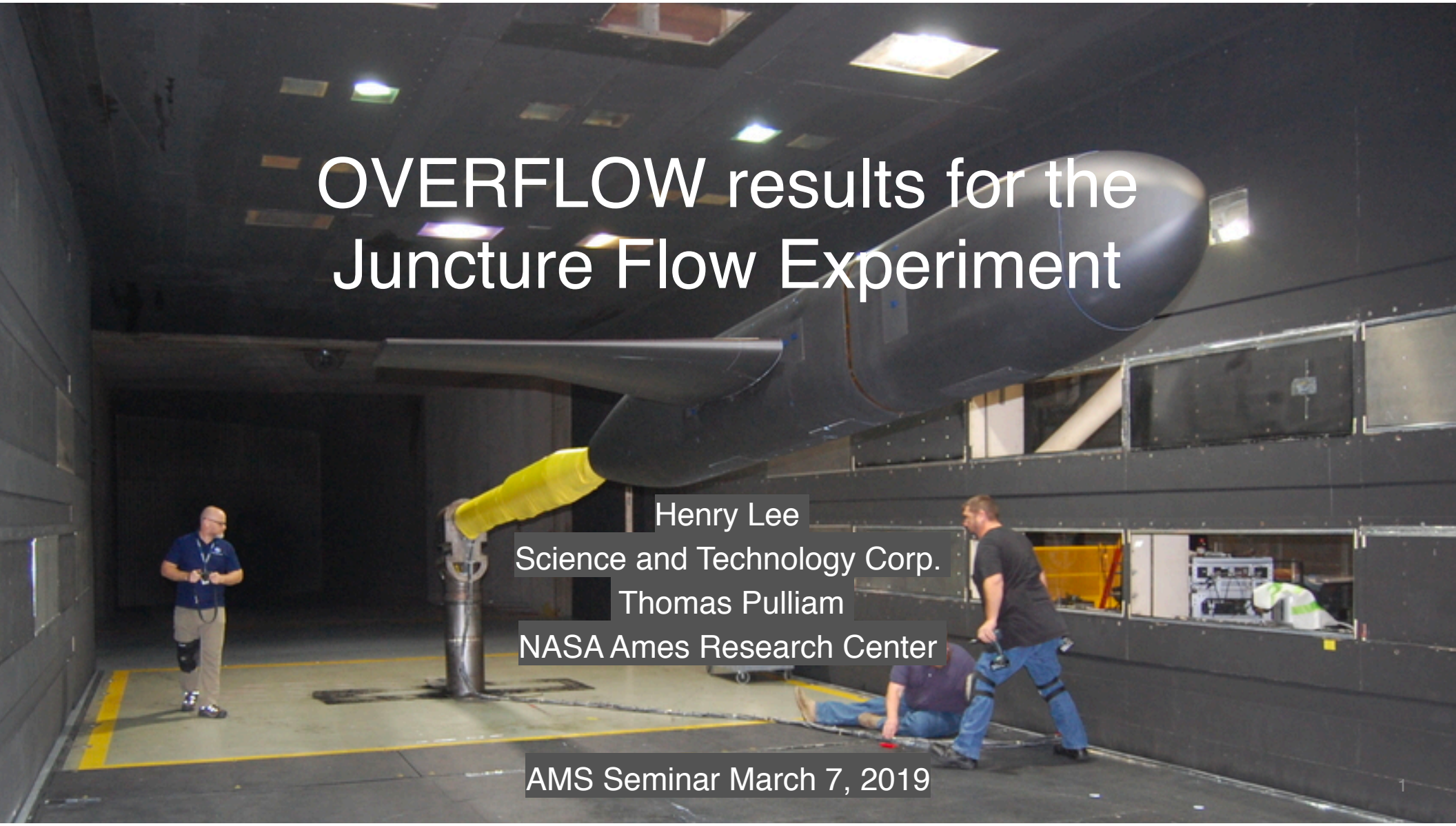


OVERFLOW results for the Juncture Flow Experiment

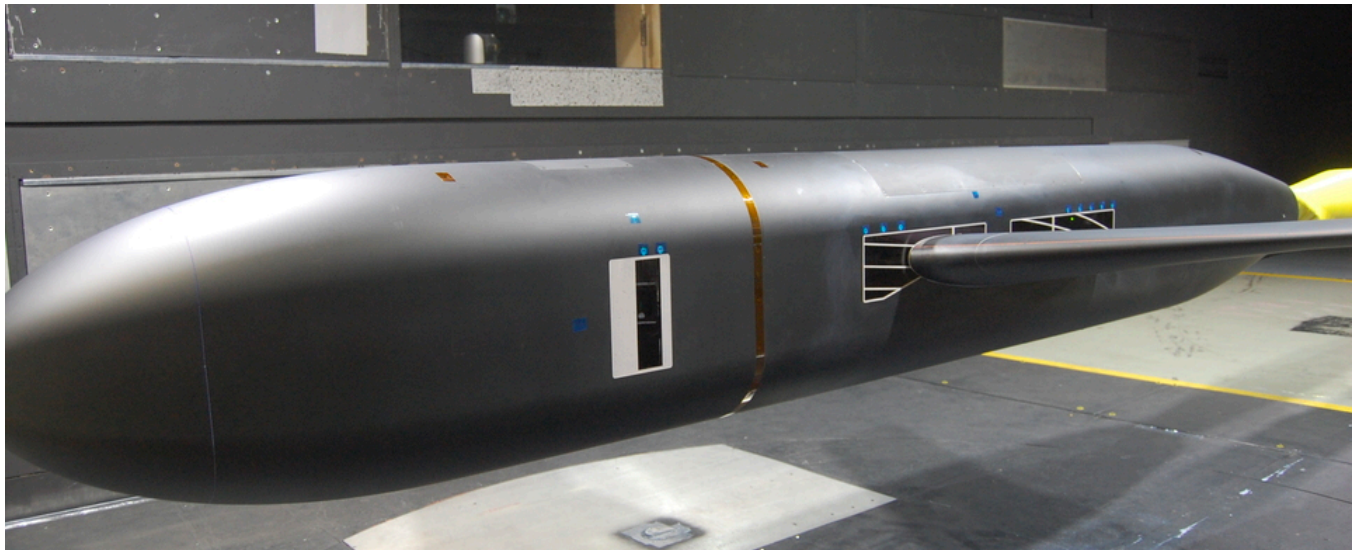
Henry Lee
Science and Technology Corp.
Thomas Pulliam
NASA Ames Research Center

AMS Seminar March 7, 2019

Juncture Flow Experiment

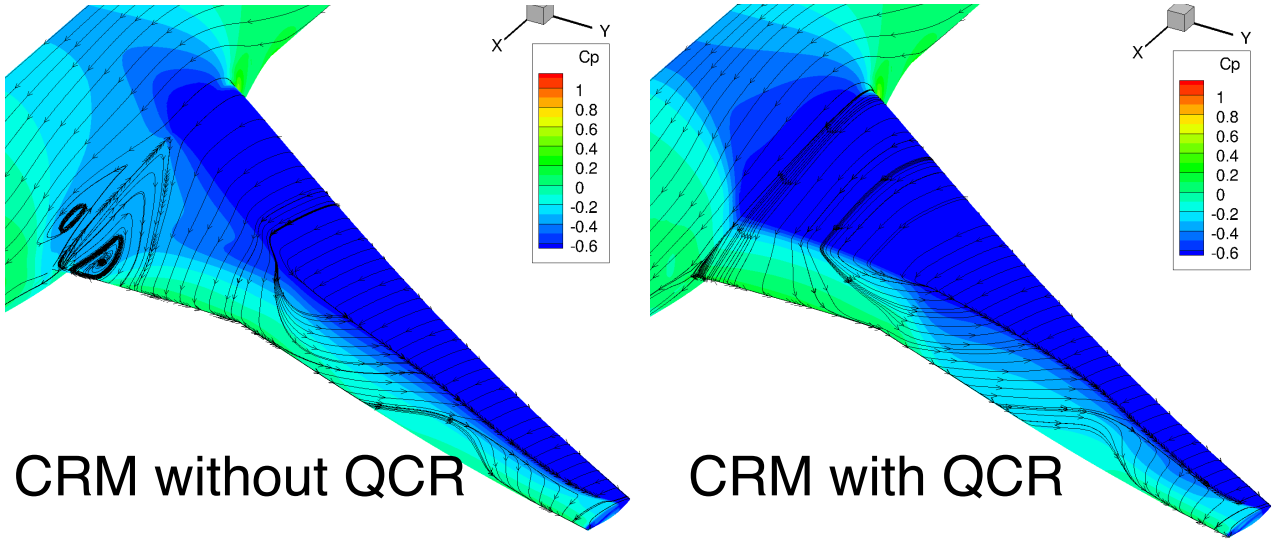
Sponsored by NASA's Transformative Aeronautics Concepts Program's Transformational Tools and Technologies (T^3) project

