CFD Comparisons with Updated NASA Juncture Flow Data

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AIAA SciTech 2021

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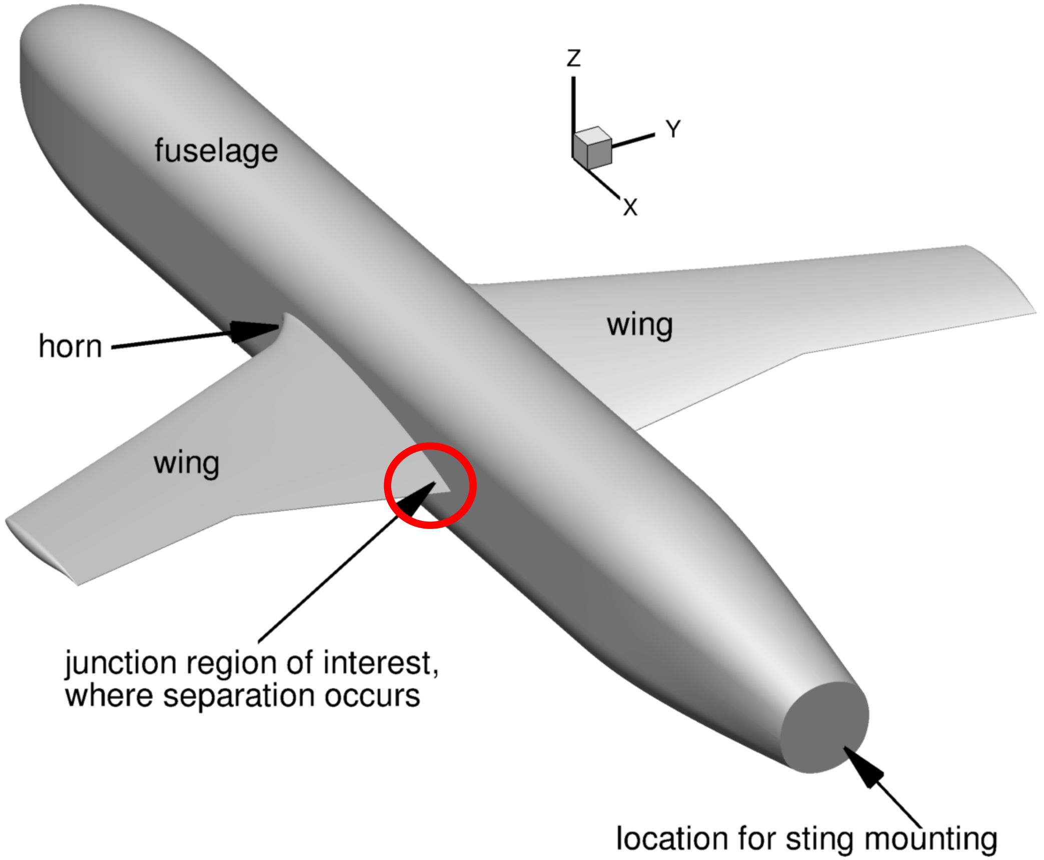
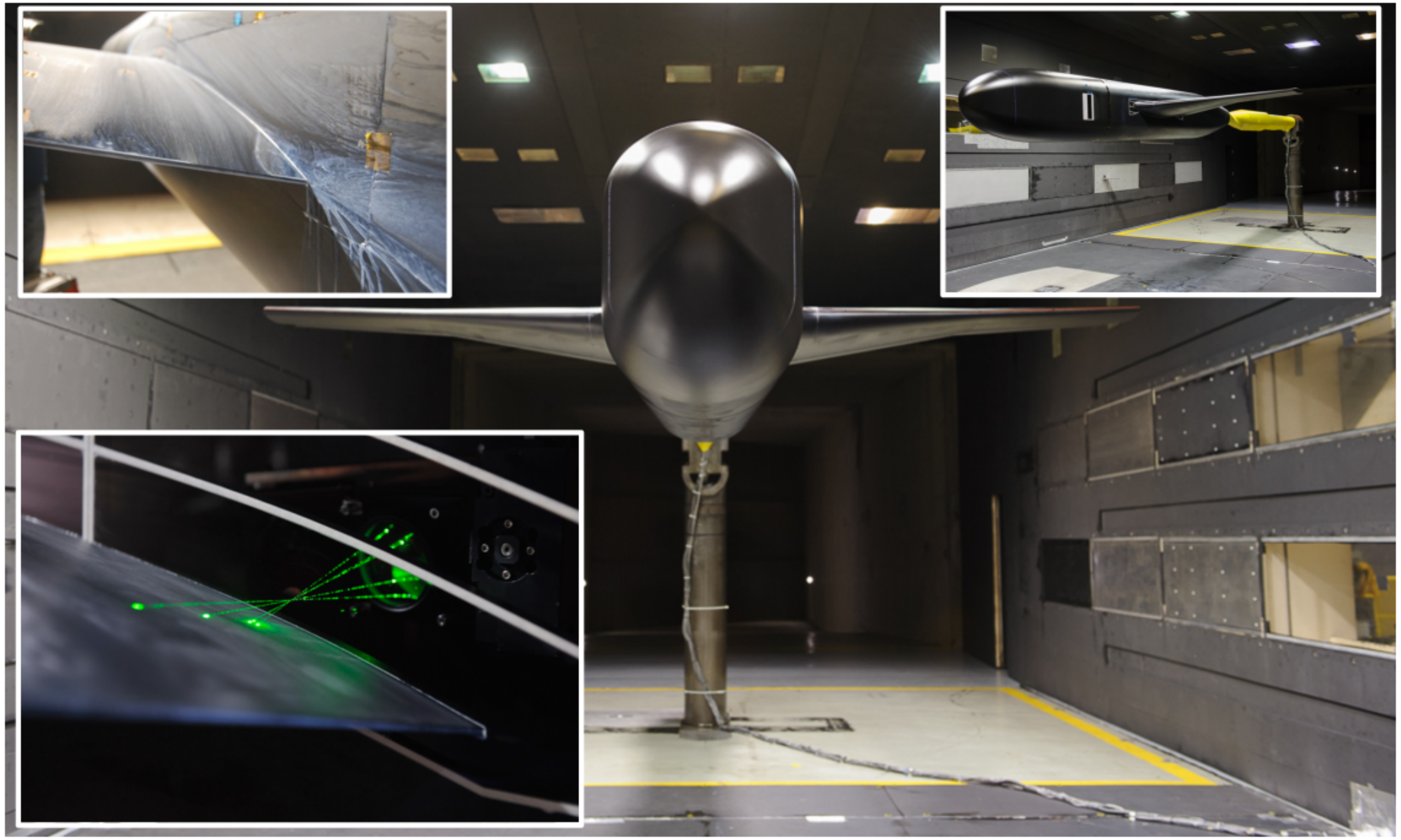
Introduction

- NASA Juncture Flow (JF) configuration
  - Goal: Conduct **CFD validation experiment** to validate/improve turbulence models for predicting wing-root corner separation
  - Focus on measuring mean and turbulence flowfield data in wing-body junction region
- Second phase of wind tunnel testing is complete
  - Tested in Langley 14- by 22-foot subsonic tunnel
  - Fuselage with F6-based wing+horn
  - Internally-mounted laser-doppler velocimetry (LDV) and particle image velocimetry (PIV)
  - Measurements made through windows in fuselage
- CFD RANS comparisons with FUN3D and OVERFLOW using new version of turbulence model



Main Outcomes of JF Phase 2 Test

- Flowfield measurements at a new angle of attack (7.5 deg.)
- LDV repeats for verification and new uncertainty quantification (UQ)*
- LDV data "planes" upstream of and within separated region
- New PIV data in separated region
- Finalized pressure data on model, including UQ



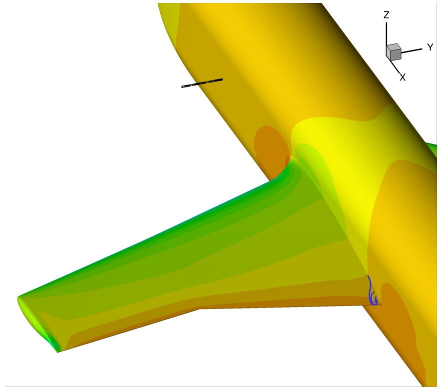
*method of Aeschliman and Oberkampf, *AIAA Journal*, Vol. 36, No. 5, 1998, pp. 733–741

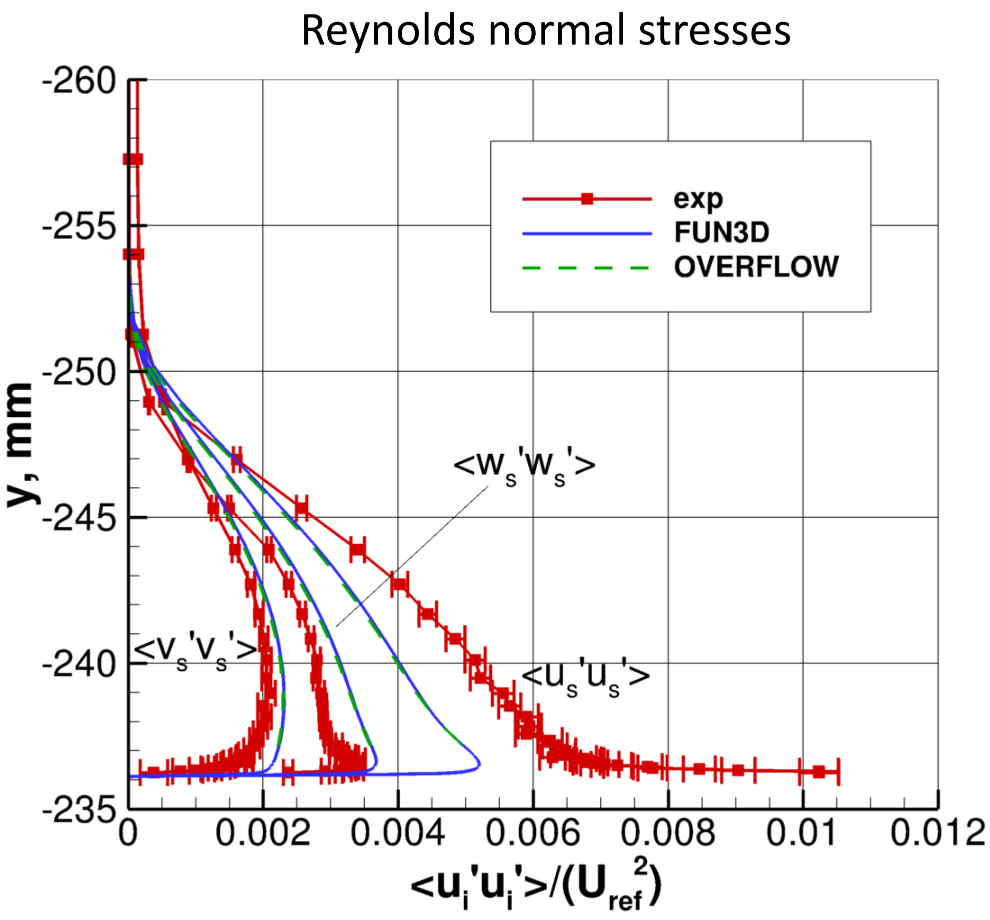
New version of Quadratic Constitutive Relation

