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Transition modelling with Simcenter STAR-CCM+ - lessons learnt

1st AIAA CFD Transition Modeling and Prediction Workshop

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Simcenter STAR-CCM+

The integrated multiphysics solution for CFD engineers

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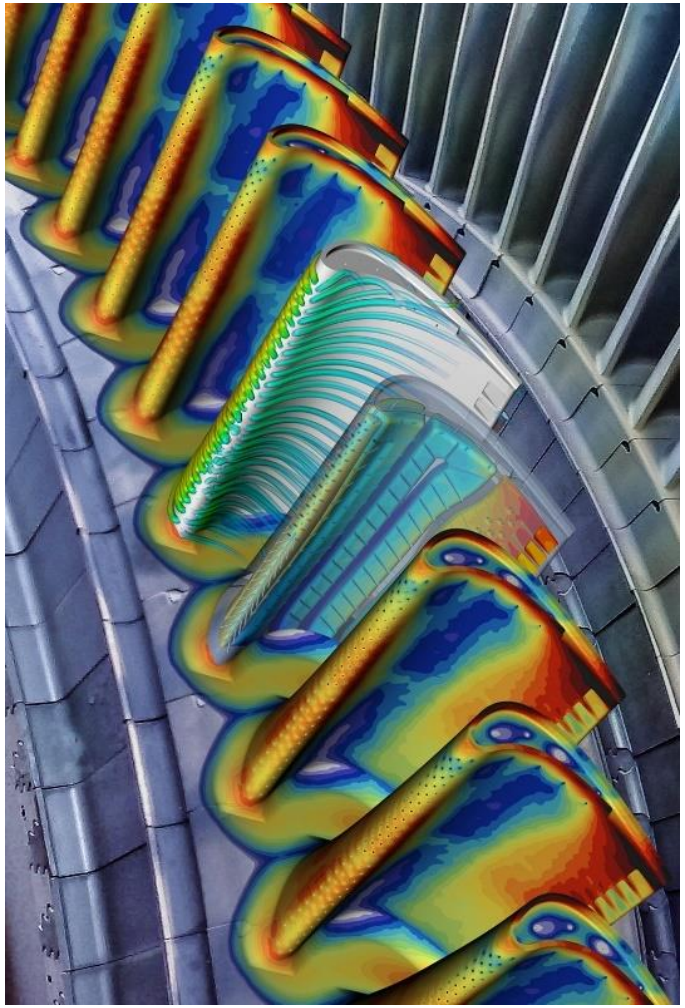

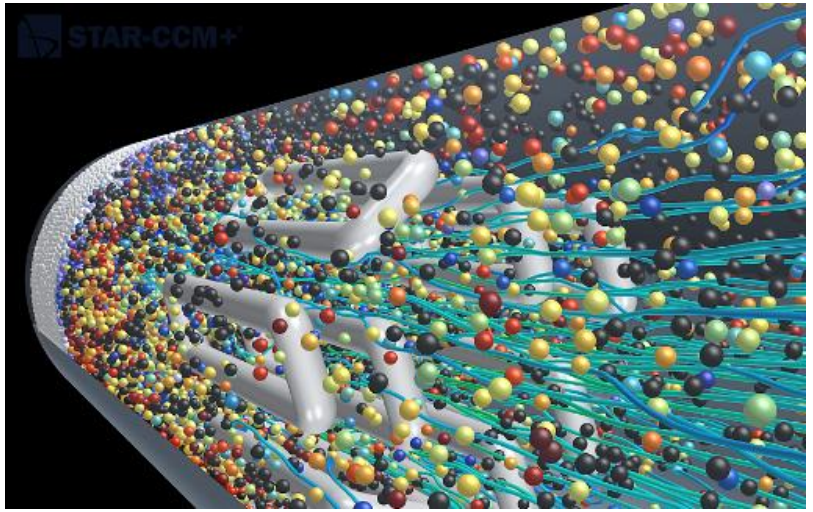

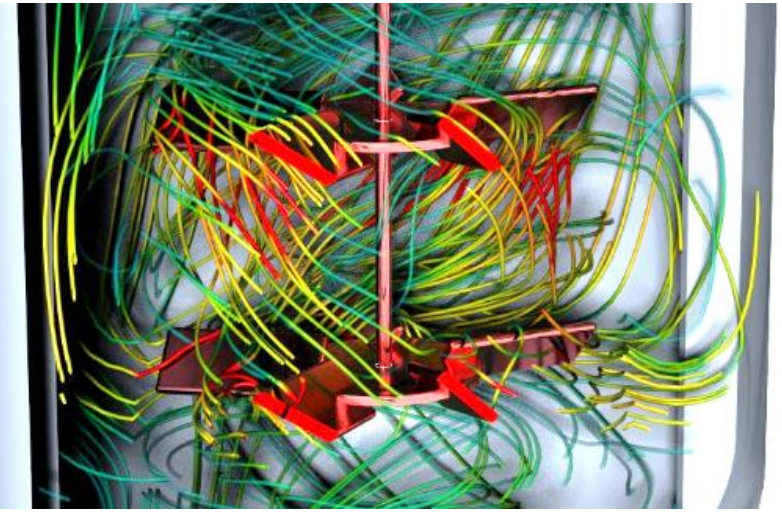

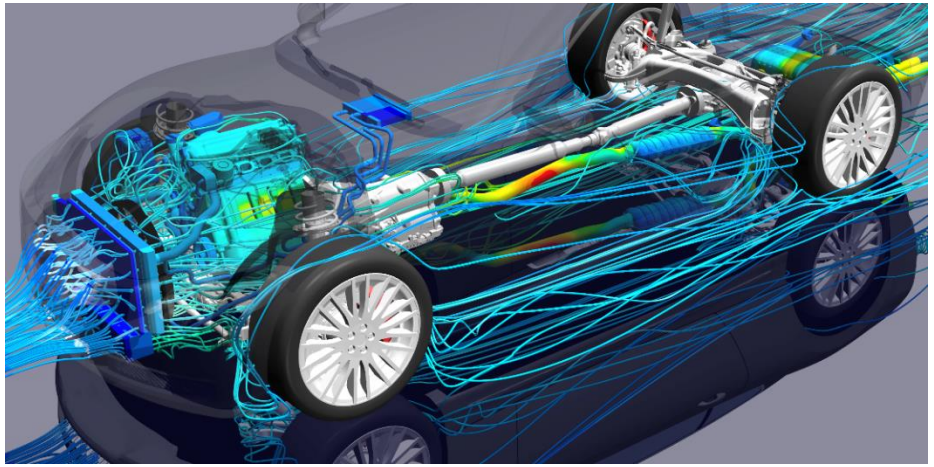

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Simcenter STAR-CCM+
Summary of the code and numerics

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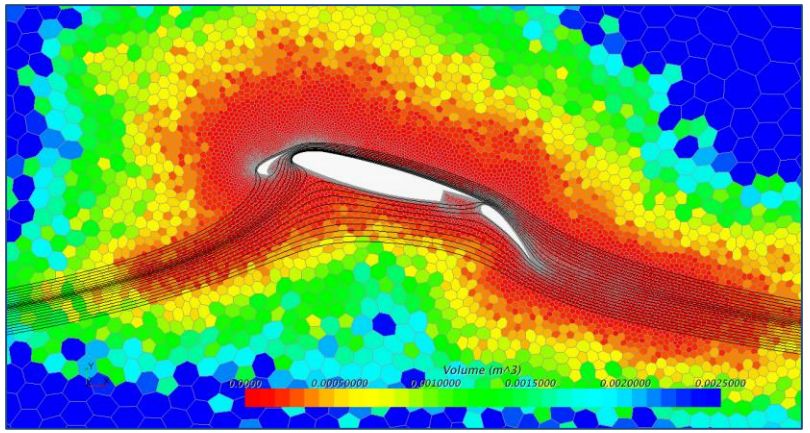
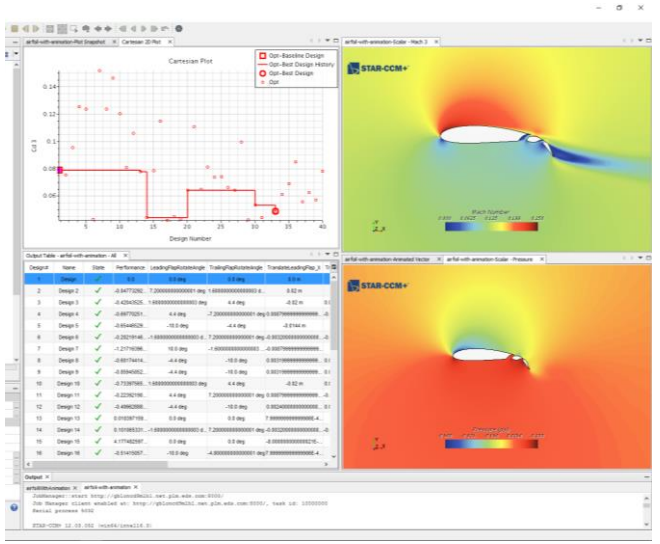
- Simcenter STAR-CCM+ 2020.3.1
- Density-based coupled-flow solver, with Grid Sequencing Initialisation, automated CFL control and dynamic explicit relaxation
- 2nd order discretization with Weiss-Smith Preconditioned Roe's Scheme for inviscid fluxes and Venkatakrishnan limiter
- Segregated SST k-ω turbulence model with compressibility correction and realizability enforced via limiting of eddy-viscosity
- Transition modelling:
  - $\gamma - Re_\theta$ based on Langtry 2006 & Langtry 2015 (cross-flow) with correlations based on Suluksna et al. 2008
  - γ based on Menter 2015 with cross-flow modification
- Mesh: Quad+Prism in 2D, Polyhedral+Prism in 3D





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Convergence

NLF(1)-0416, $\alpha = 0.0^o$, grid scale = 0.5

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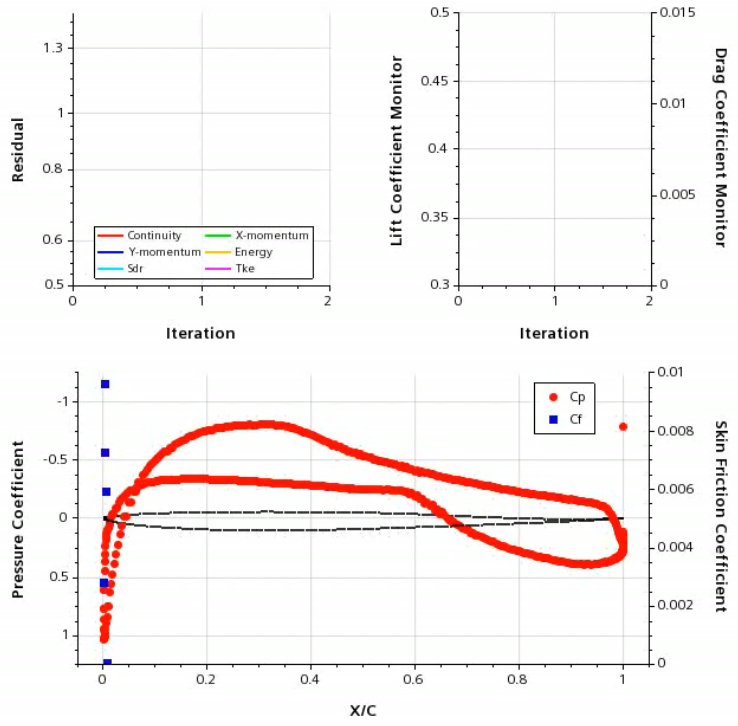
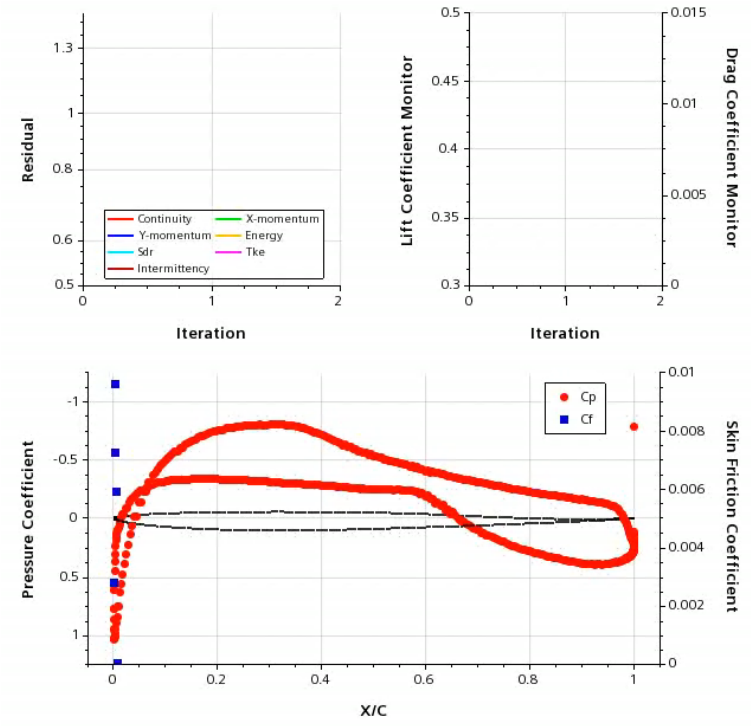
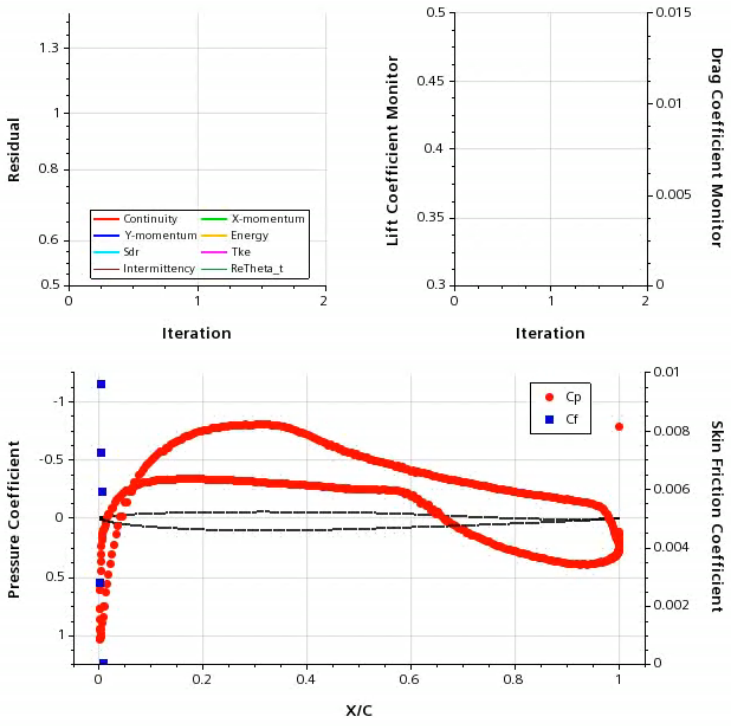
turbulent



γ transiton



$\gamma - Re_\theta$ transiton



- Transition severely affects the convergence rate
- Convergence is dominated by diffusion of the transition region

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Grid convergence
NLF(1)-0416

