# 2nd AIAA CFD High Lift Prediction Workshop

## RANS and PANS Approach

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June 22, 2013

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# Physics Objectives

- Assess the numerical prediction capability of current-generation CFD for swept, medium-to-high aspect ratio wings in high-lift configurations
- Evaluate VULCAN on a challenging, relevant, incompressible flow
- Evaluate PANS on a flow with small separated regions

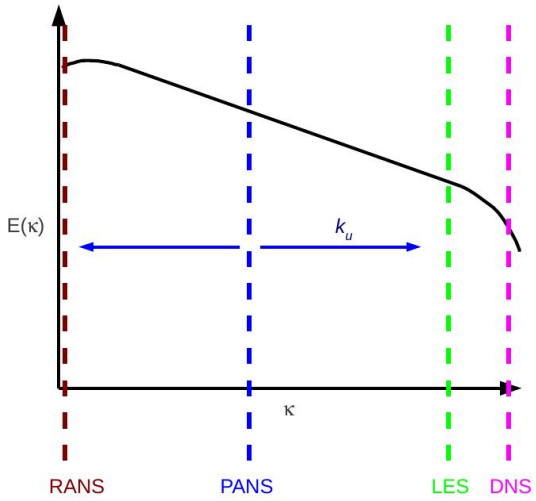
# CFD & Modeling

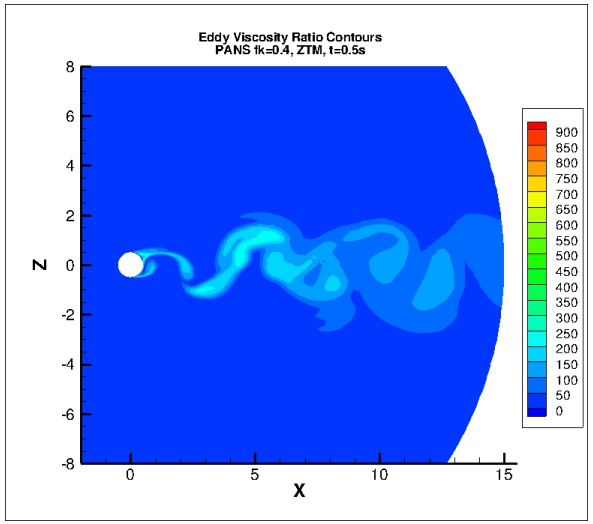
- CFD Tool
  - VULCAN CFD Package - NASA Langley
  - Specifications
    - Multi-block, structured, finite volume
    - Factorization: Diagonalized approximate with dual time-stepping
    - Inviscid flux: Roe's flux difference split scheme
    - Viscous flux: Full Navier-Stokes
    - Integrate to the wall
- Turbulence Modeling
  1. RANS: 1988 Wilcox $k - \omega$
  2. PANS with 1988 Wilcox $k - \omega$ parent

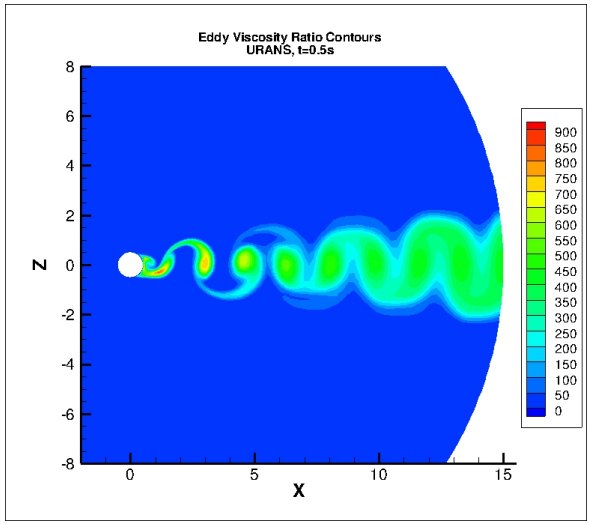
# Partially Averaged Navier Stokes (PANS) Model [2]

- Variable-resolution model; varies smoothly from DNS to RANS via filter control parameters $f_k$ and $f_\varepsilon$

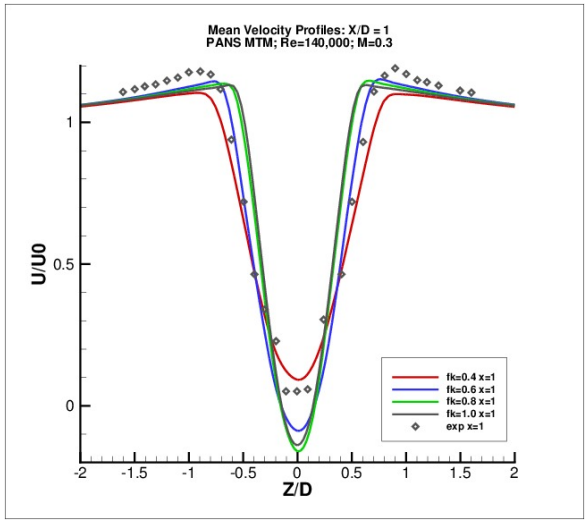
$$f_k = \frac{k_u}{k} \qquad f_\varepsilon = \frac{\varepsilon_u}{\varepsilon} \qquad \nu_u = C_\mu \frac{k_u^2}{\varepsilon_u}$$

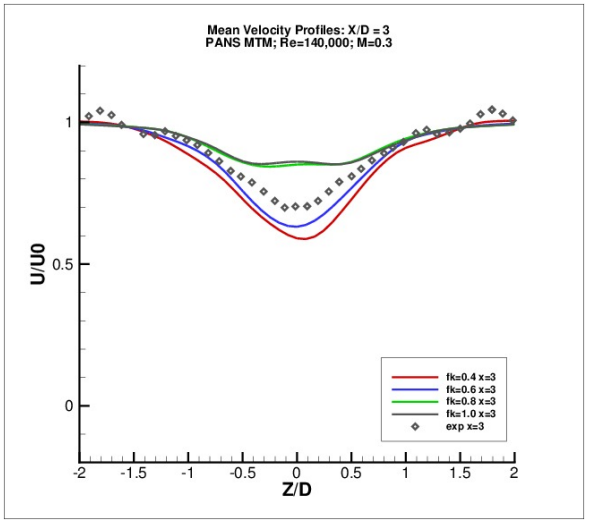


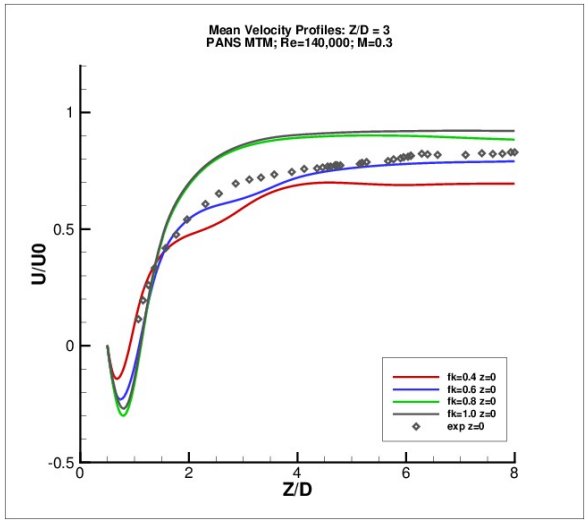



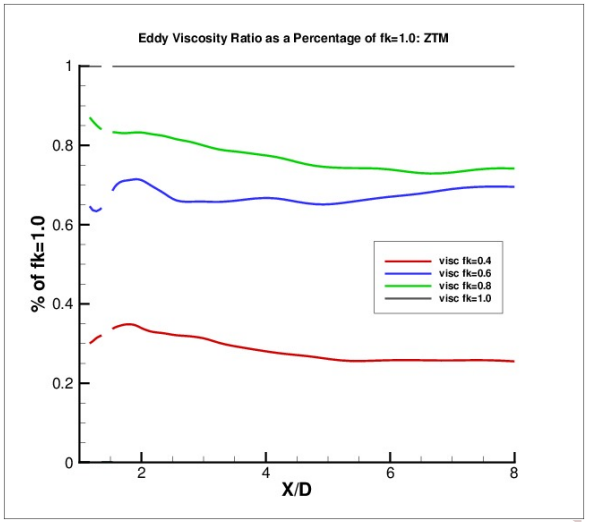
# VULCAN PANS Validation: Circular Cylinder