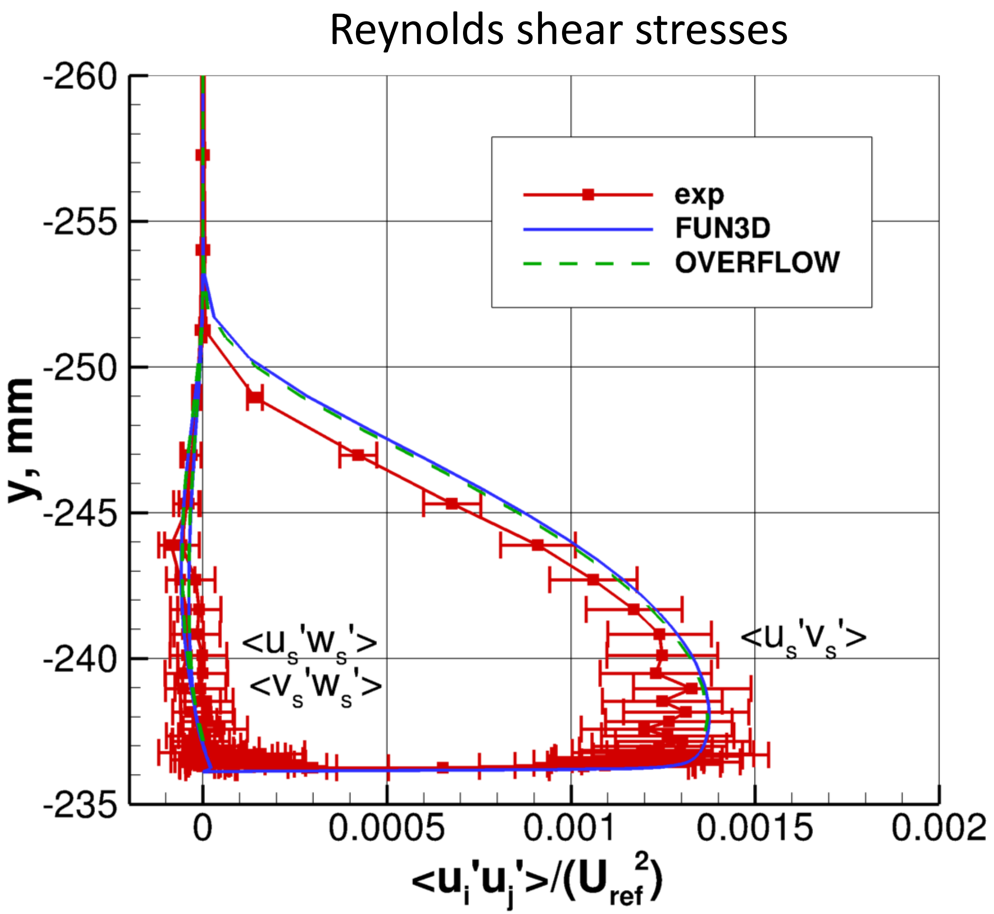
- QCR2020
  - Developed by members of the JF team in 2020, based on JF data
  - *AIAA Journal*, Vol. 58, No. 10, 2020, pp. 4374-4384
  - Includes revised functional coefficients, C''_{cr1} and C''_{cr2}, that improve predictions of turbulent normal stresses
  - $\tau_{ij,QCR2020} = \tau^L_{ij} - C''_{cr1}[O_{ik}\tau^L_{jk} + O_{jk}\tau^L_{ik}] - C''_{cr2}\mu_t\sqrt{2W_{mn}W_{mn}}\delta_{ij}$
  - Improves results for JF configuration as well as independent cases
- Used in conjunction with Spalart-Allmaras + Rotation-Curvature correction:

SA-RC-QCR2020

SA-RC-QCR2020 results far upstream on fuselage

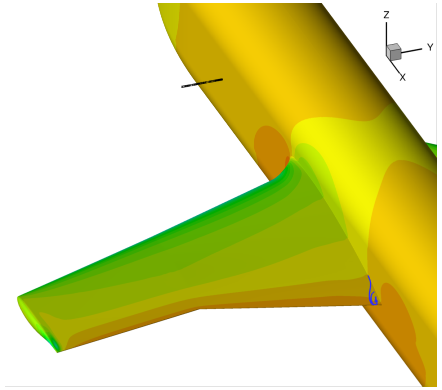




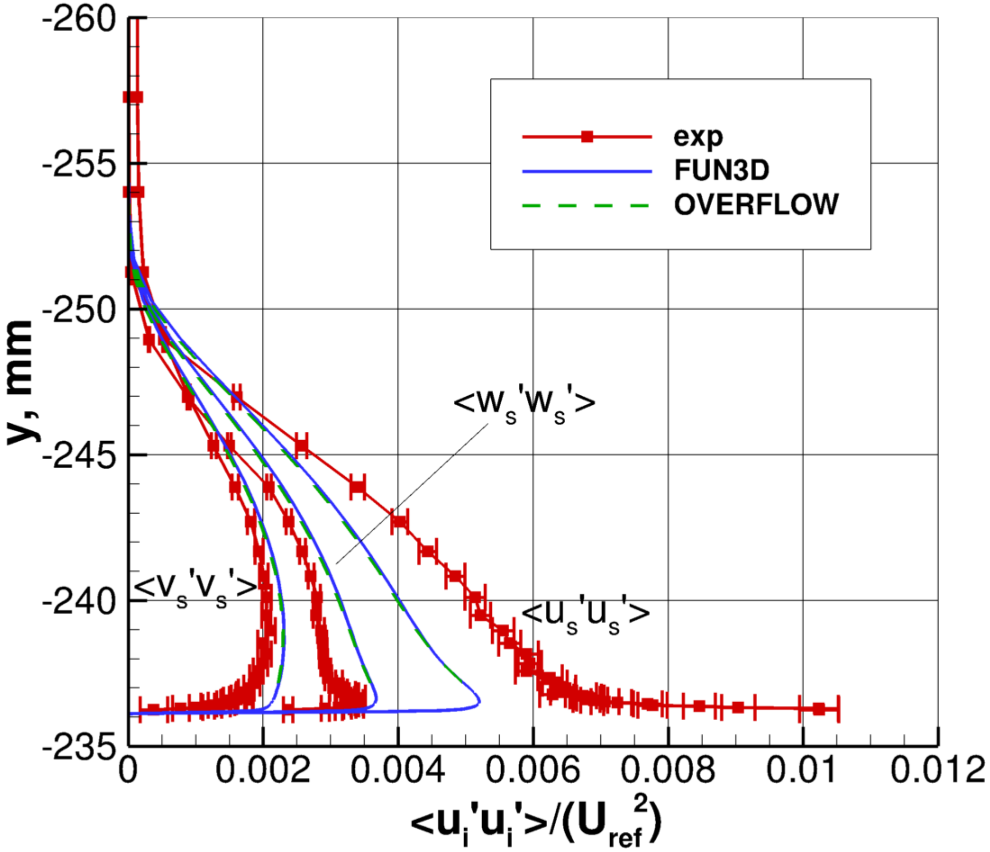


Angle of incidence = 5 deg.

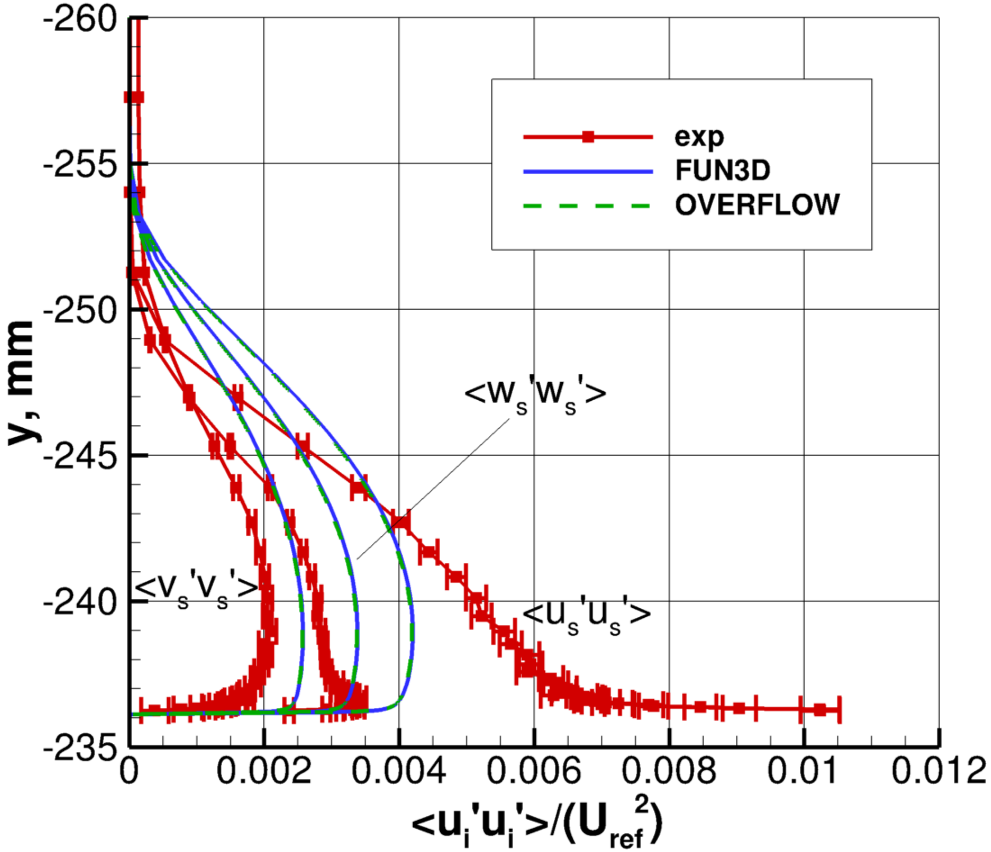
Improved normal stress predictions with QCR2020