- Substantial effort to investigate the origin of separation bubbles found in wing-body juncture zones
- Primary goal is to gather validation level data, for future CFD code & turbulence model development
- Multi-year effort including several large-scale wind tunnel tests
  - First set of entries just finished: Nov 2017-April 2018
  - Planned Entries in the future



Juncture Flow Experiment Motivation

- Drag prediction workshops
  - Inconsistency between CFD codes
  - Sensitive to Grid Resolution (Air), solution methods, turbulence models
- Quadratic constitutive relation (QCR)
  - Reduced the inconsistency substantially



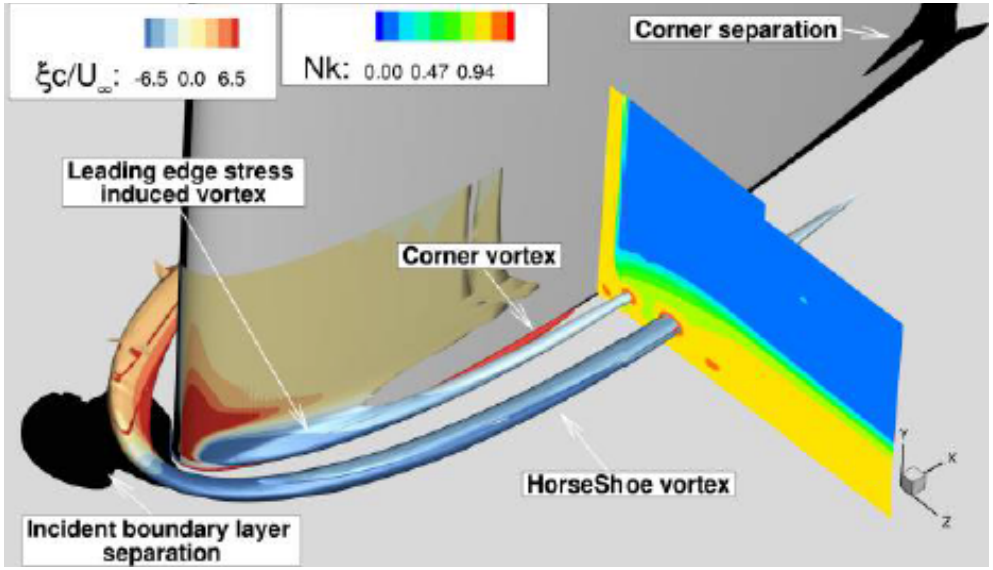
CRM without QCR

CRM with QCR

Juncture Flow Physics

- Flow physics of juncture flows are complex
  - Several vortical structures coexist: e.g., Horseshoe Vortex (HSV), corner vortex, stress-induced vortex
  - Many factors: incoming boundary layer momentum thickness, wing bluntness, and wing sweep, etc

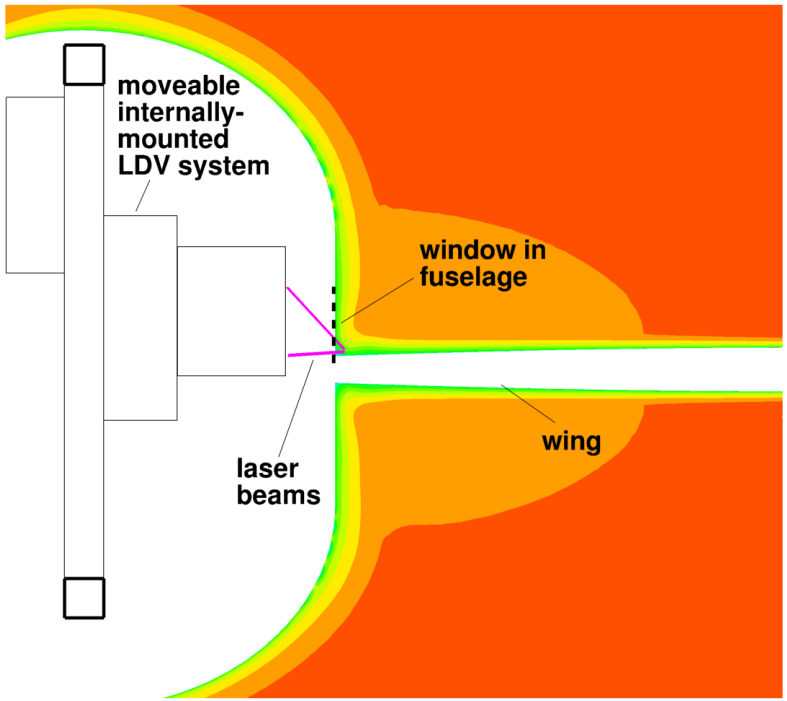
- JFM Experiment:
  - Swept wing / fuselage full-span configuration
  - Collect data for CFD validation
  - Obtain flow field details very near the corner



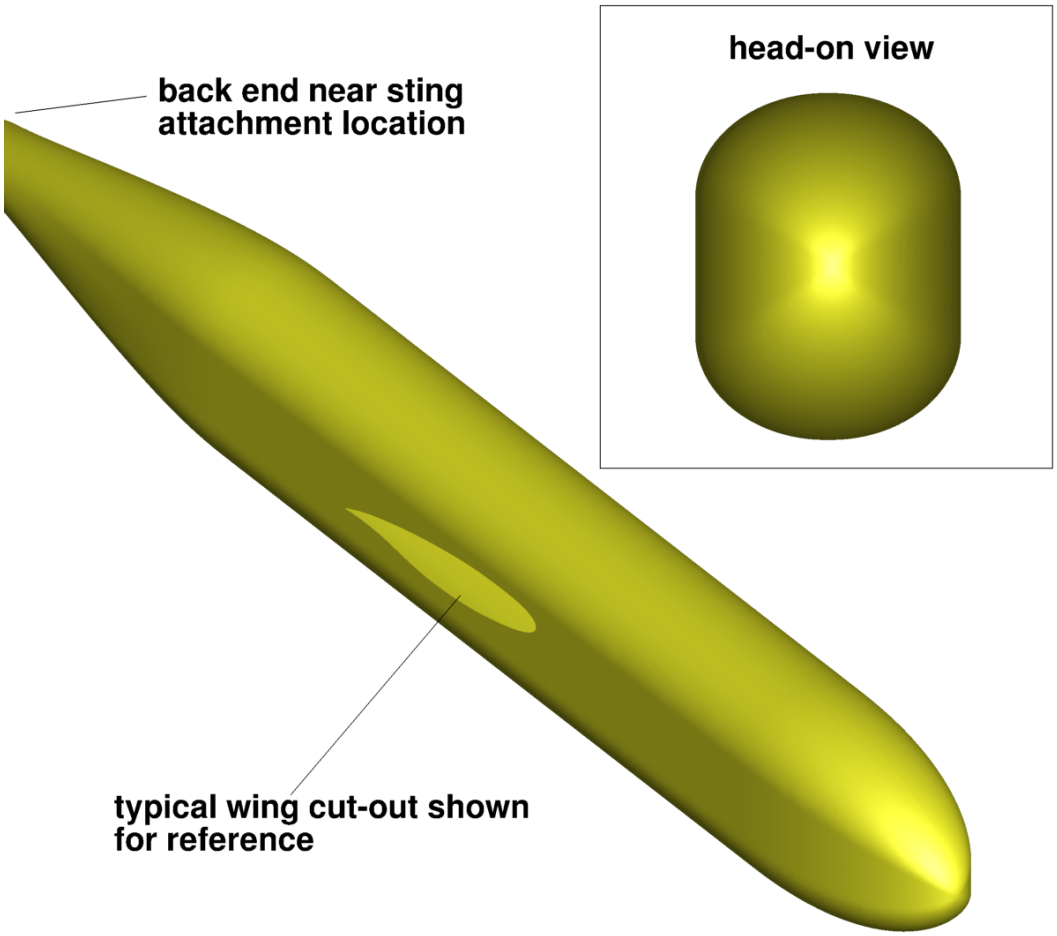
From AIAA-2014-2690 (Bordji et al)