$U/U_\infty$ at $X/D = 1, 3$



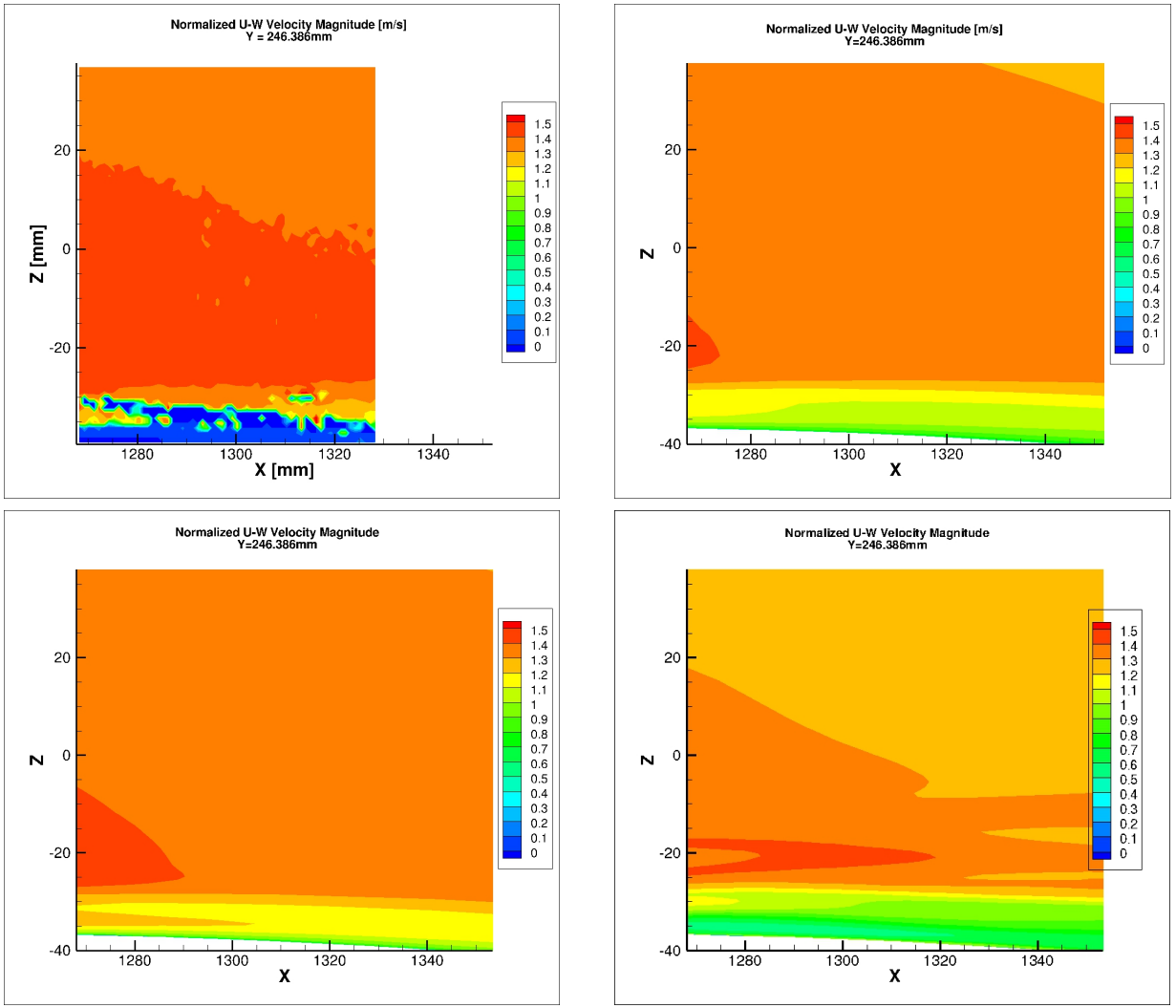




- $U/U_\infty$ along wake centerline
- $\nu_{t,pans}/\nu_{t,urans}$ along wake centerline

# High Lift Prediction Workshop Cases

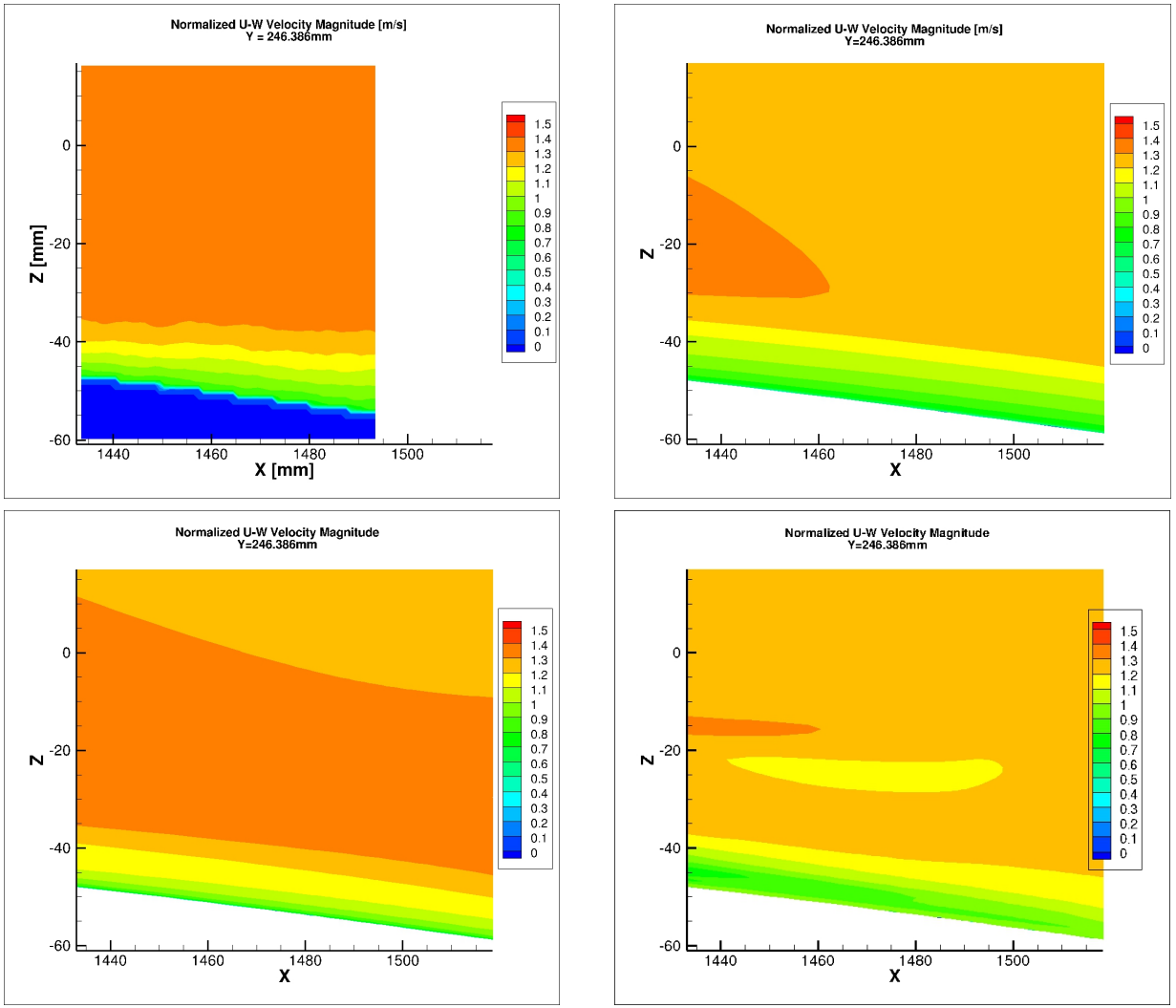
- Case 1: Grid Convergence
  - Code: VULCAN
  - Jacob Cooper (steady state), Tim Assel (time-accurate)
- Case 4: Turbulence Model Grid Convergence Verification
  - Code: OpenFoam
  - Pooyan Razi