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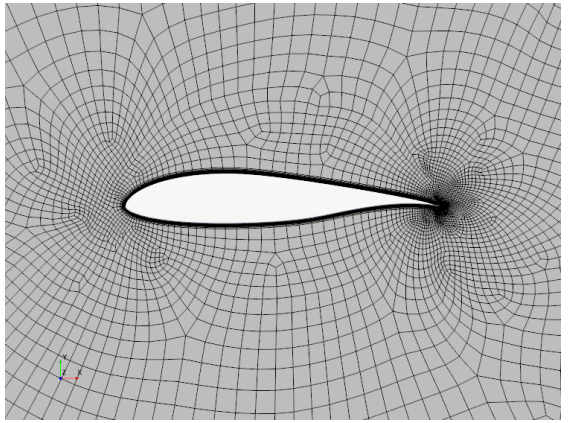
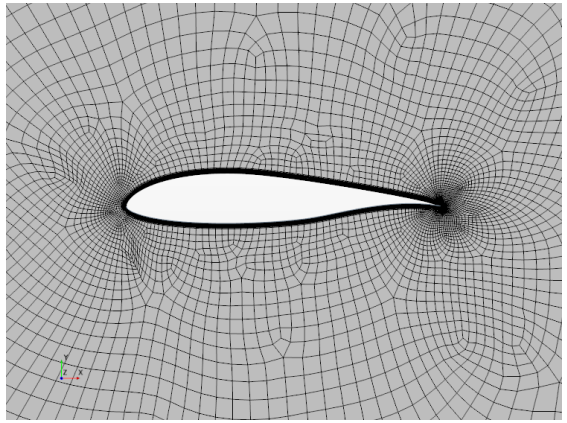
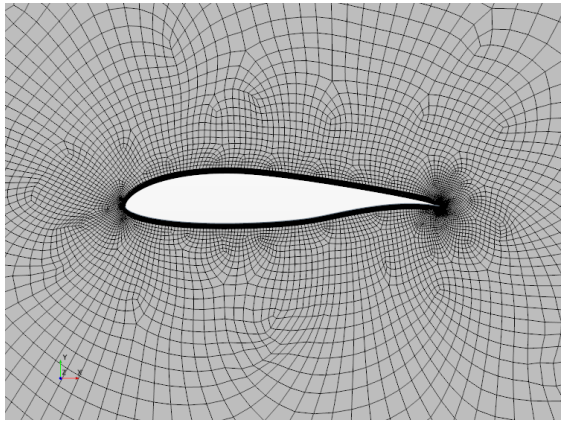
Grid Scale = 4.0



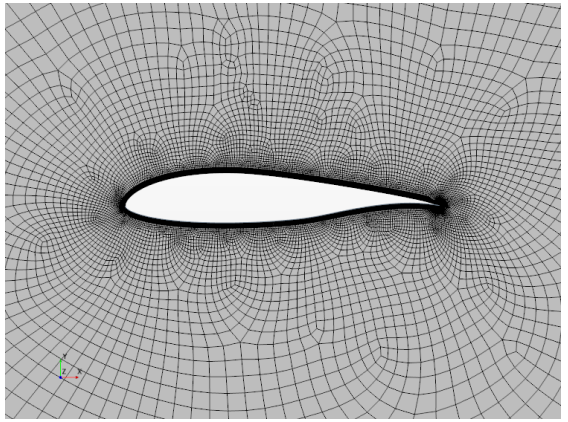
Grid Scale = 2.0



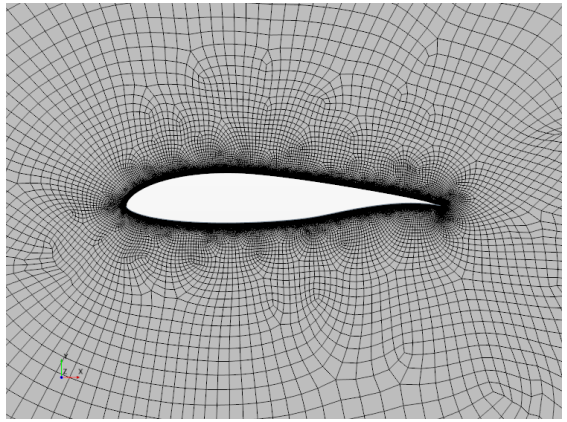
Grid Scale = 1.0



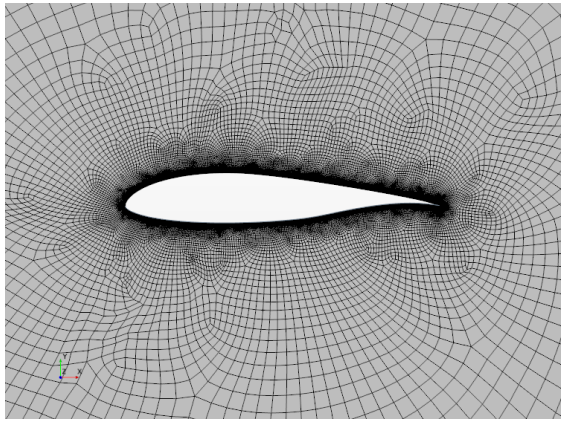
Grid Scale = 0.5



Grid Scale = 0.25



Grid Scale = 0.125



- BS = $0.01 \cdot c \cdot \boldsymbol{GridScale}$
- BL Parameters:
  - $\delta_0 = \frac{25\, c\, y_0^+}{Re} \boldsymbol{GridScale}$
  - $\delta_{tot} = 0.37 \cdot c \cdot Re^{-0.2}$
  - $\delta_N = \frac{\log(\delta_{tot}/\delta_0)(r-1)+1}{\log(r)}$
  - $r = 1.15,\ y_0^+ = 0.9$

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Grid convergence
NLF(1)-0416 - turbulent

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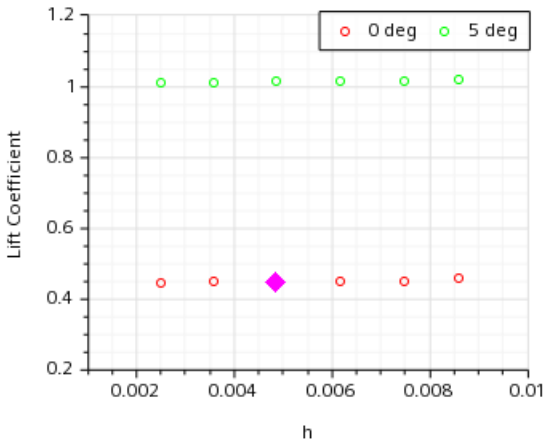

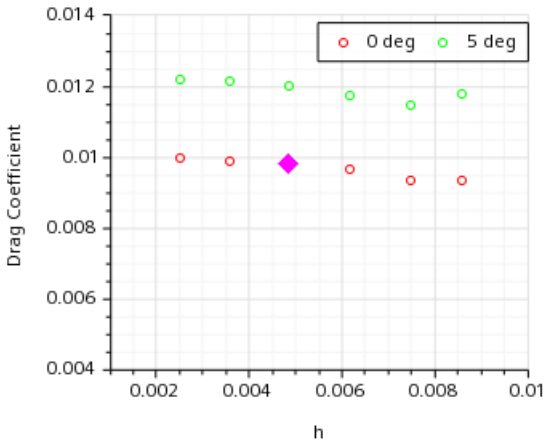

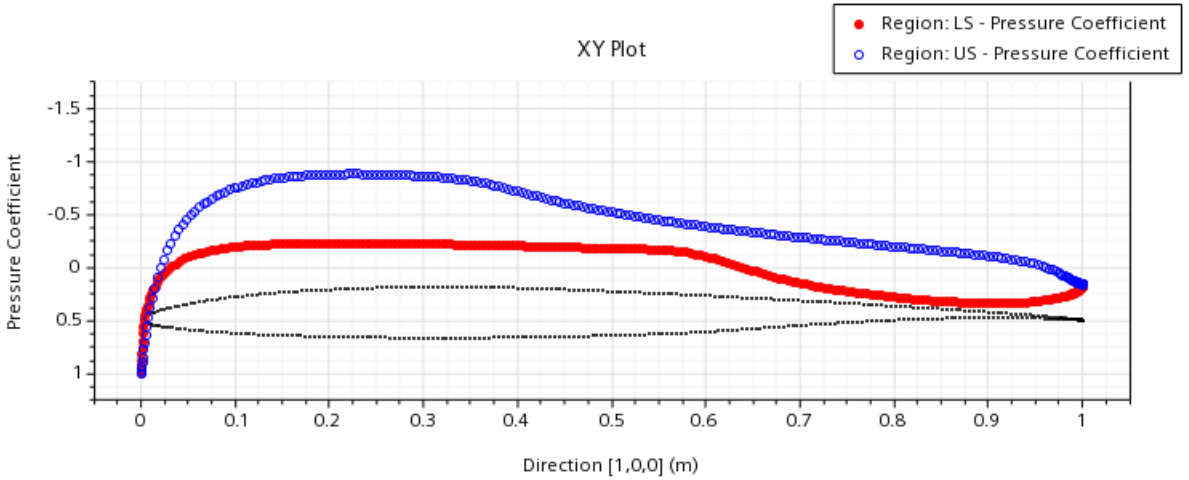

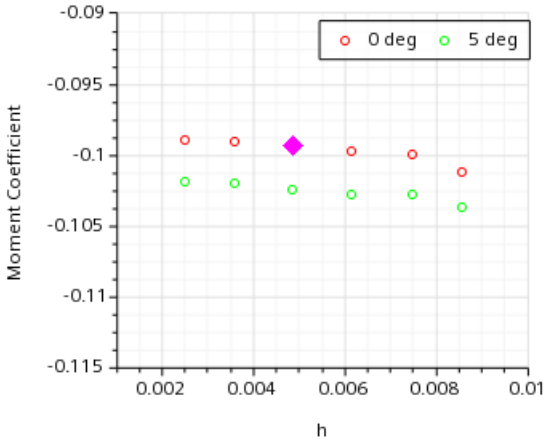

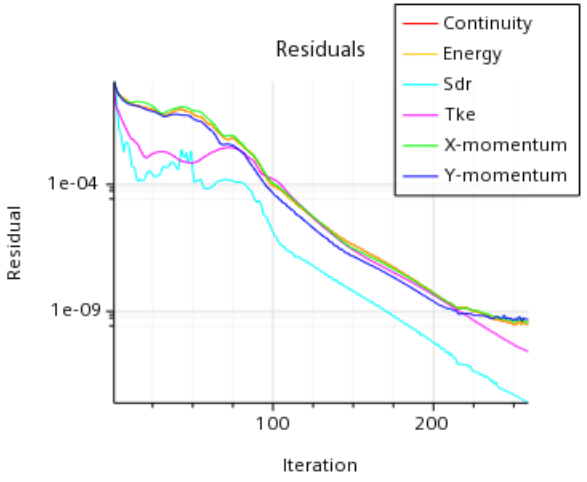

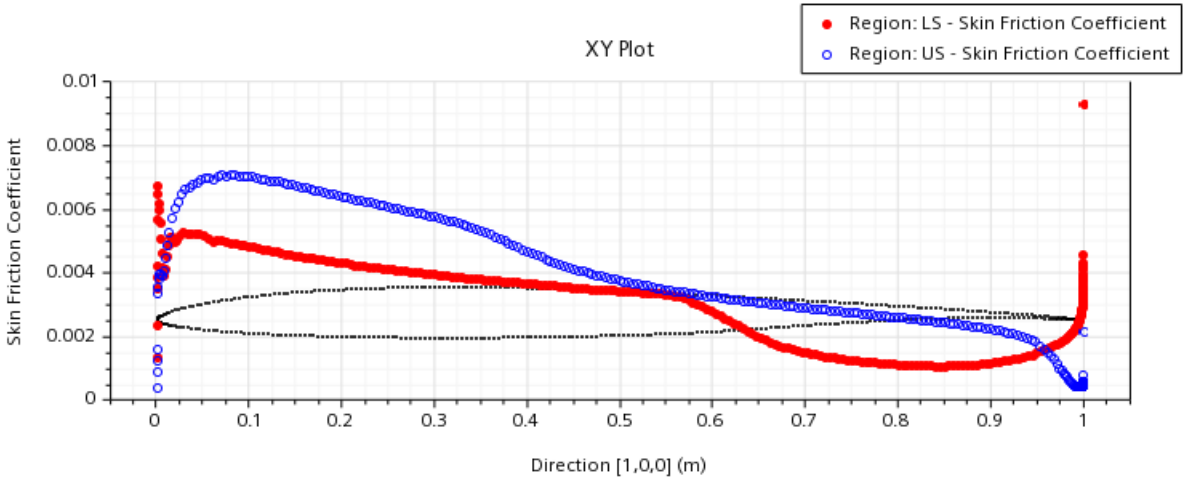

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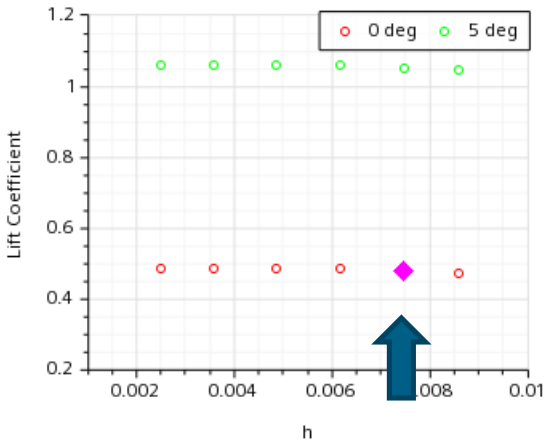
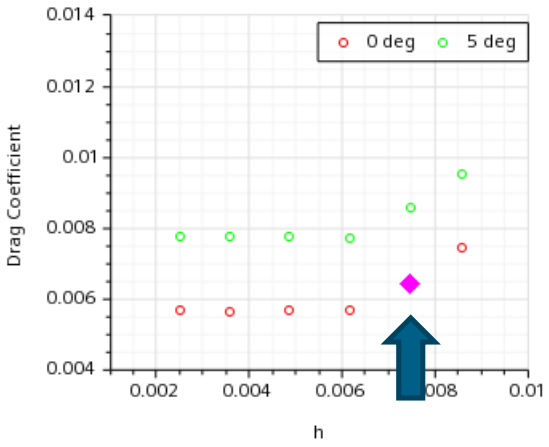
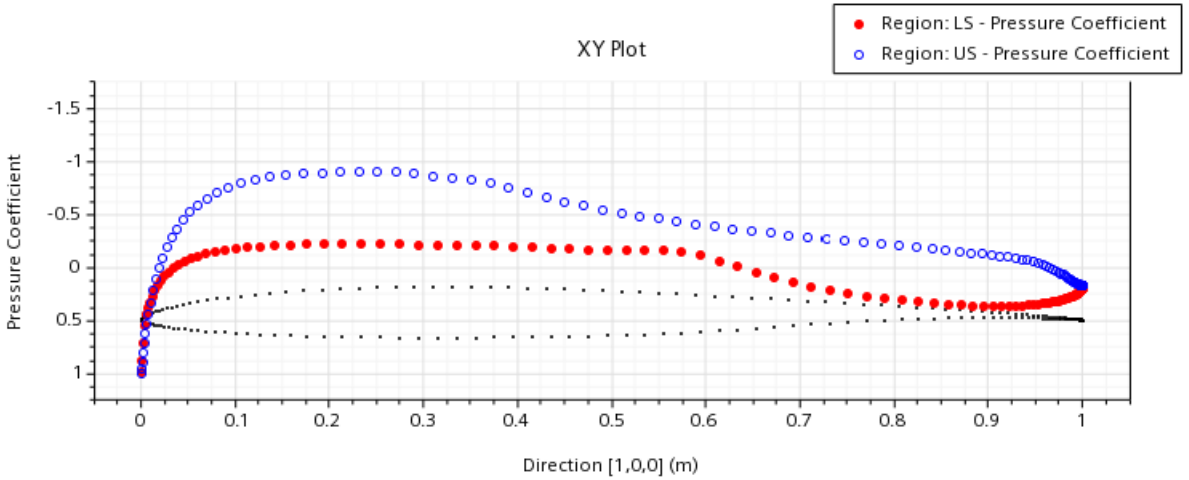
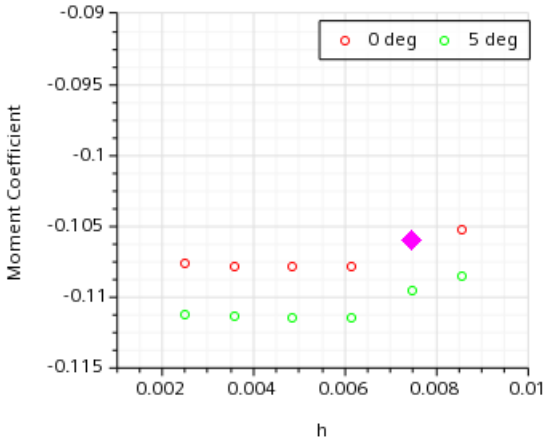
Grid convergence

