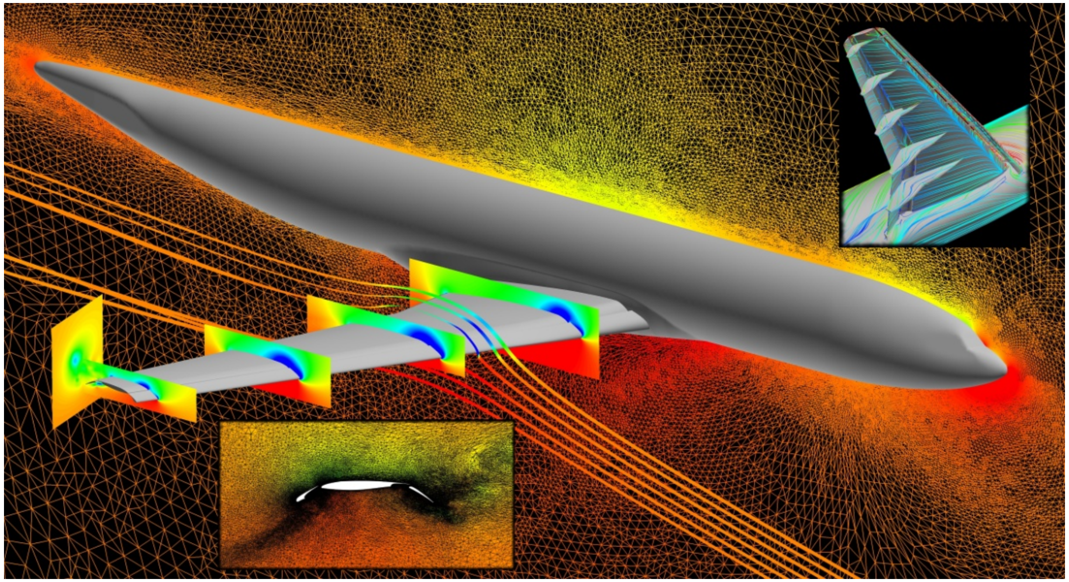
Grid-Adapted FUN3D Computations for the Second High Lift Prediction Workshop (Invited)



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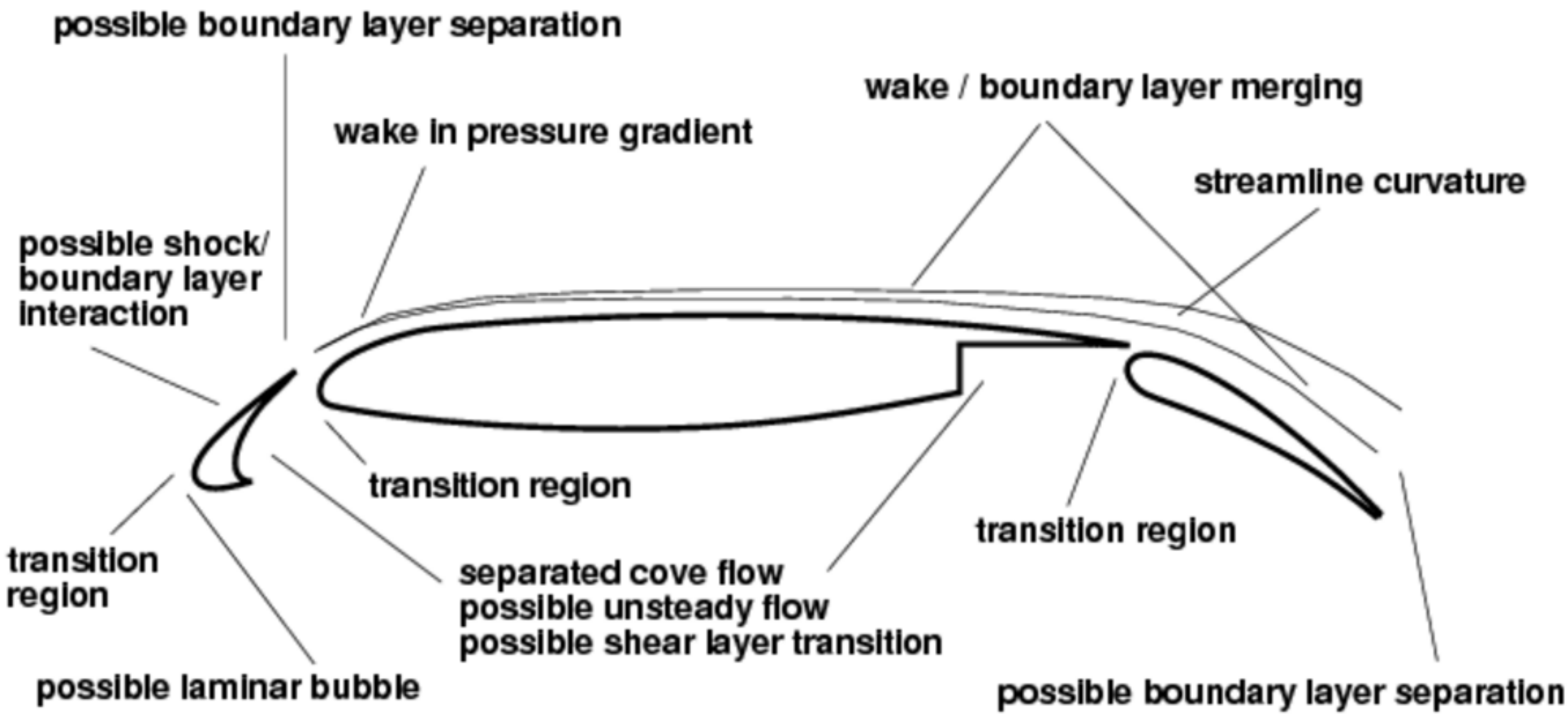
NASA Langley Research Center

32nd AIAA Applied Aerodynamics Conference,
AIAA Aviation and Aeronautics Forum and Exposition 2014
Atlanta, Georgia
June 16-20, 2014

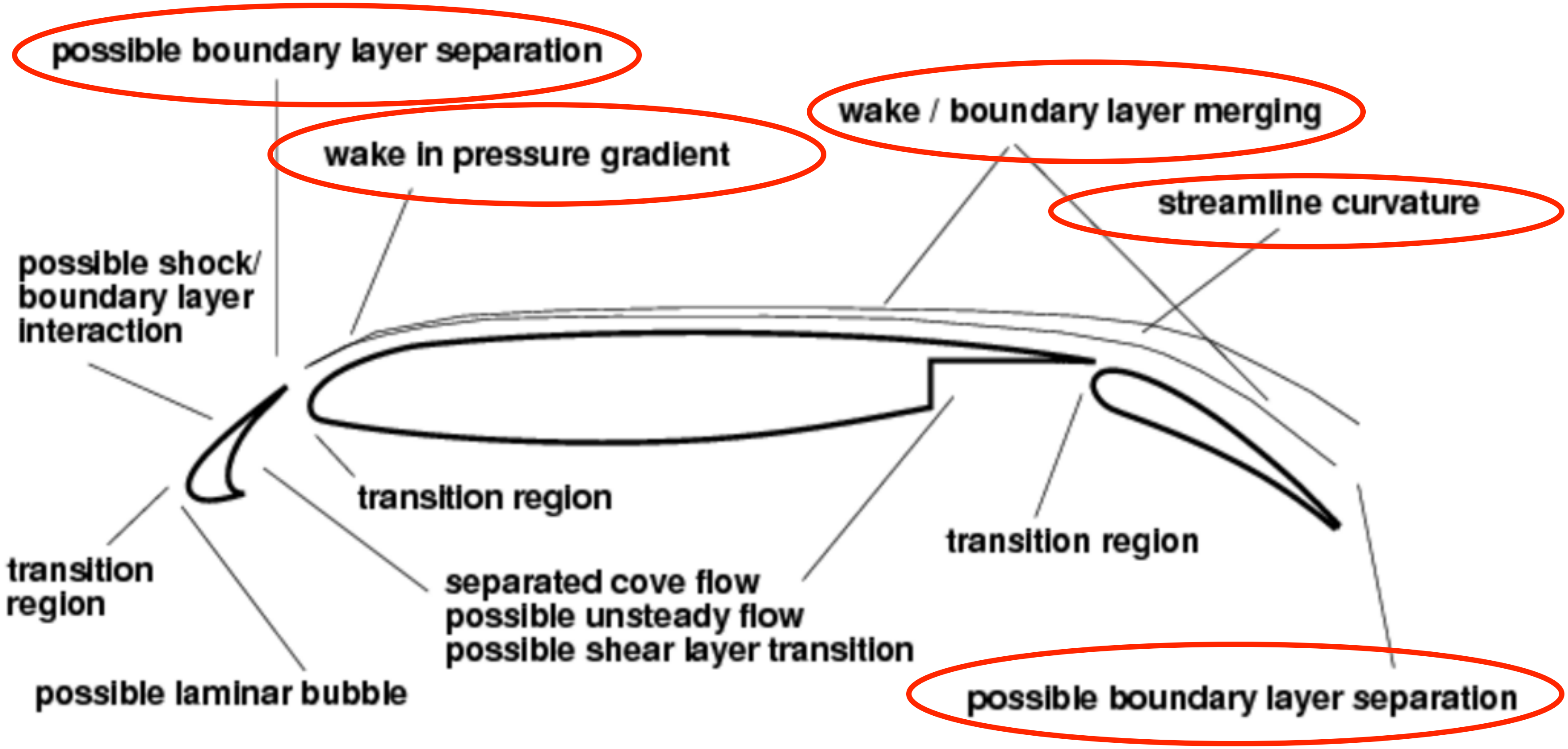
Motivation

Prediction of high-lift flows is challenging



Motivation

Prediction of high-lift flows is challenging



AIAA 2nd High Lift Prediction Workshop

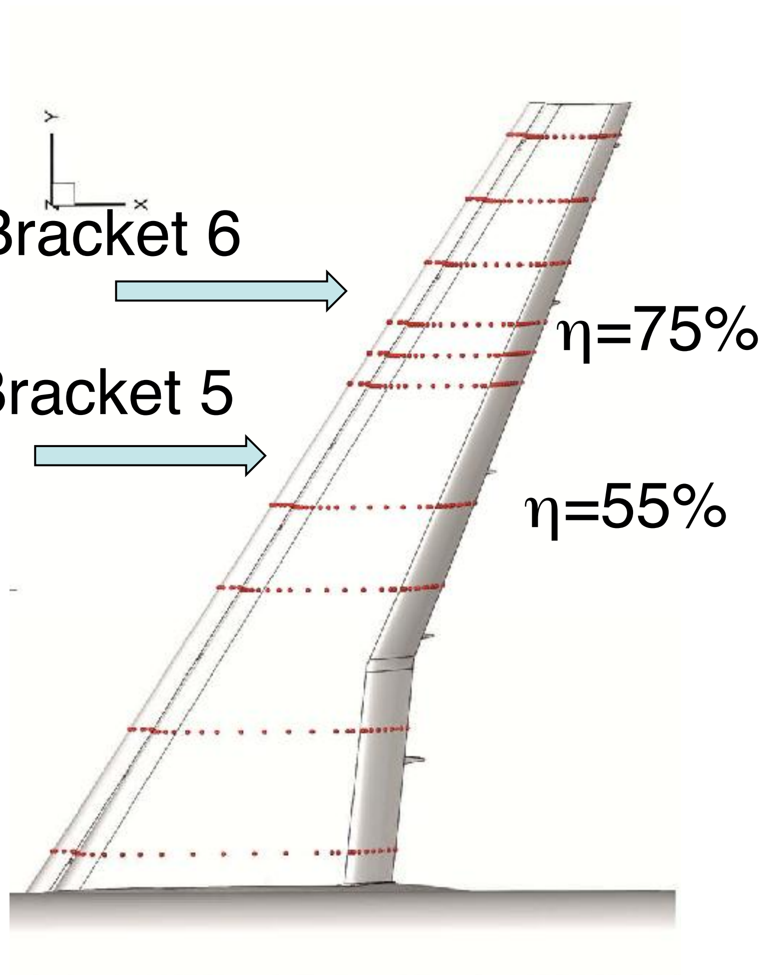
Main Objective

- Assess the numerical prediction capability of current-generation CFD technology/codes for swept, medium-to-high-aspect ratio wings for landing/take-off (high-lift) configurations.