# RANS Results: $\alpha = 7^o$, Y=246mm, Window C, $U/U_\infty$



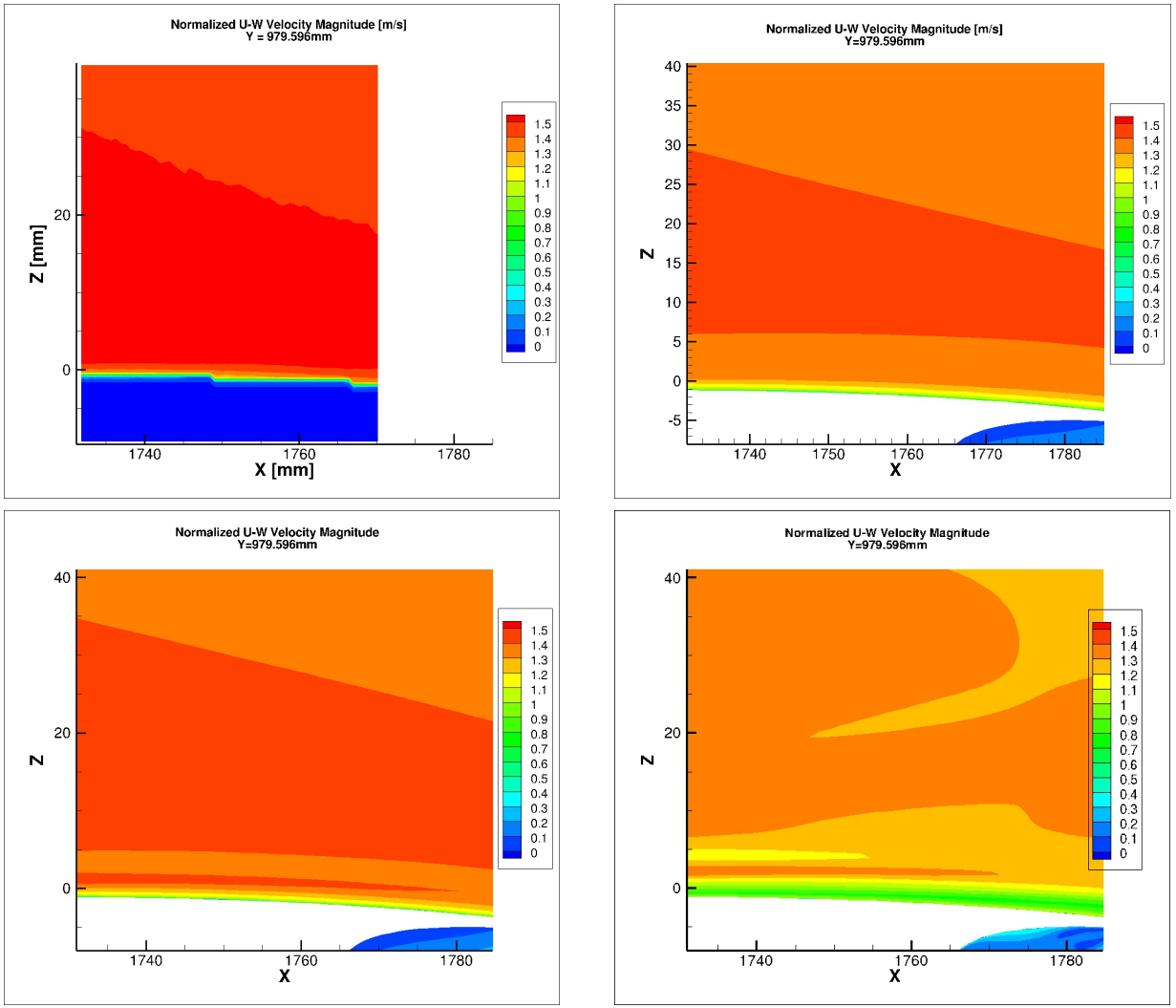

- PIV, coarse
- medium, fine

# RANS Results: $\alpha = 7^o$, Y=246mm, Window D, $U/U_\infty$



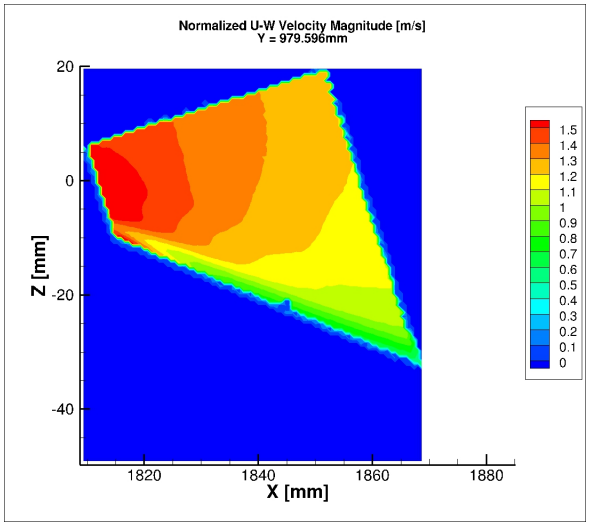

- PIV, coarse
- medium, fine

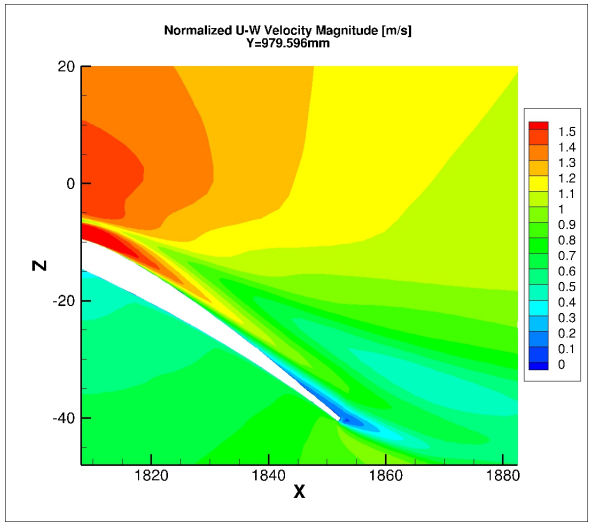
# RANS Results: $\alpha = 7^o$, Y=979mm, Window D, $U/U_\infty$



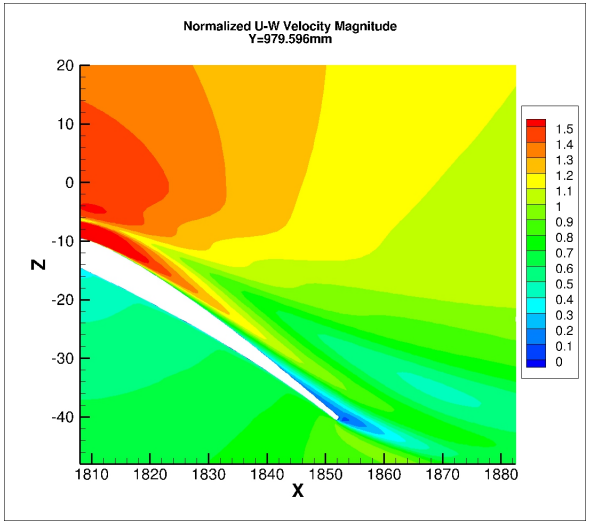

- PIV, coarse
- medium, fine

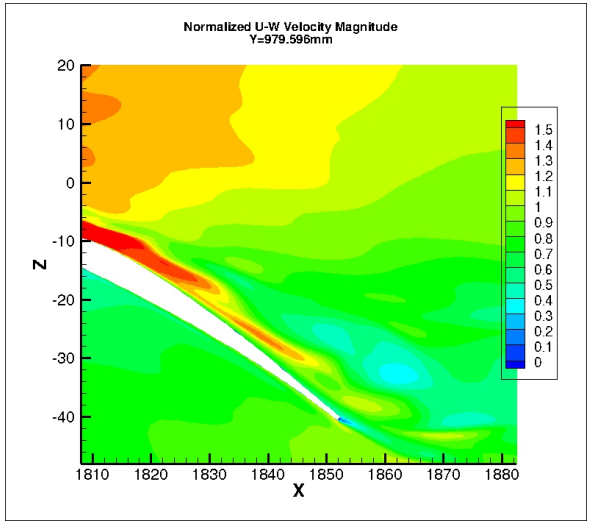
# RANS Results: $\alpha = 7^o$, Y=979mm, Window E, $U/U_\infty$