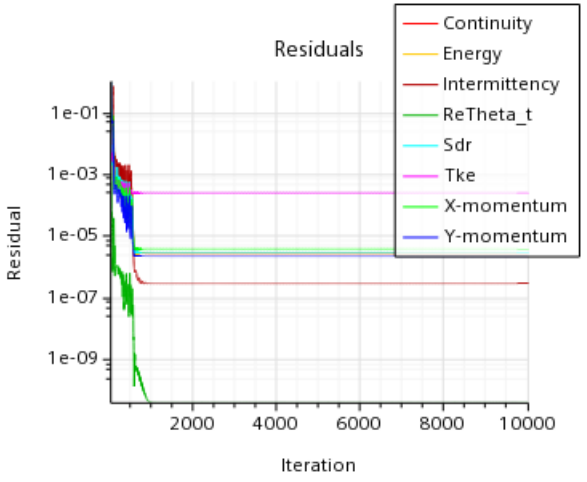
NLF(1)-0416 - $\gamma - Re_\theta$

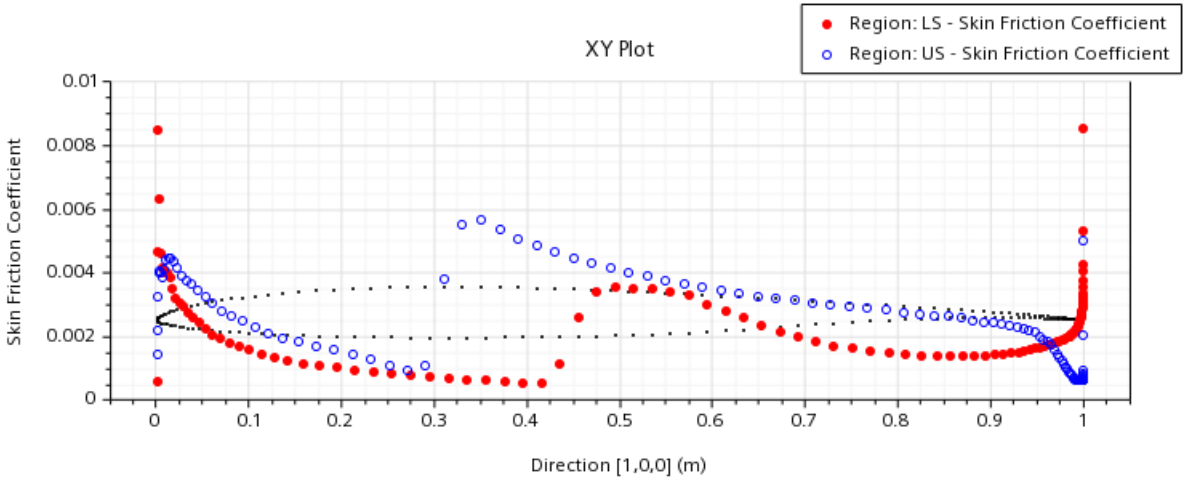












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Grid convergence

NLF(1)-0416 - $\gamma - Re_\theta$

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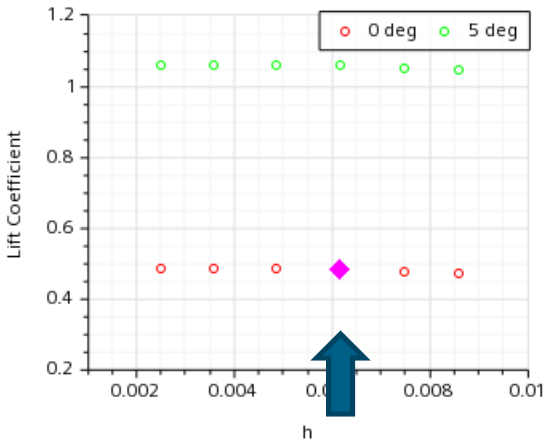

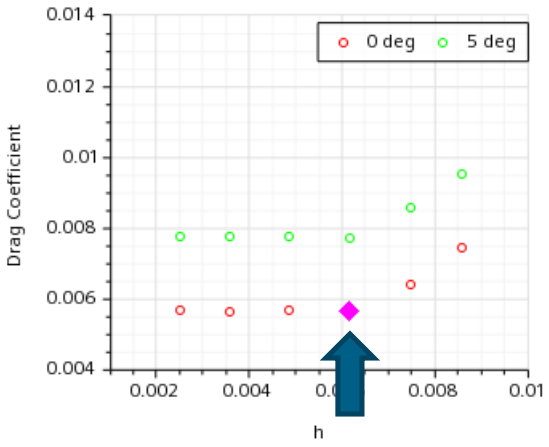

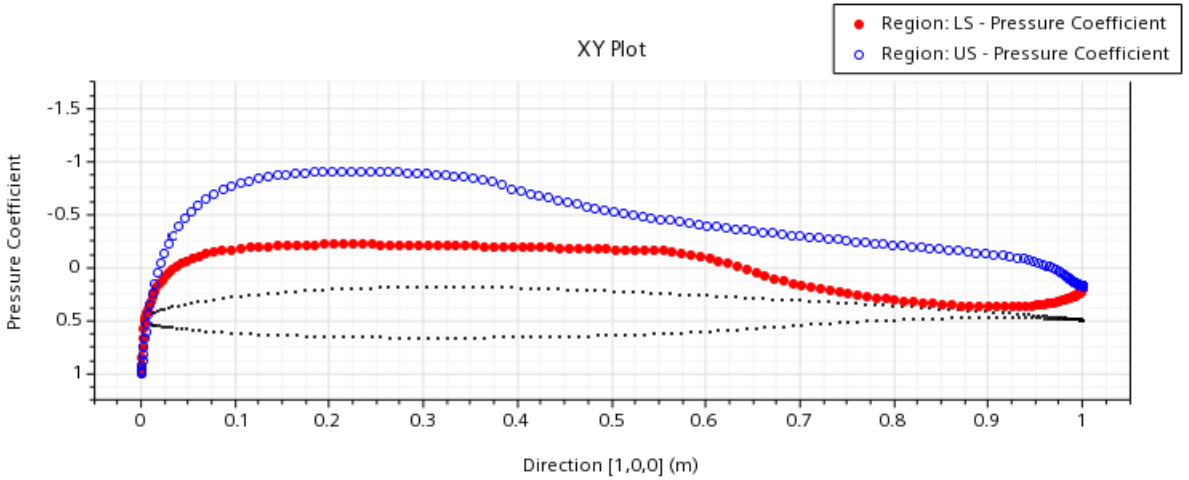

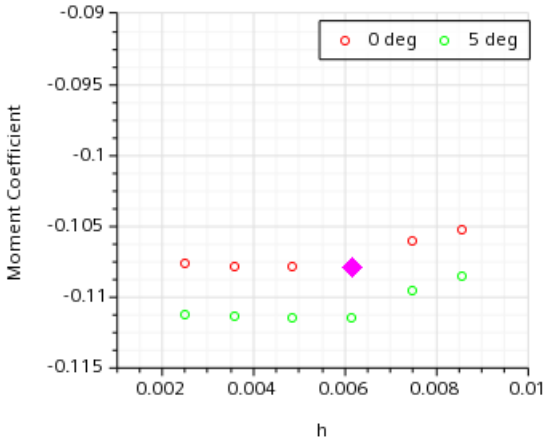

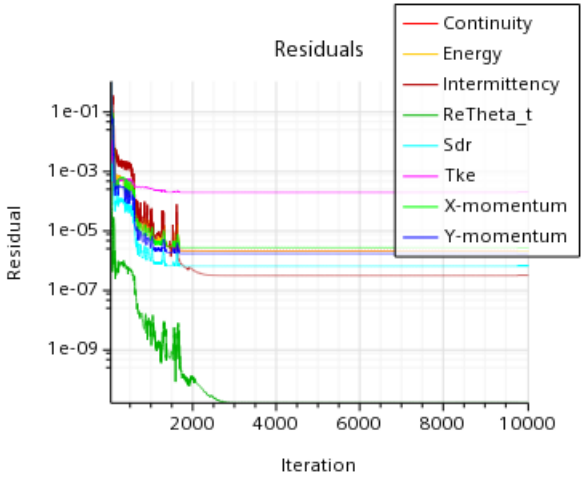

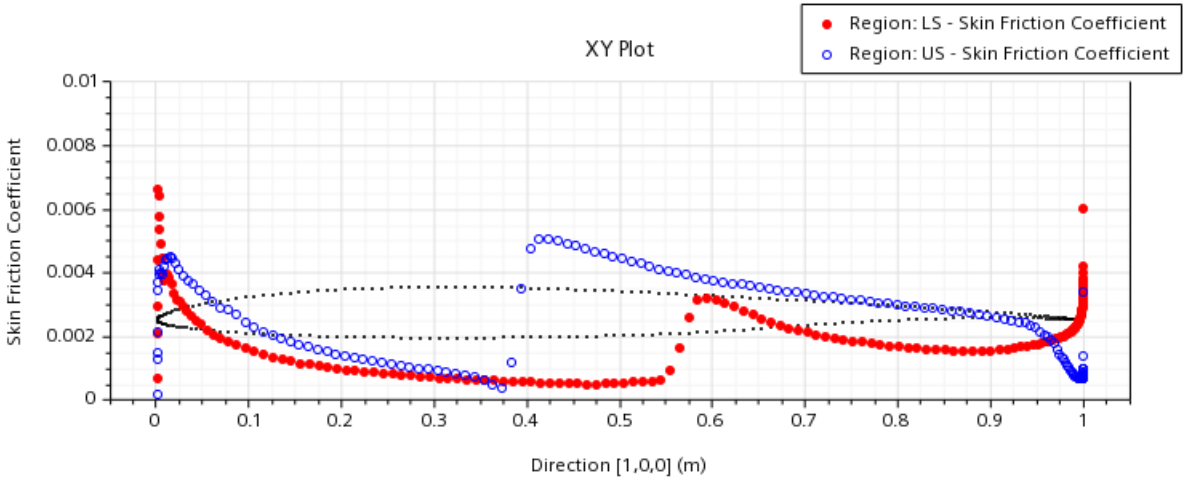

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Grid convergence

NLF(1)-0416 - $\gamma - Re_\theta$

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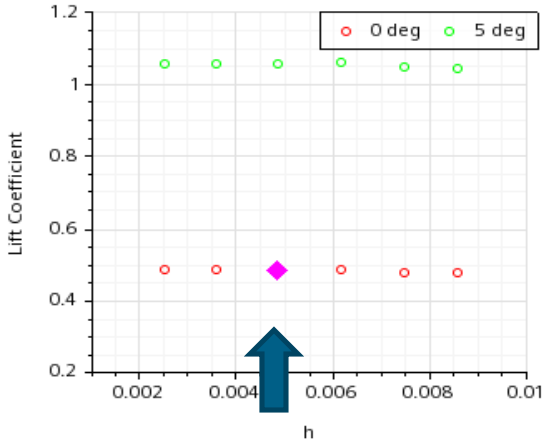

