convergence Verification Study

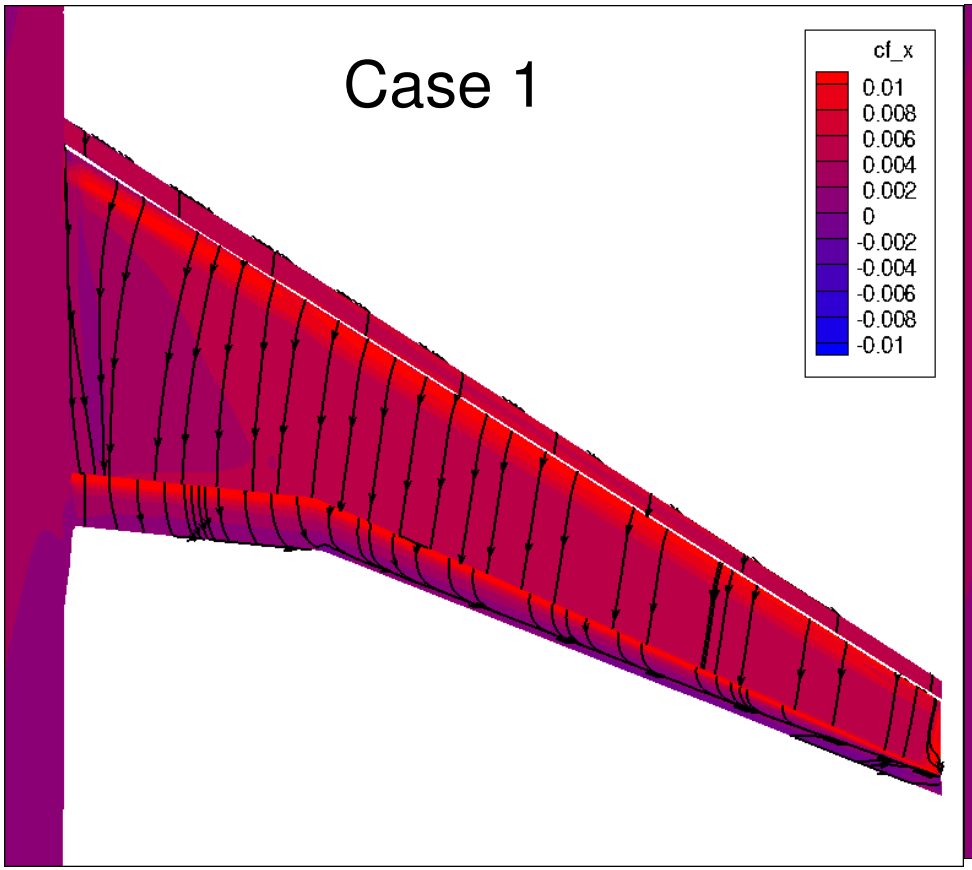
Case 1 Surface Restricted Streamlines

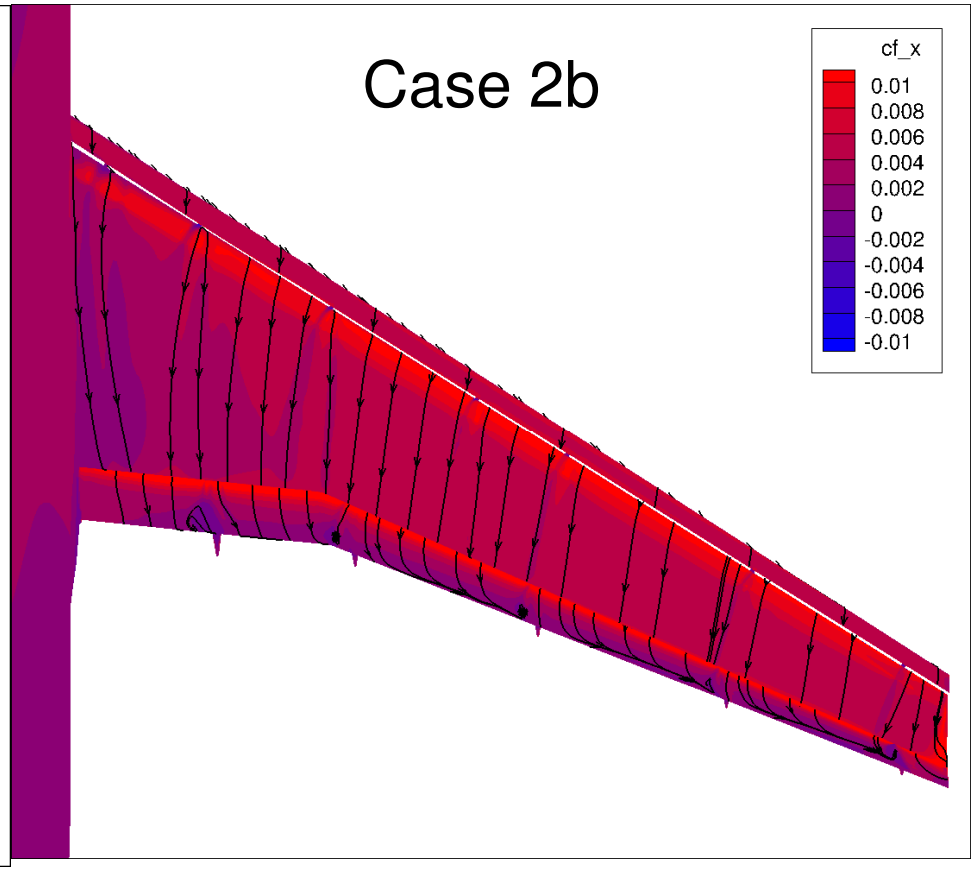
AOA 7deg
Medium Grids