Juncture Flow Experiment Design

- Use internal Laser Doppler Velocimetry (LDV) system
  - Mounted inside of the fuselage
  - Movable three-axis traverse system
  - Measure the flow field through window on fuselage
  - Closest possible location to wing-body juncture

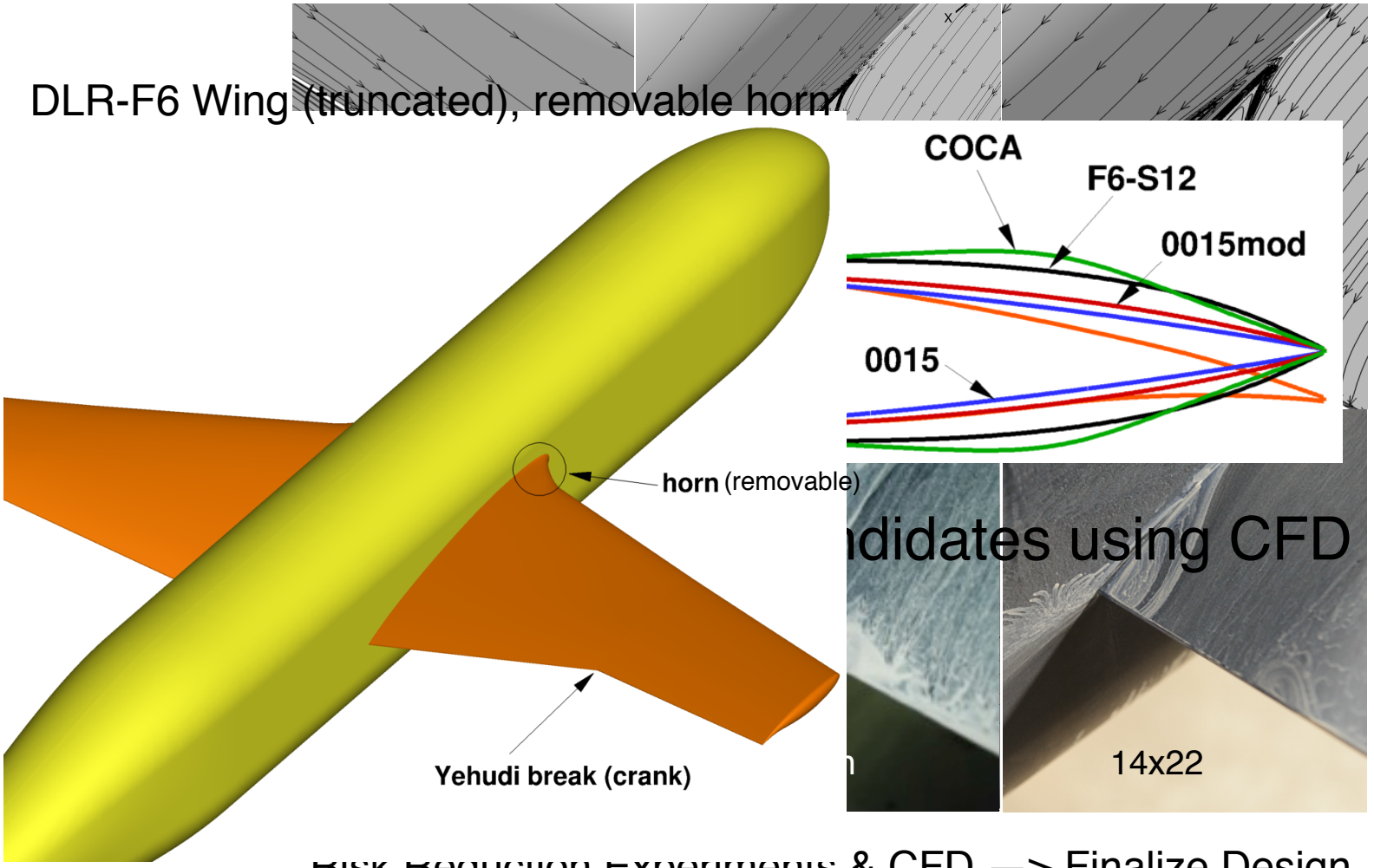


Fuselage Configuration



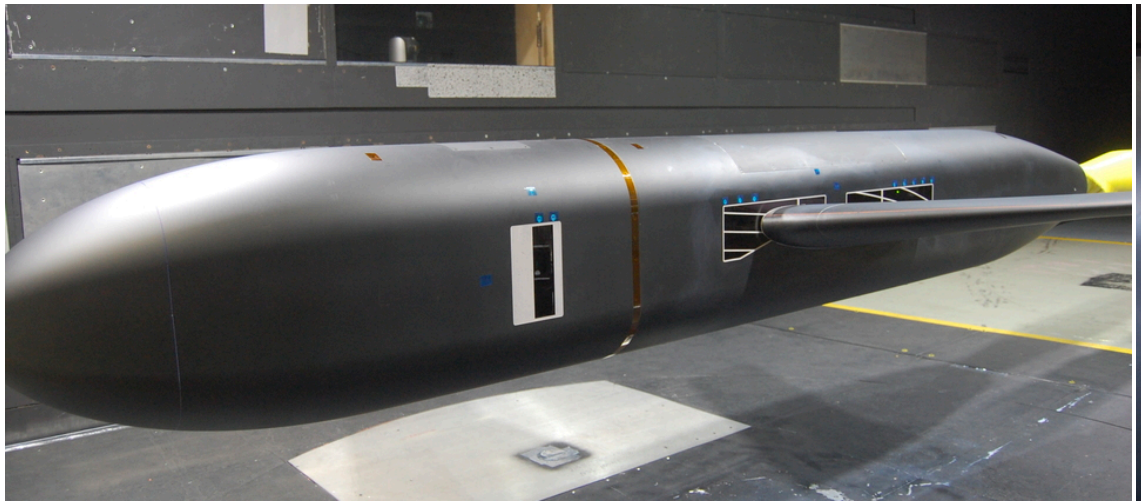
Wing Configuration Design

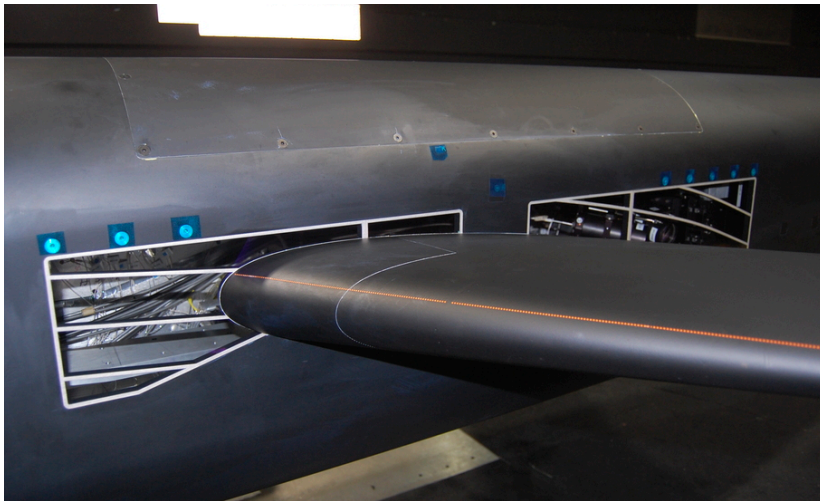
DLR-F6 Wing (truncated), removable horn

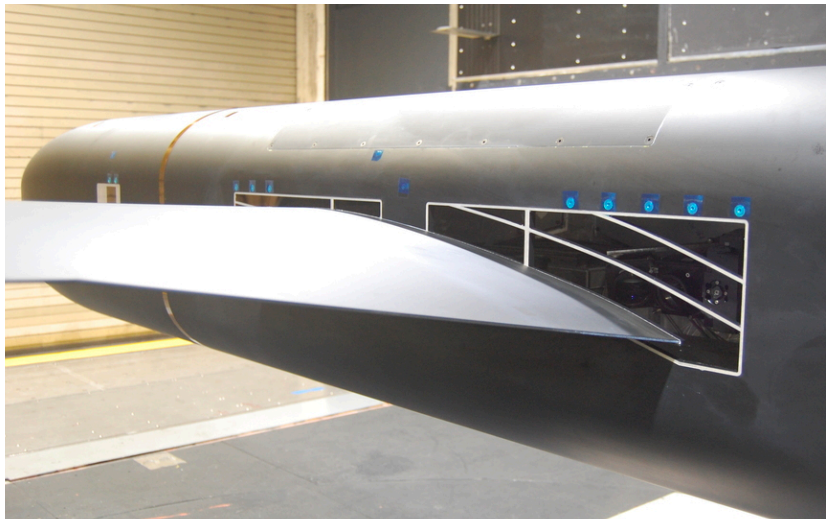


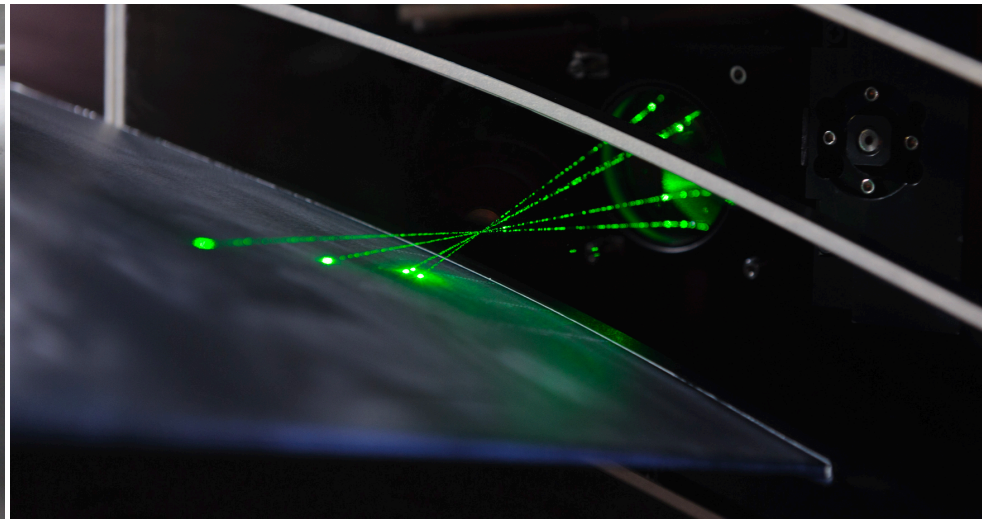
Risk Reduction Experiments & CFD —> Finalize Design

Experiment Pictures