SA-RC-QCR2020

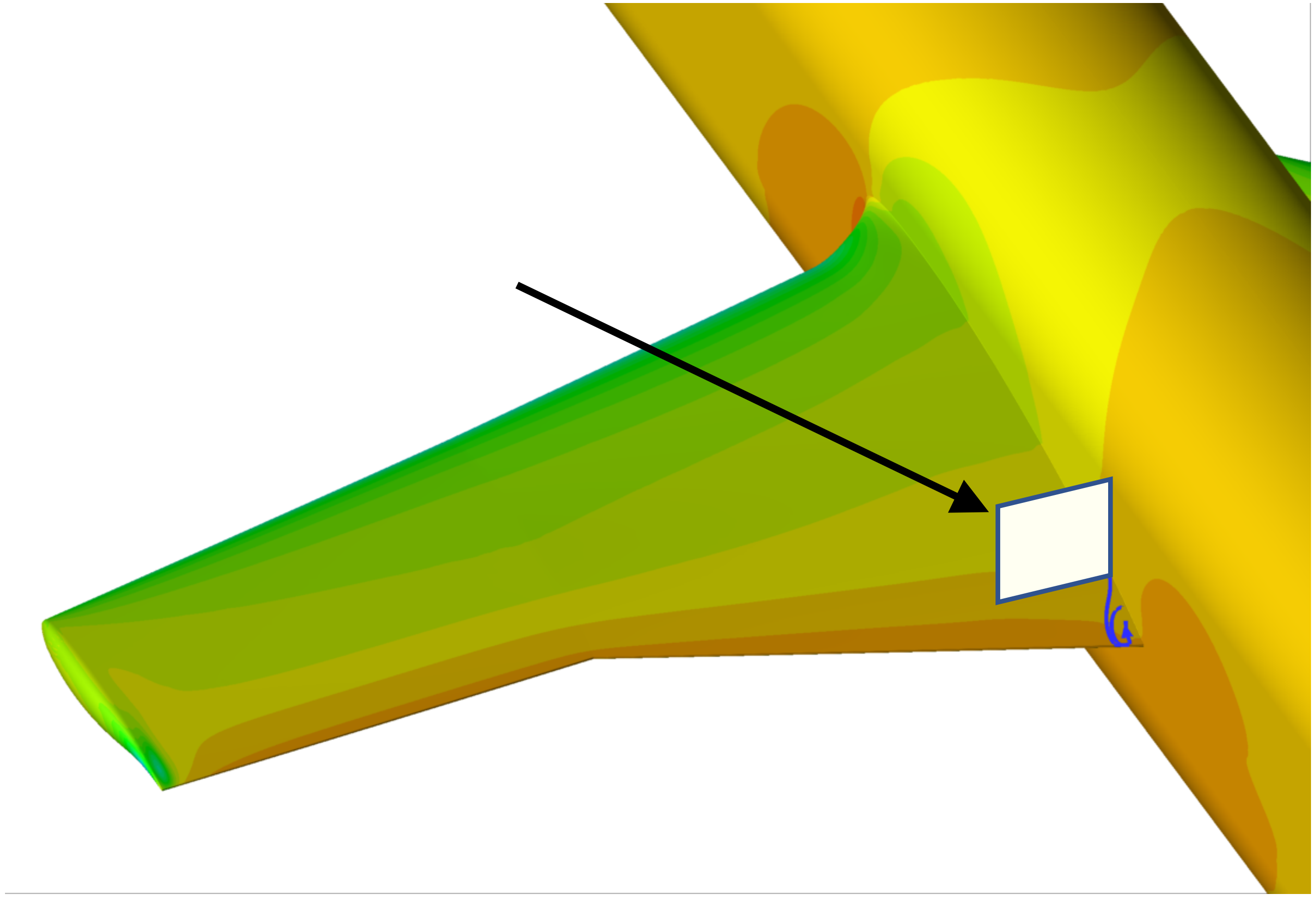


SA-RC-QCR2013



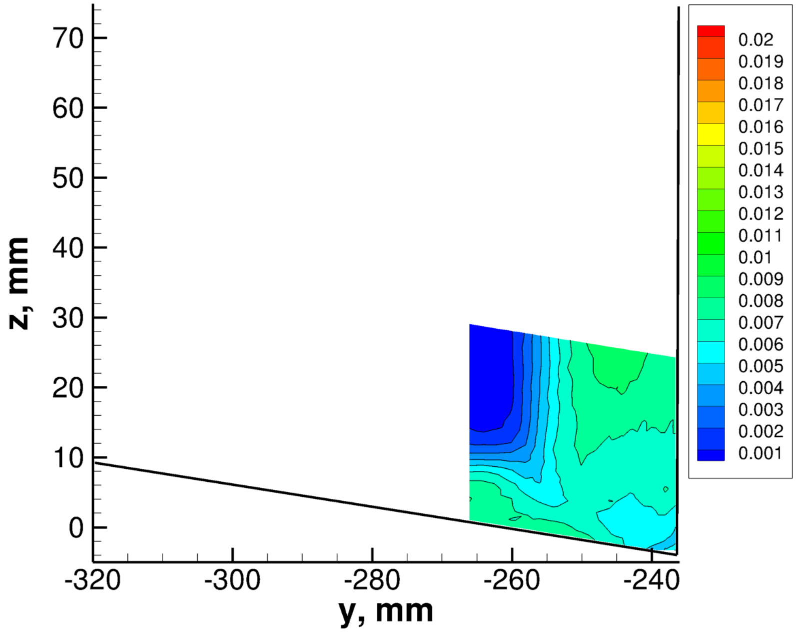
Angle of incidence = 5 deg.

Focus on start of separation region

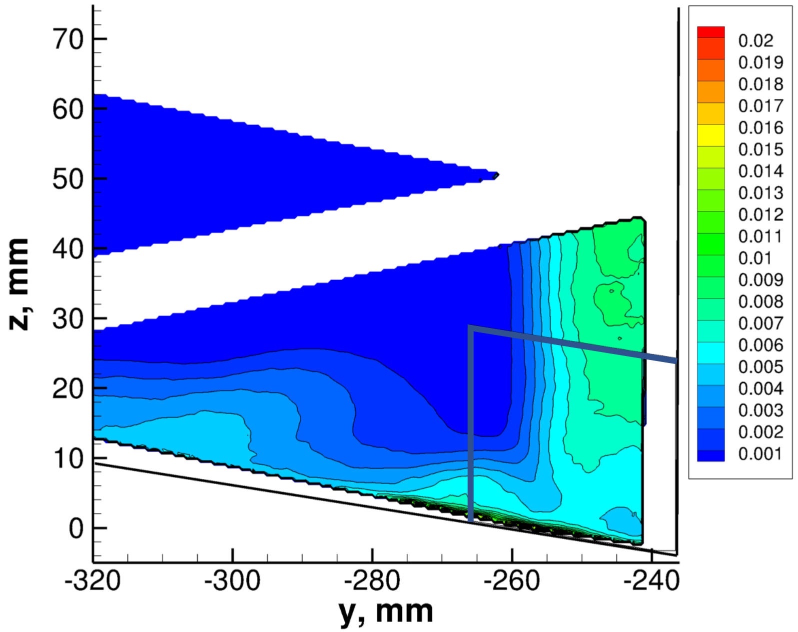


Comparison of flowfield near separation, 7.5 deg.

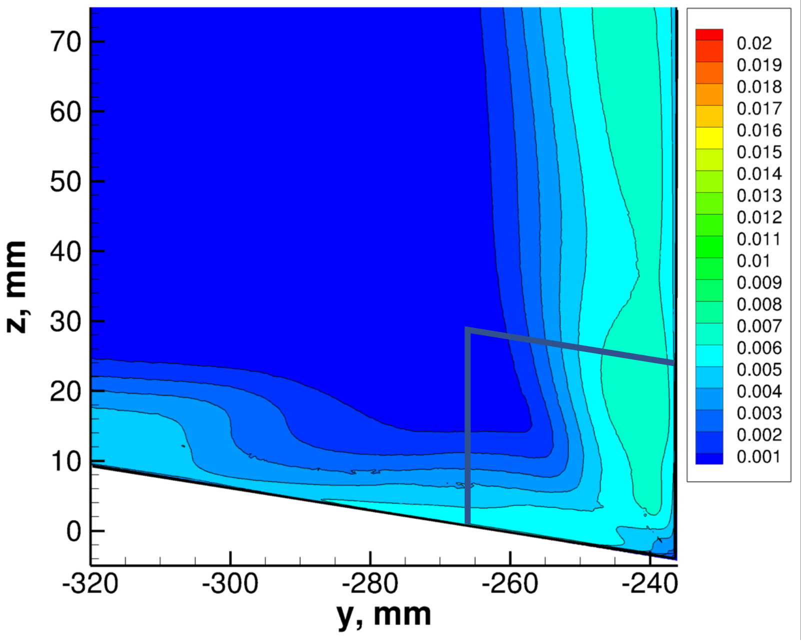
LDV



PIV



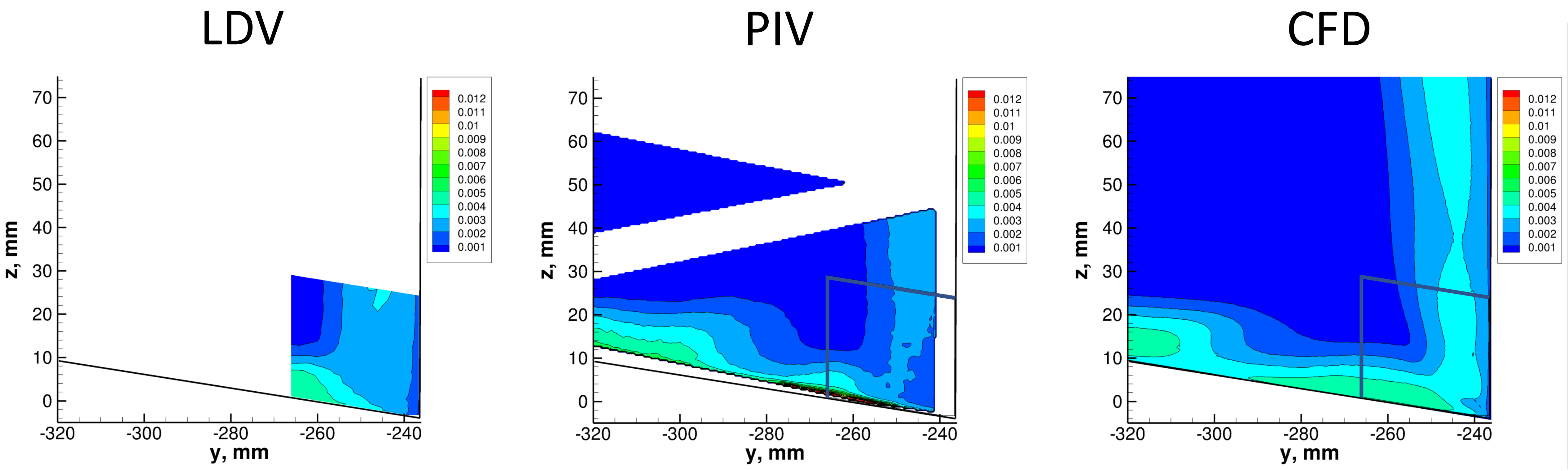
CFD



This example shows $\langle u'u' \rangle/(U_{ref}^2)$ contours at x=2836.6 mm

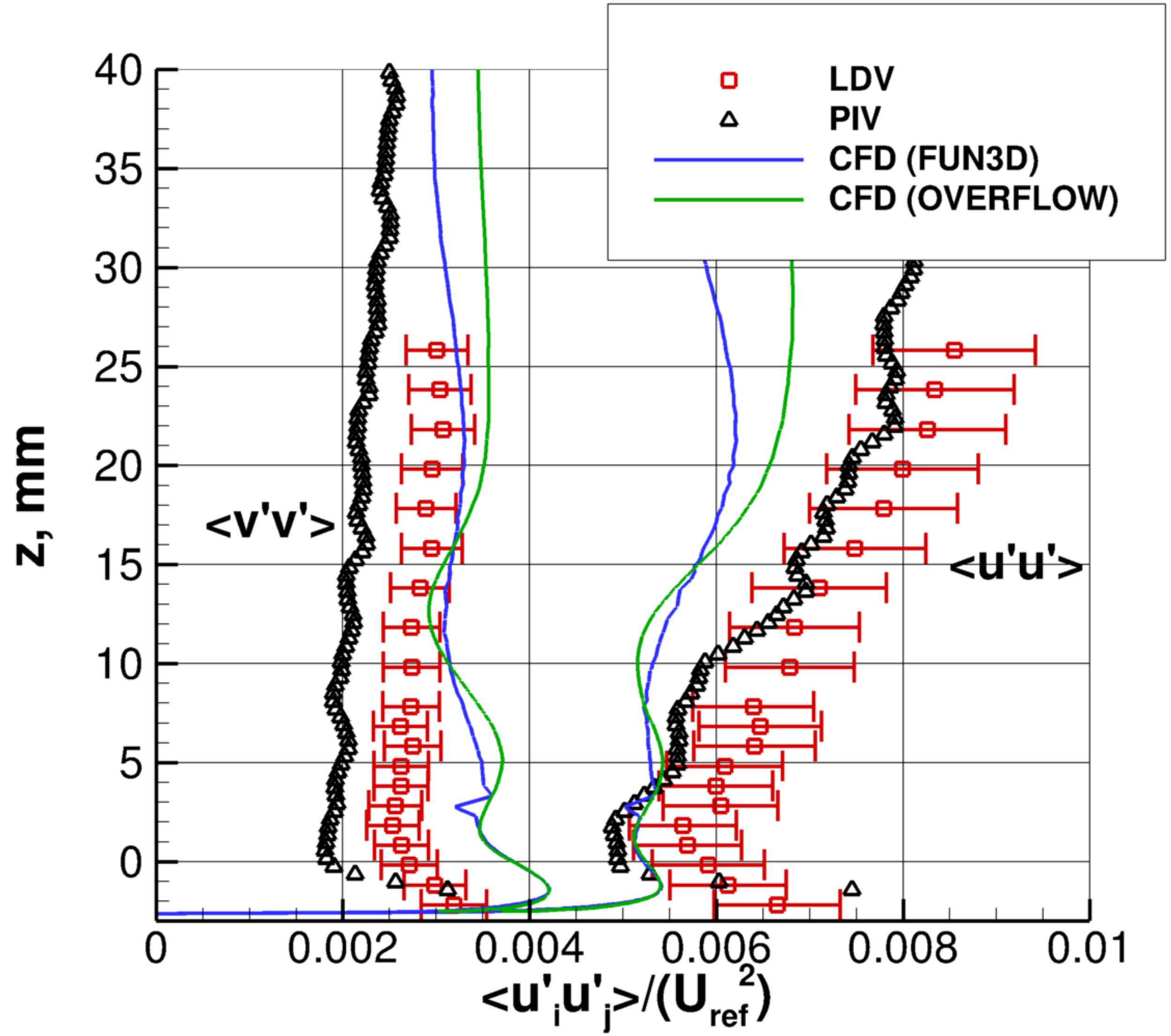
(blank region in PIV figure caused by “rib” that blocked view)

Comparison of flowfield near separation, 7.5 deg.