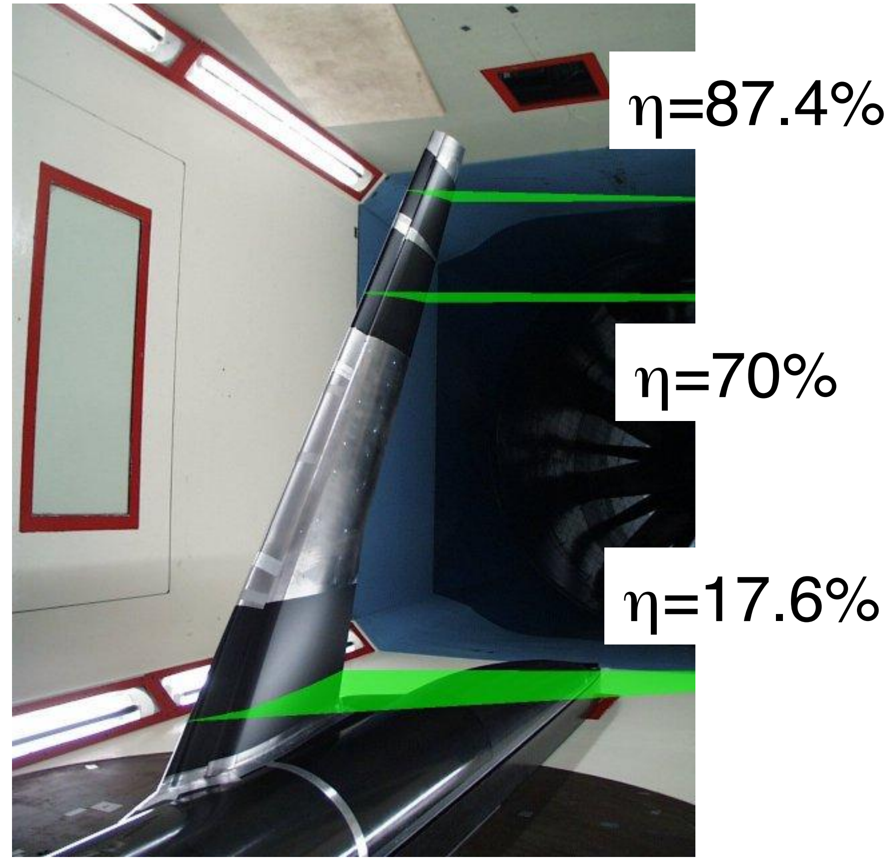
Focus

- 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
- A significant amount of high-quality surface and flow field experimental data are available
  - Force and moment (high and low Reynolds number)
  - Surface pressures (high and low Reynolds number)
  - PIV and oil flow (low Reynolds number)

HiLiftPW-2 – DLR F11

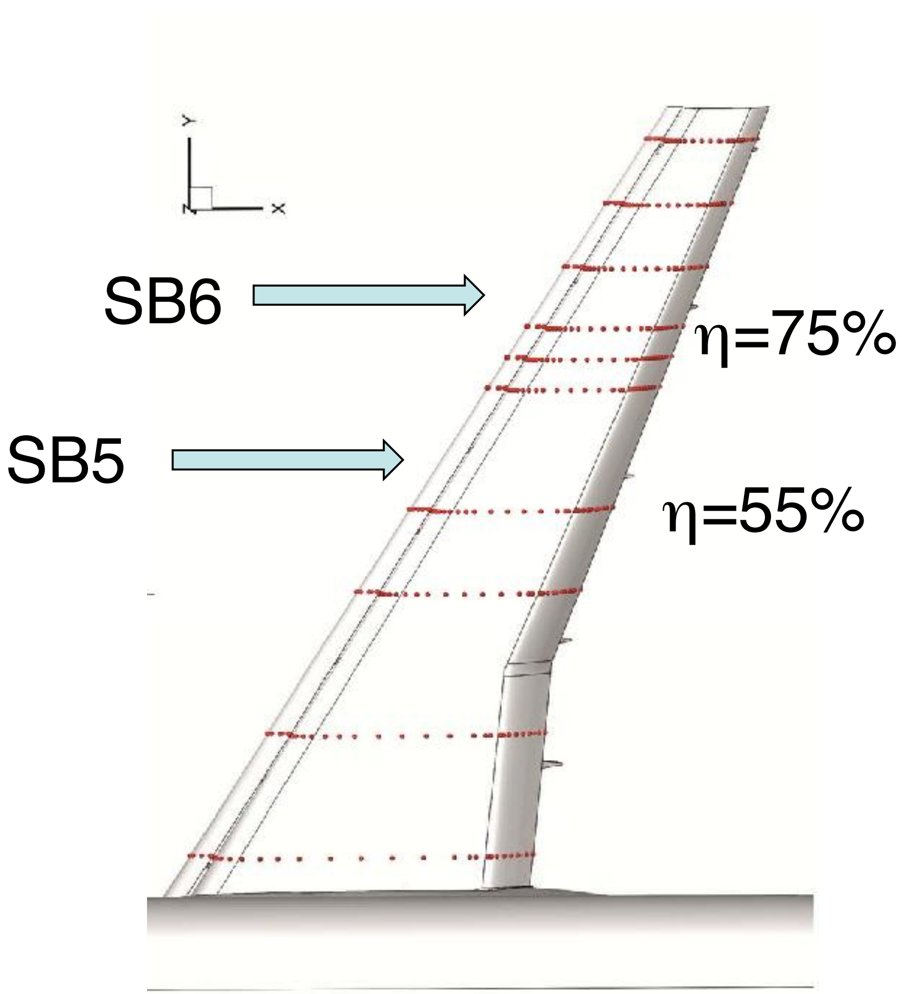


10 Pressure Tap Stations



3 PIV Planes

HiLiftPW-2 – DLR F11



10 Pressure Tap Stations

Oil Flow – Low Re_c
AOA = 18.5^o

HiLiftPW-2 – Workshop Cases

- Case 1 : Grid convergence study (required)
  - "Config 2" - Wing/Body/HL system + SOB Flap Seal
  - Re_C = 15.1 M
  - AOA (deg) = 7^o - 22.4^o
  - Coarse, medium, fine
- Case 2: Reynolds number study (required)
  - "Config 4" - Config 2 + Slat Bracket and Flap Bracket Fairings
  - Re_C = 1.35M (Case2a) and 15.1M (Case2b)
  - AOA polar
  - Medium density mesh
- Case 3b - Full Configuration Study (optional)
  - "Config 5" - Config 4 + Slat Pressure Tube bundles
  - Re_C = 15.1 M
  - AOA polar with medium density mesh

Required test cases requested on Workshop provided grids
Free-Air Computations, Fully Turbulent

Computational Methods

- FUN3D Unstructured-Grid Code
  - Compressible finite-volume RANS for mixed-element meshes
  - Full Navier-Stokes equations-node centered/UMUSCL 0.5 scheme
  - Spalart-Allmaras turbulence model, fully-turbulent
  - SA rotation variant (SAR), fully turbulent
  - Implicit local time-stepping
- FUN3D Output-Based (Adjoint) Adaption
  - Adapting to reduce error in engineering output function (lift to drag ratio)
  - Adjoint equations are used to estimate the impact of local grid induced errors to the output function
  - Anisotropic off-body adaption
  - Surface grid and grid near body frozen within 0.144% MAC (y^+~ 900)
- CFL3D Structured-Grid Code
  - Compressible cell-centered finite-volume RANS
  - Results in paper