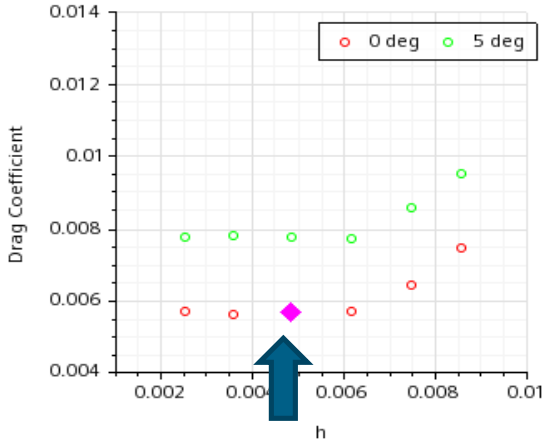

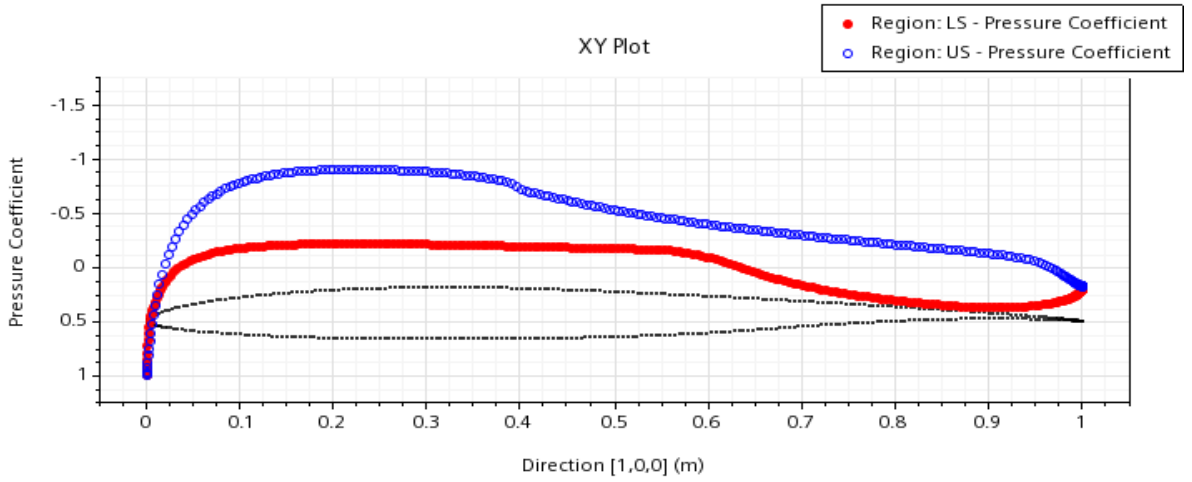

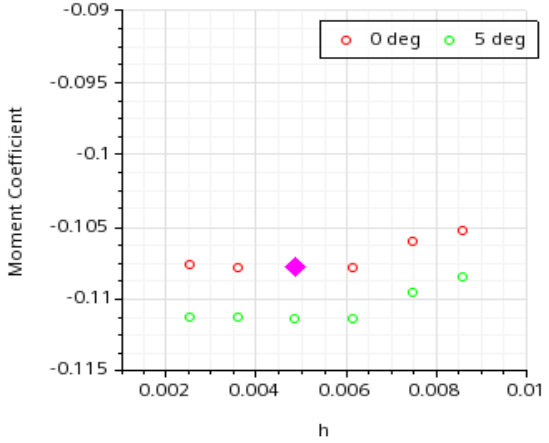

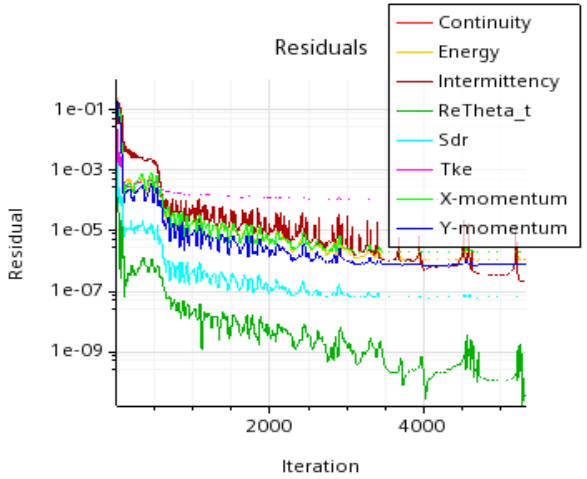

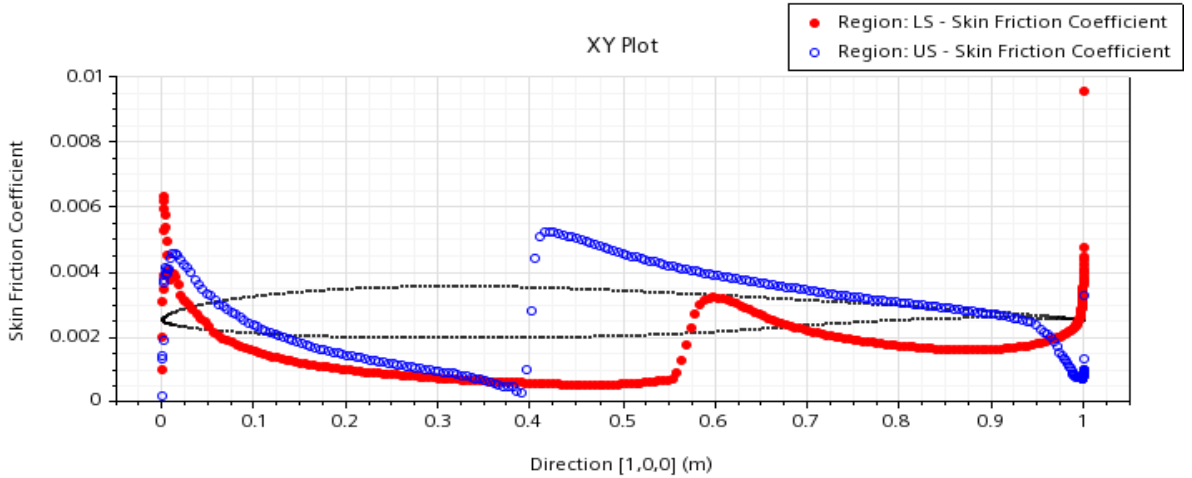

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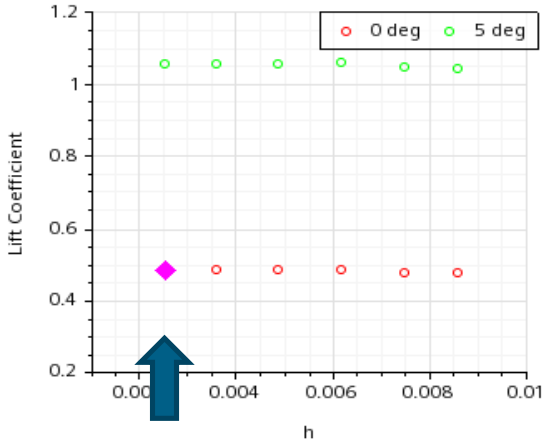

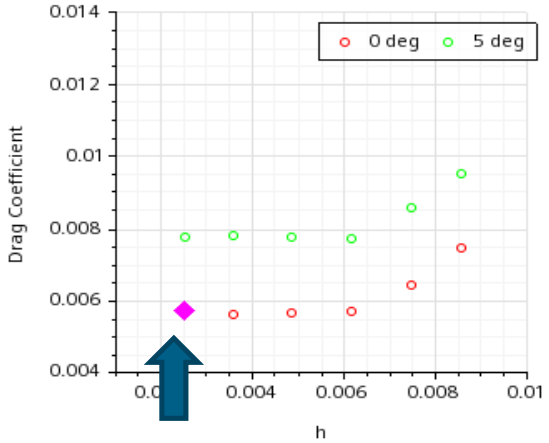

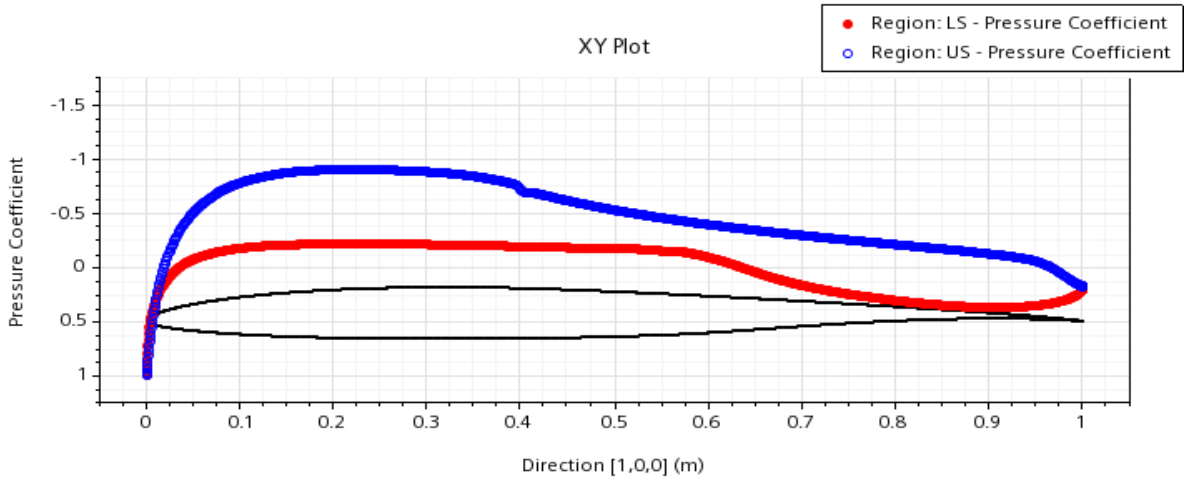

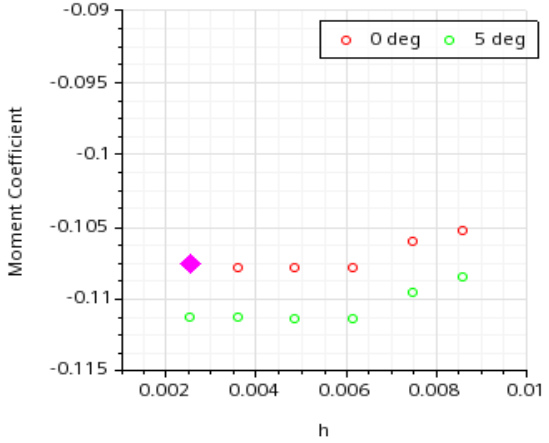

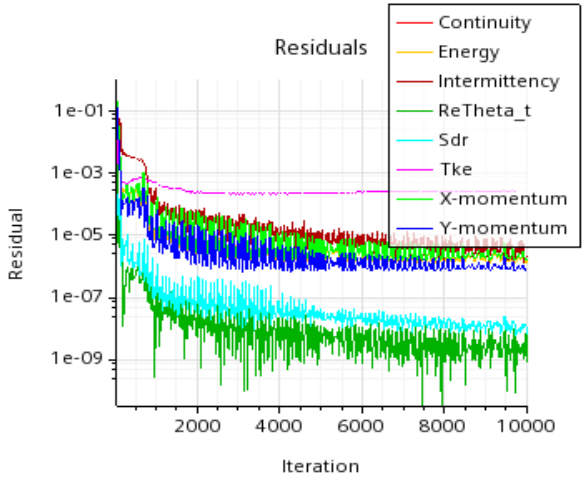

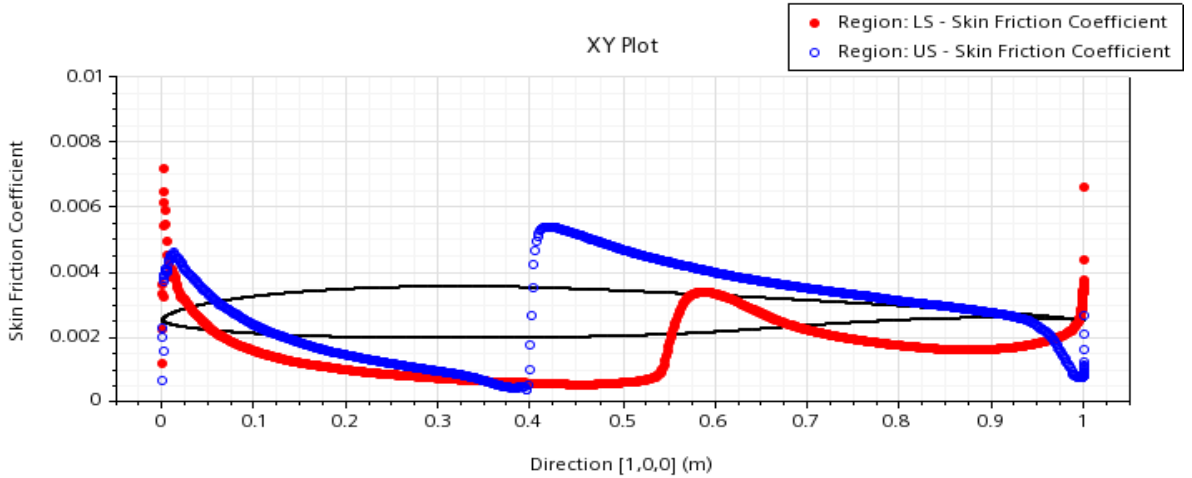

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Grid convergence
NLF(1)-0416 - γ

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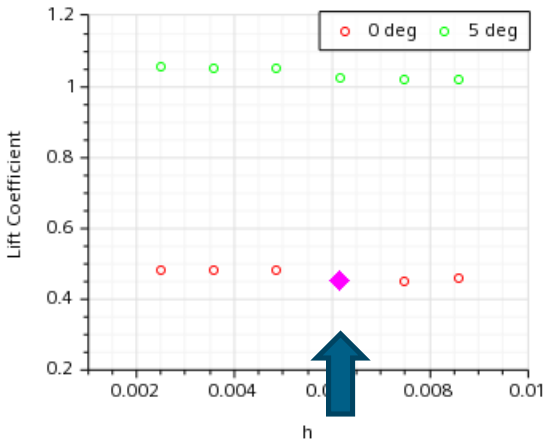

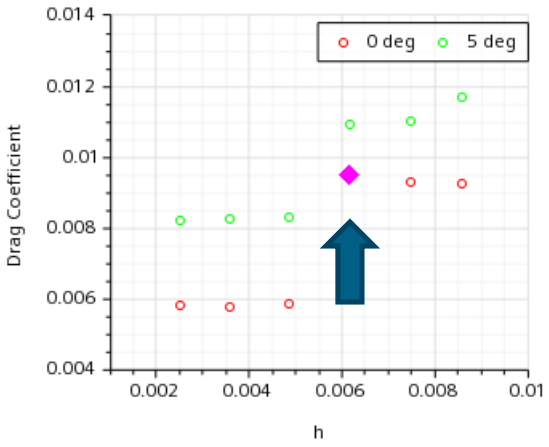

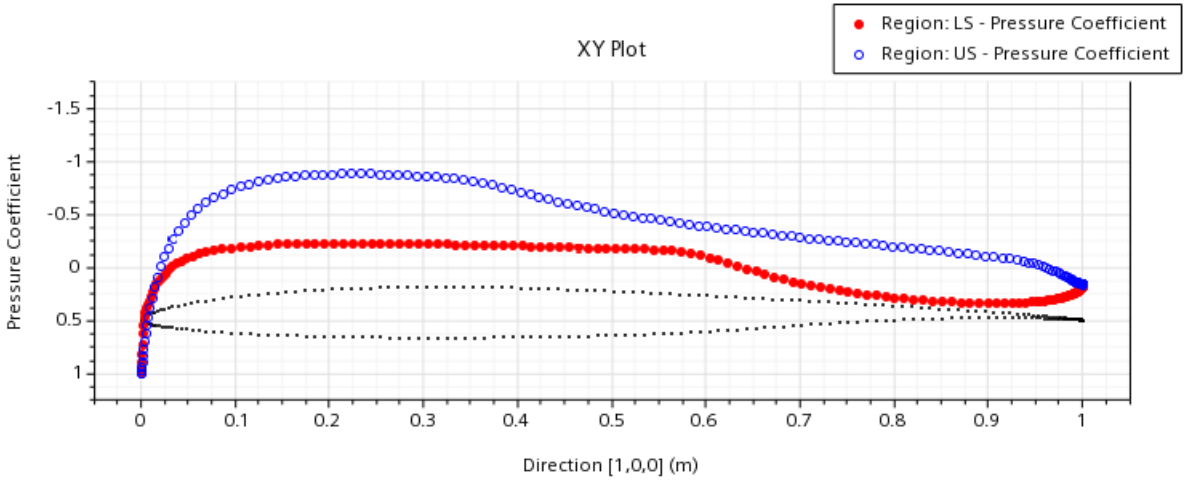

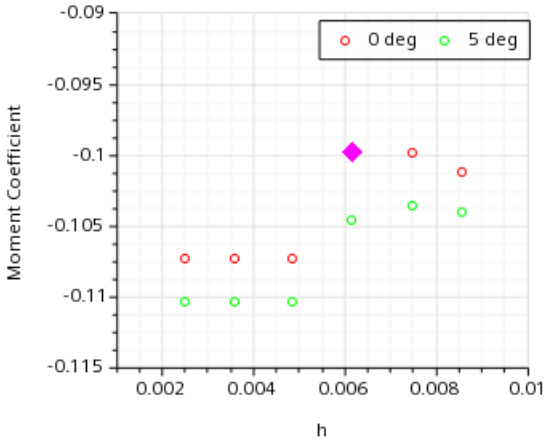

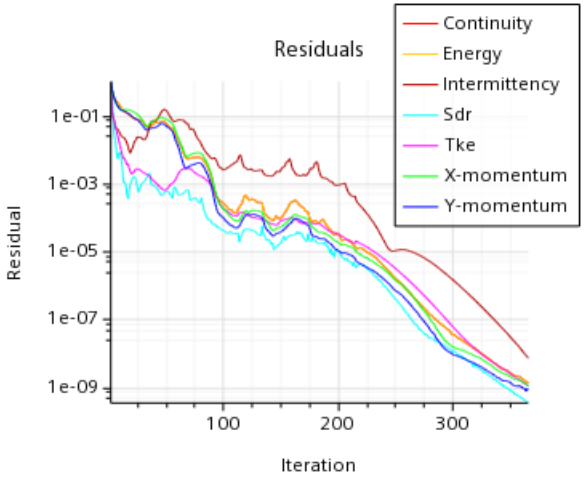

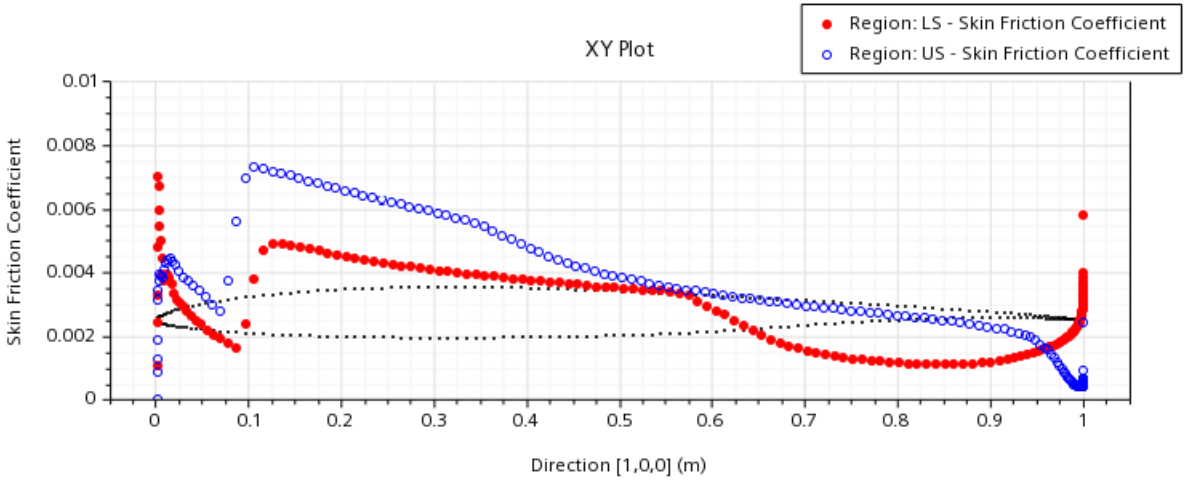

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Grid convergence
NLF(1)-0416 - γ