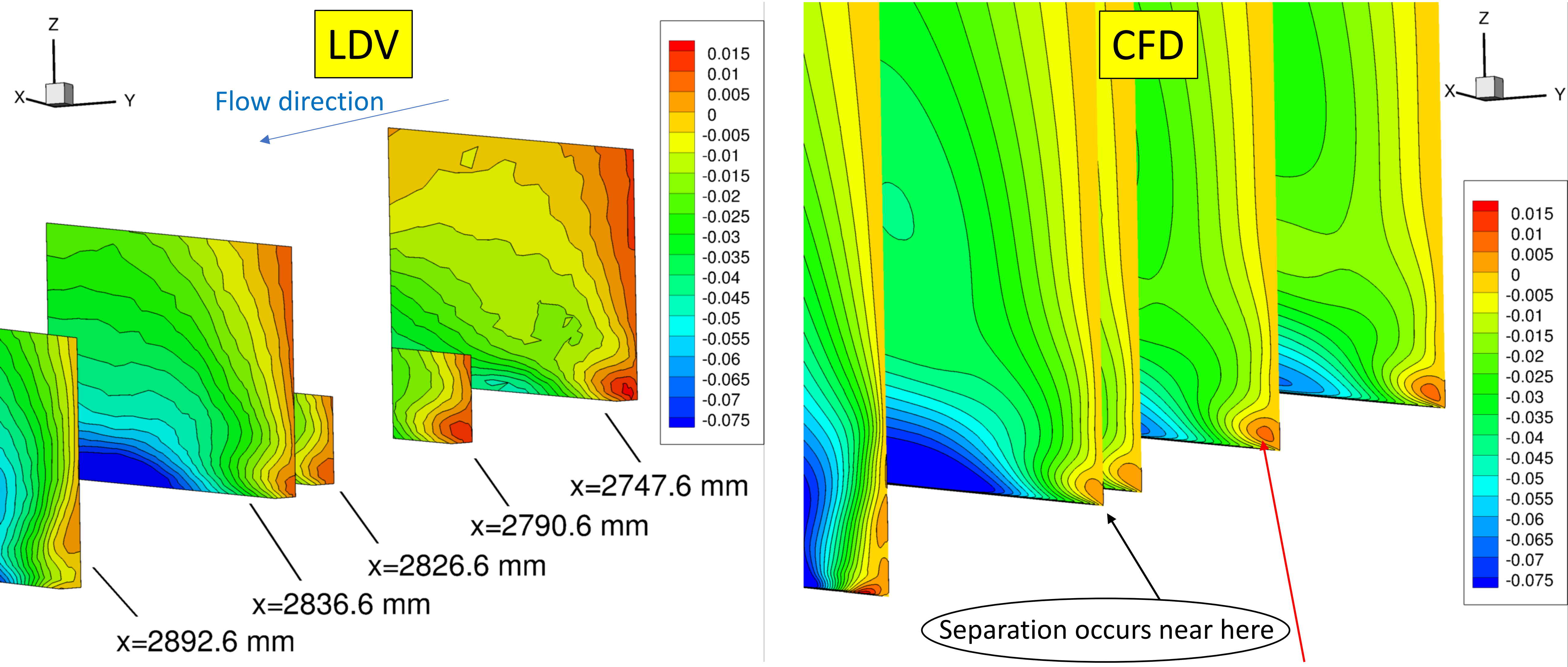
This example shows $\langle v'v' \rangle/(U_{ref}^2)$ contours at x=2836.6 mm

Comparison of profiles near separation, 7.5 deg.



Profiles above wing, within the fuselage boundary layer: x=2836.6 mm, y=-246.1 mm

Progression of flowfield, v/U_{ref} contours, 7.5 deg.

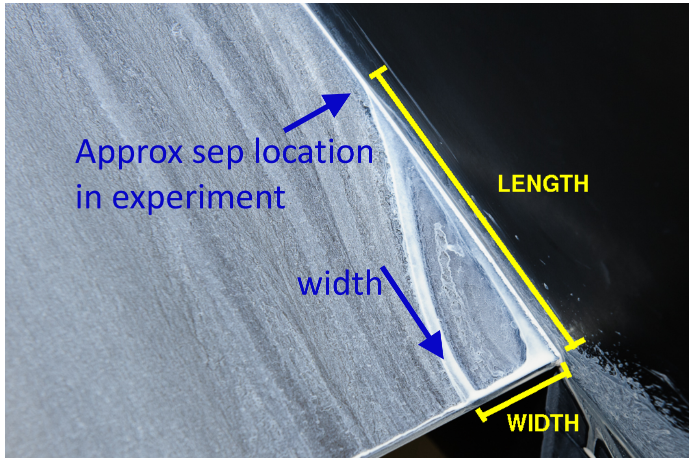


Evidence of stress-induced corner vortex, which helps delay corner separation

Typical Previous CFD Results

- RANS models with Boussinesq constitutive relation
  - Separation sizes predicted FAR too large (100% or more)
- RANS models with nonlinear constitutive relations (including SA-RC-QCR2000 and SA-RC-QCR2013)
  - Separation sizes predicted SOMEWHAT too large (30%)
- RANS Reynolds Stress Transport (RST) model
  - Separation sizes predicted well, but dependent on particular RST model

Using SA-RC-QCR2020, agreement with separation sizes/shapes is **extremely good** (within error bars of experiment)

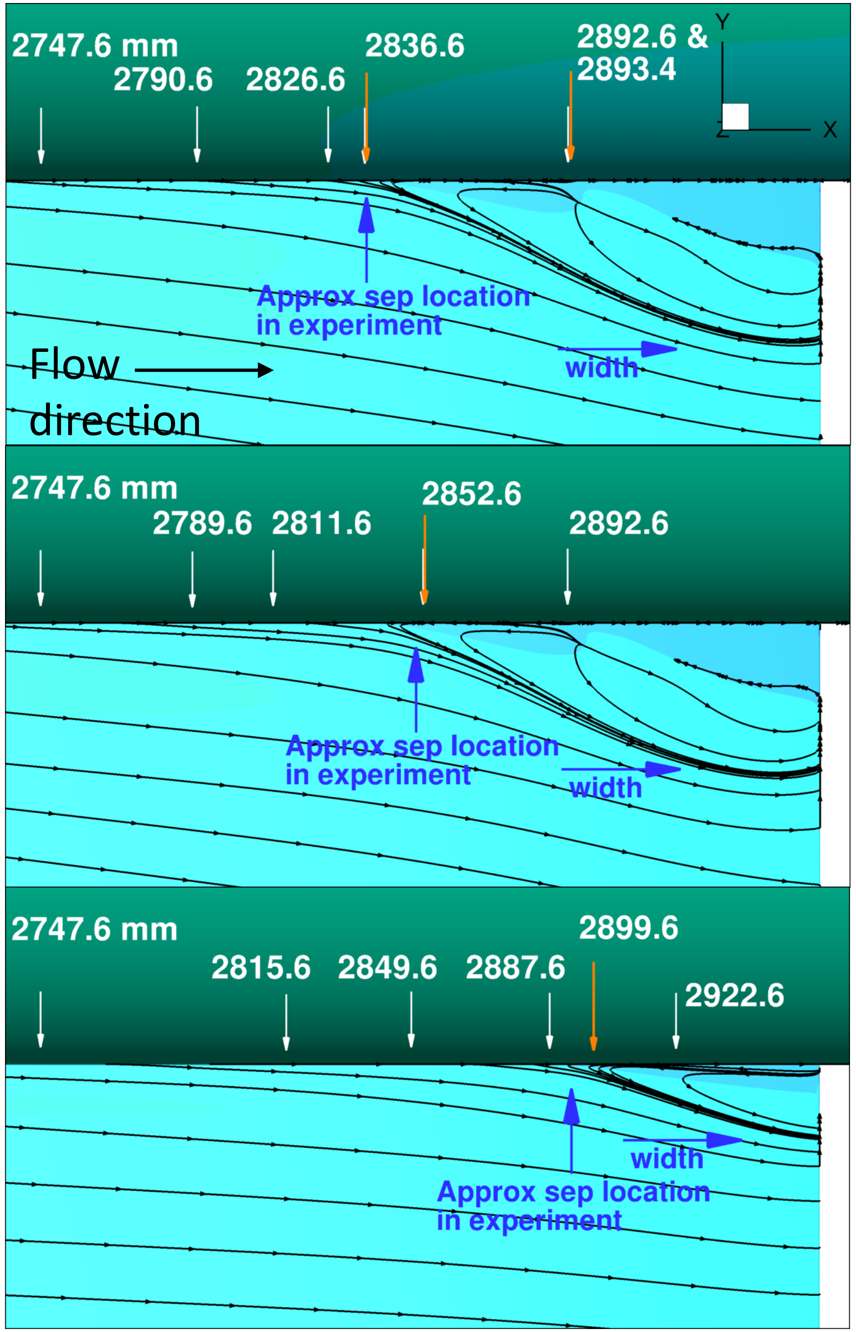


(looking down on wing near junction corner at trailing edge)

$\alpha = 7.5^o$

$\alpha = 5.0^o$

$\alpha = -2.5^o$



Summary

- LDV data
  - Includes “planes” of mean flow and turbulence data upstream of and within separated region
  - Updated uncertainty analysis
- PIV data
  - Within separated region; allows direct comparisons with LDV data
  - PIV results do not always lie within the uncertainty bands of the LDV
  - Significant fraction of PIV data is still being processed
- SA-RC-QCR2020 improves turbulent normal stress predictions
  - Compared to earlier versions of QCR
  - This model version yields very good predictions of separation size

The NASA JF data set is an invaluable reference for CFD validation of separated juncture flows

https://turbmodels.larc.nasa.gov/Other_exp_Data/junctureflow_exp.html

Future Work

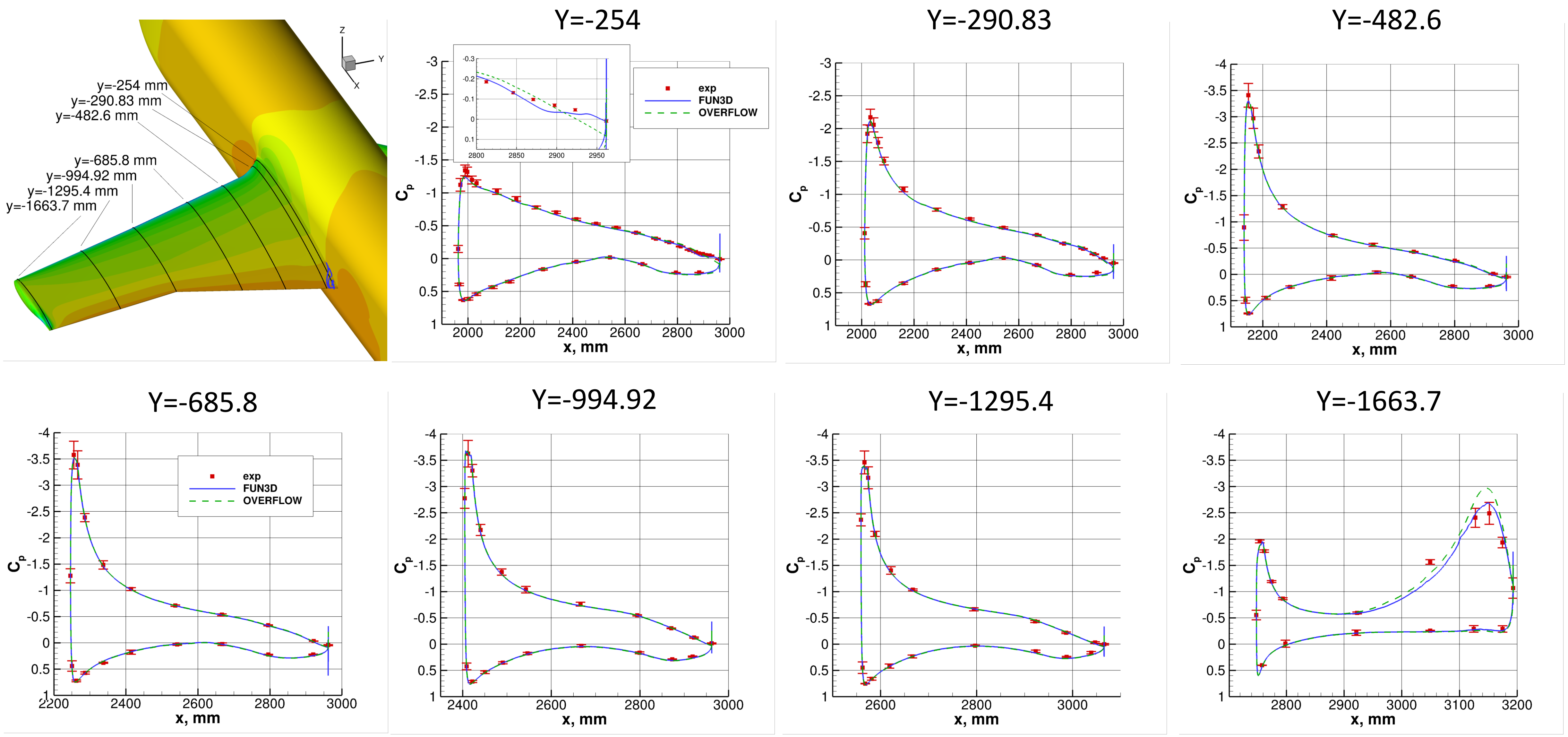
Phase 3 data collection on a different wing (attached and incipient separation):
Dec 2021 – Mar 2022