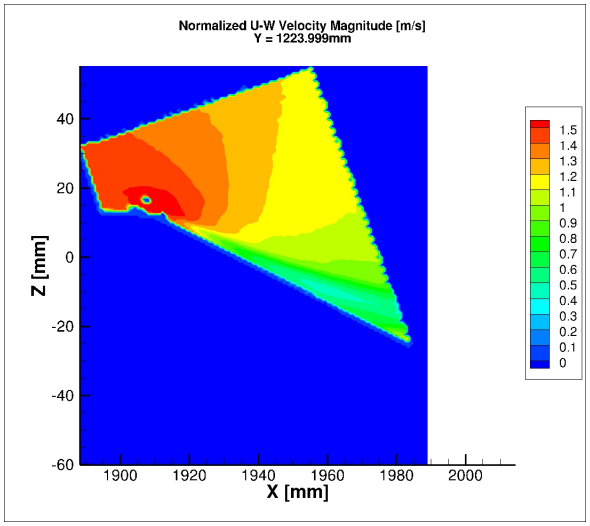

- PIV, coarse

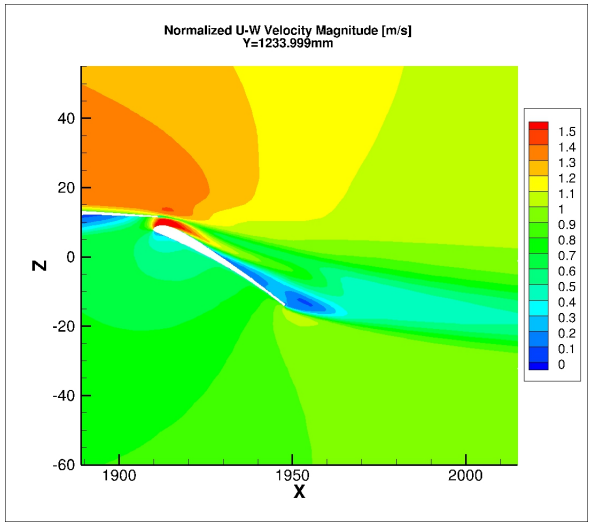


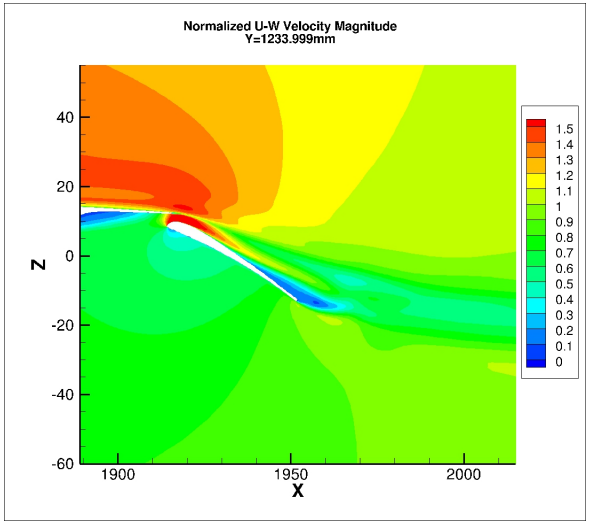



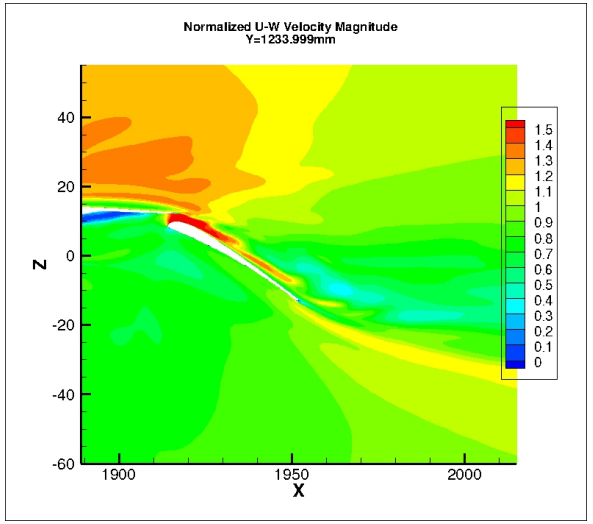

- medium, fine

# RANS Results: $\alpha = 7^o$, Y=1233mm, Window E, $U/U_\infty$



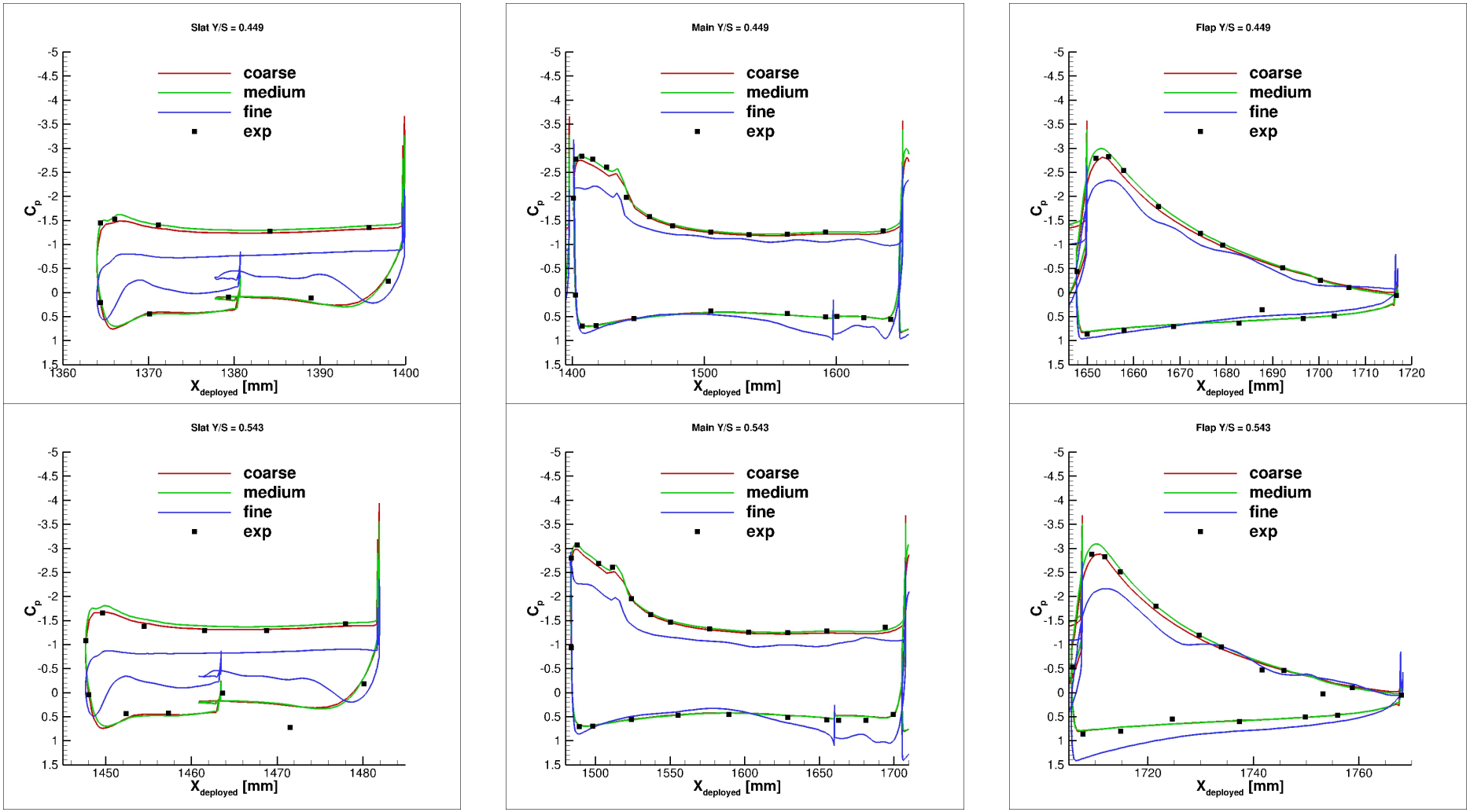



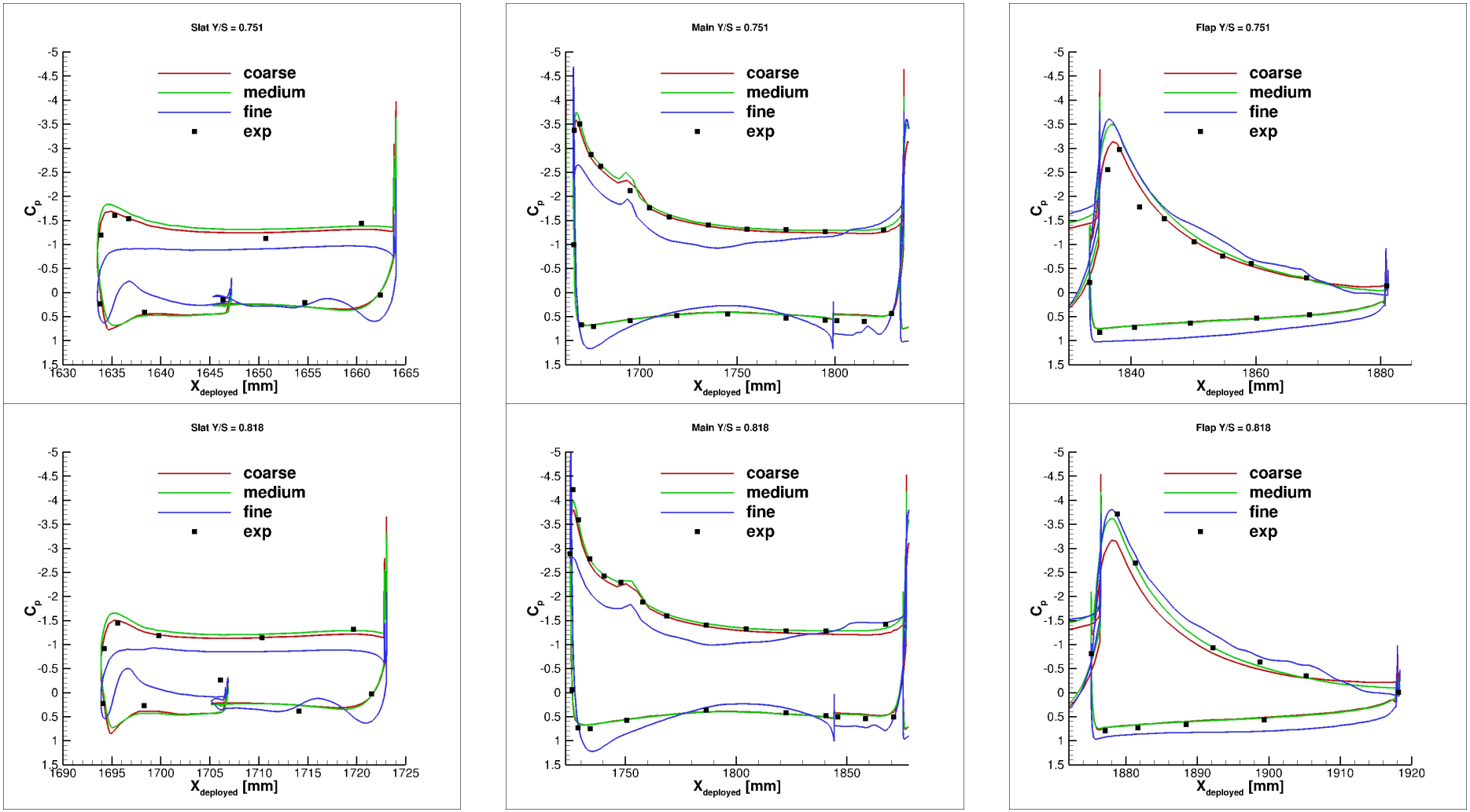




- PIV, coarse
- medium, fine

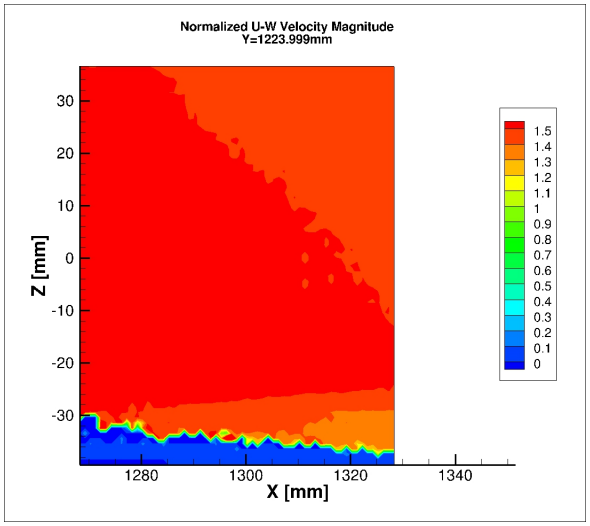
# RANS Results: $\alpha = 7^o$, $C_p$, $Y/S = 45\%$ and $54\%$

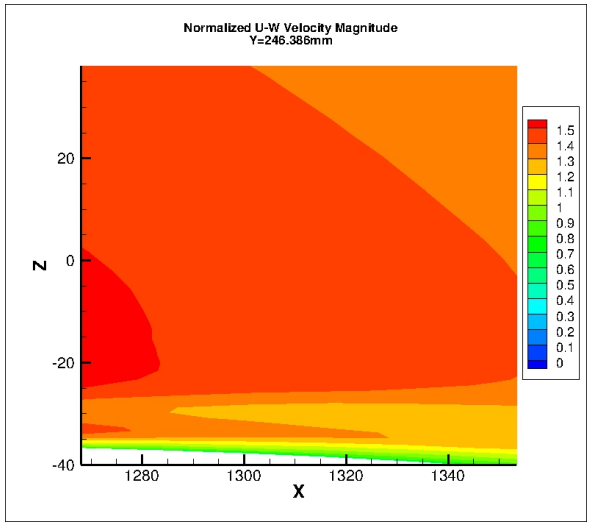


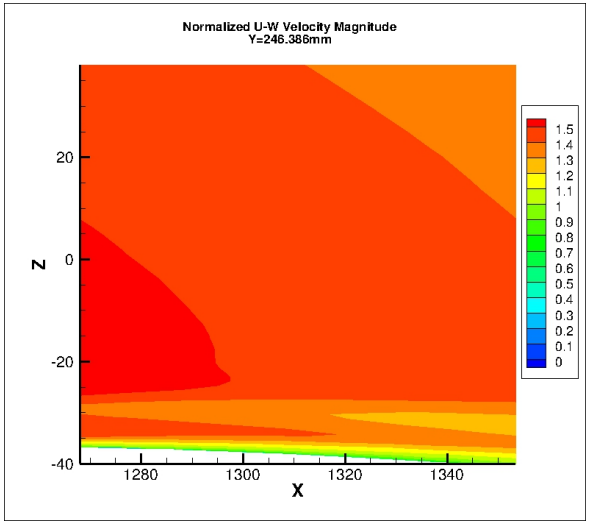
# RANS Results: $\alpha = 7^o$, $C_p$, $Y/S = 75\%$ and $82\%$