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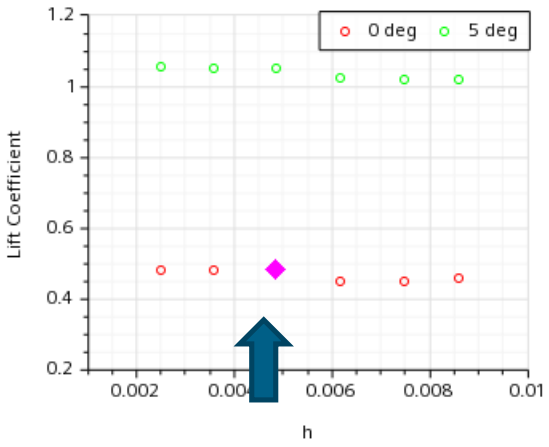

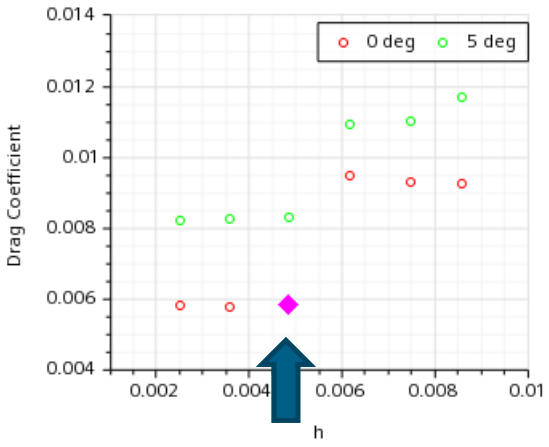

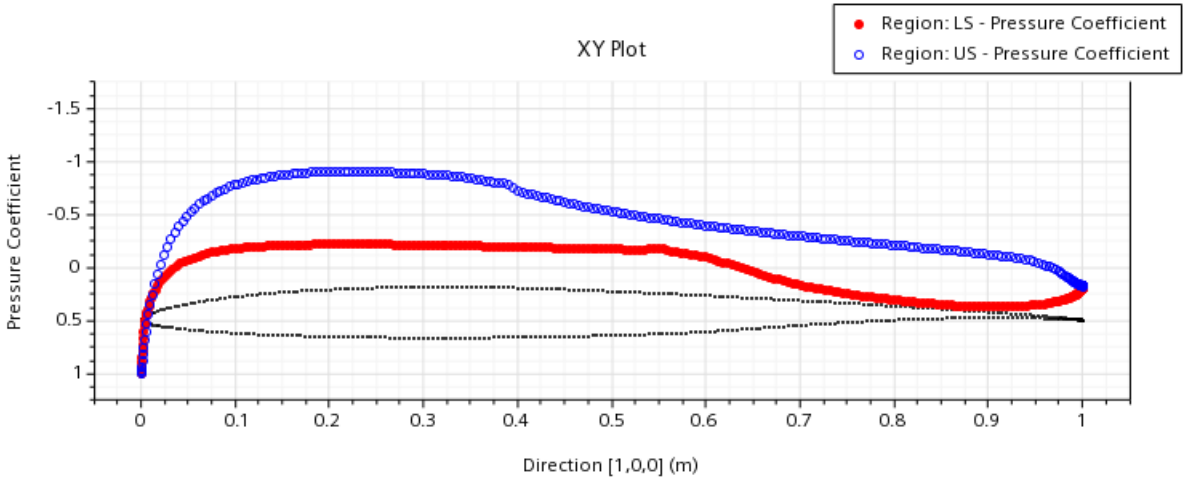

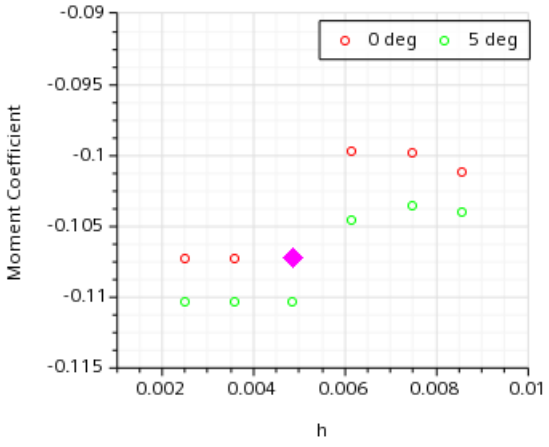

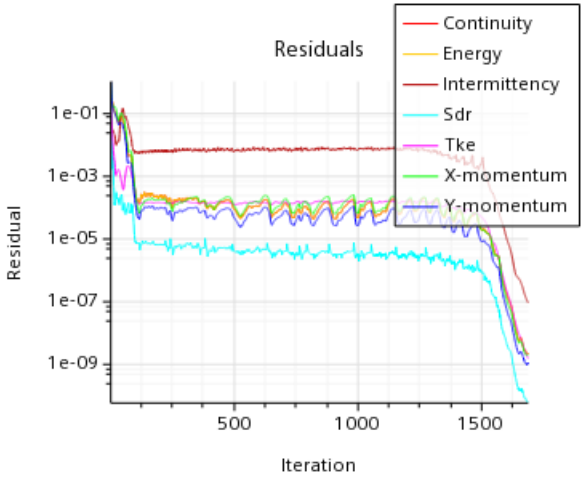

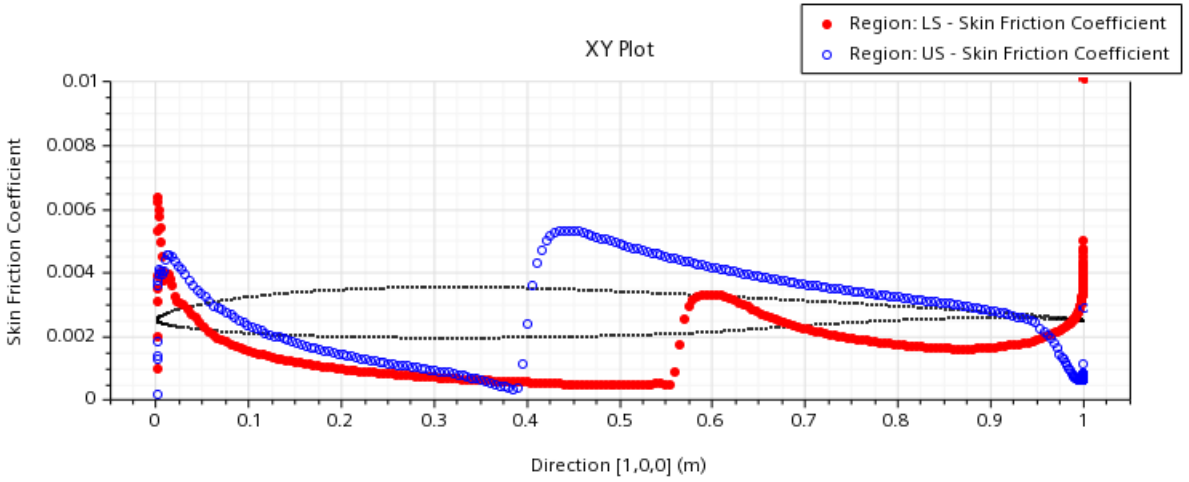

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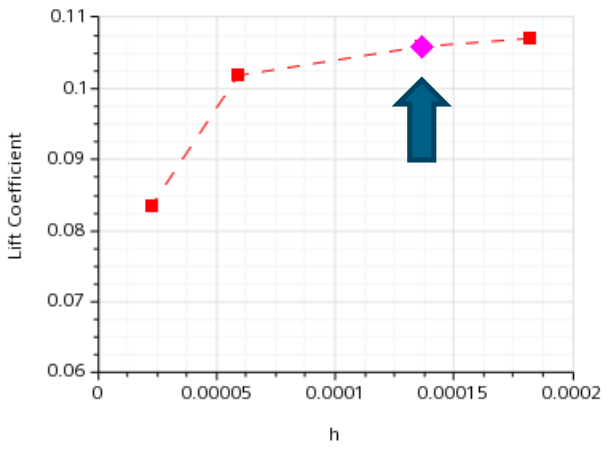
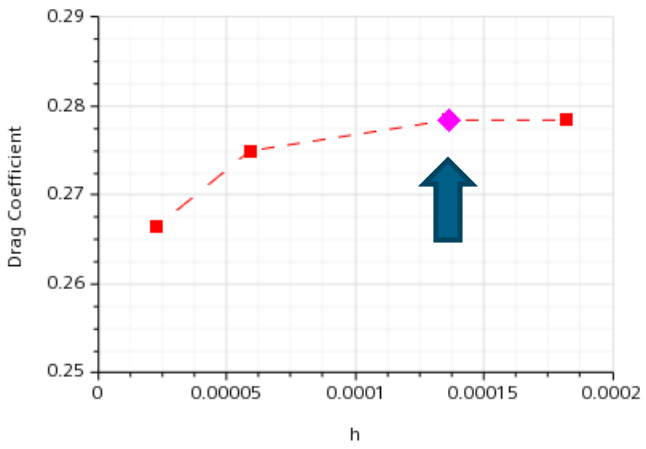
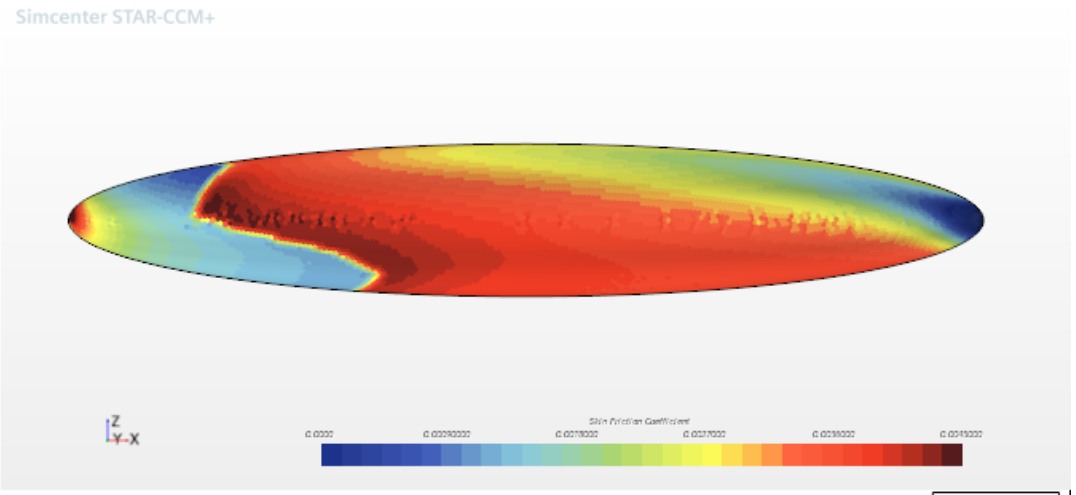
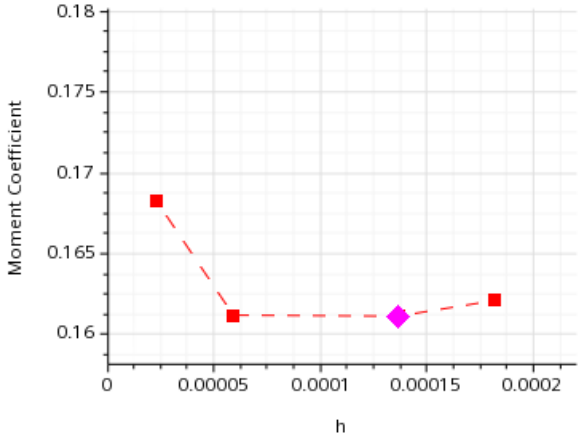
Grid convergence

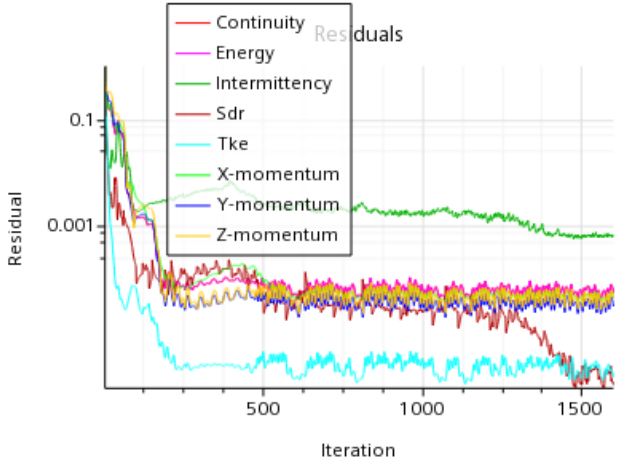
Prolate Spheroid - $\gamma + x-\text{flow}$