Acknowledgements

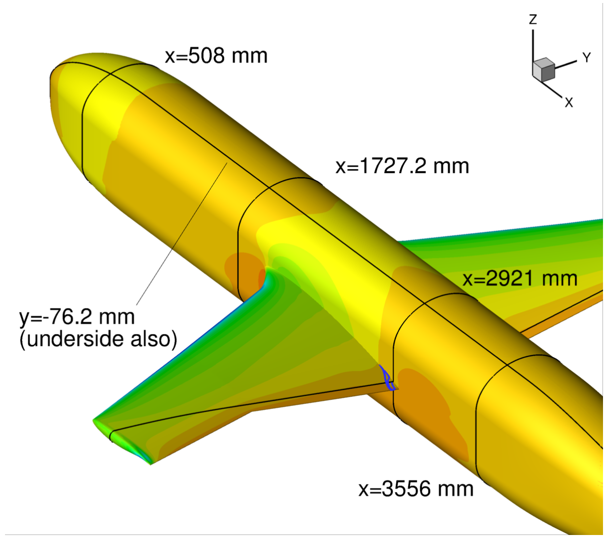
NASA's Transformational Tools and Technologies (TTT) project of the Transformative Aeronautics Concepts Program

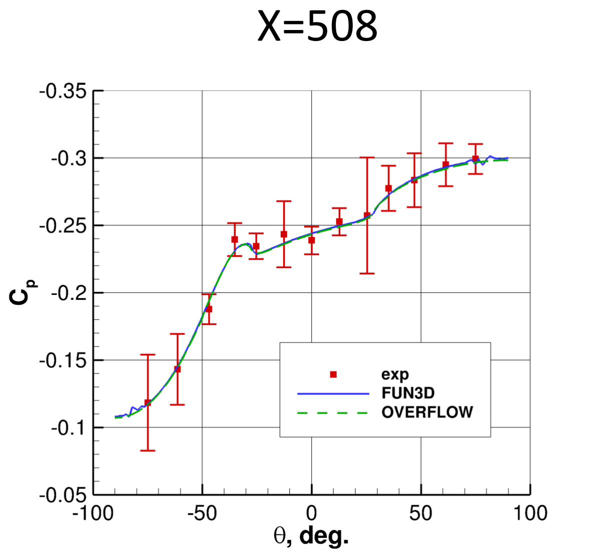
Back-up slides

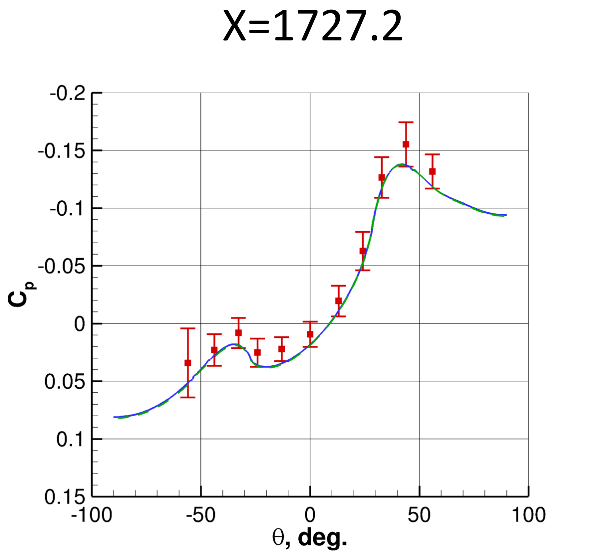
Surface pressure coefficients, 7.5 deg.

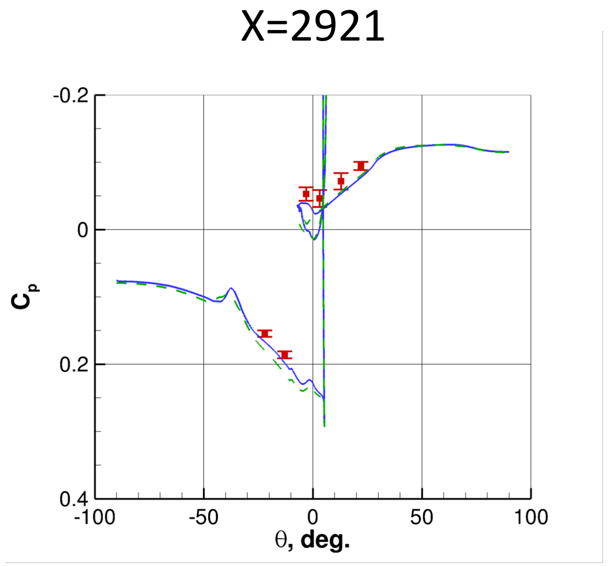


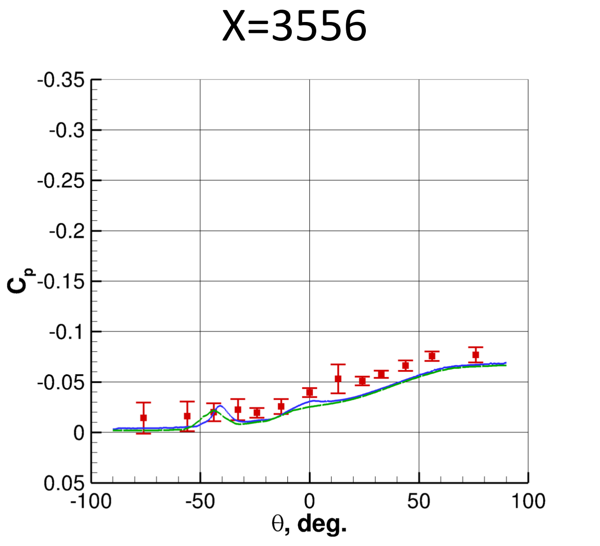
Surface pressure coefficients, 7.5 deg., cont'd