FUN3D Surface Restricted Streamlines

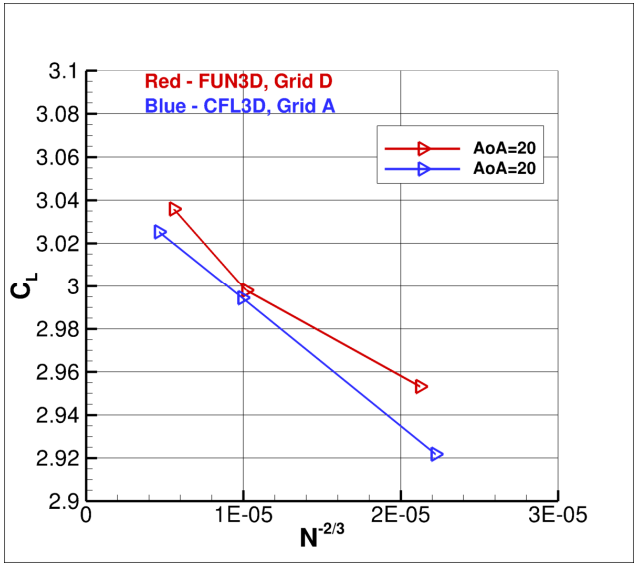
AOA 7deg
Medium Grid



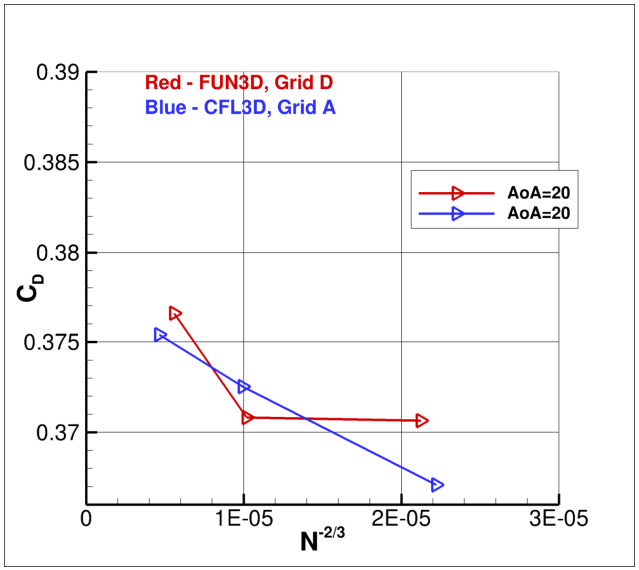


Case 1 – Grid Convergence, AoA=20