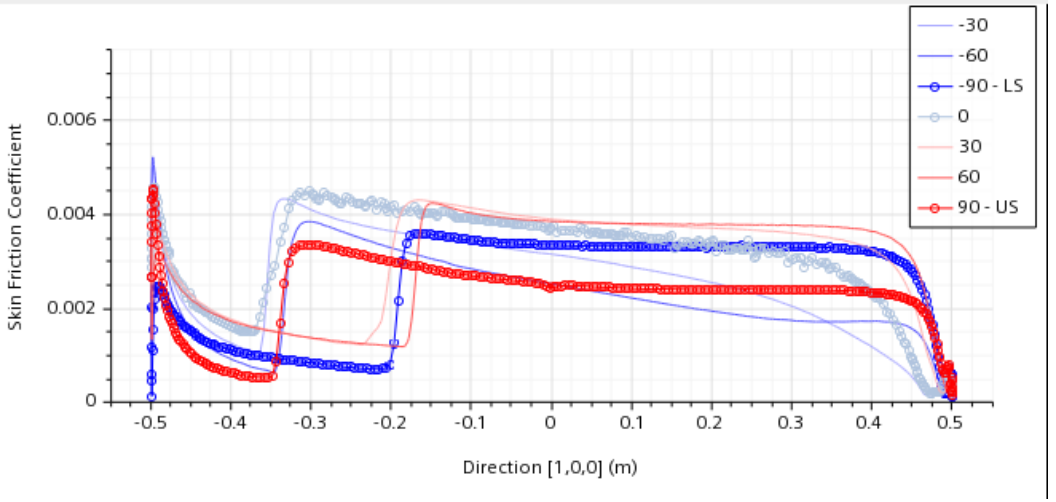












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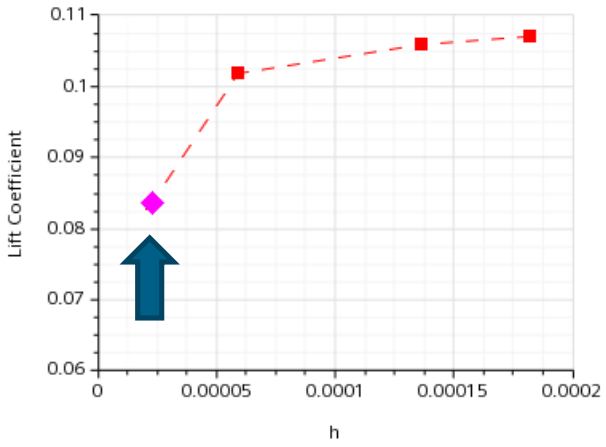
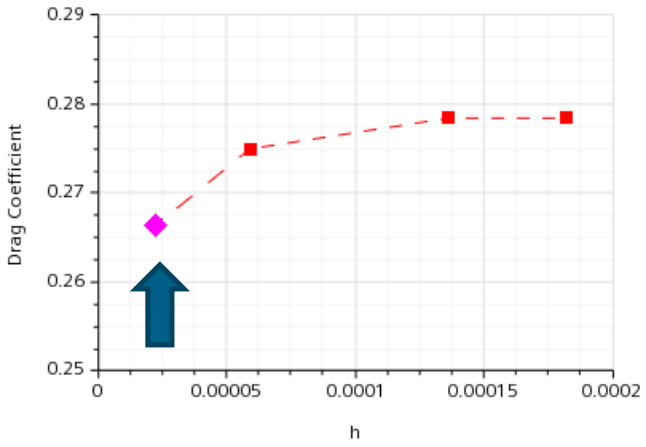
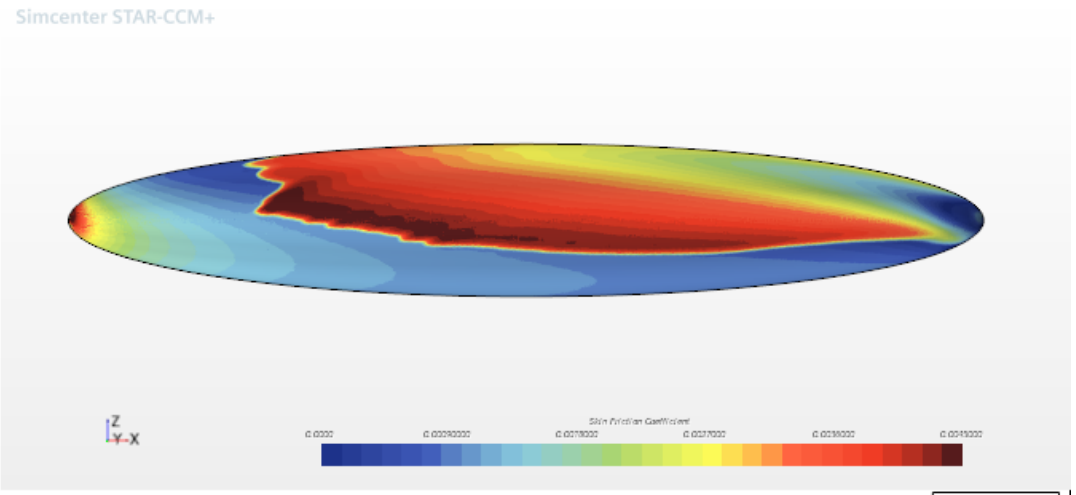
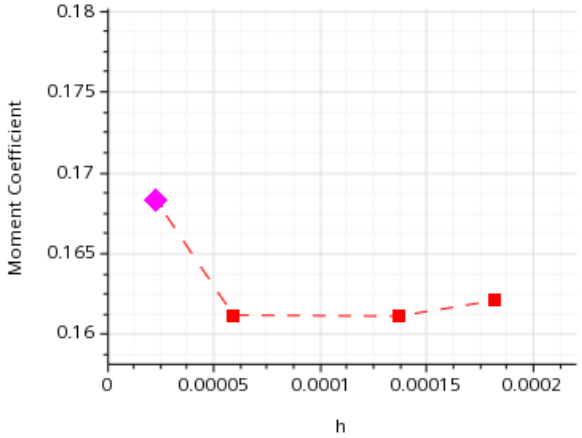
Grid convergence

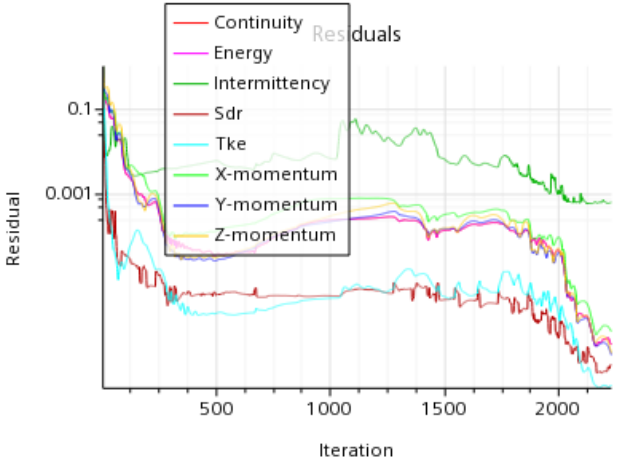
Prolate Spheroid - $\gamma + x-\text{flow}$

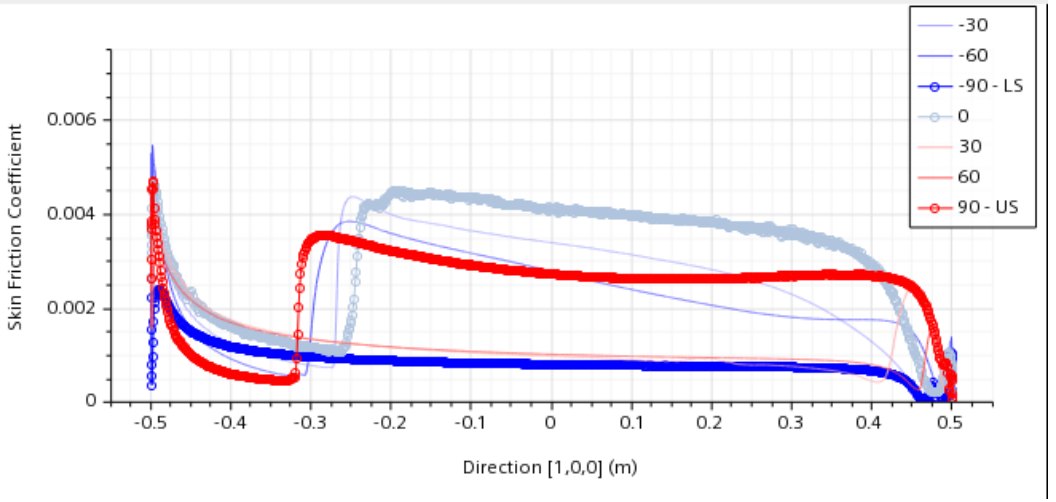












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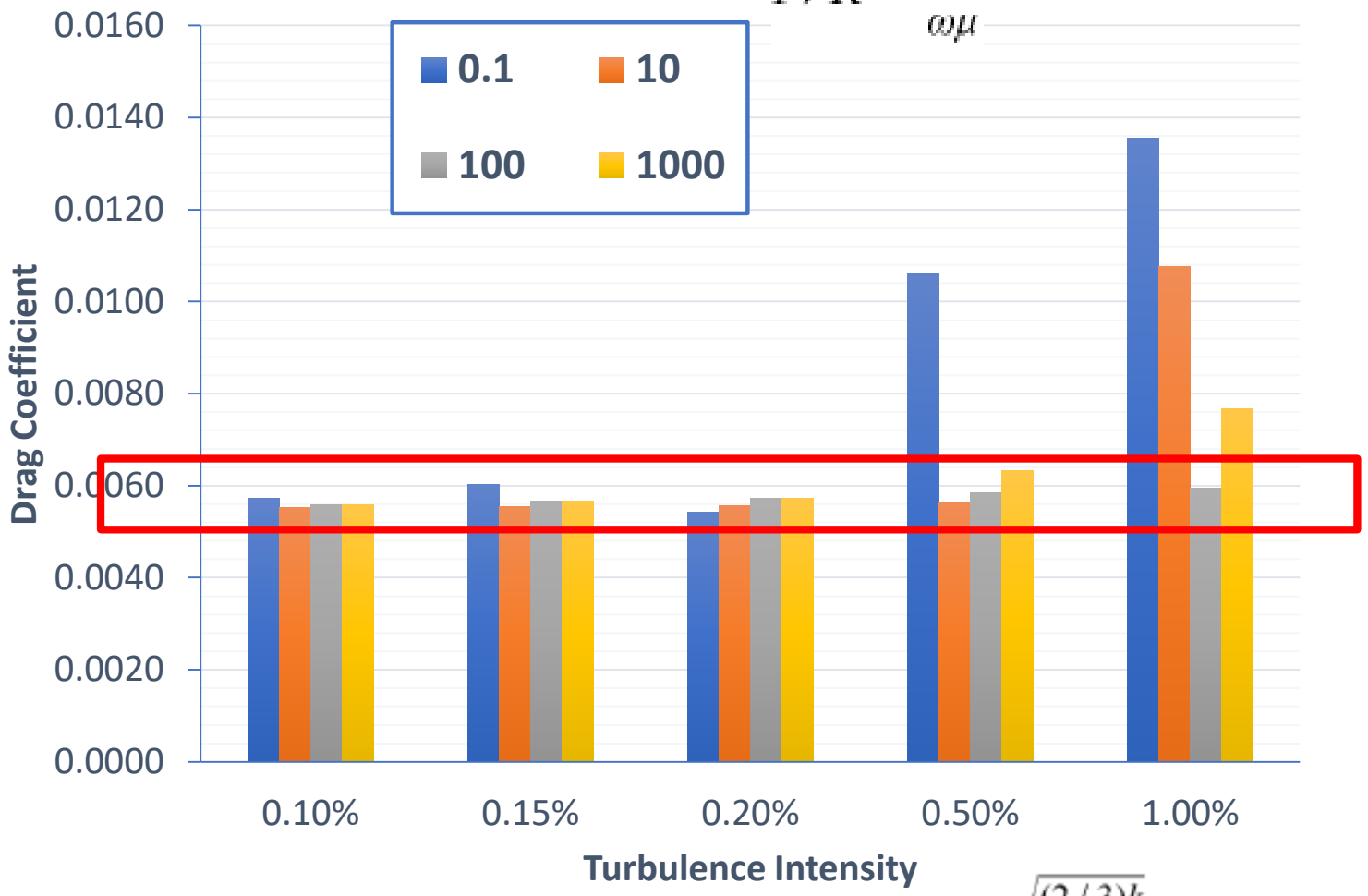
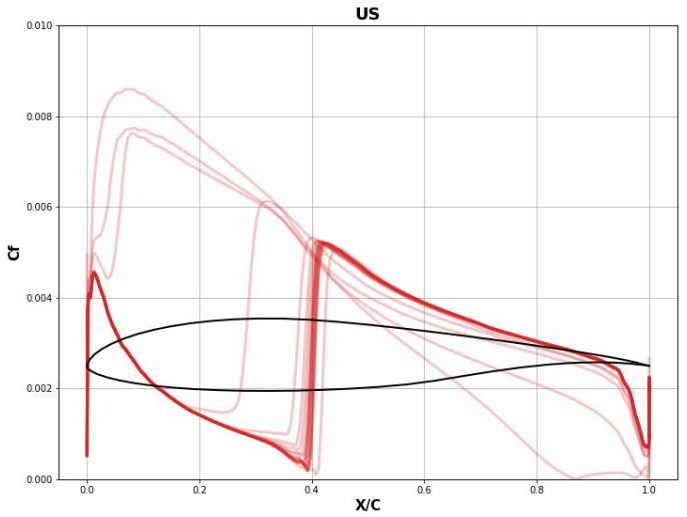
Boundary conditions

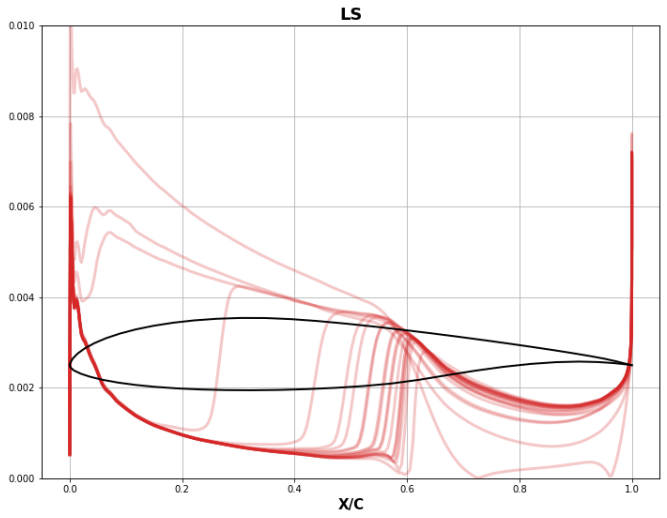
NLF(1)-0416 $\alpha = 0.0^o$ - $\gamma - Re_\theta$ with ambient turbulence