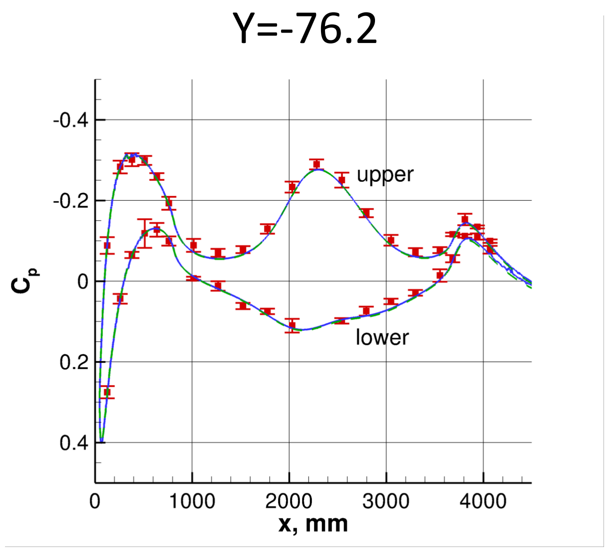






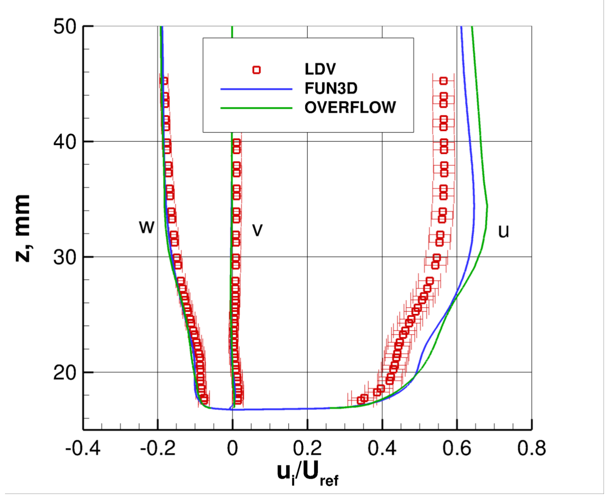


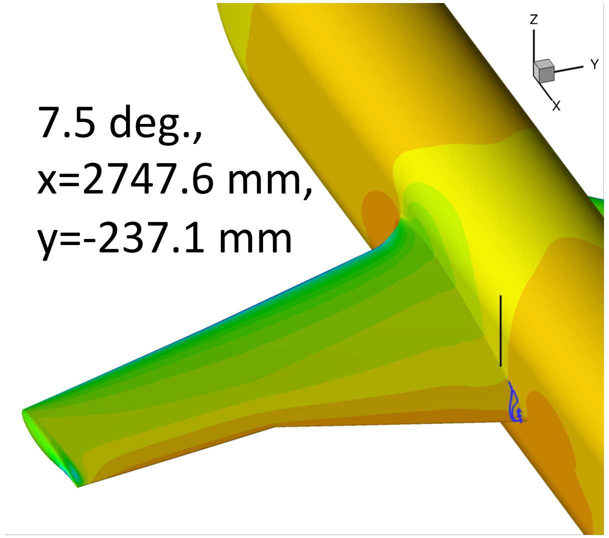




Profiles on wing well upstream of separation

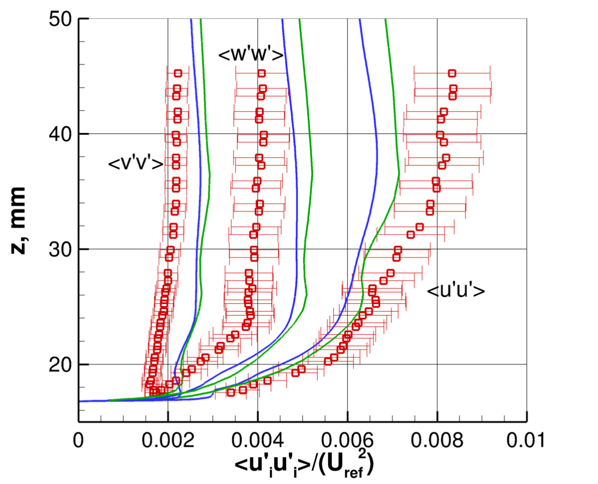
velocity



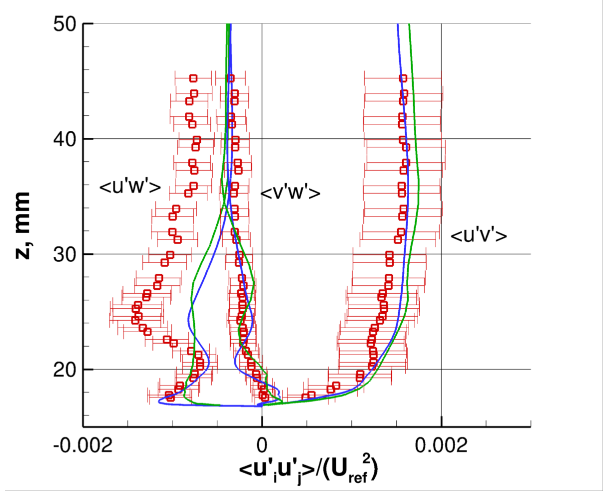


7.5 deg.,
x=2747.6 mm,
y=-237.1 mm

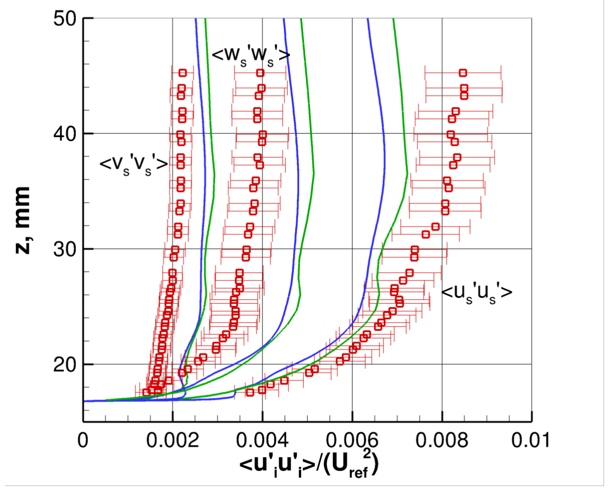
normal stresses



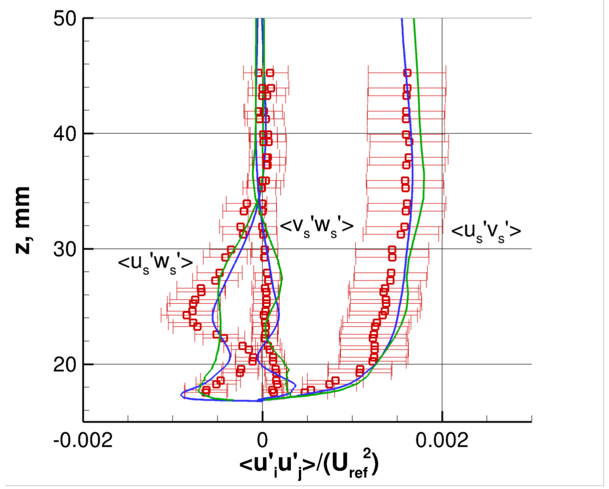
shear stresses



normal stresses (rotated)

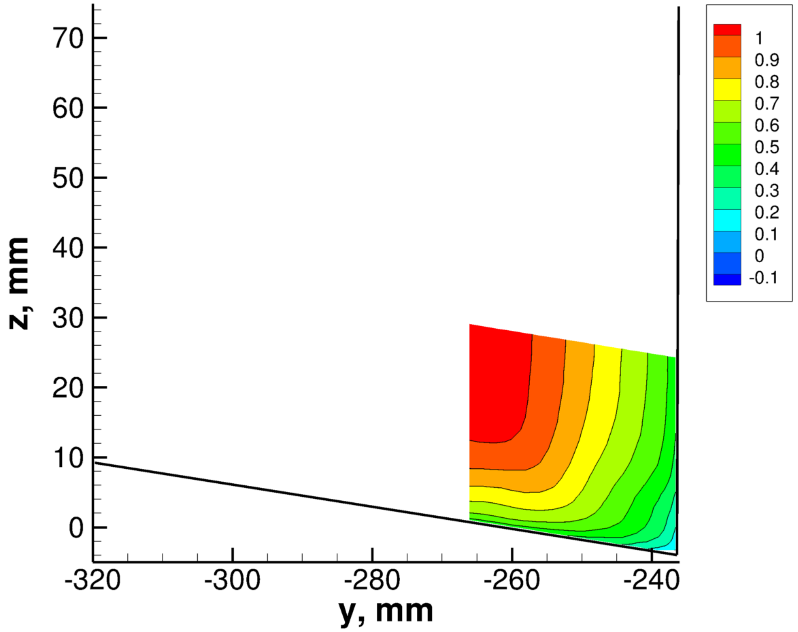


shear stresses (rotated)

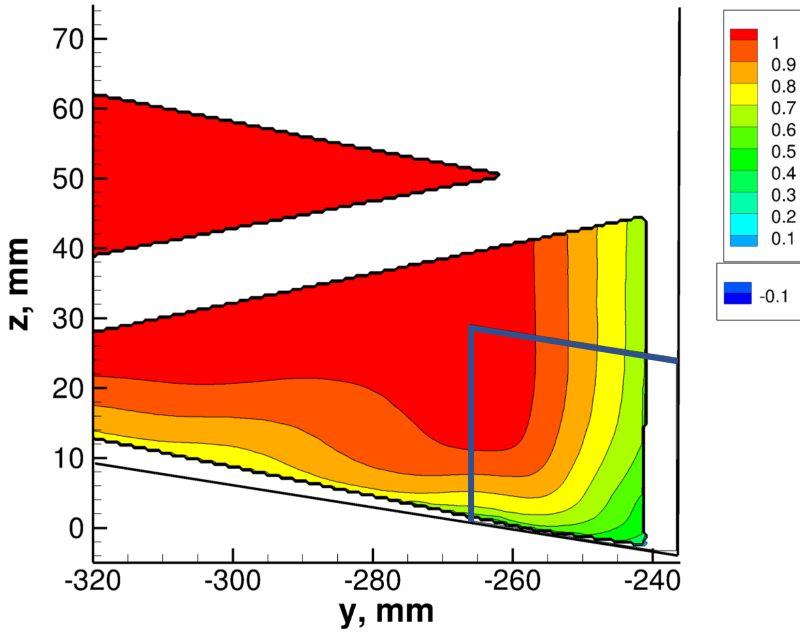


Comparison of flowfield near separation, 7.5 deg.

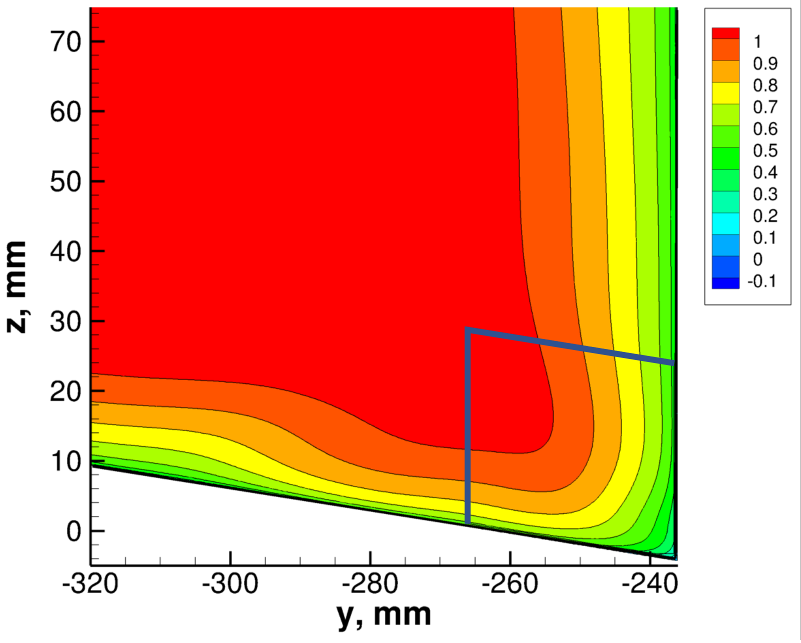
LDV



PIV



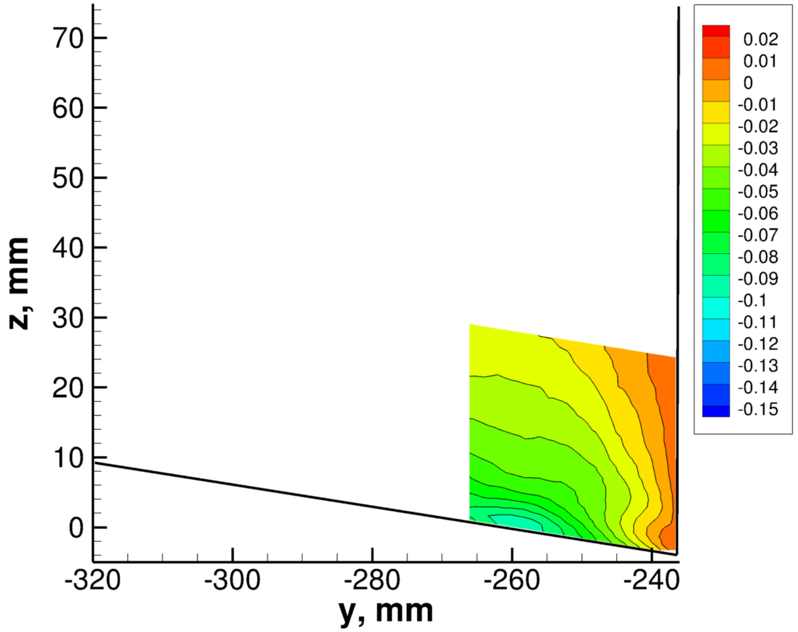
CFD



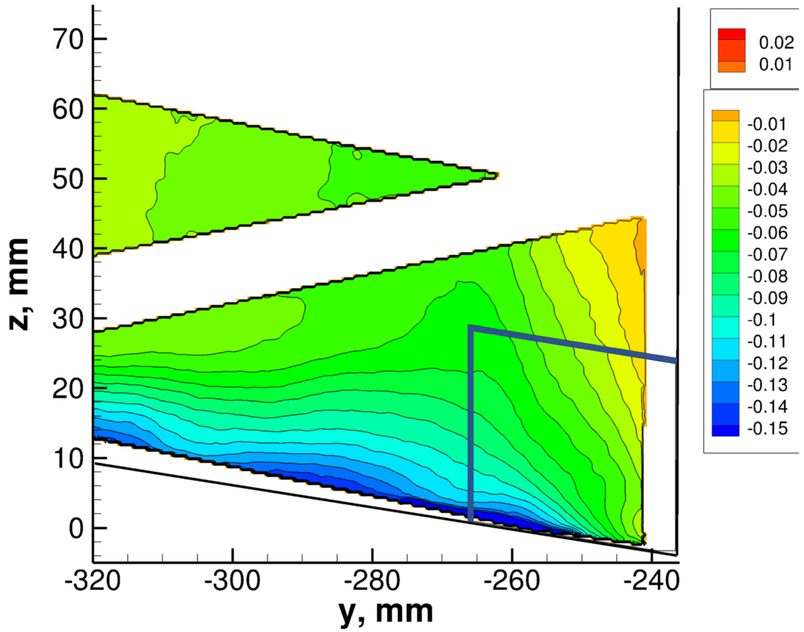
This example shows $u/(U_{ref})$ contours at x=2836.6 mm

Comparison of flowfield near separation, 7.5 deg.