Juncture Flow Experiment



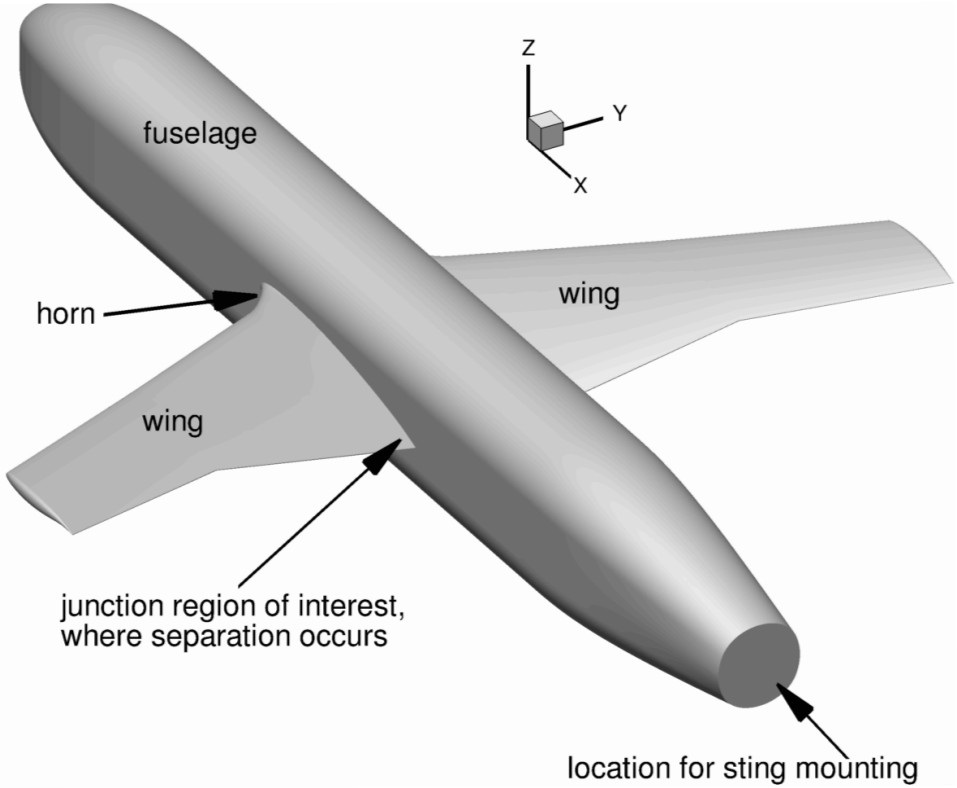
- Heavy collaboration: CFD and WT design team
  - CFD used extensively in the experiment design
  - Companion CFD runs for all risk assessment experiments
- Publications:
  - AIAA 2016-1557, AIAA 2016-1558, AIAA 2017-4127, AIAA 2017-4126, NASA TM-2016-219348, STO-MP-AVT-284-02

- Have experimental data now, how well does CFD RANS (OVERFLOW) do?

OVERFLOW Approach

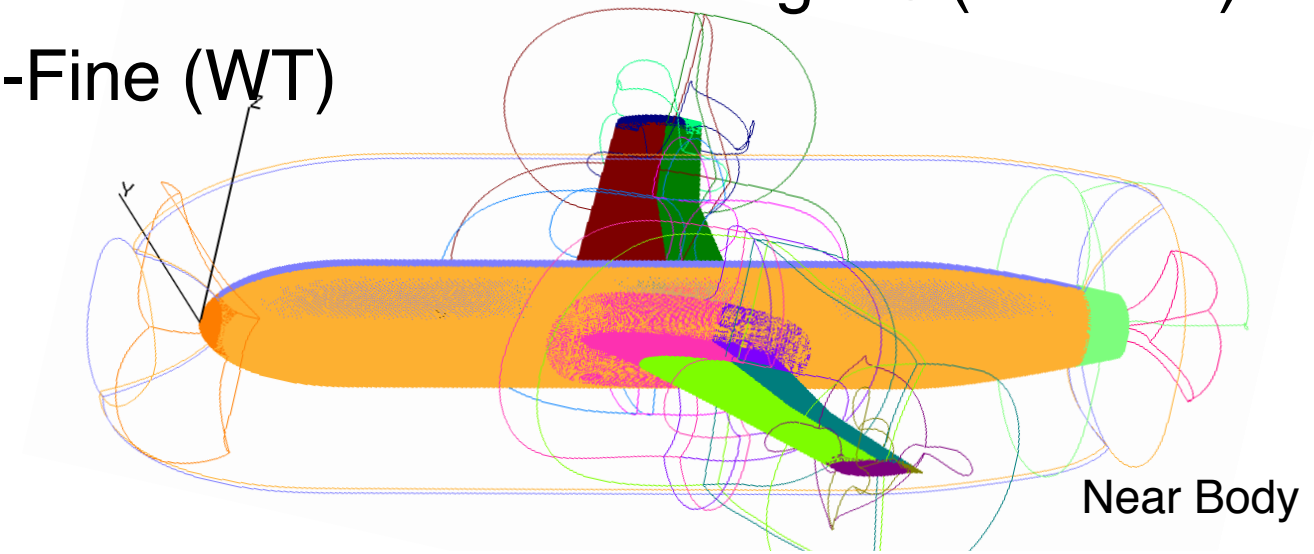
- OVERFLOW CFD RANS current “state of the art” evaluation
  - Grid Resolution (in Free Air)
  - Wall Effect, Free Air vs WT walls
  - Turbulence Model (in Free Air)