$$TVR = \frac{k}{\omega\mu}$$



$$I = \frac{\sqrt{(2/3)k}}{U}$$





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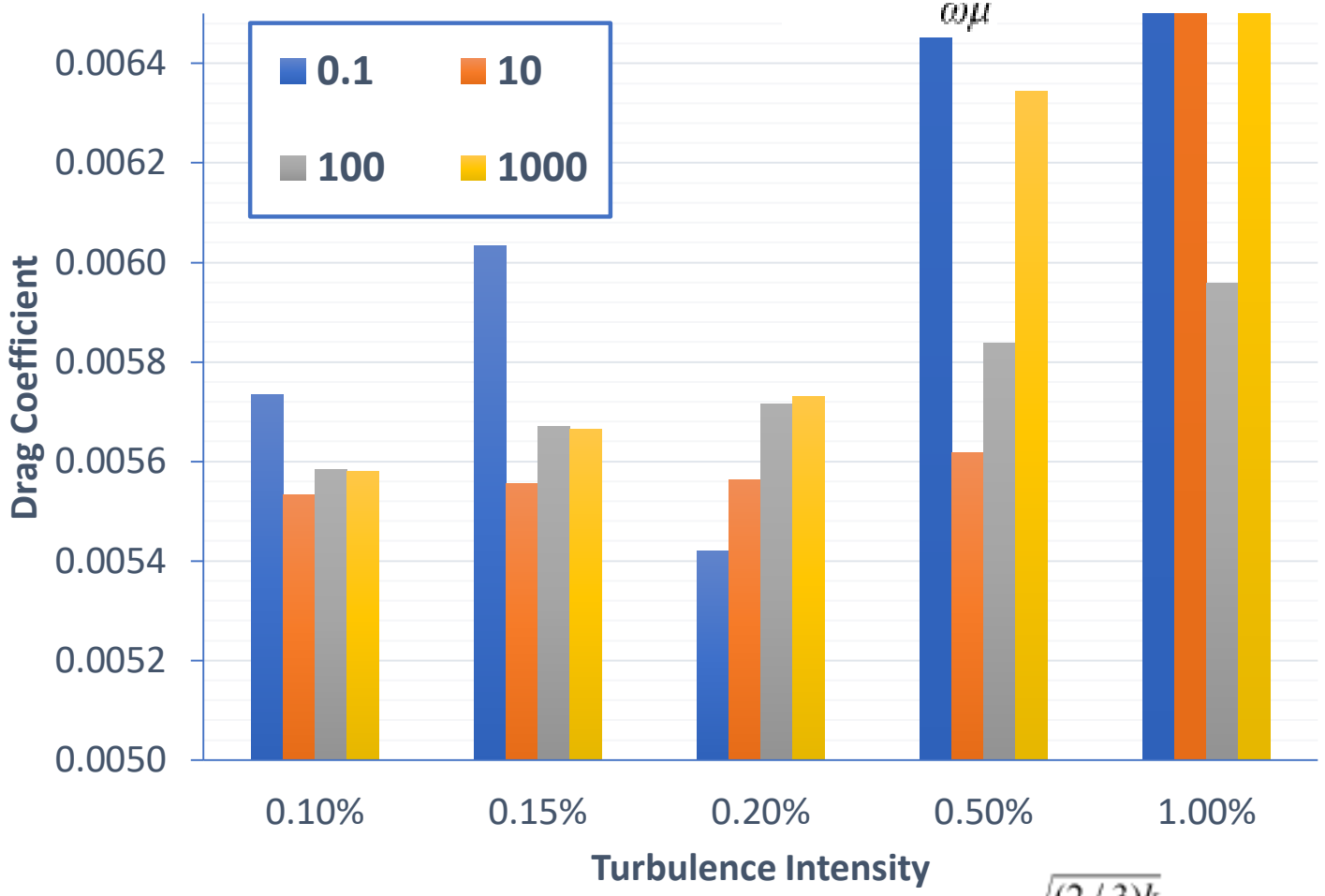
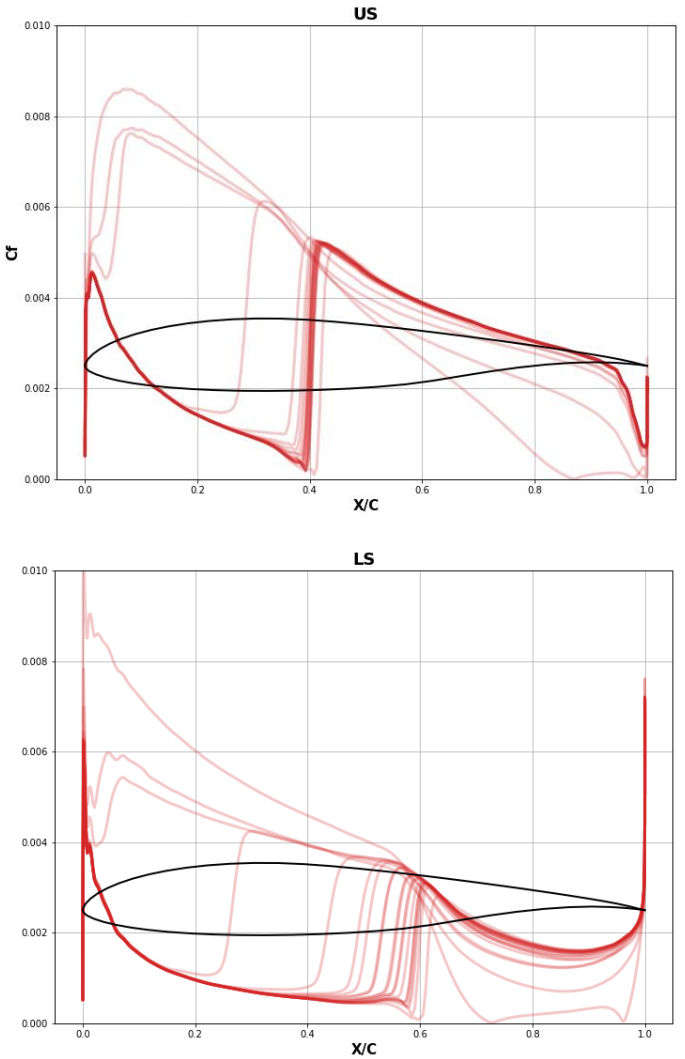
Boundary conditions

NLF(1)-0416 $\alpha = 0.0^o$ - $\gamma - Re_\theta$ with ambient turbulence

$$TVR = \frac{k}{\omega\mu}$$



$$I = \frac{\sqrt{(2/3)k}}{U}$$



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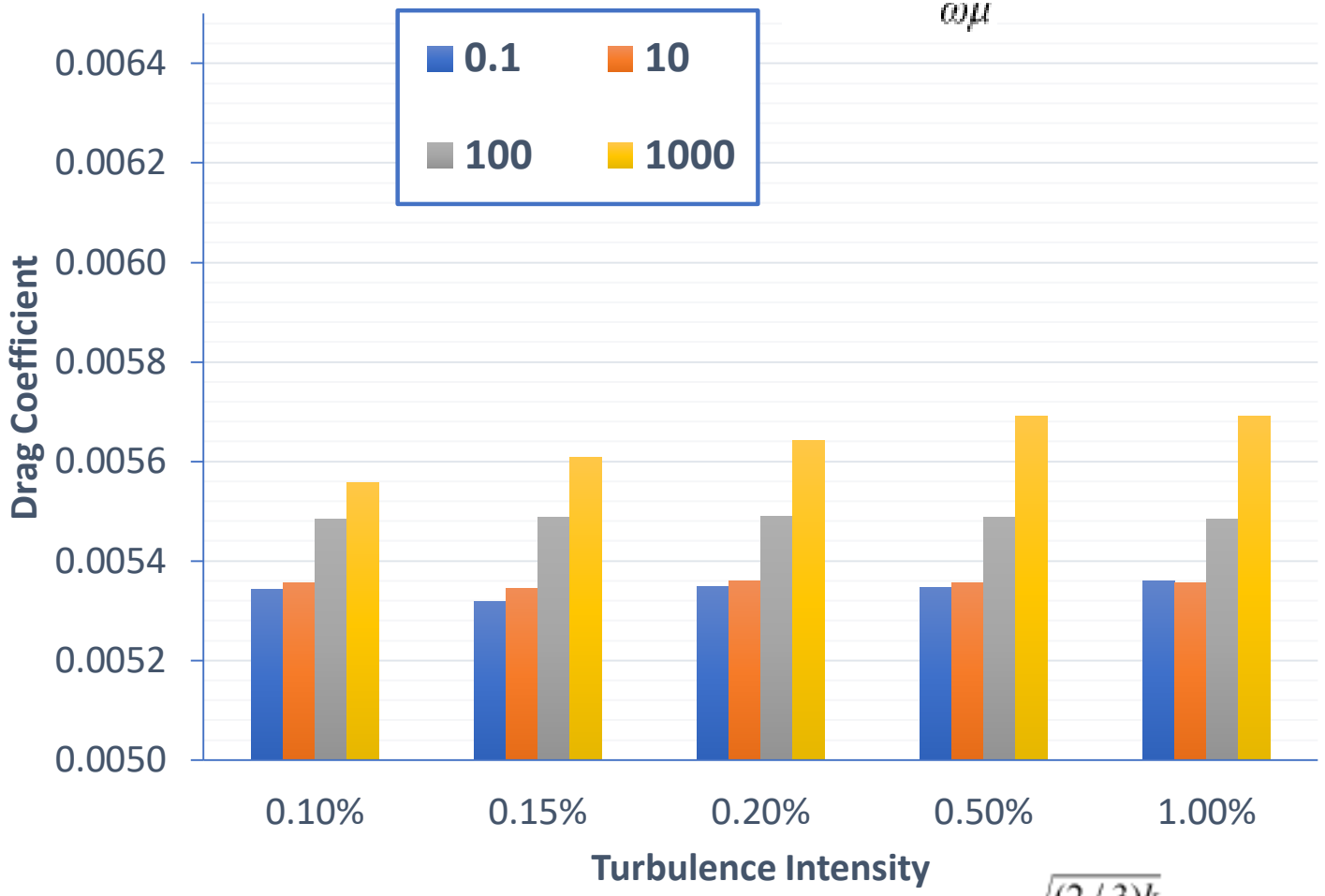
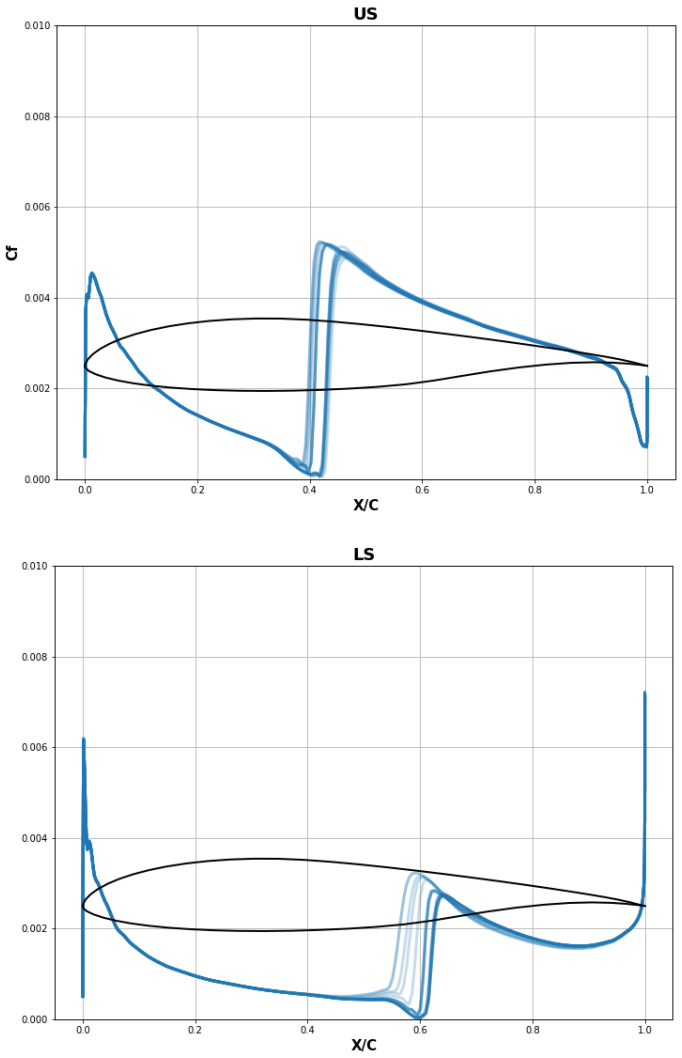
Boundary conditions

NLF(1)-0416 $\alpha = 0.0^o$ - $\gamma - Re_\theta$ natural turbulence decay

$$TVR = \frac{k}{\omega\mu}$$



$$I = \frac{\sqrt{(2/3)k}}{U}$$



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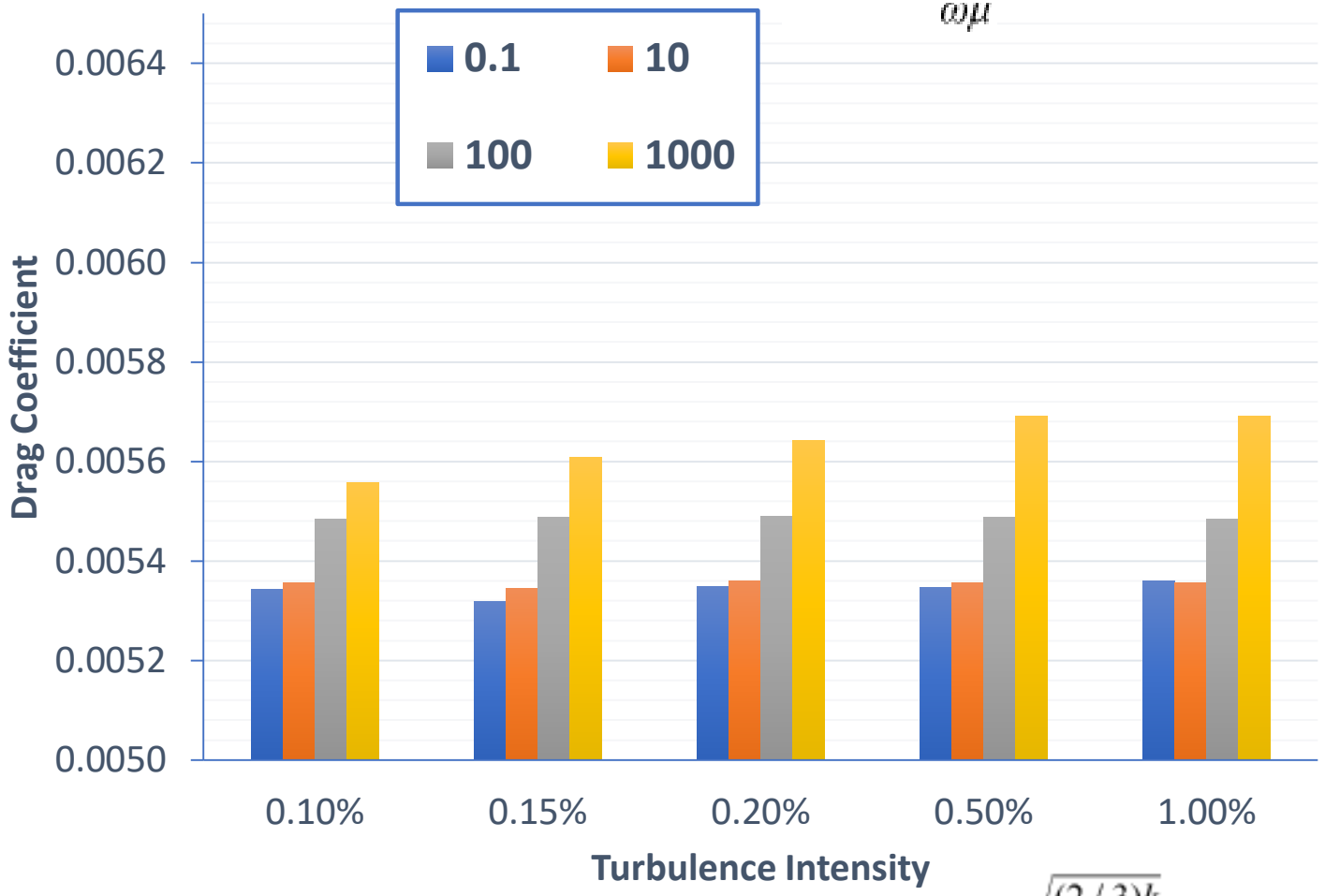
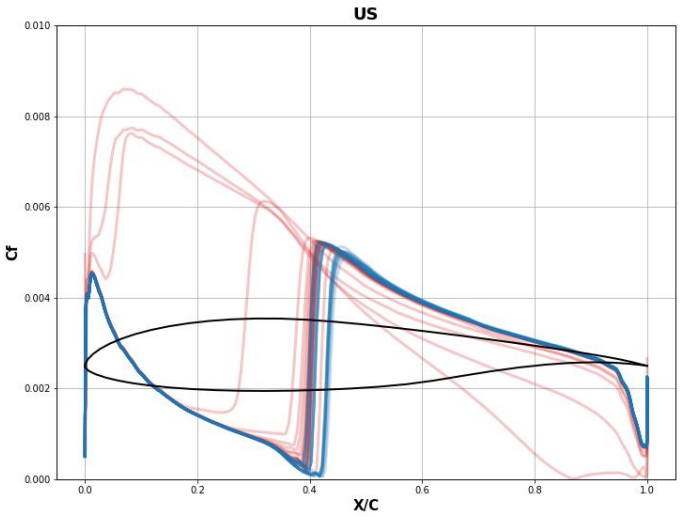
Boundary conditions