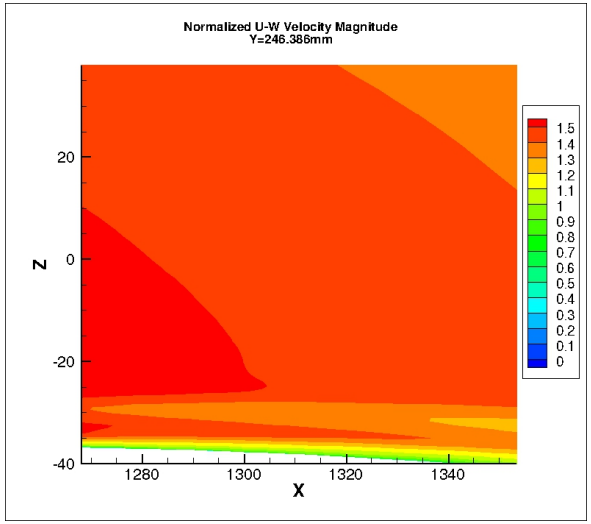


# RANS Results: $\alpha = 16^o$, Y=246mm, Window C, $U/U_\infty$



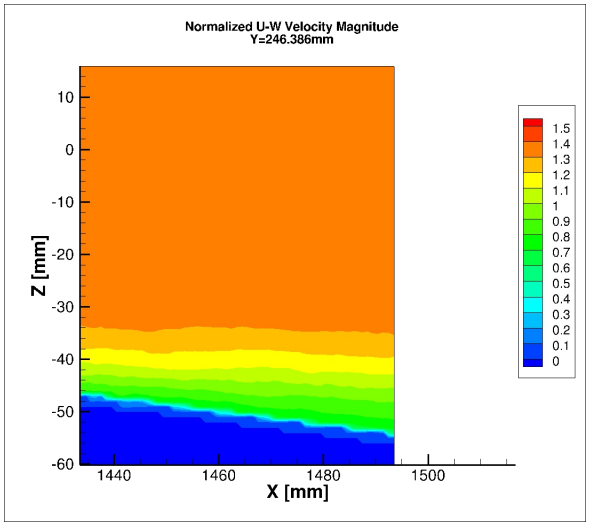



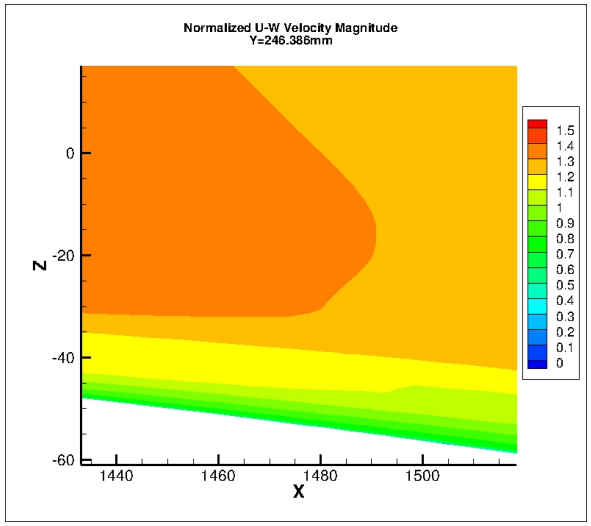



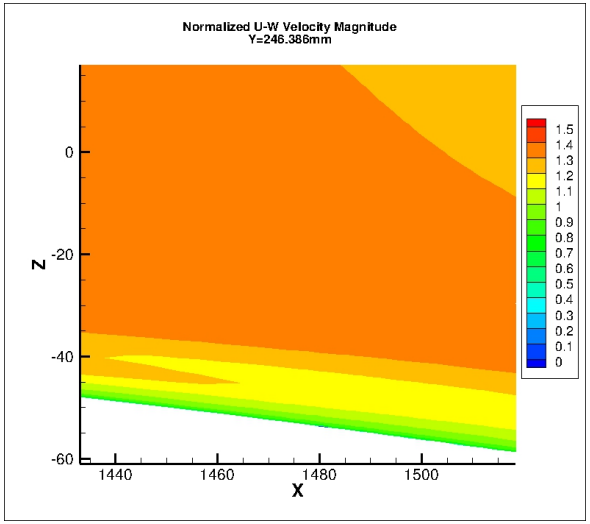

- PIV, coarse
- medium, fine

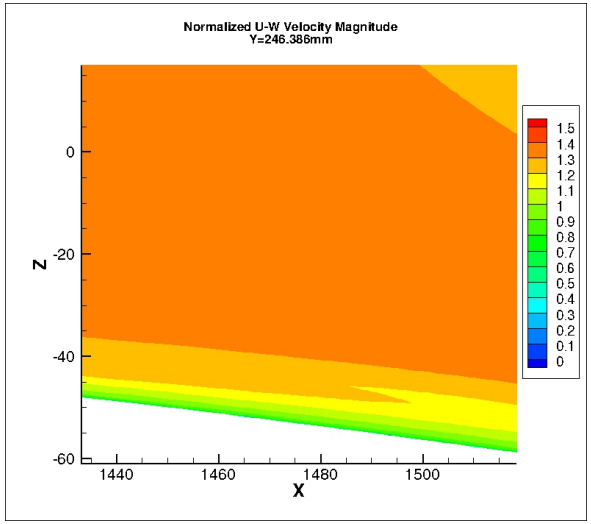
# RANS Results: $\alpha = 16^o$, Y=246mm, Window D, $U/U_\infty$



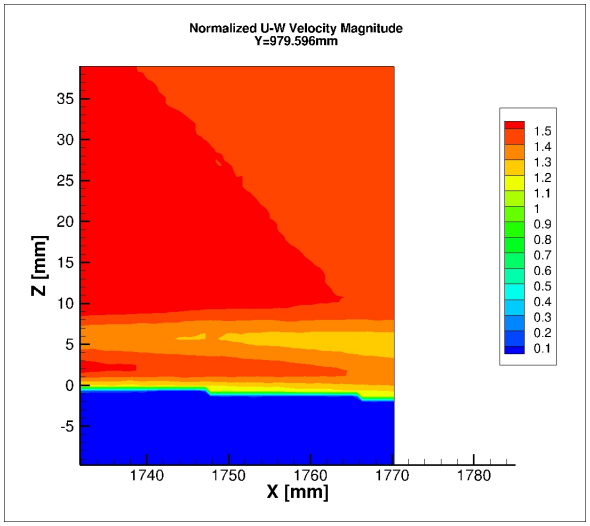

- PIV, coarse

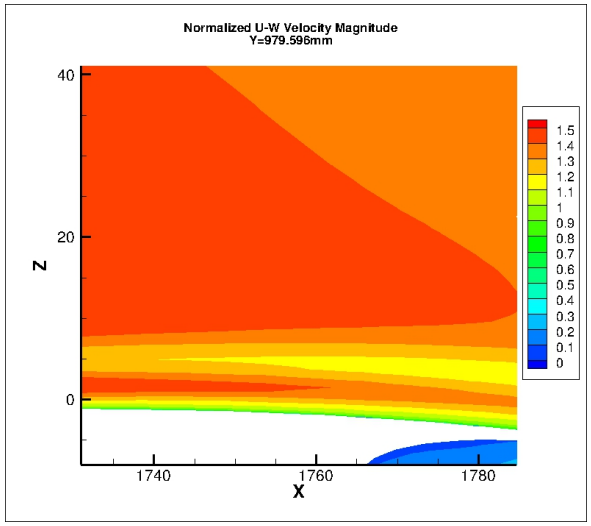


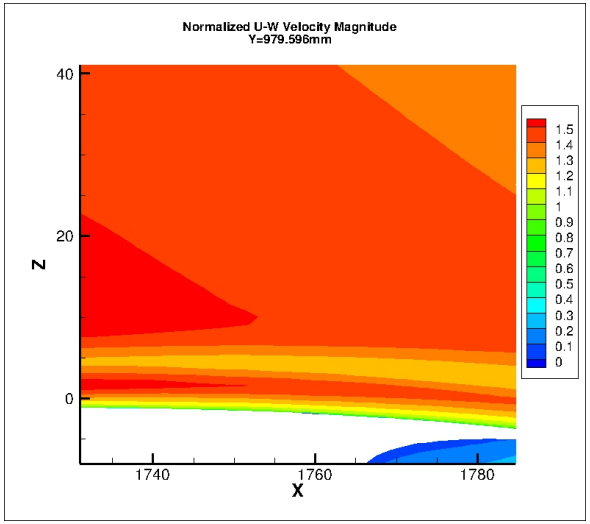

- medium, fine

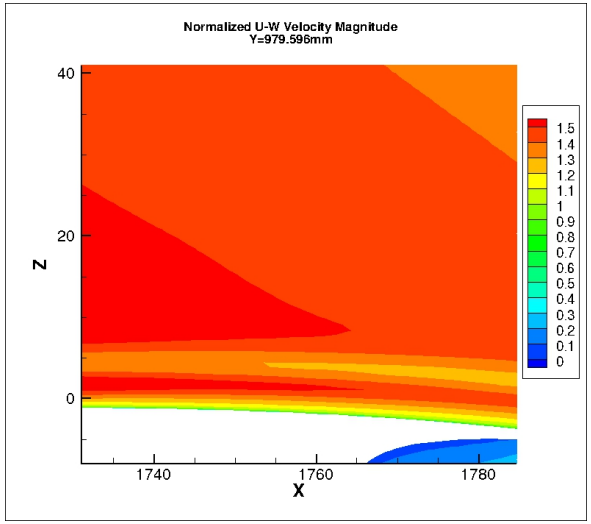
# RANS Results: $\alpha = 16^o$, Y=979mm, Window D, $U/U_\infty$