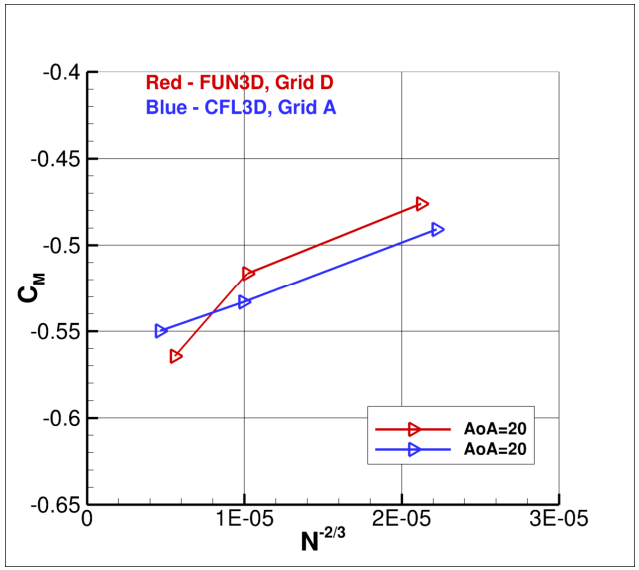
Lift



Drag

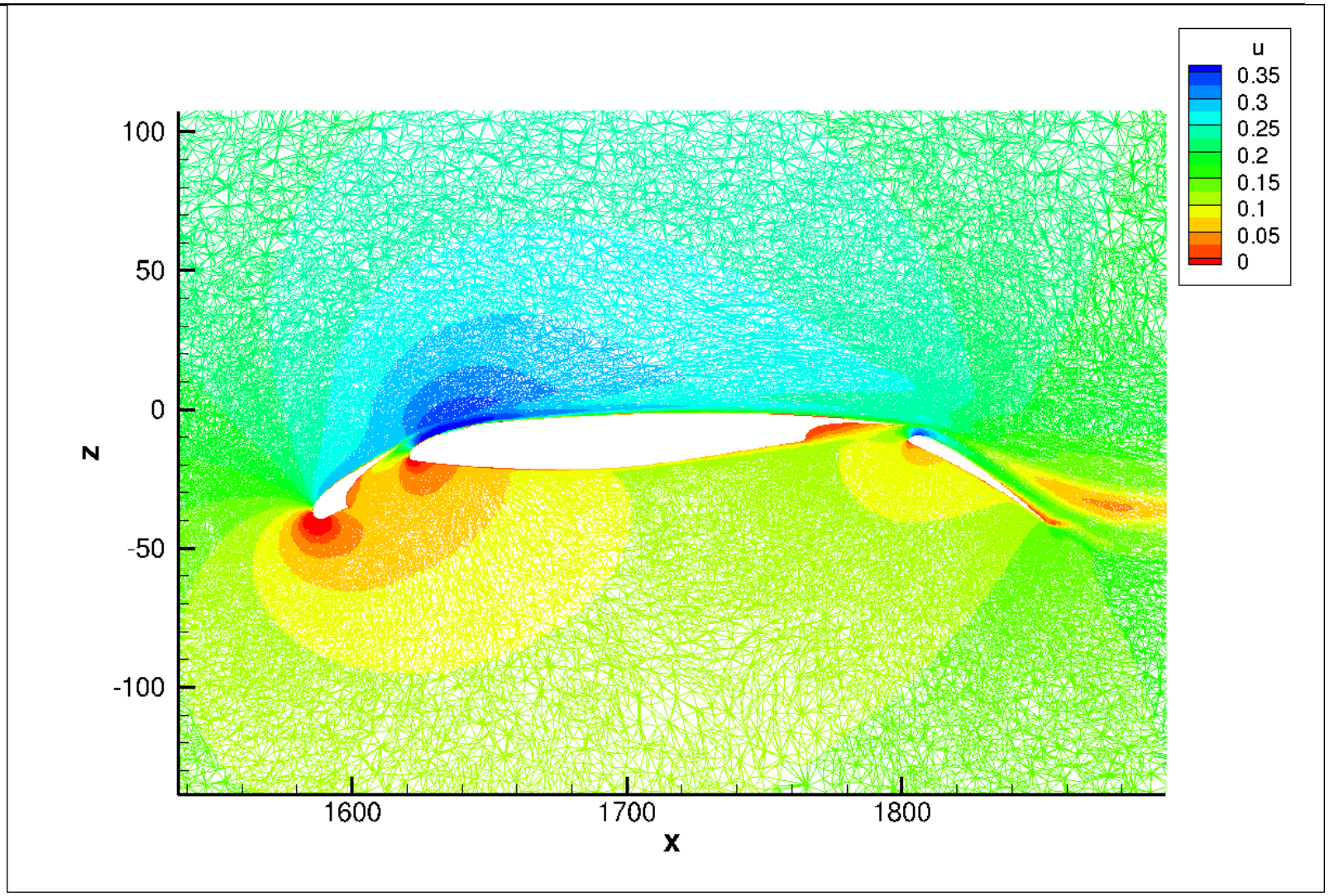


Pitching Moment



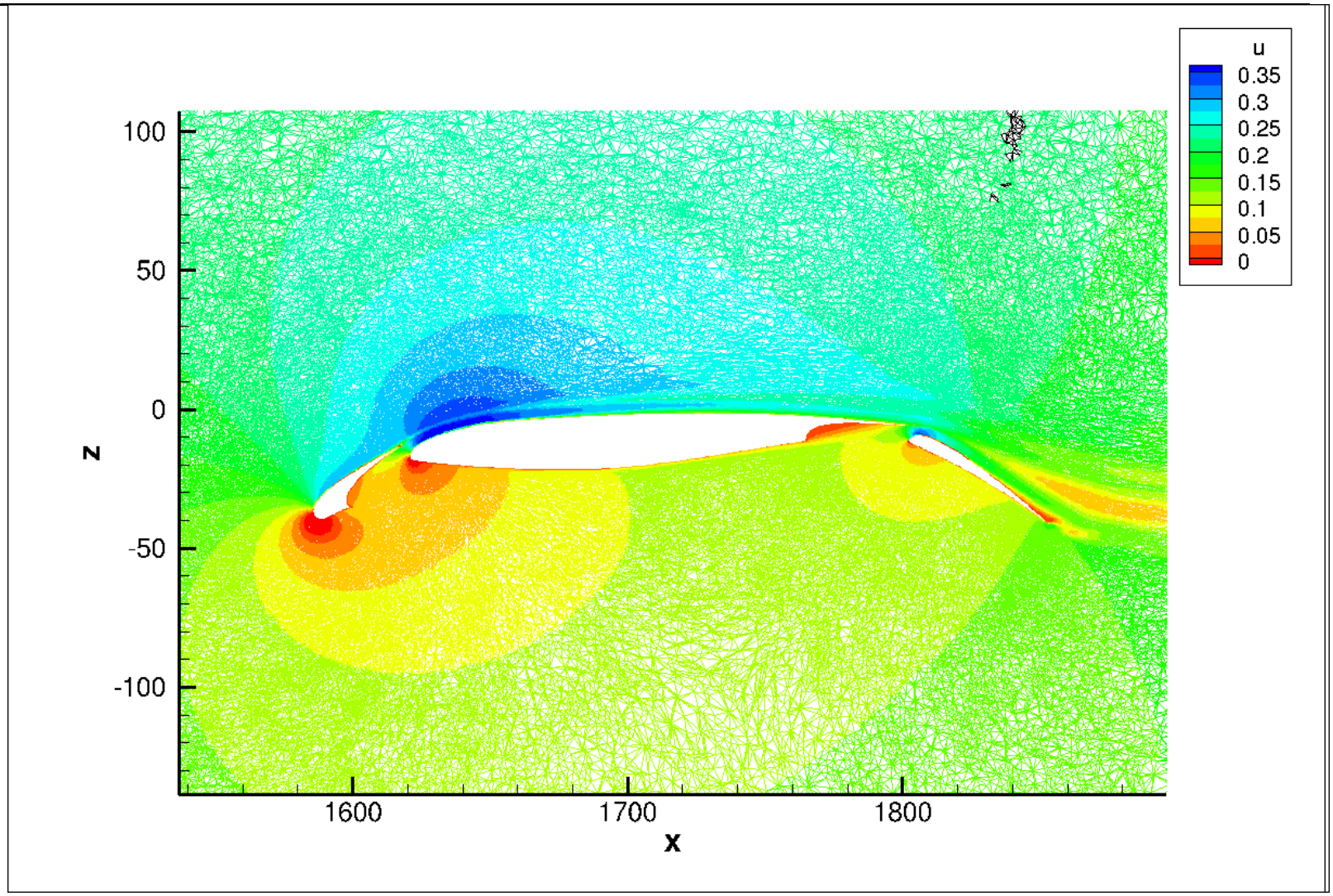
Note: Grid D (fine) was discovered to have incorrect min spacing – so not of similar family to C and M.

C1 Medium Grid Adaption η=70%



Adapted 1 – 37M nodes

C1 Medium Grid Adaption η=70%



Adapted 2 – 42M nodes