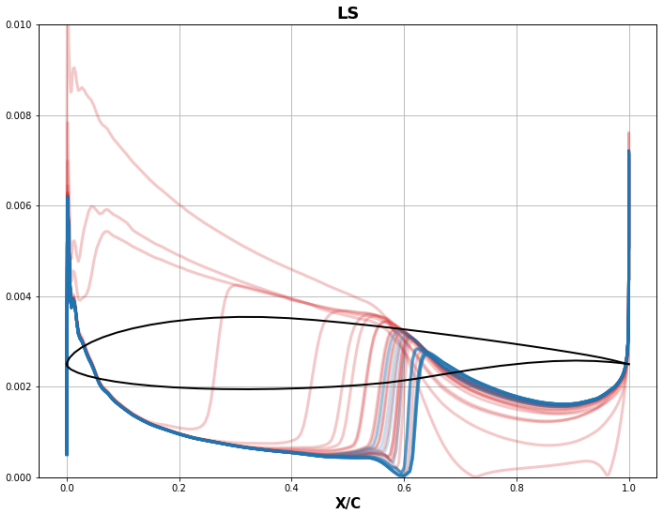
NLF(1)-0416 $\alpha = 0.0^o$ - $\gamma - Re_\theta$ natural turbulence decay

$$TVR = \frac{k}{\omega\mu}$$



$$I = \frac{\sqrt{(2/3)k}}{U}$$





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Determining transition location
#1 - Flat plate

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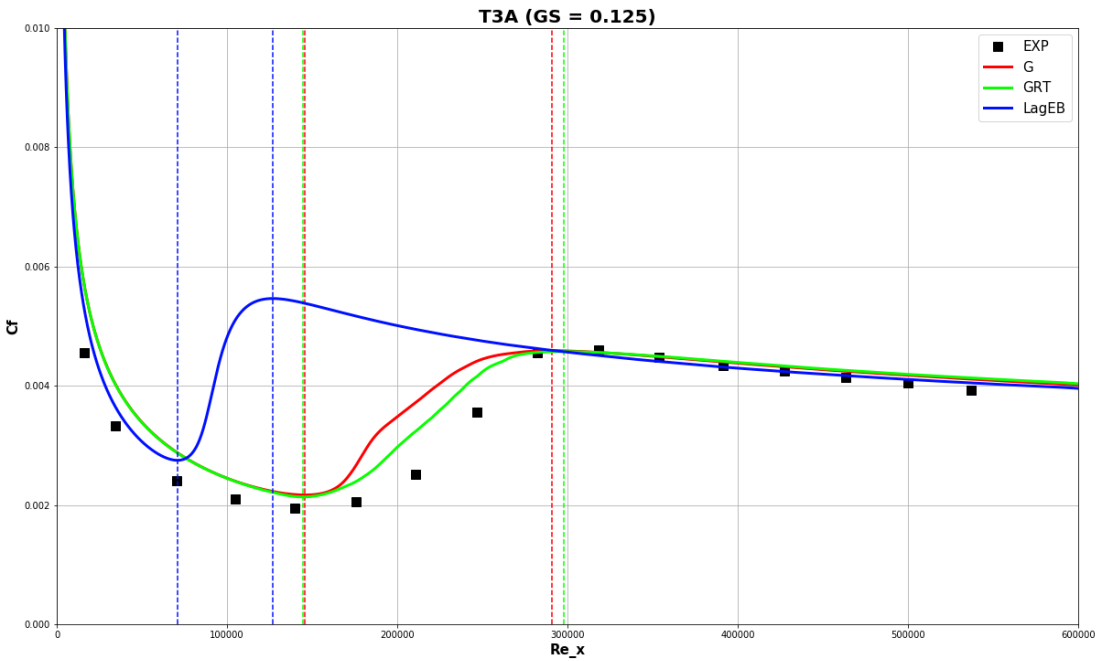
- Assumptions:
  - C_f is monotonically decreasing along the length of the plate
  - Change of gradient sign indicates the start-end of transition
- Algorithm:

```
Extract relevant data (25 000 < Re_x < 500 000)

Smooth data & interpolate onto uniform grid
[25 000 : 500 : 500 000]

Compute the dCf/dRe_x

Find Re_x where dCf/dRe_x changes sign
```



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Determining transition location
#2 – General Case

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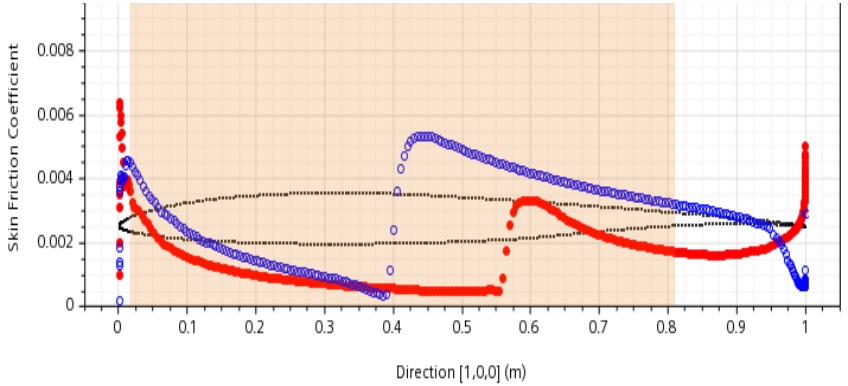
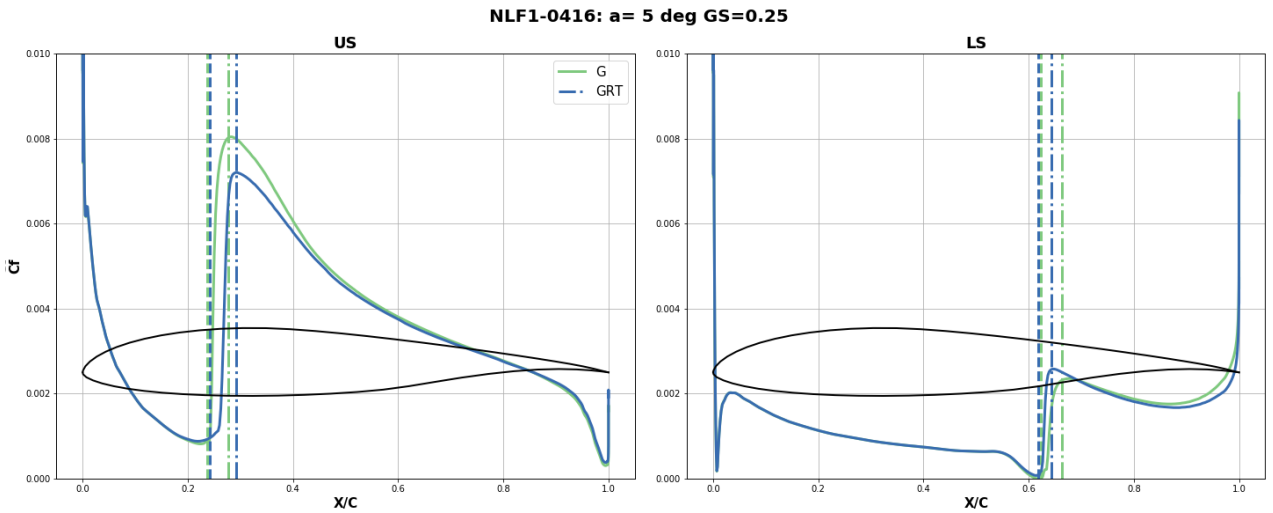
Ingenuity for life

- Assumptions:
  - ~~C_f is monotonically decreasing~~
  - dC_f/dx is highest in the transition region
- Algorithm:

```
Extract relevant data (0.025 < x/c < 0.80)

Smooth data & interpolate onto uniform grid
with dx = 0.005

Compute the dCf/dx

Find max dCf/dx location

Loop forward/backward:
  dcf1dcf2 = dcf[i] * dcf[i+1]
  if (dfc1dcf2 < 0 or abs(dfc1dcf2) < 1e-4):
    transition = 0.5 * x[i] * x[i+1]
```





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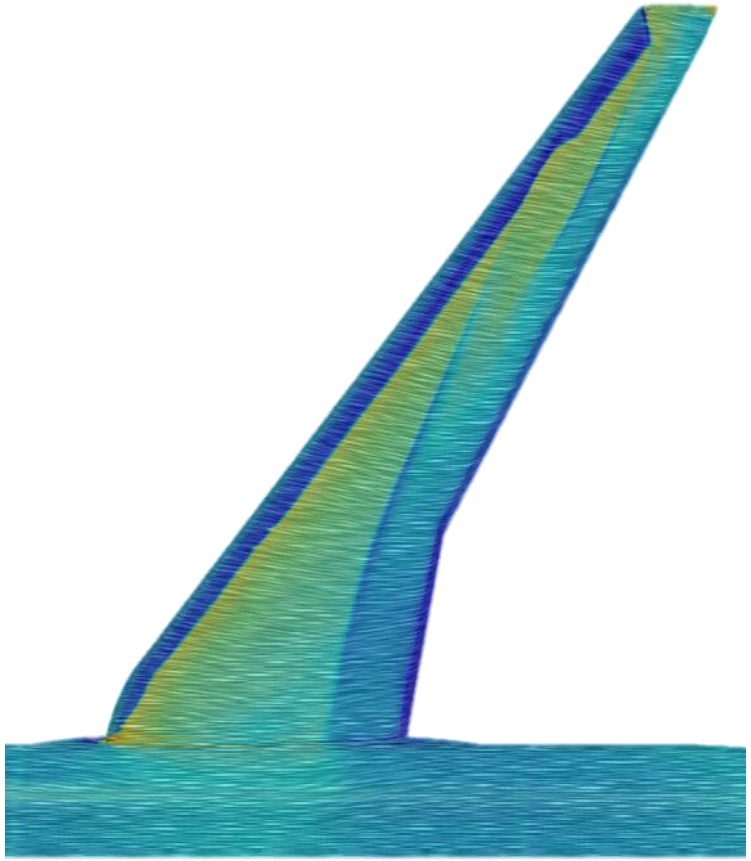
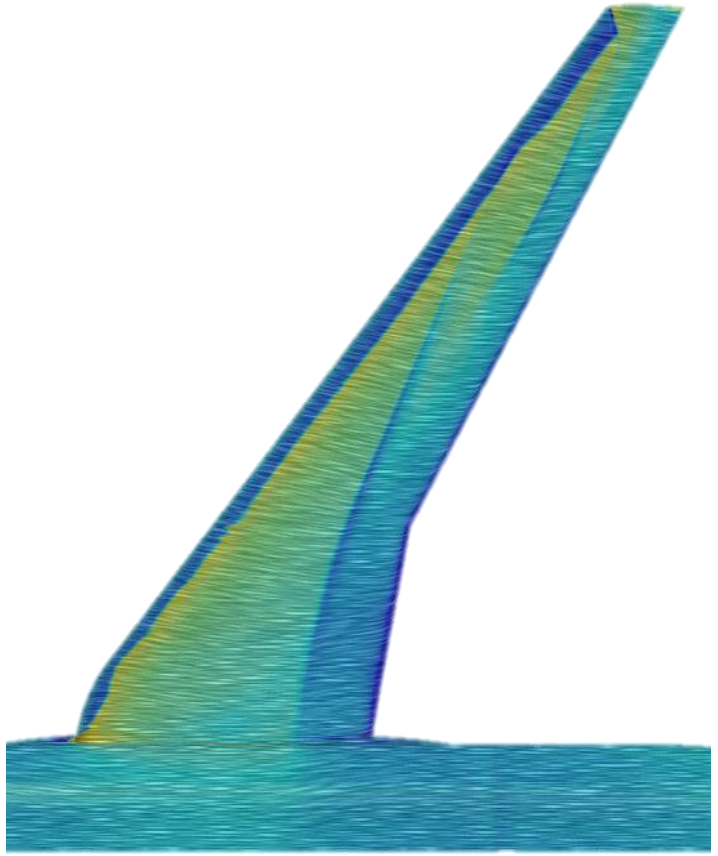
NLF-CRM

$\gamma - Re_\theta \, , \alpha = 1.98$



w/o cross-flow



w/ cross-flow

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Summary

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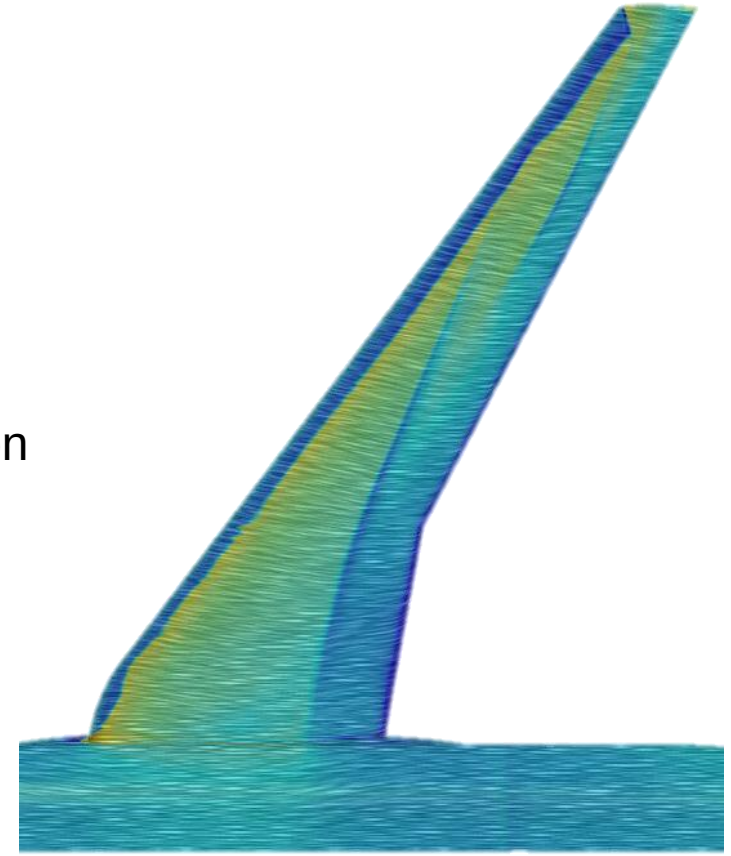
- Modelling transition significantly affects the simulation time/cost
- Transition convergence is driven by diffusion of laminar region
- Simulations with transition are more grid sensitive than turbulent runs
- γ model shows bi-modal behaviour depending on the grid refinement
- Both Turbulent Intensity and Turbulent Viscosity Ratio affect the transition prediction, LS of NLF more sensitive than US
- There is a need for well defined transition identification methodology
- $\gamma - Re_\theta$ model underpredicts the laminar region for NLF-CRM



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