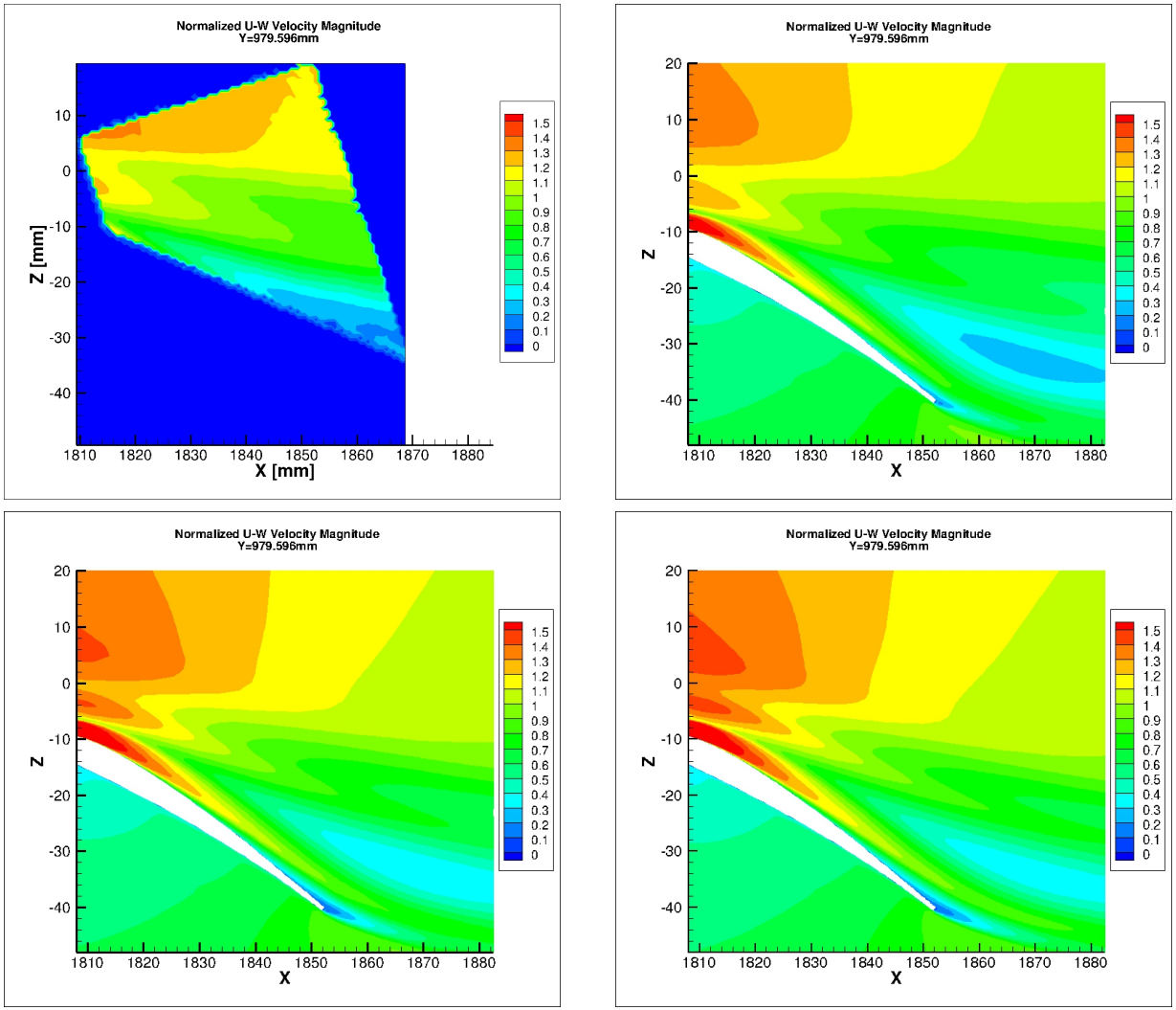

- PIV, coarse



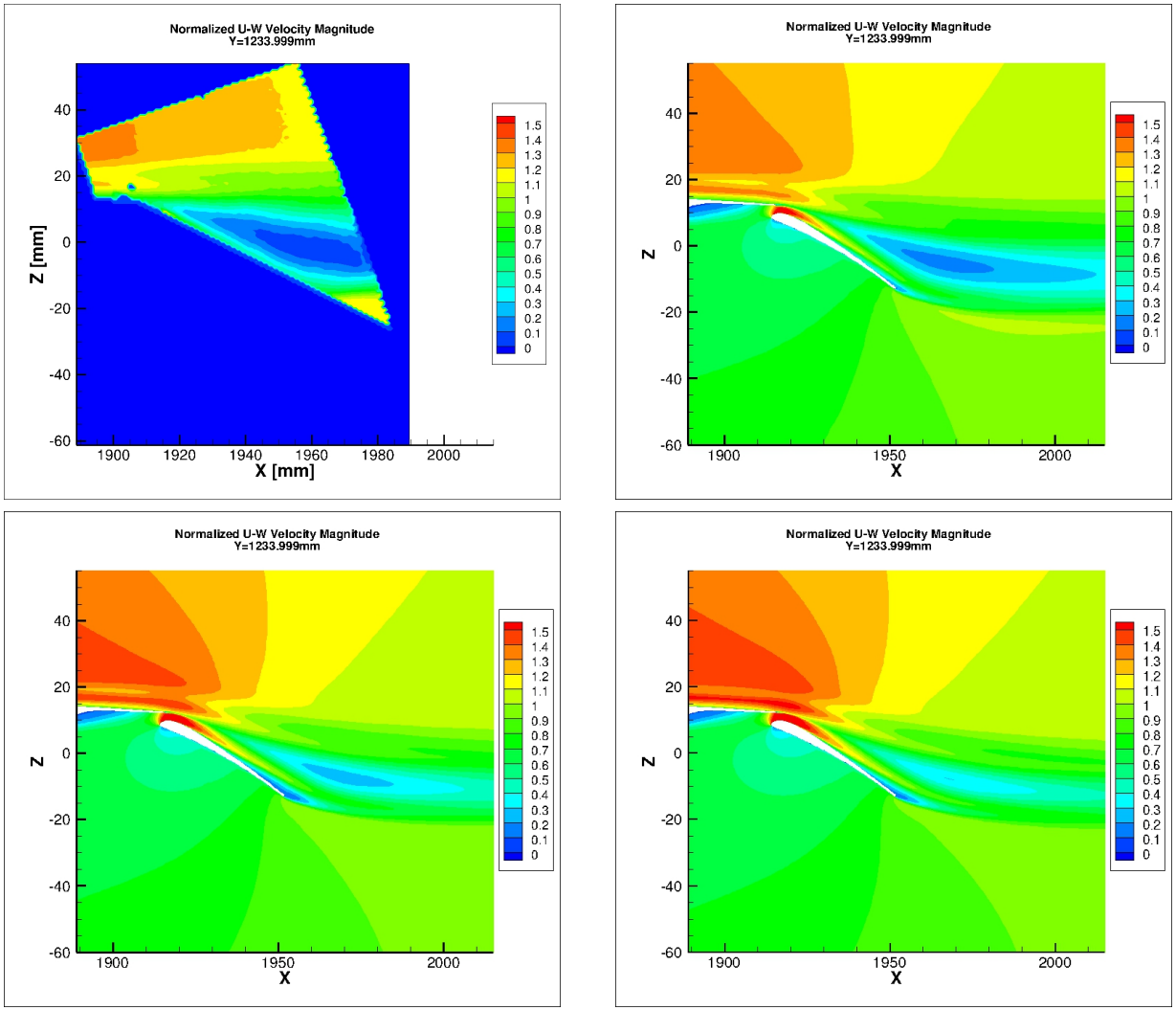

- medium, fine

# RANS Results: $\alpha = 16^o$, Y=979mm, Window E, $U/U_\infty$



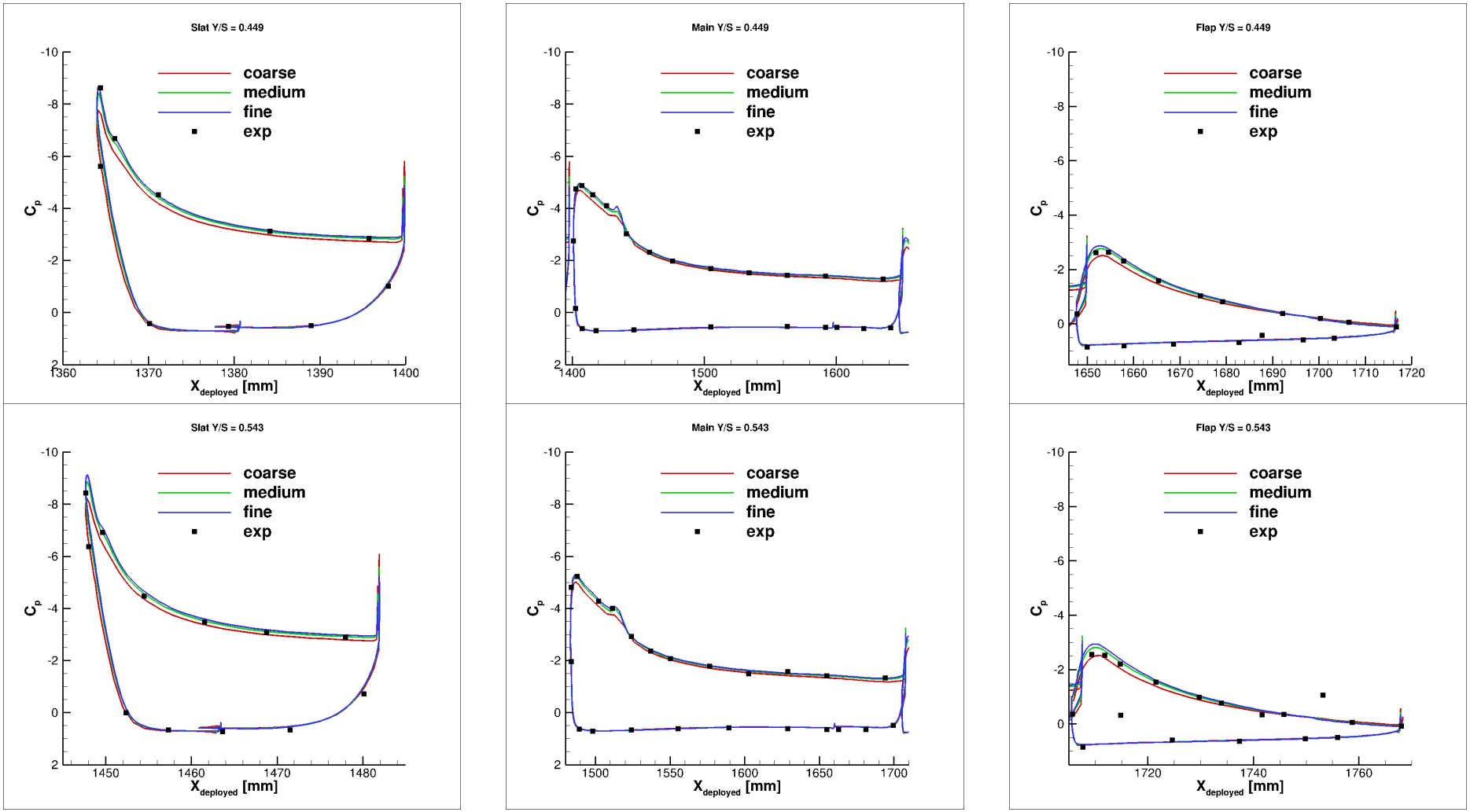

- PIV, coarse
- medium, fine