- Data Comparisons
  - Separation Size
  - Wing Pressure (cuts)
  - Surface Streamlines
  - Velocity Profiles
  - Reynolds Stress Profiles



OVERFLOW Grids

- Structured overset grid system
  - Free Air: Curvilinear near-body, Cartesian off-body
  - WT: Curvilinear near-body, Curvilinear wind tunnel wall grids
- Grid family created using guidelines from DPW series
  - Coarse-Medium-Fine-Extra Fine grids (Free Air)
  - Medium-Fine (WT)



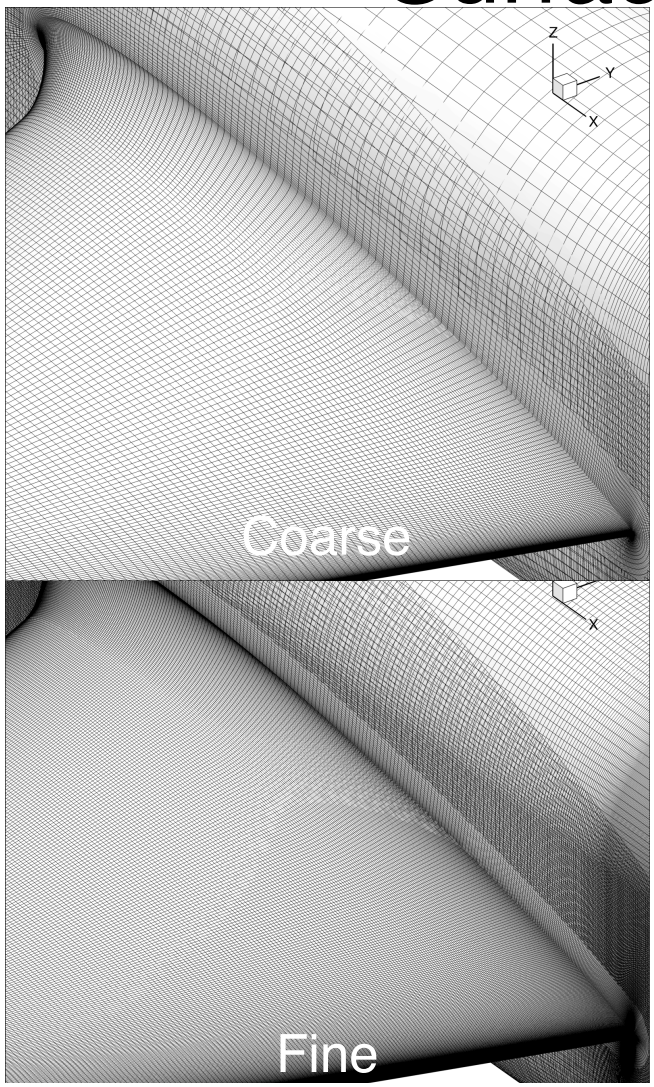
Near Body Grids

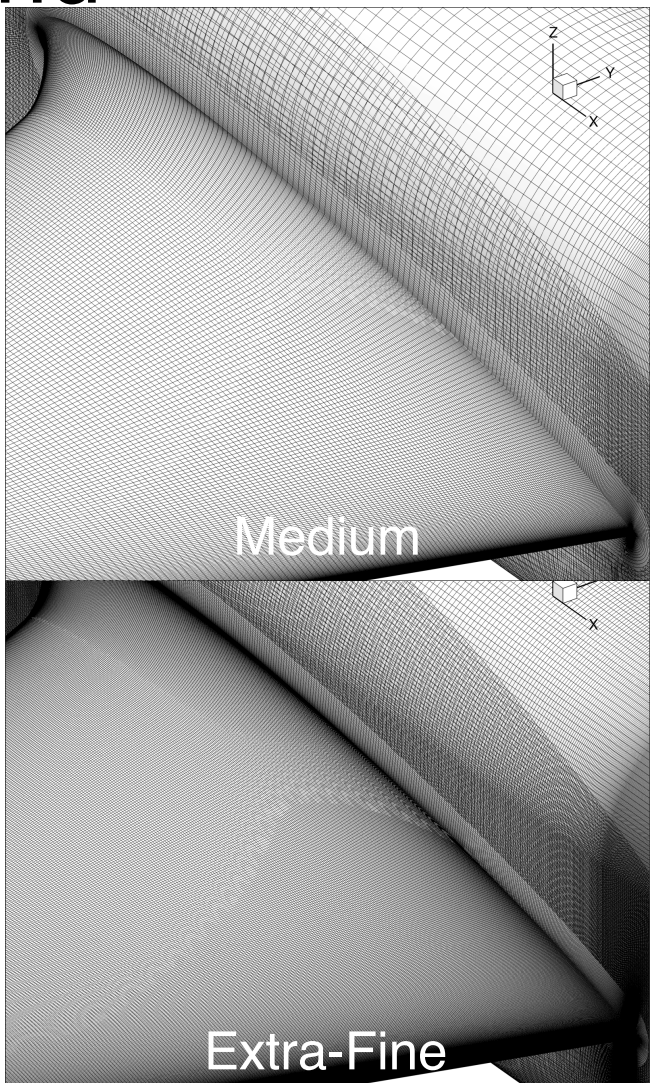
OVERFLOW Grid Parameters

Configuration	Stretching Ratio	Near Body Grid Points	Total Grid Points
Free Air Coarse		19.4M	21.4M
Free Air Medium	1.15	47.6M	48.7M
Free Air Fine	1.10	163.6M	165.7M
Free Air Extra-Fine	1.08	382.1M	398.4M
Wind Tunnel Medium	1.15	47.6M	92.6M
Wind Tunnel Fine	1.10	163.6M	325.5M