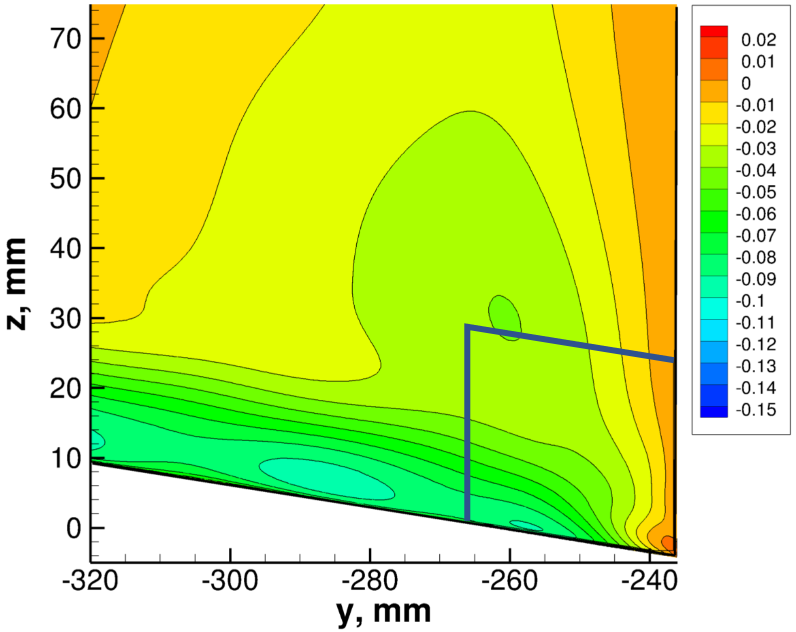
LDV



PIV

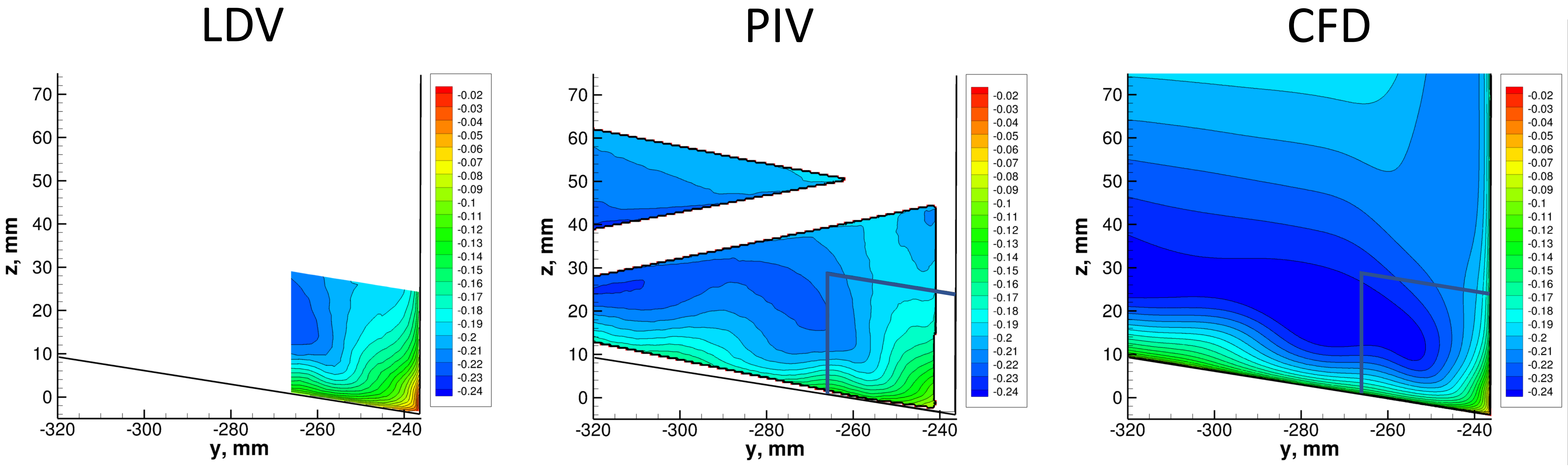


CFD



This example shows $v/(U_{ref})$ contours at x=2836.6 mm

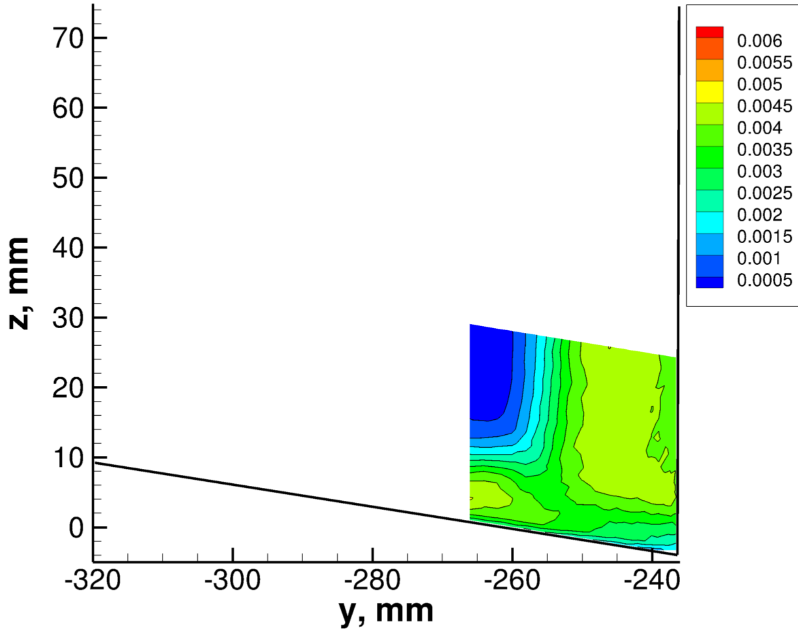
Comparison of flowfield near separation, 7.5 deg.



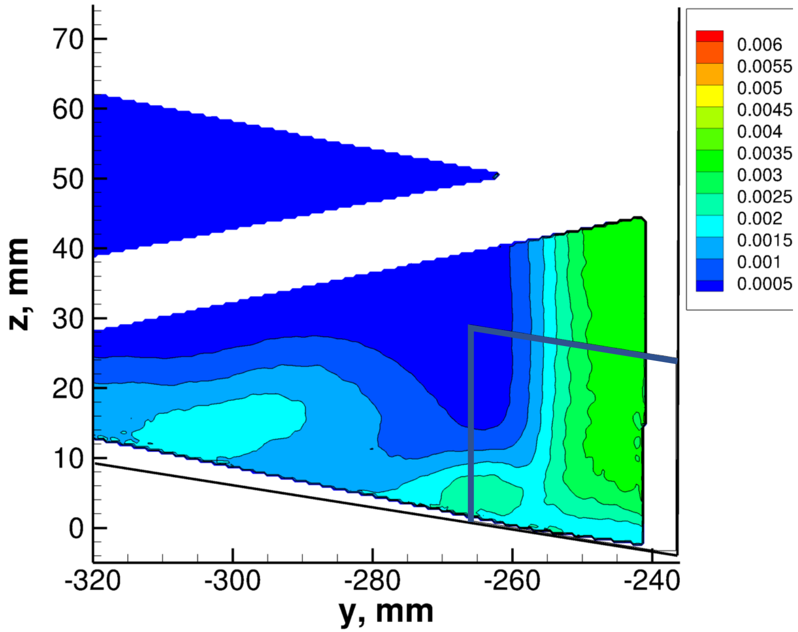
This example shows w/(U_{ref}) contours at x=2836.6 mm

Comparison of flowfield near separation, 7.5 deg.

LDV



PIV



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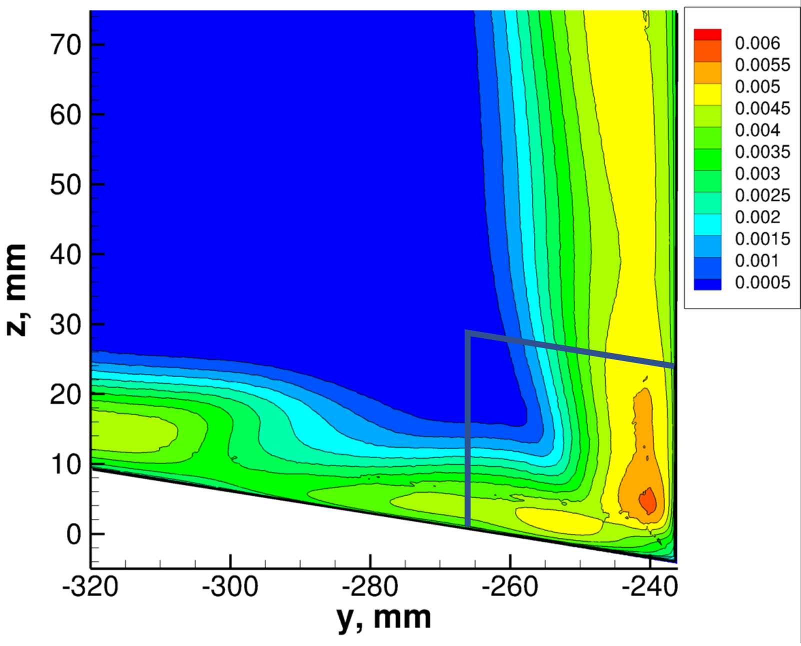
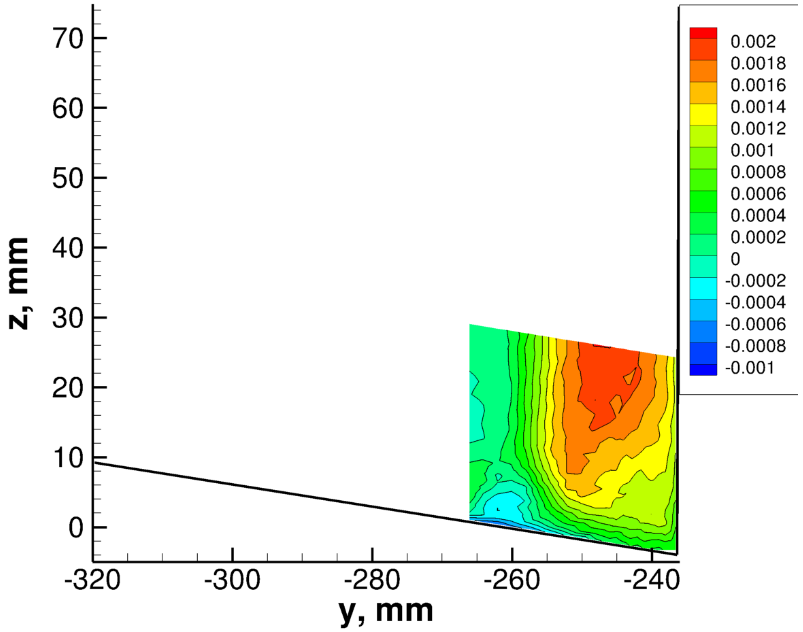


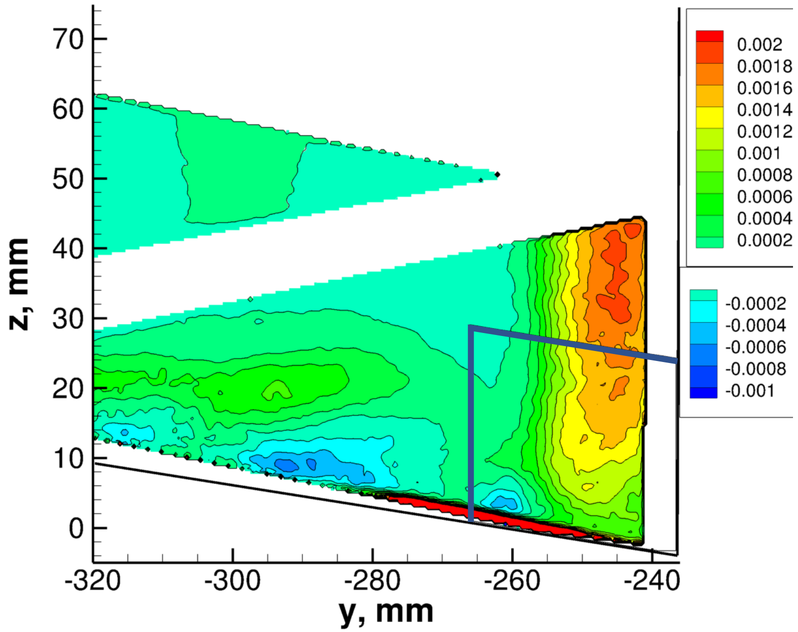
This example shows $\langle w'w' \rangle/(U_{ref}^2)$ contours at x=2836.6 mm

Comparison of flowfield near separation, 7.5 deg.