# RANS Results: $\alpha = 16^o$, Y=1233mm, Window E, $U/U_\infty$

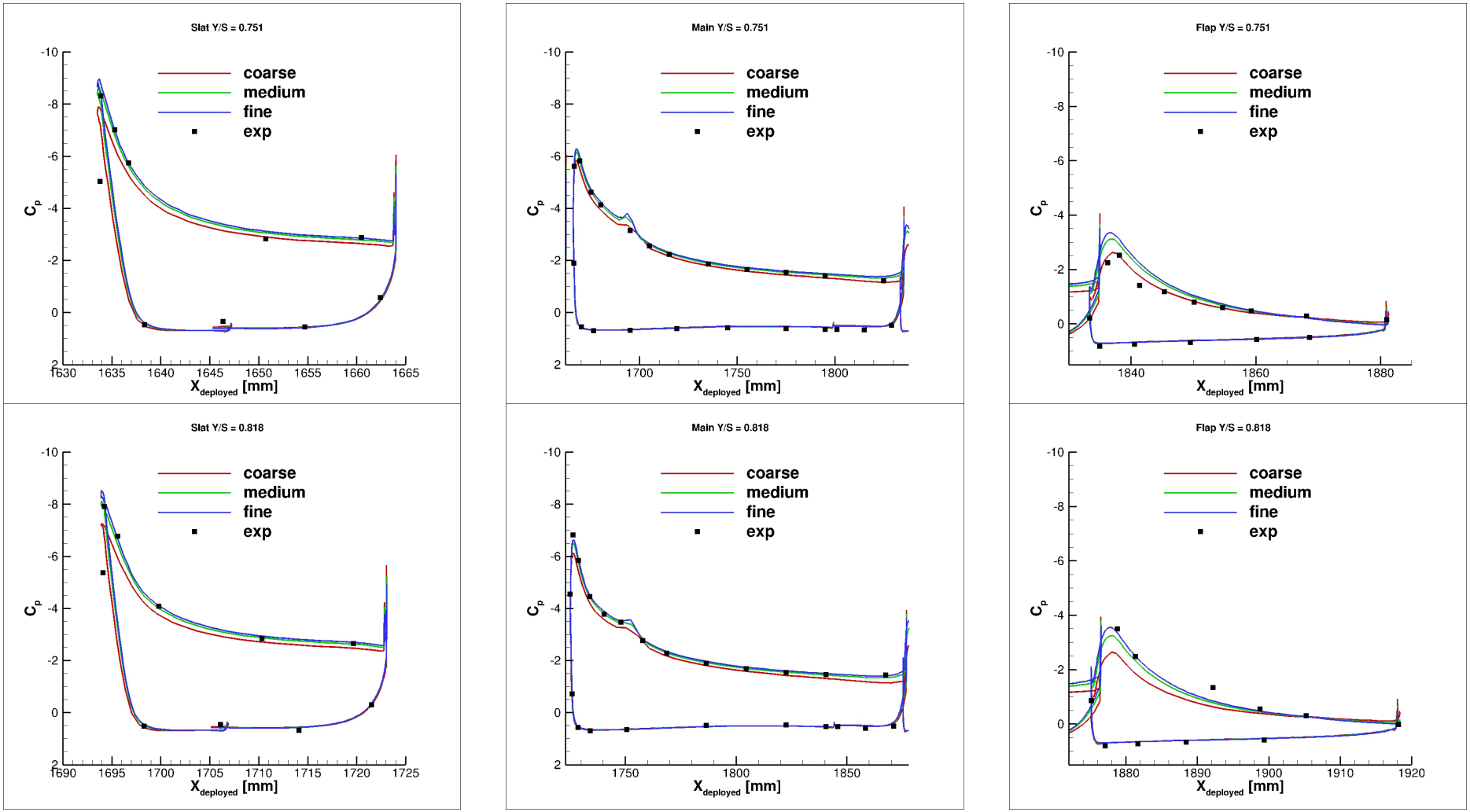



- PIV, coarse
- medium, fine

# RANS Results: $\alpha = 16^o$, $C_p$, $Y/S = 45\%$ and $54\%$



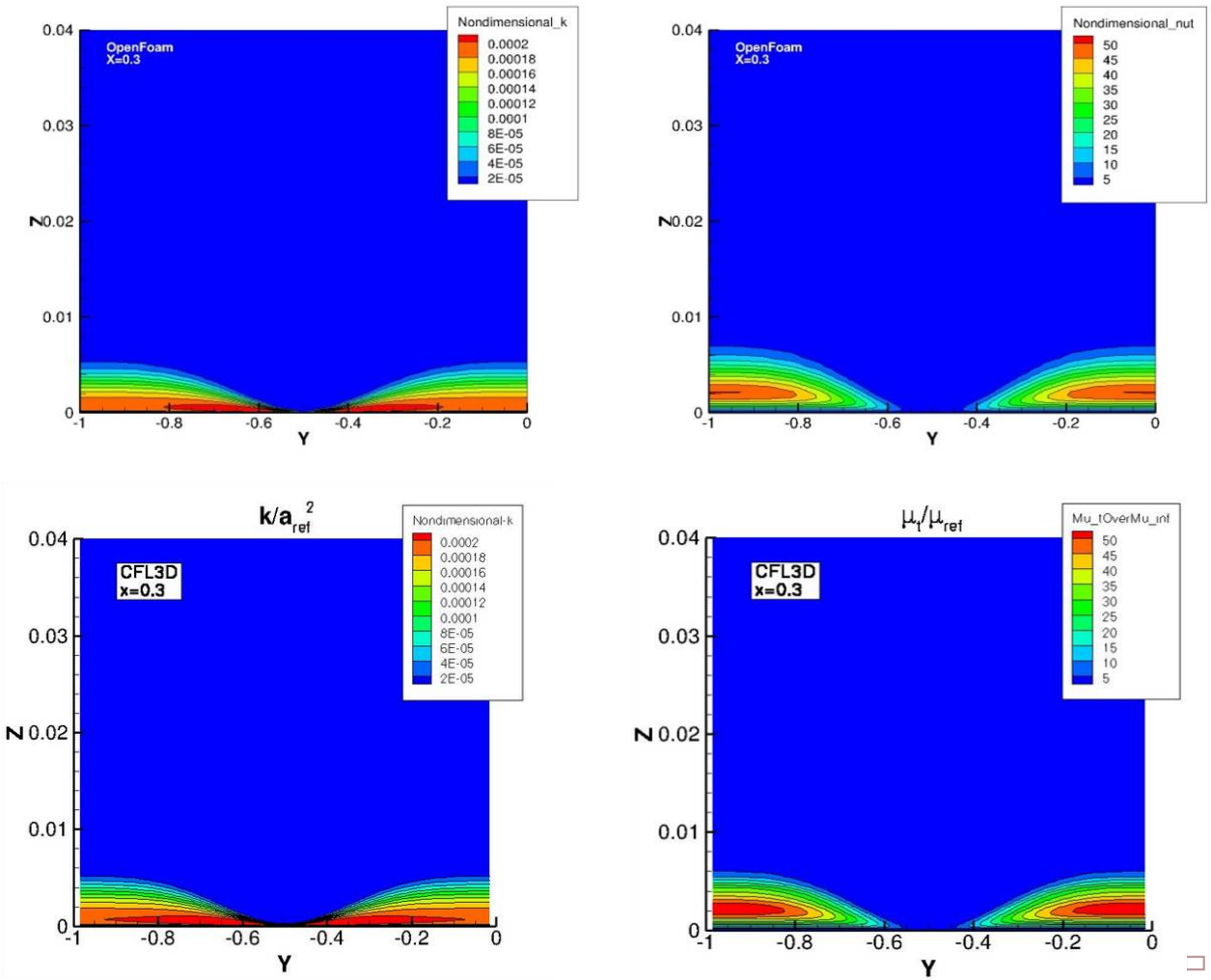
# RANS Results: $\alpha = 16^o$, $C_p$, $Y/S = 75\%$ and $82\%$