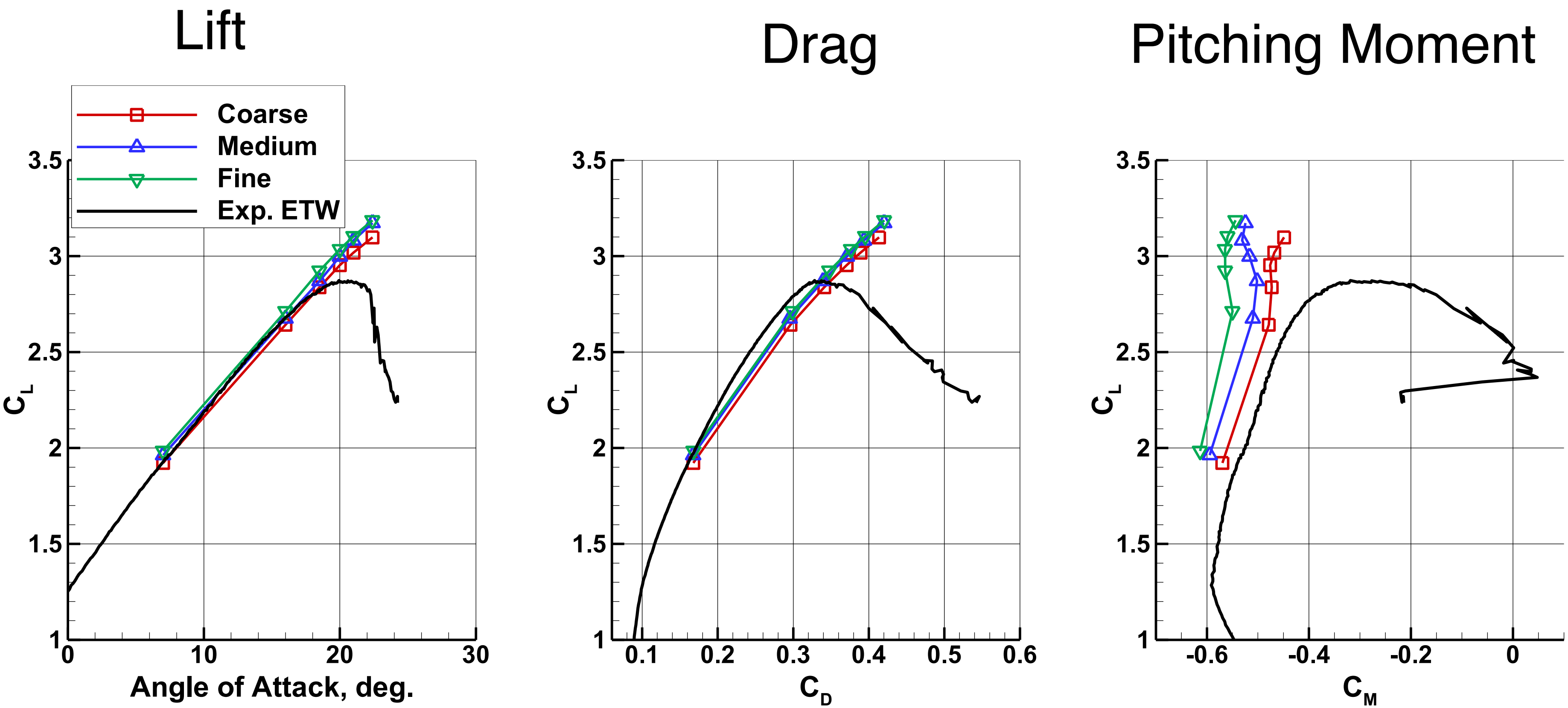
Summary Cases and Grids

	Coarse	Medium	Fine
Case 1	D(10M)-polar adapted 16^o	D(31M)-polar adapted 16^o	D(76M)-polar
Case 2a		D(42M)-polar	
Case 2b		D(42M)-polar adapted 16^o-21^o	
Case 3b		D(44M)-polar adapted 16^o-20^o	

D(nodes) – Unstructured Mixed D (UWYO/Cessna)
adapted – ouput-based adapted grids

Case 1 – Grid Convergence Study

Workshop Grids – SA model



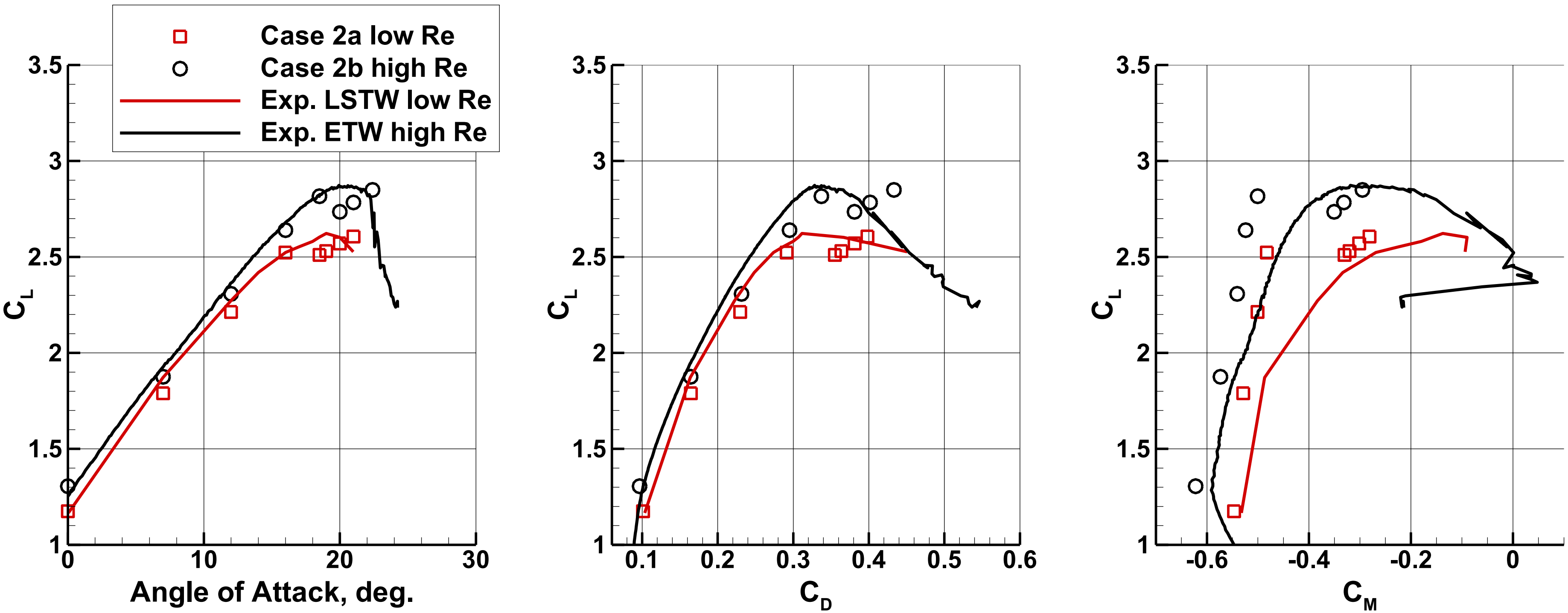
Case 2 – Reynolds Number Study

Workshop Grid – SA Model

Lift

Drag

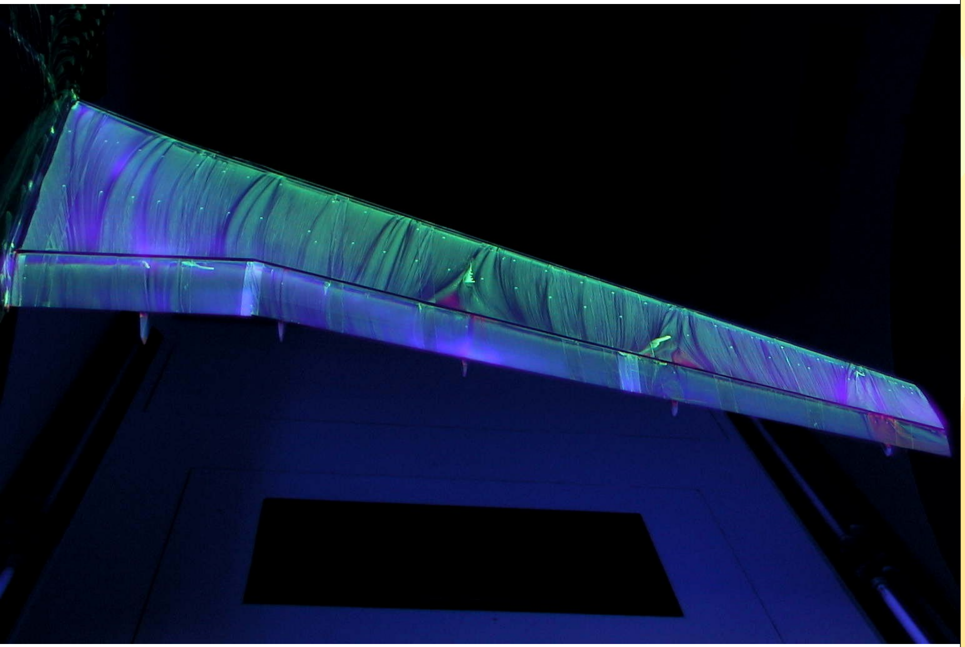
Pitching Moment

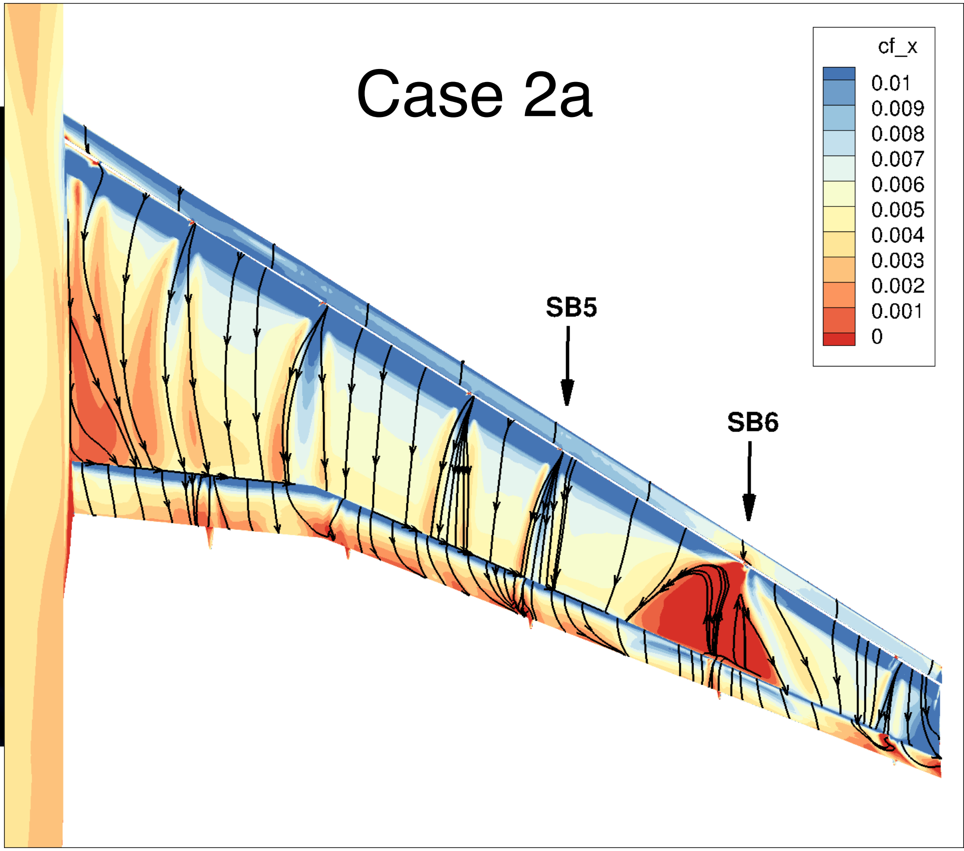


FUN3D Surface Restricted Streamlines

AOA 18.5deg
Medium Workshop Grid

Exp. Oil Flow



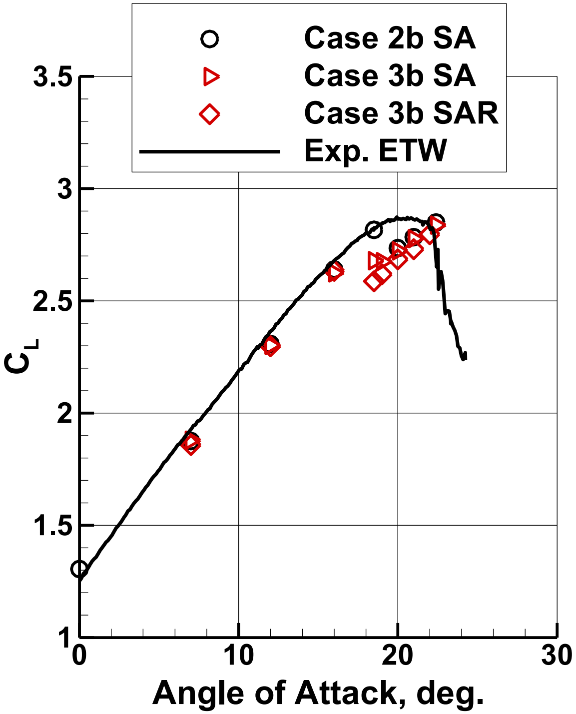


Contours – streamwise skin friction (dark red indicates reversed flow)