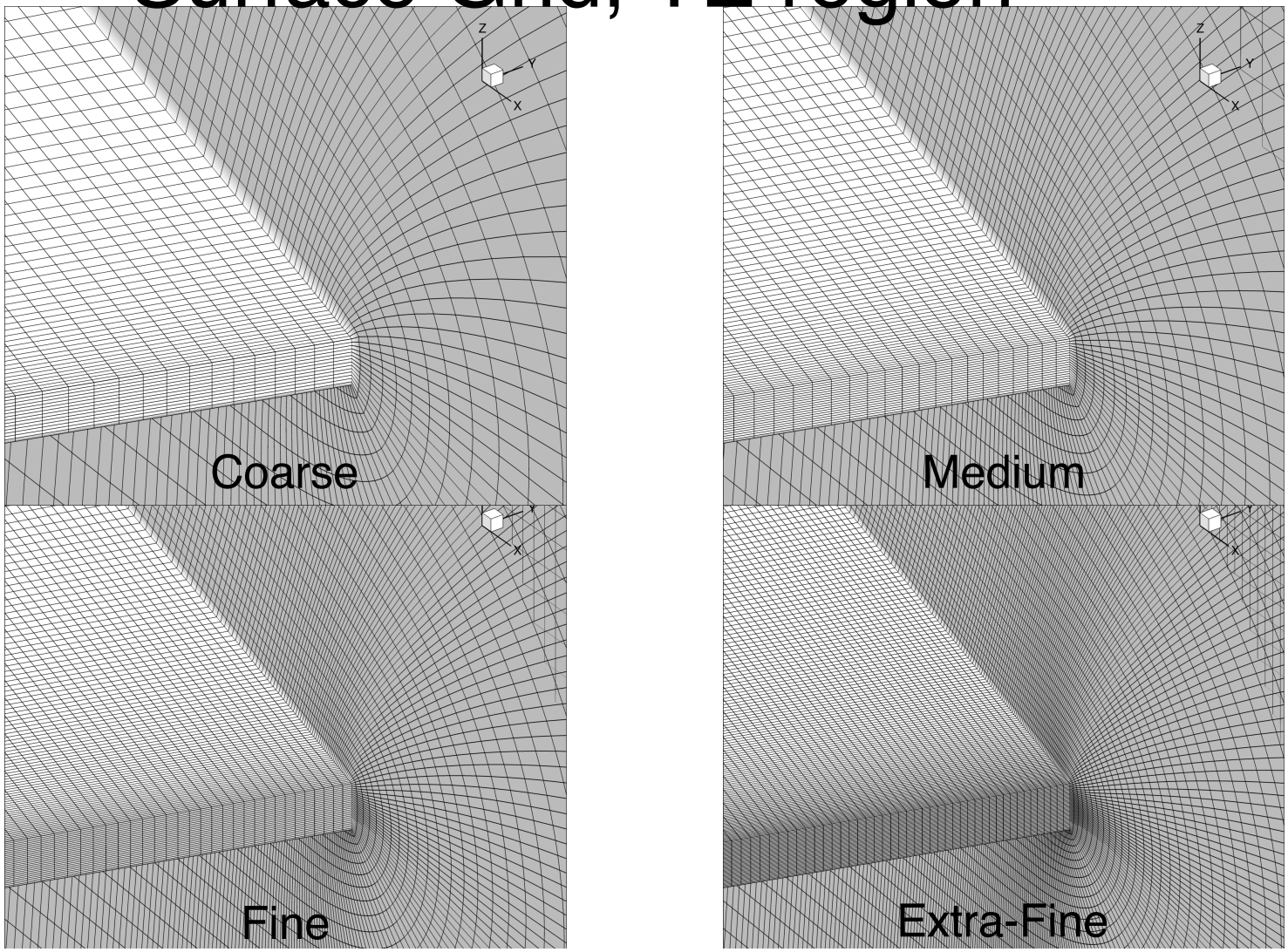
Same Near Body Grids

Surface Grid

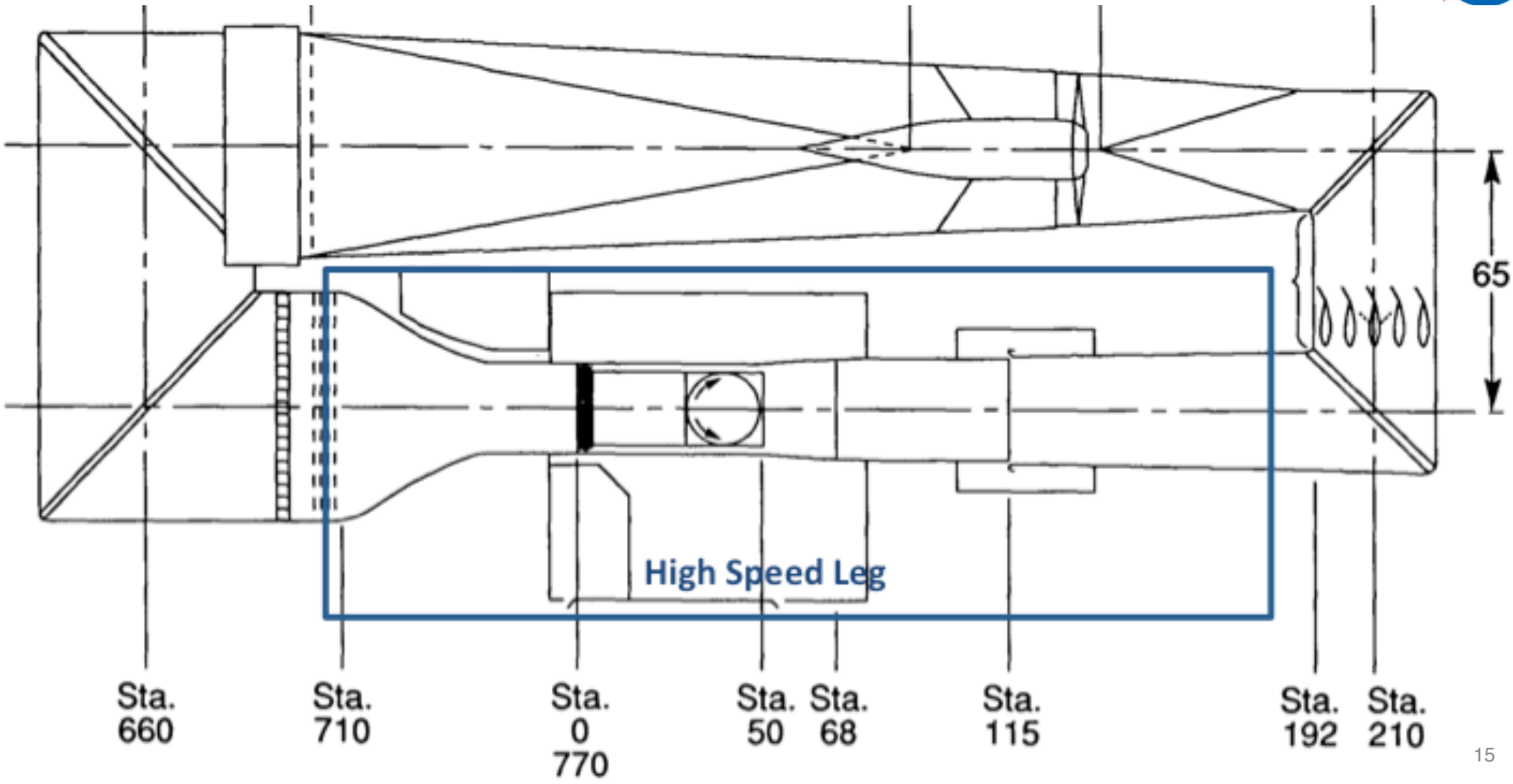




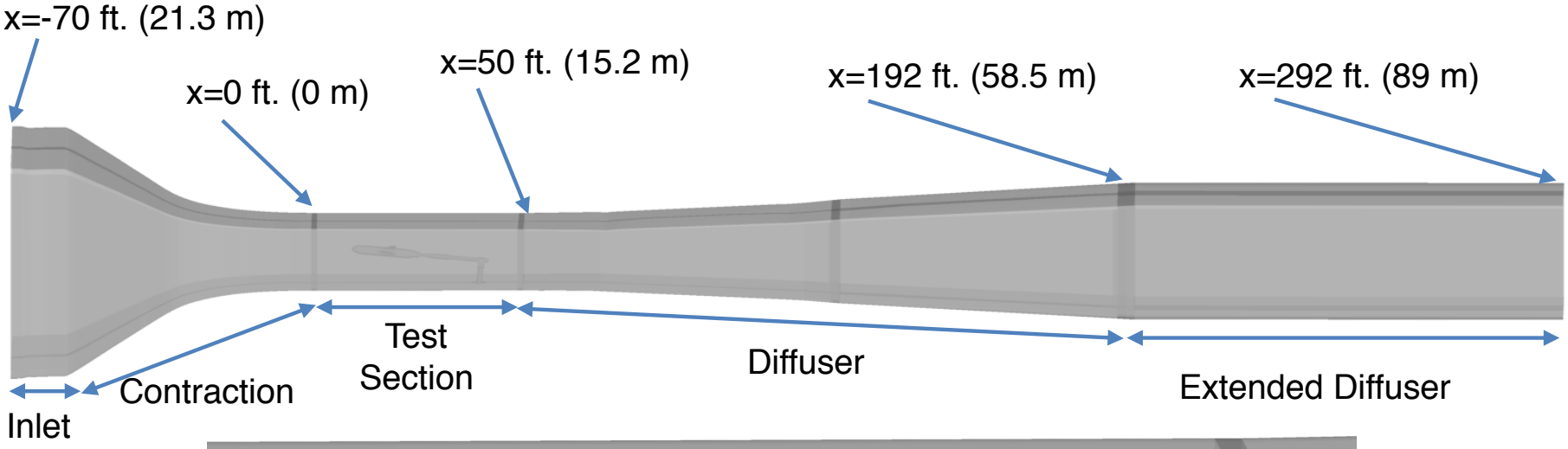
Surface Grid, TE region

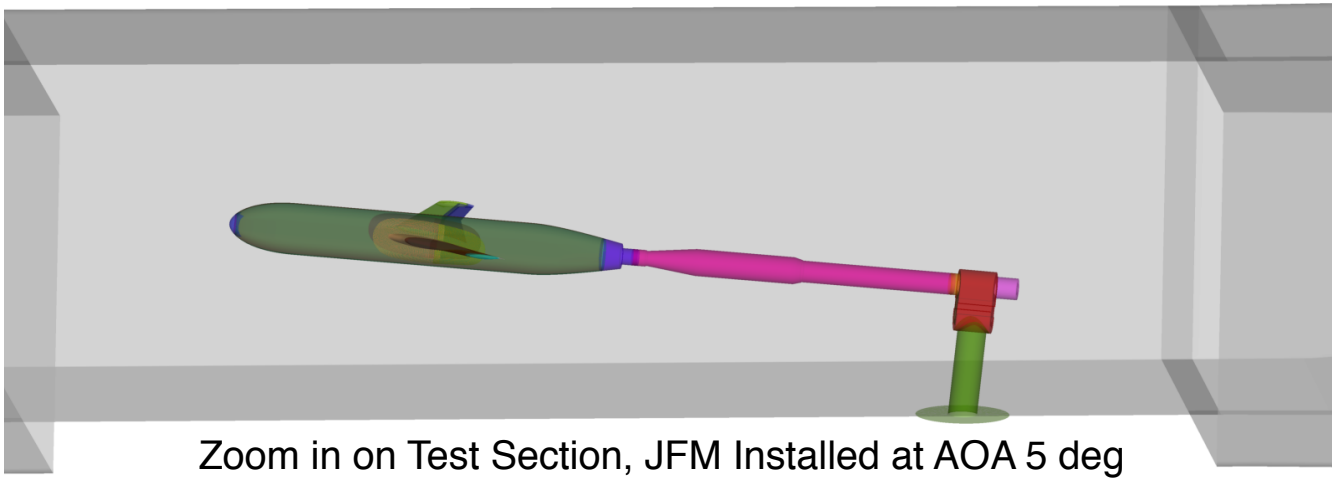


Langley 14- by 22-Ft. Subsonic Tunnel (14x22)



CFD 14x22 Wind Tunnel





Zoom in on Test Section, JFM Installed at AOA 5 deg