# PANS Results

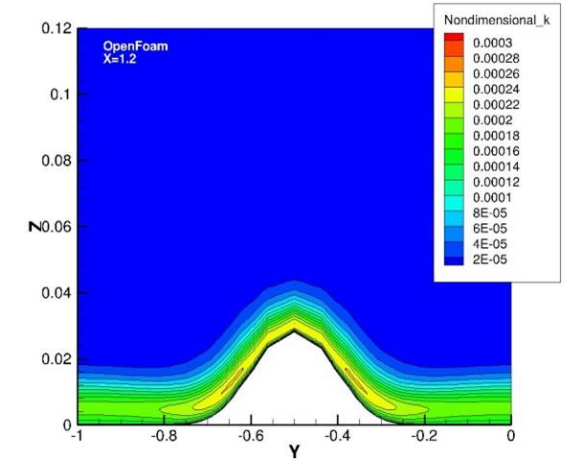
- In progress...

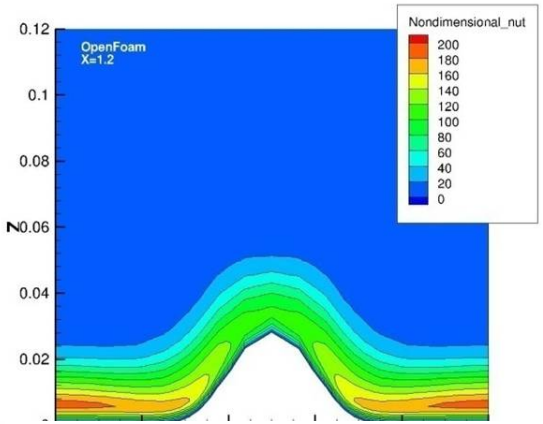
# Case 4 Results; $x = 0.3$

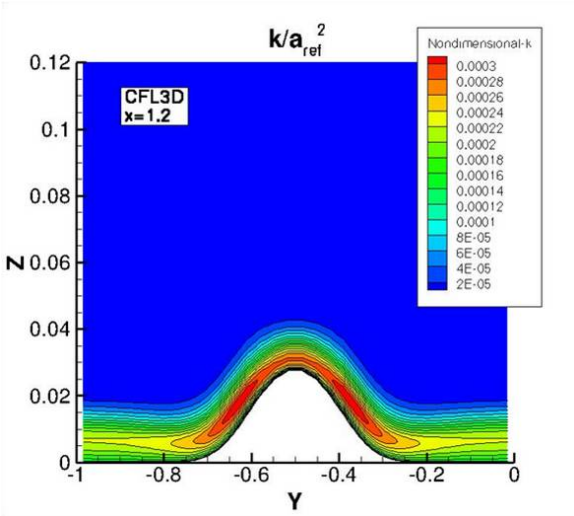


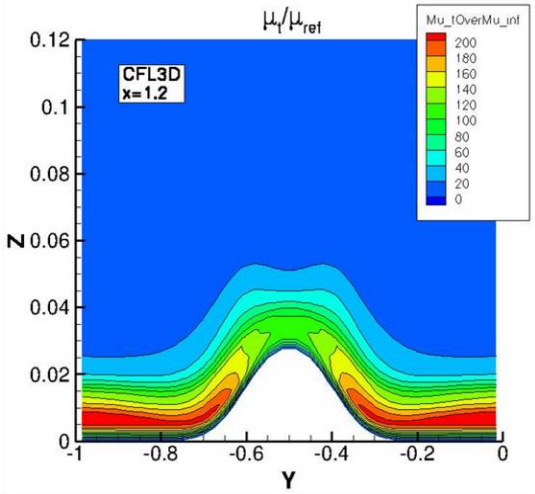

- OpenFoam $\frac{k}{a_{ref}^2}$; $\frac{\mu_t}{\mu_{ref}}$
- NASA Langley [1] $\frac{k}{a_{ref}^2}$; $\frac{\mu_t}{\mu_{ref}}$

# Case 4 Results; $x = 1.2$



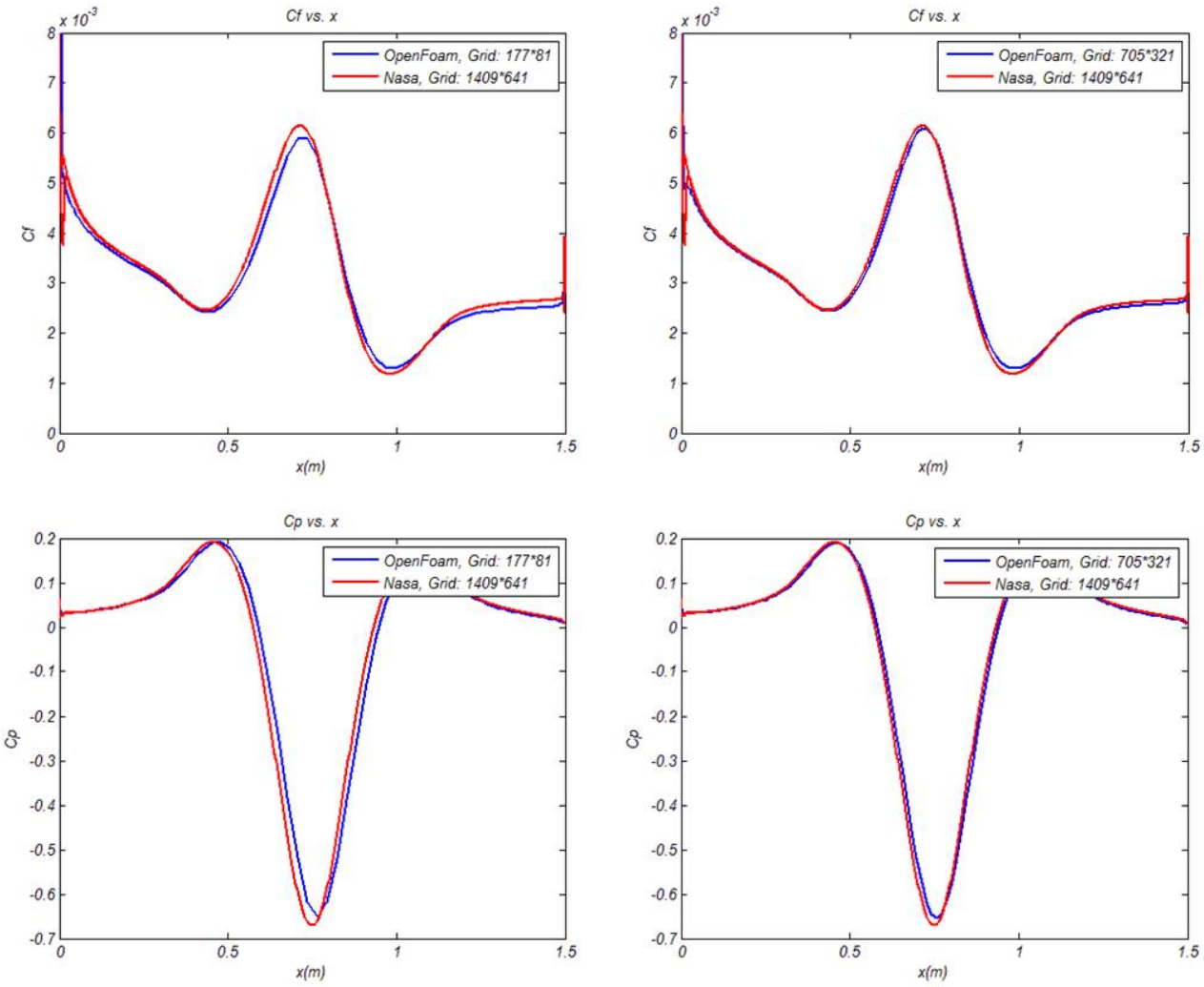




- OpenFoam
  $\frac{k}{a_{ref}^2}$; $\frac{\mu_t}{\mu_{ref}}$
- NASA Langley
  [1] $\frac{k}{a_{ref}^2}$; $\frac{\mu_t}{\mu_{ref}}$

# Case 4 Results; $C_f$ and $C_p$




- $C_f$ vs. $x$ [1]
- coarse, fine

- $C_p$ vs. $x$ [1]
- coarse, fine

# Conclusions and Future Work

- 1988 Wilcox steady-state RANS does a good job matching $C_p$
- Higher-fidelity models will be required to resolve separated regions
- Future: complete PANS simulations to characterize separated regions

# References

Nasa langley research center turbulence modeling resource; http://turbmodels.larc.nasa.gov.

Girimaji, S. S.
Partially-averaged navier-stokes method for turbulence: A reynolds-averaged navier-stokes to direct numerical simulation bridging method.
*Journal of Applied Mechanics 73* (2006), 413–421.