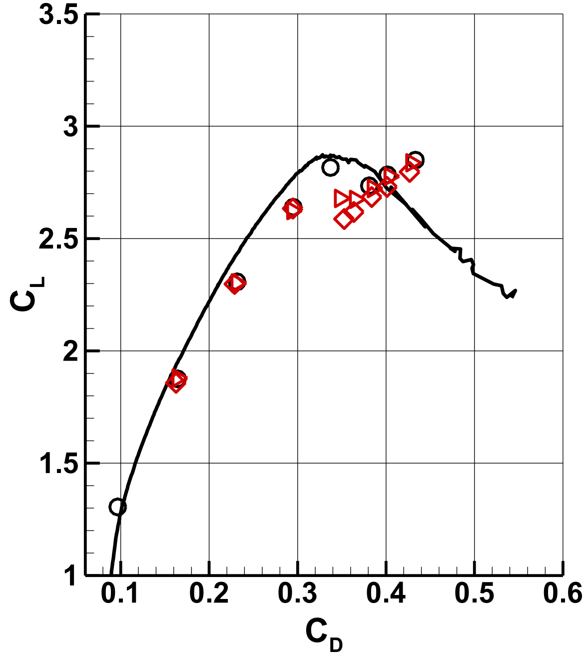
Case 3b – Full Config. Study

Workshop Grids

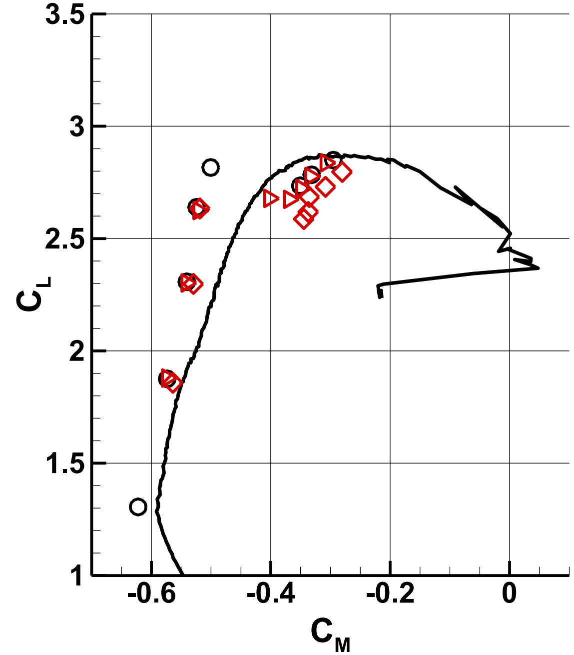
Lift



Drag



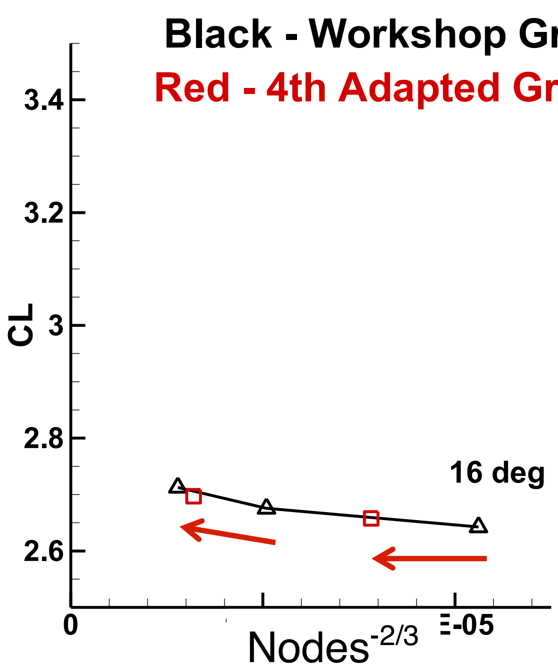
Pitching Moment



Case 1 : Grid Adaption

- Adjoint-based adaption : output functional L/D
  - Off-body adaption
  - Case 1 coarse and medium grids (SA model)
  - Four adaption cycles (4 additional adjoint and flow solutions)
  - AOA 16deg

Lift



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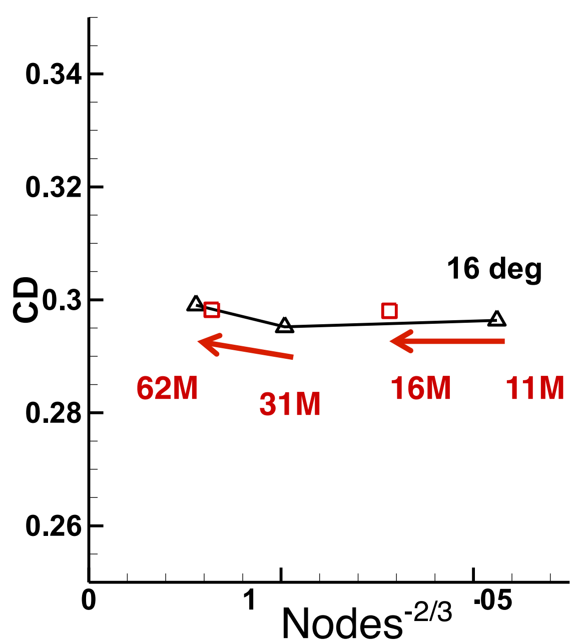
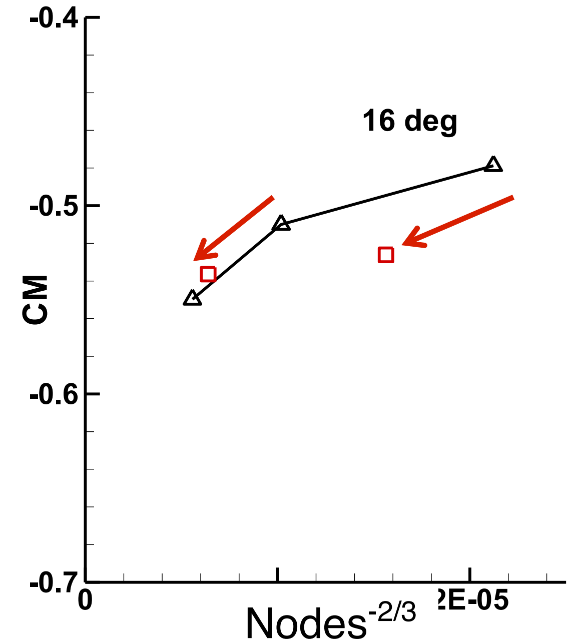
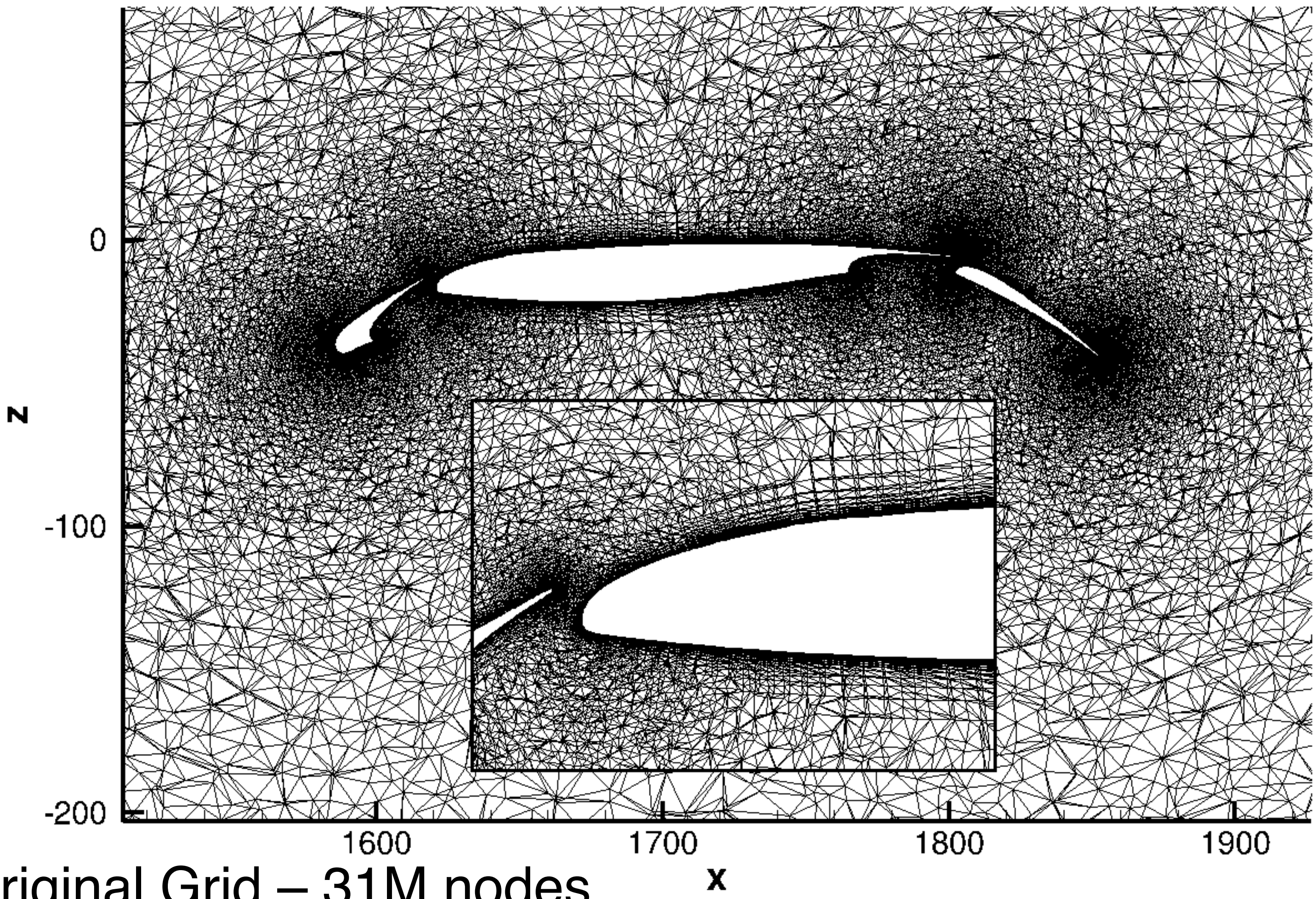