CFD 14x22 Wind Tunnel Setup



Walls Treatment:

- Inviscid Inlet + Inviscid Diffuser Extension
- Viscous everywhere else

Tunnel speed:

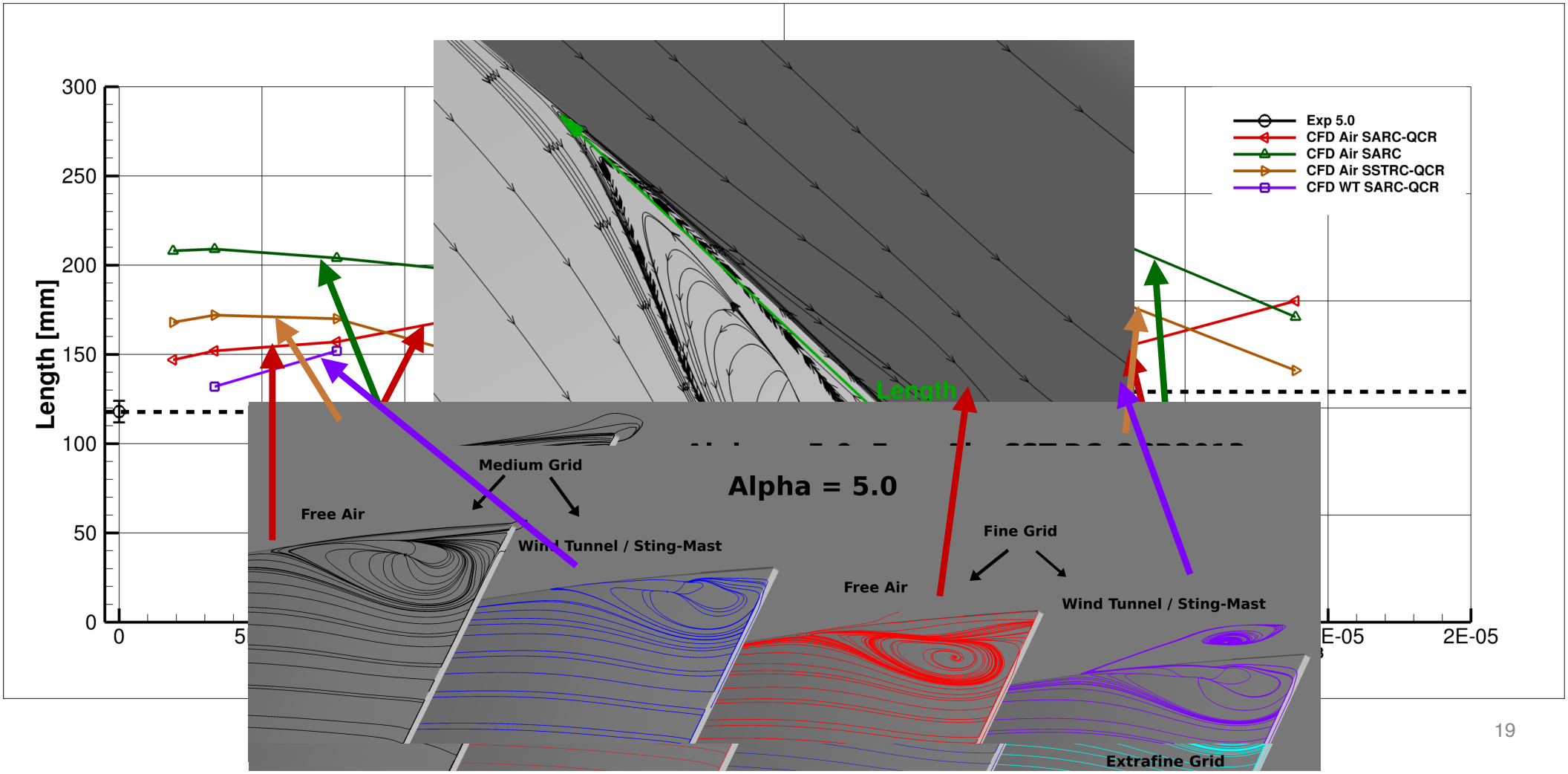
- Uses total pressure & static pressure “probe” values from their locations
- Calibrated equations -> tunnel speed
- Ref: Lee, et.al. STO-MP-AVT-284-02