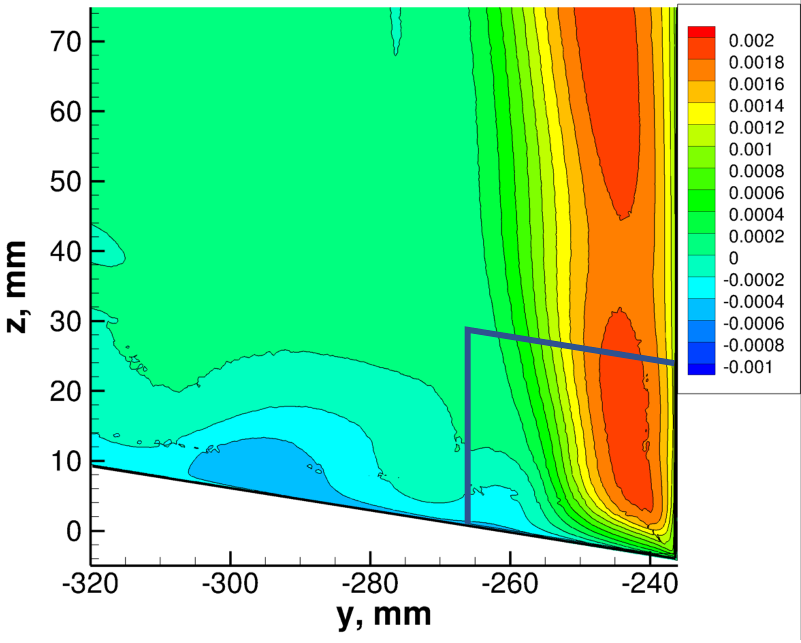
LDV



PIV



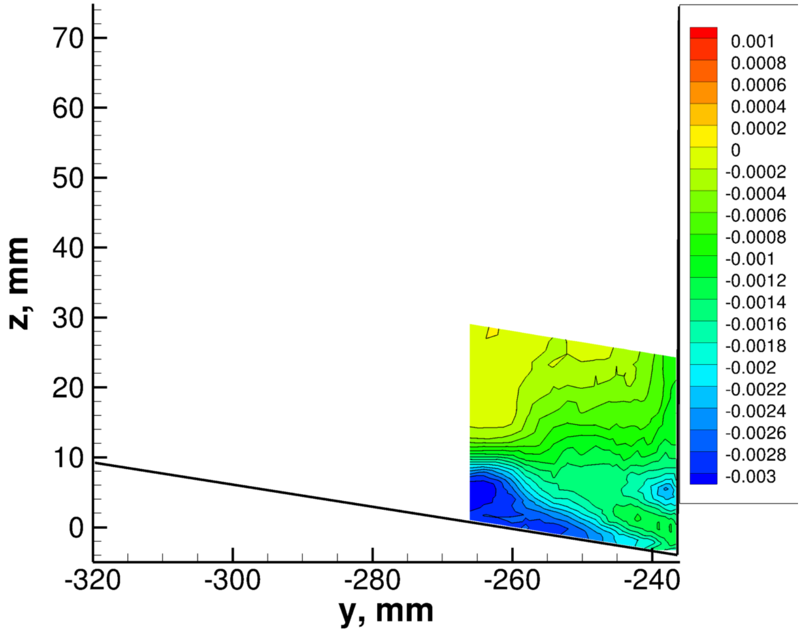
CFD



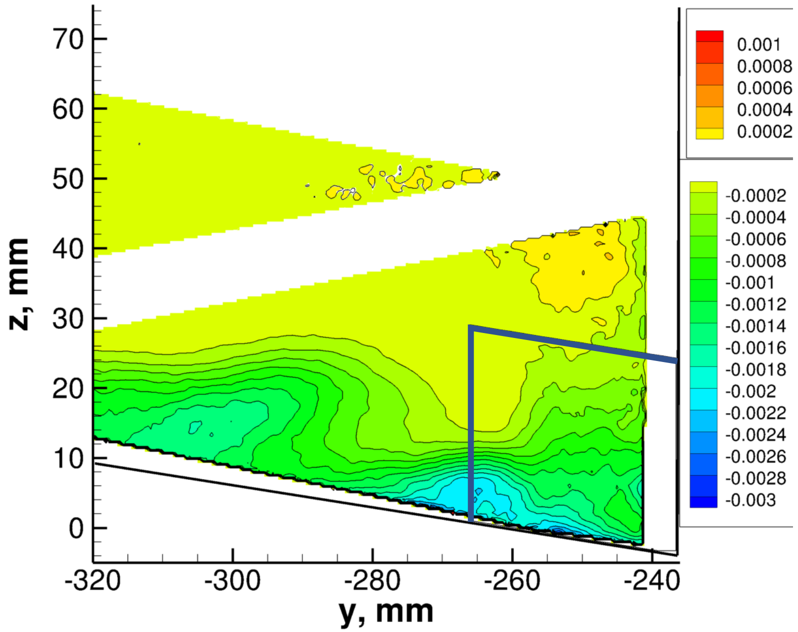
This example shows $\langle u'v' \rangle/(U_{ref}^2)$ contours at x=2836.6 mm

Comparison of flowfield near separation, 7.5 deg.

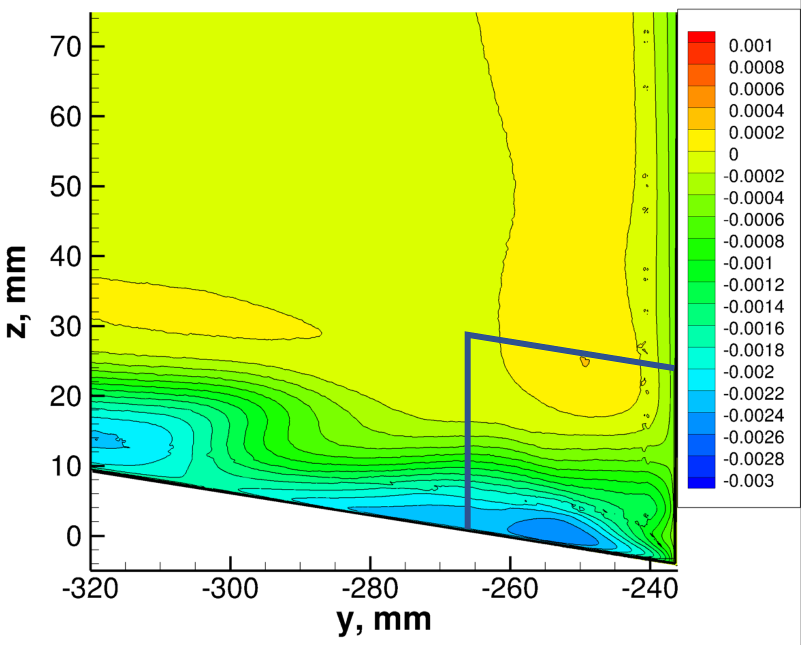
LDV



PIV



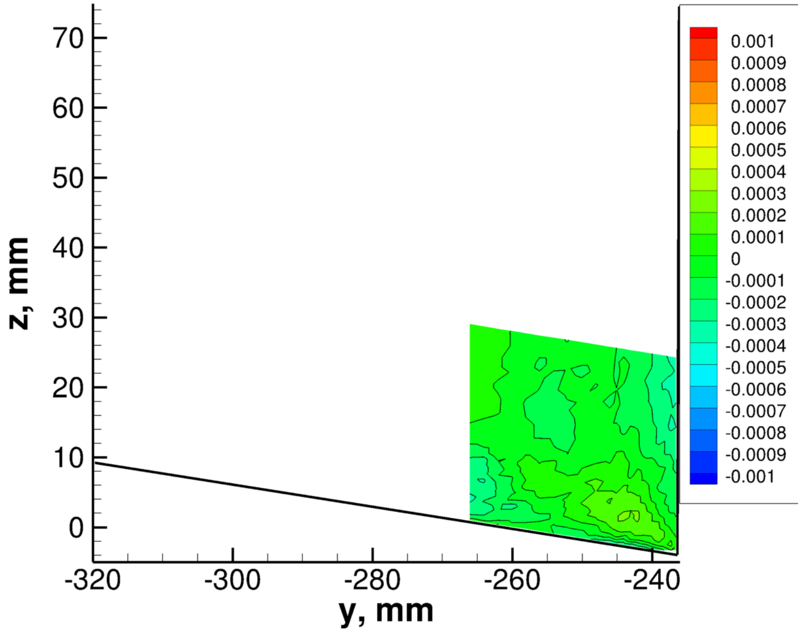
CFD



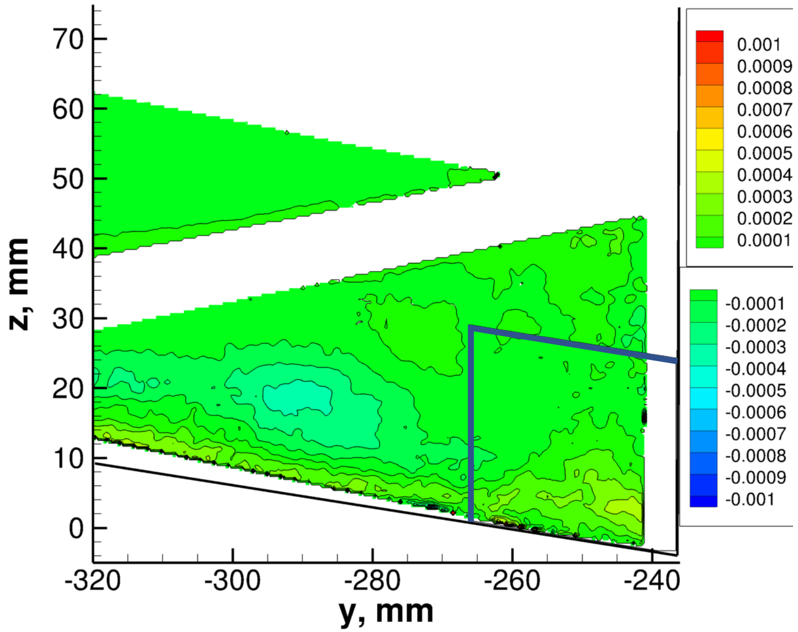
This example shows $\langle u'w' \rangle / (U_{ref}^2)$ contours at x=2836.6 mm

Comparison of flowfield near separation, 7.5 deg.

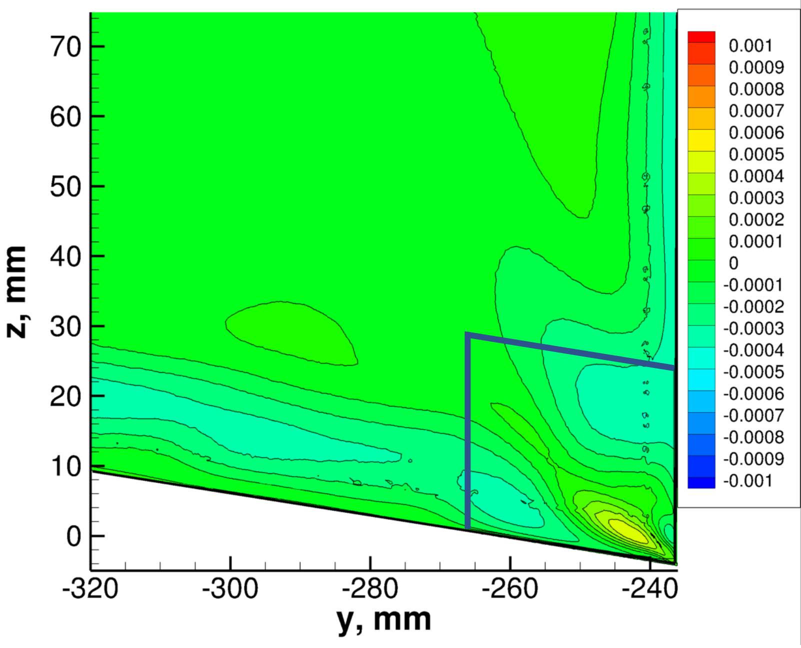
LDV



PIV



CFD



This example shows $\langle v'w' \rangle/(U_{ref}^2)$ contours at x=2836.6 mm