Pitching Moment

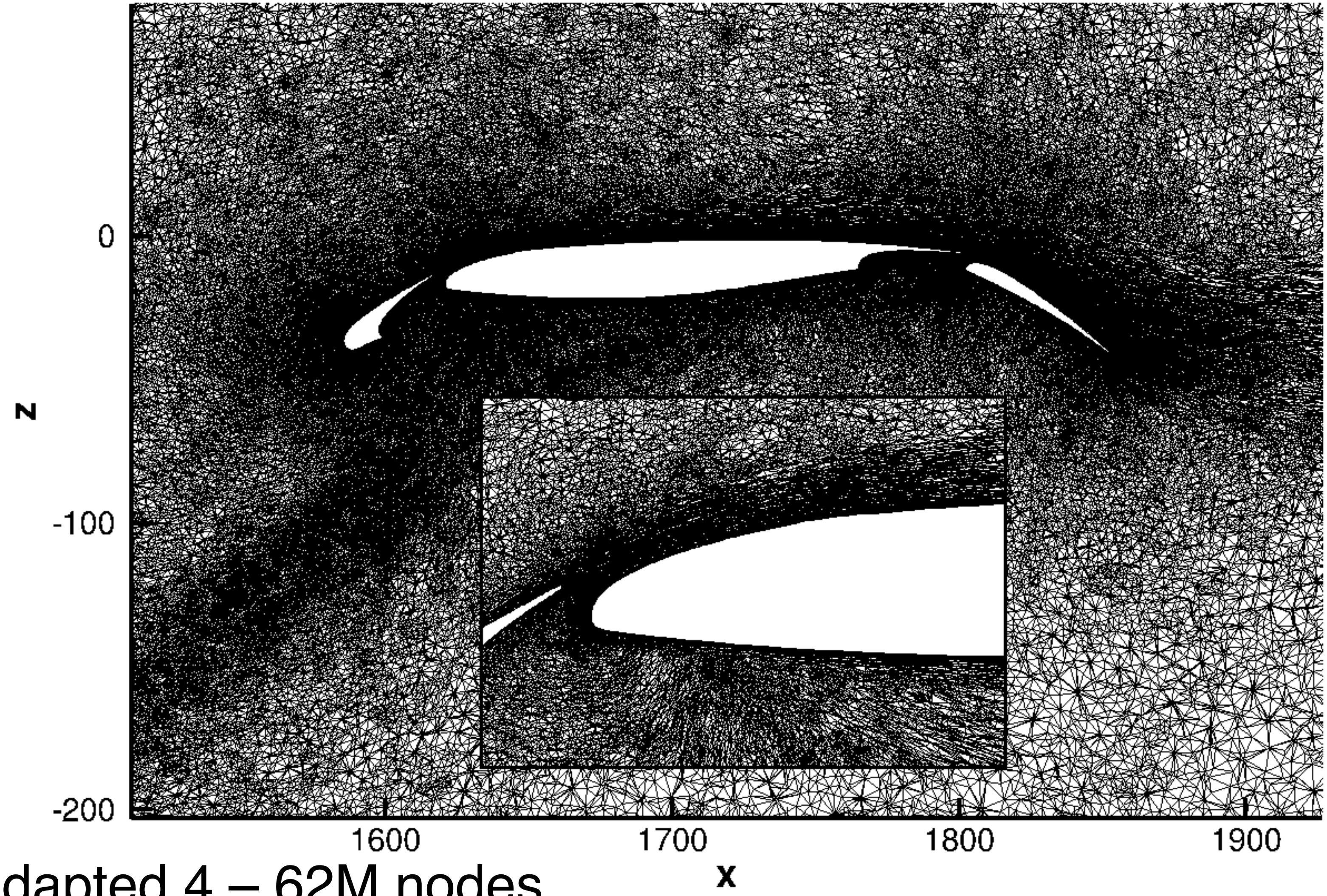


Case 1 Medium Grid η=70%



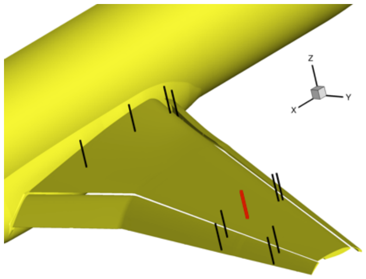
Original Grid – 31M nodes

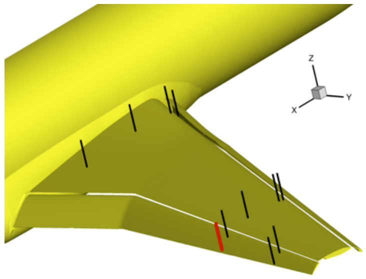
Medium Adapted Grid η=70%

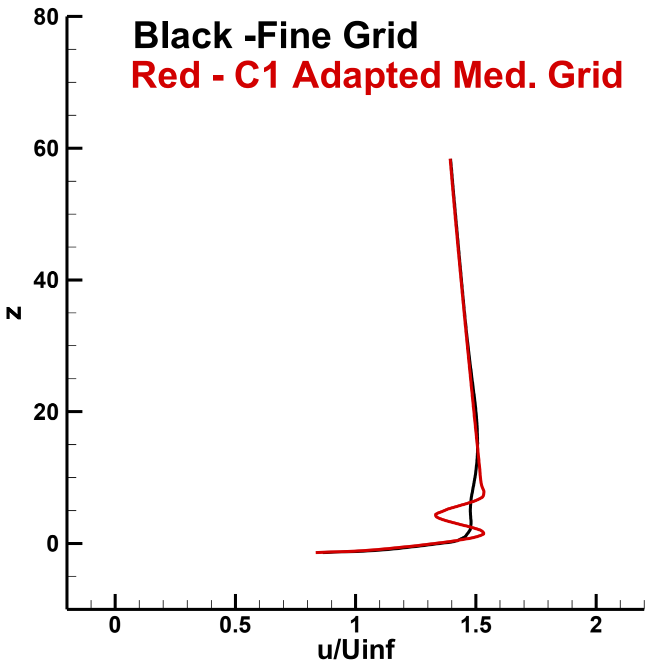


Adapted 4 – 62M nodes

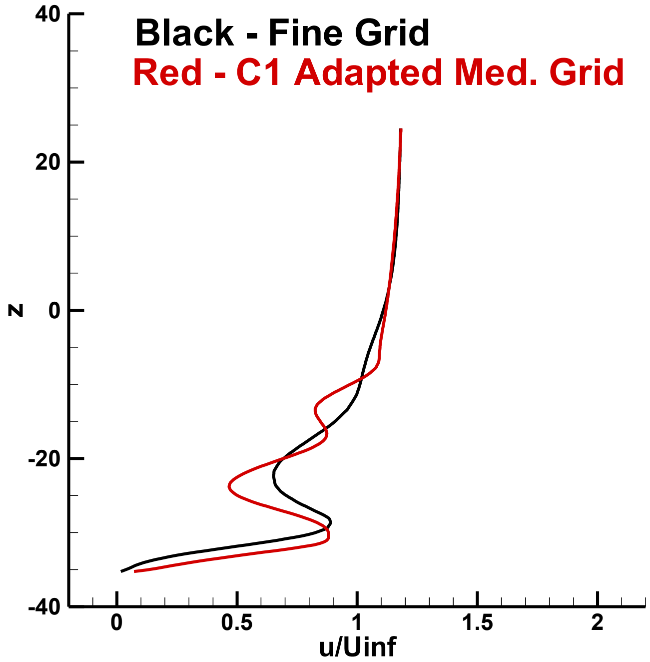
Case 1 Velocity profiles AOA= 16^o





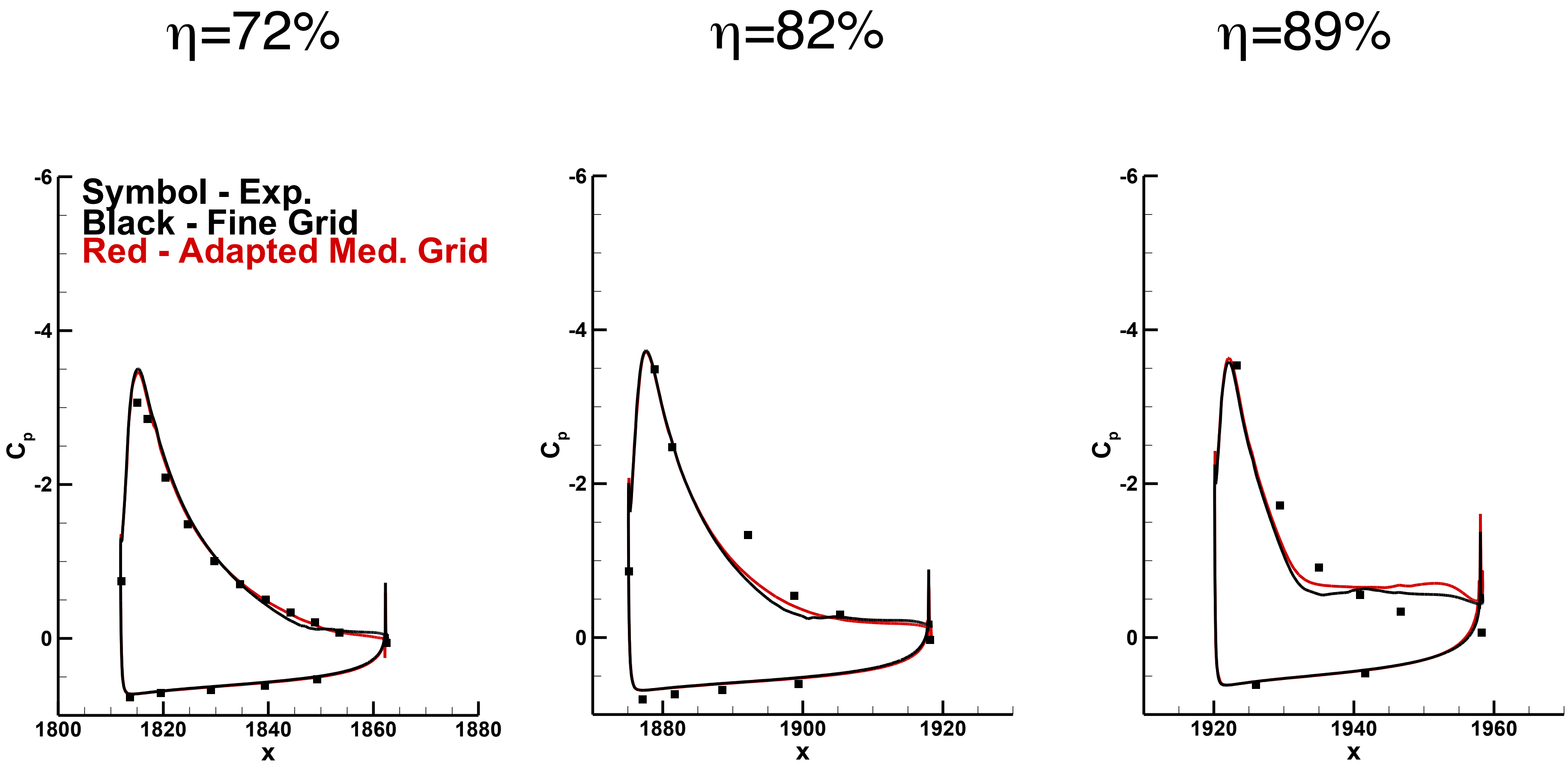


Main



Flap

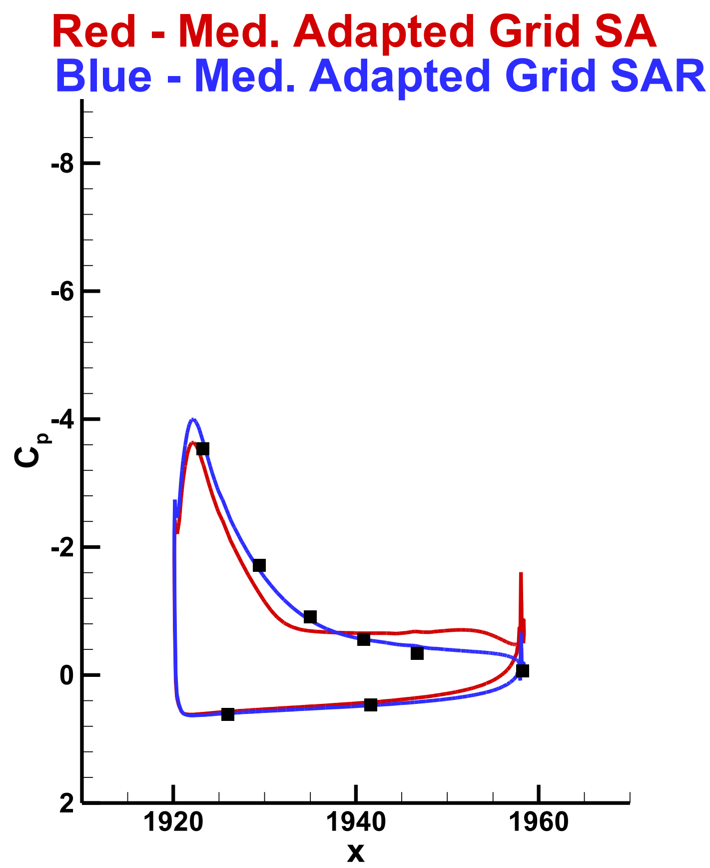
C1 Medium Grid Adaption Flap Cp



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

Effect of Turb. Model on Flap Cp

η=89%



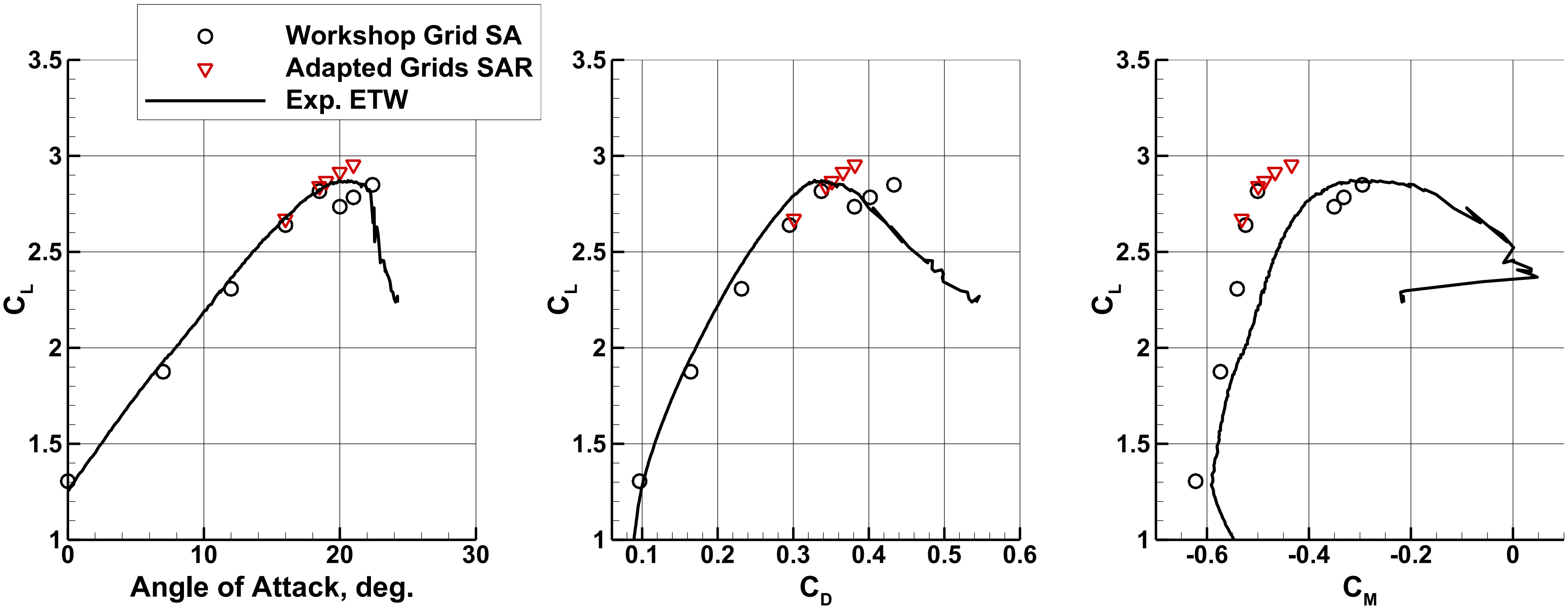
SAR – SA model with rotation (Dacles-Mariani) correction

Case 2b – Adapted Grid Polars

Lift

Drag

Pitching Moment



Workshop Grid – 42 million nodes

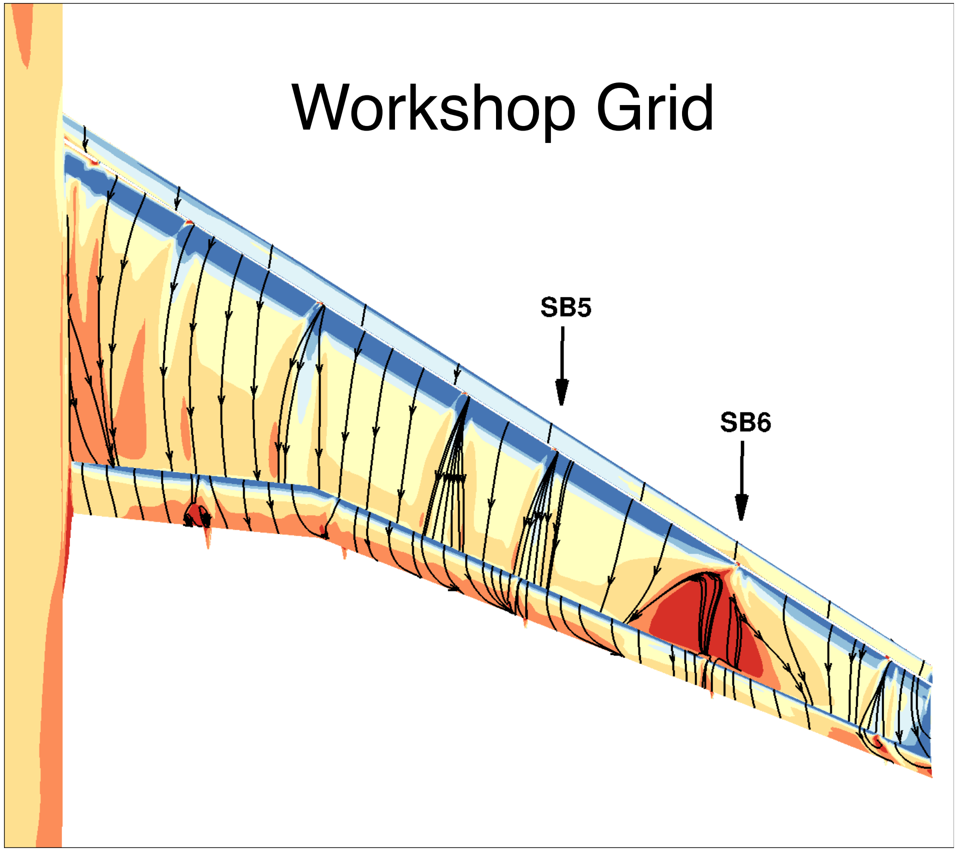
AOA 16^{o} – 58 million nodes

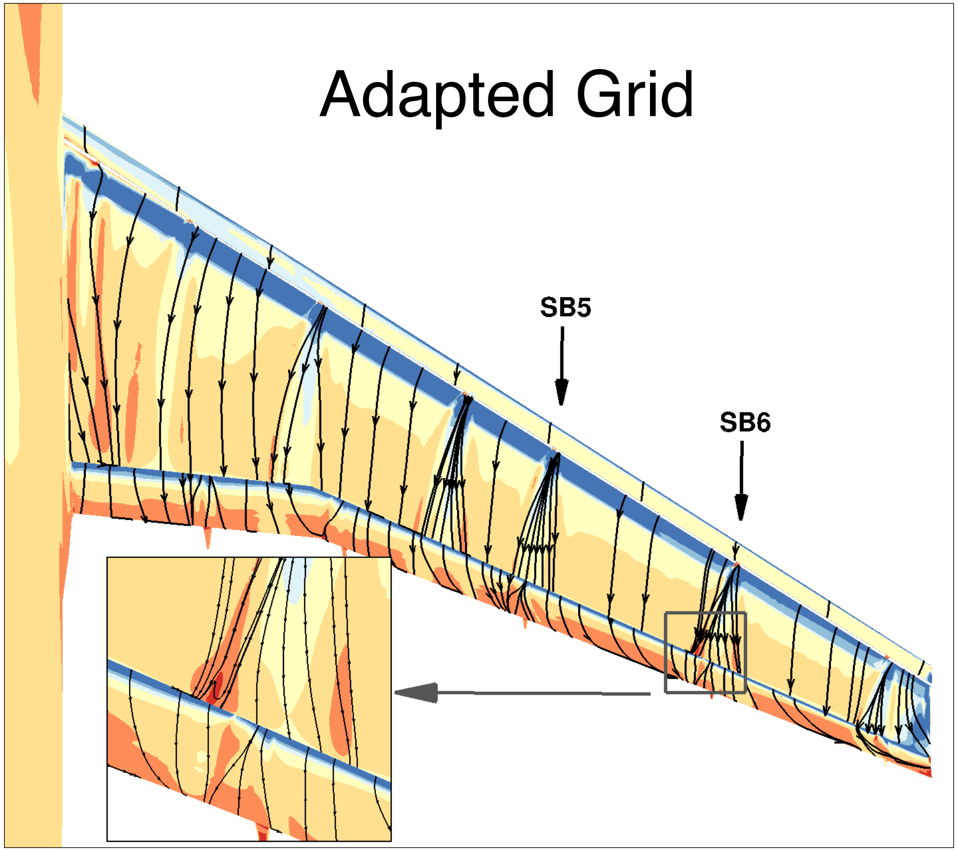
AOA 18.5^{o} – 78 million nodes

AOA 20^{o} and 21^{o} – Adapted grid from 18.5^{o}

FUN3D Surface Restricted Streamlines

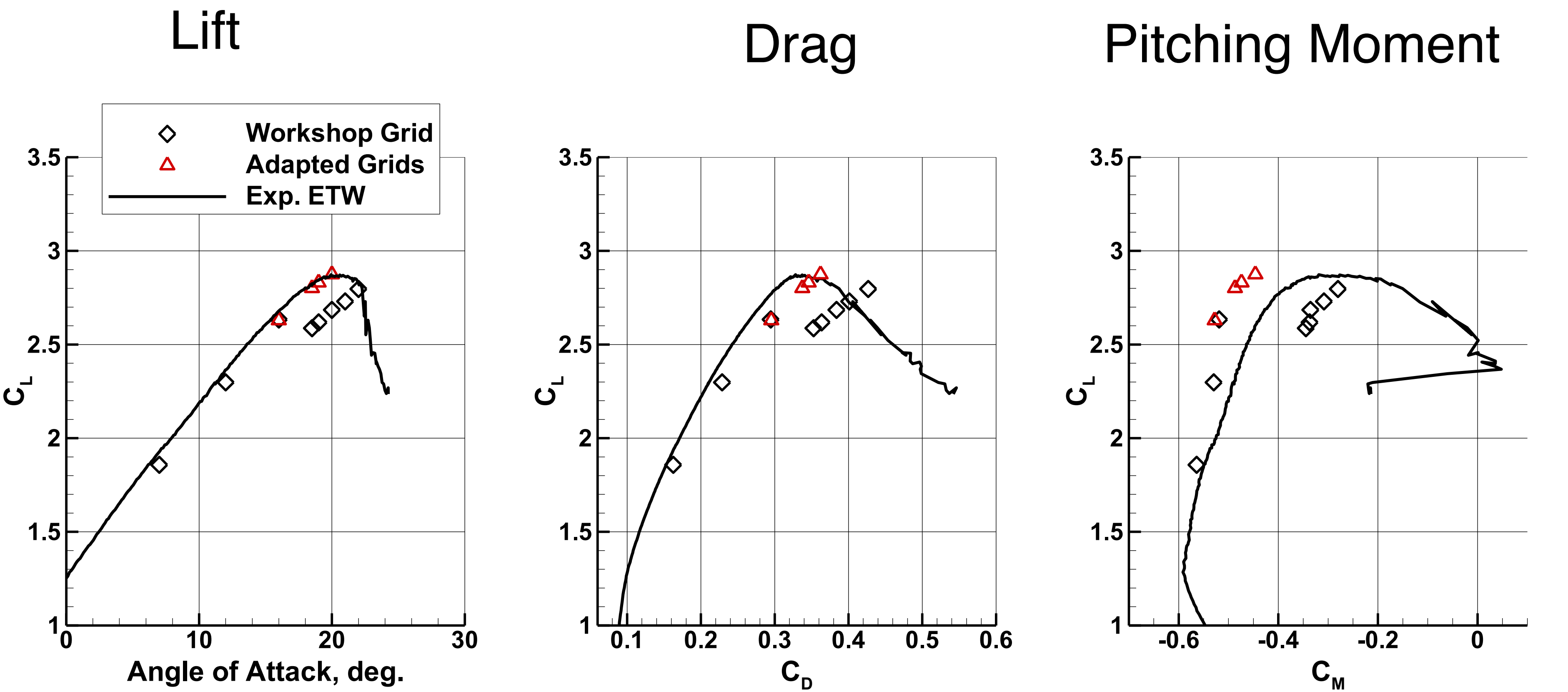
Case 2b
AOA 20^{o}





Contours – streamwise skin friction (dark red indicates reversed flow)

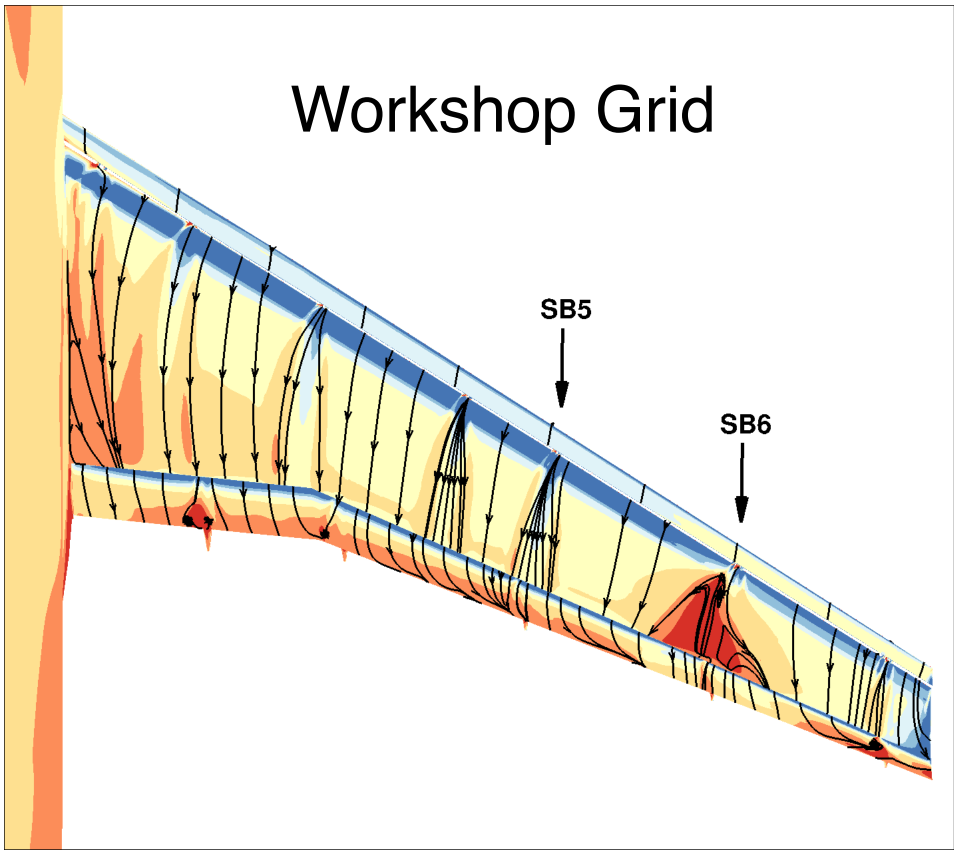
Case3b – Adapted Grid Polars

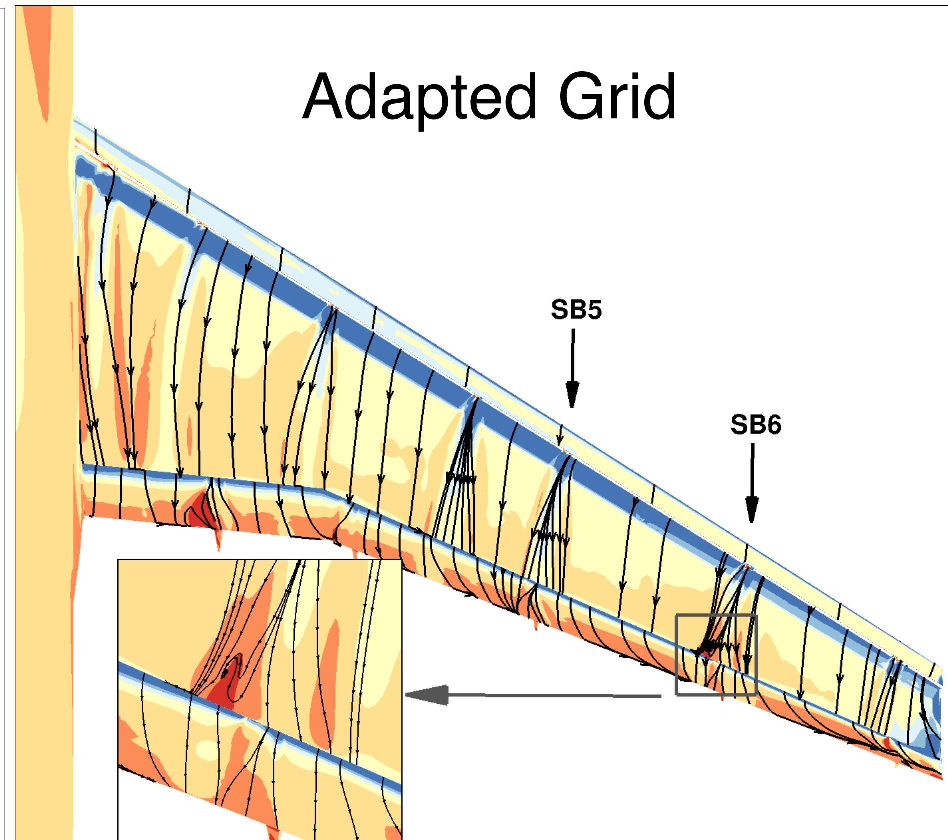


Workshop grid – 44 million nodes
AOA 16^o – 58 million
AOA 18.5^o – 93 million
AOA 20^o – Adapted grid from 18.5^o
AOA 21^o – flow solver did not converge

FUN3D Surface Restricted Streamlines

Case 3b
AOA 18.5°

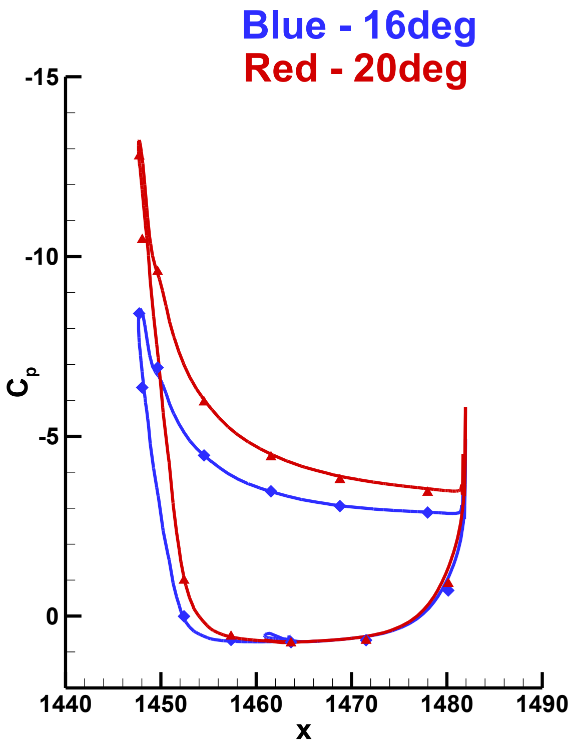




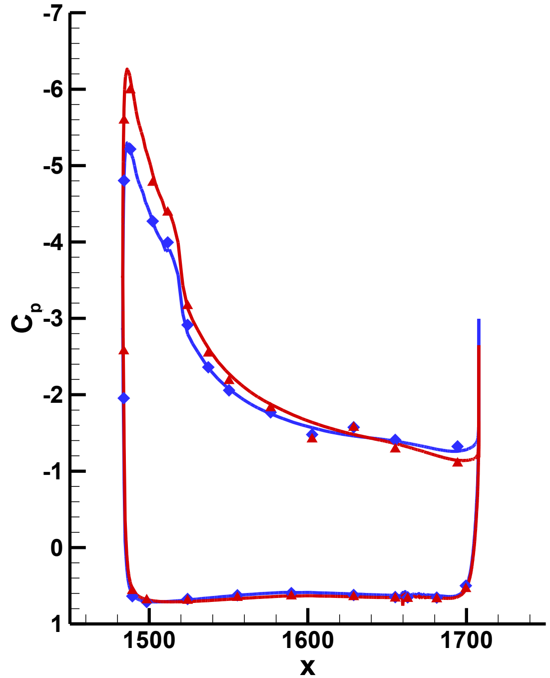
Contours – streamwise skin friction (dark red indicates reversed flow)

FUN3D Pressure Distributions

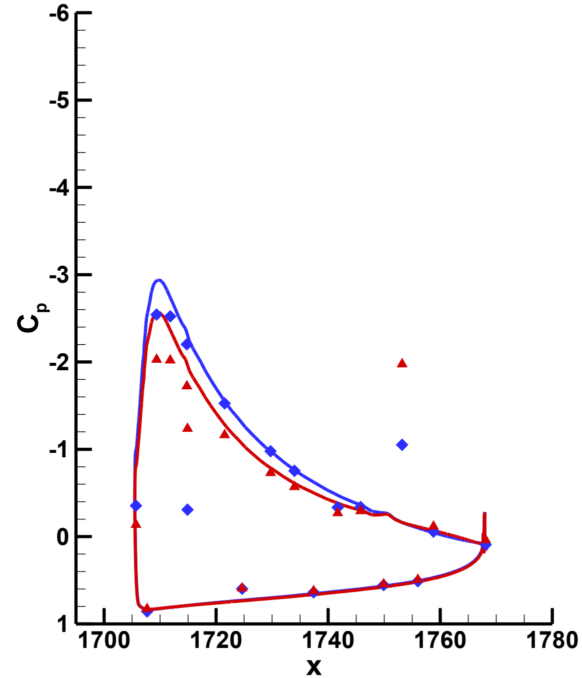
Case 3b Adapted Grids
Eta = 0.55



Slat



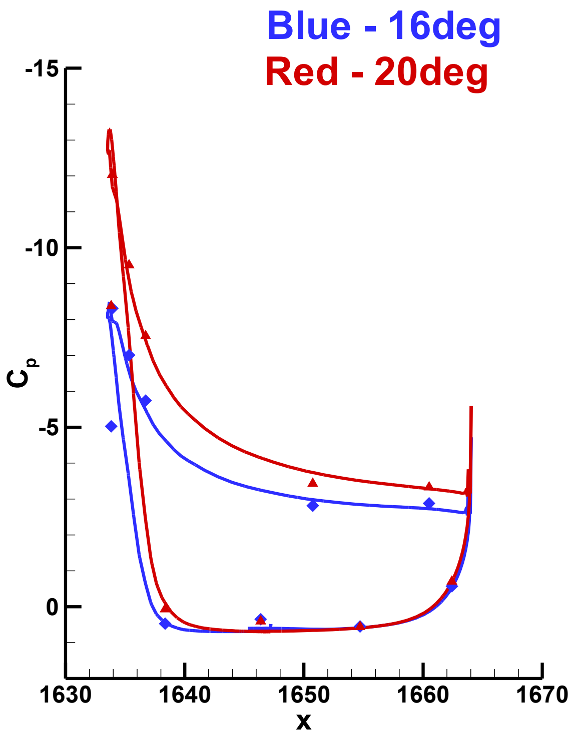
Main



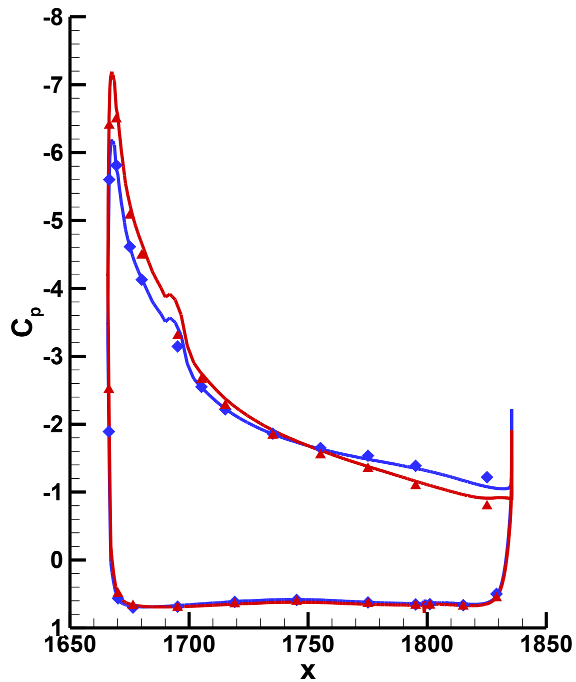
Flap

FUN3D Pressure Distributions

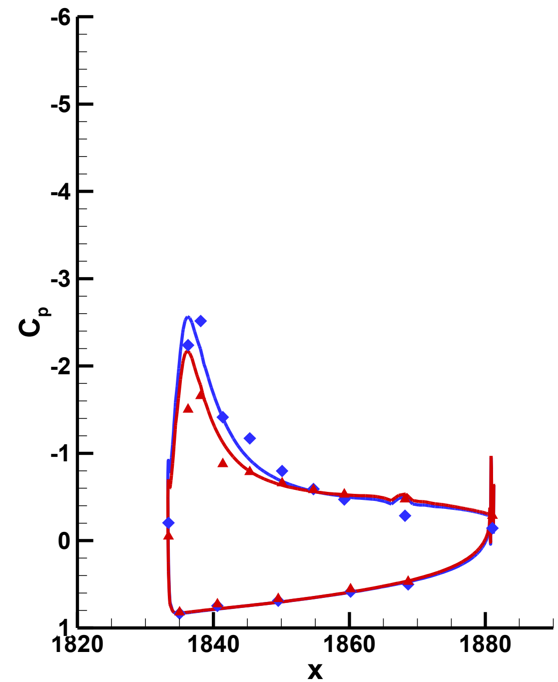
Case 3b Adapted Grids
Eta = 0.75



Slat



Main



Flap

Summary Workshop Grid Results

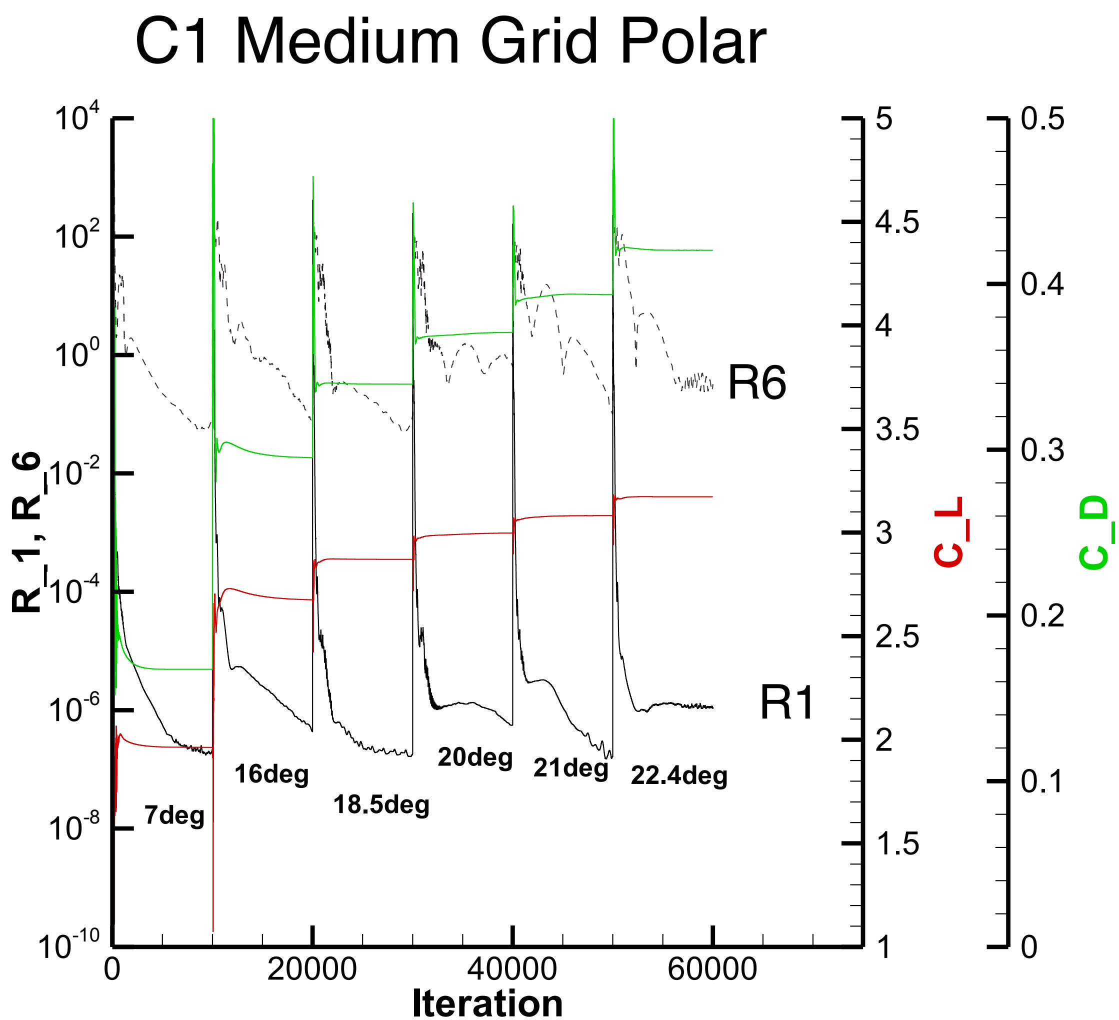
- Grid convergence study (Case 1)
  - Slat and main wakes not resolved on D grids
  - Maximum lift coefficient was over-predicted
- Reynolds number study (Case 2a and 2b)
  - Additional geometric complexity improved results (forces, moments, surface pressures) before stall
  - General trends captured, but $C_{L,max}$ not predicted well due to excessive main wing separation
  - Velocity profiles compared with experiment only qualitatively
- Full configuration study (Case 3b)
  - Addition of slat pressure tube bundles caused main wing separation ($C_{L,max}$) at lower AOA
  - SAR did not have significant impact on outboard pressures

Summary Adapted Grid Results

- Case 1 (no brackets)
  - Similar trends in force and moment variation to global grid convergence
  - Adapted grids captured wake profiles better than unstructured D grid series
  - SAR improved outboard pressure prediction on flap in comparison with experiment
- Case 2b & 3b
  - Additional geometric complexity improved results (forces, moments, surface pressures) before stall and near stall
  - Adaption reduced the excessive main wing separation seen on workshop grids
  - Slat and main wakes more resolved than on D grids
  - Adapted grid solutions not run past stall so did not predict a value of C_{Lmax}

Backup Slides

FUN3D Residual Convergence



CFL3D Residual Convergence