Overflow Run Parameters

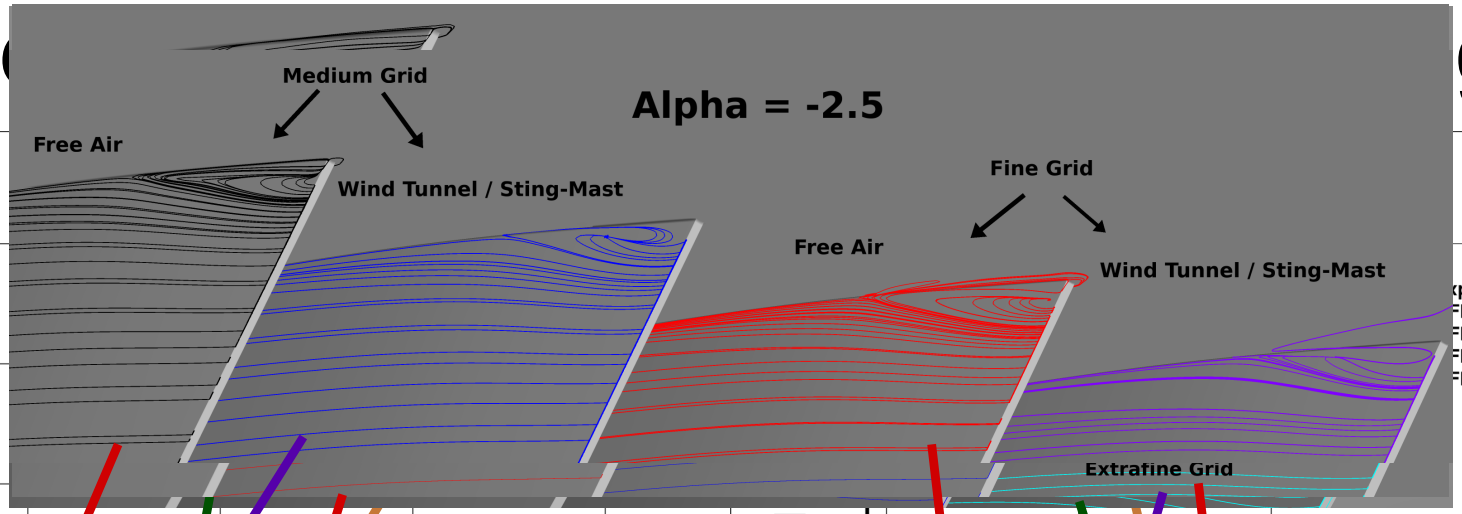


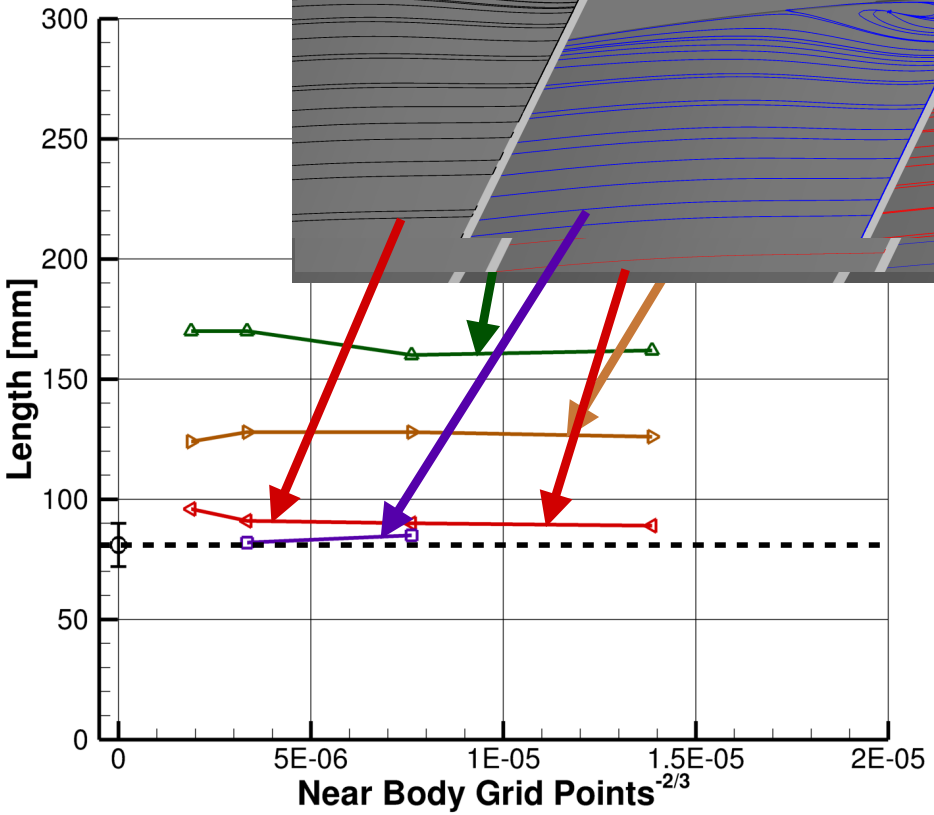
- OVERFLOW 2.2N
- 3rd-Order Roe upwind RHS
- ARC3D scalar pentadiagonal LHS
- Low-Mach preconditioning (in CFD WT)
- Fully Turbulent, Steady State
- RE = 2.4 Million based on crank chord
- Mach= 0.189, T= 519 Rankine (288.8 Kelvin) (median of run conditions)
- Turbulence Models:
  - SA-Noft2-RC-QCR2013 (SARC-QCR)
  - SA-Noft2-RC (SARC)
  - SST-RC-QCR2013 (SSTRC-QCR)

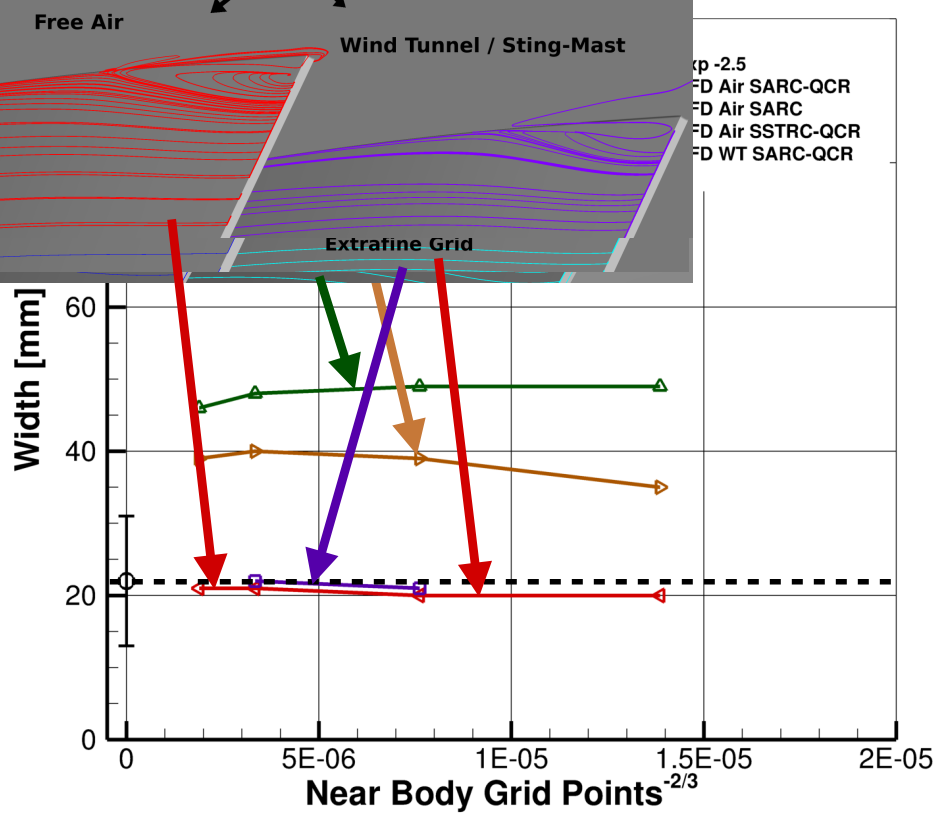
Side of Body Separation AOA = 5.0 deg



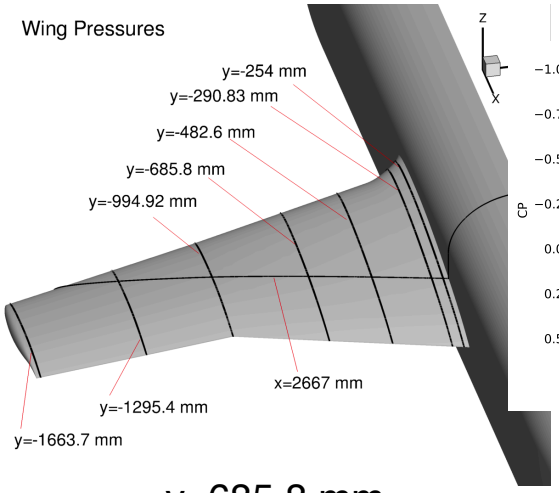
Side g


Alpha = -2.5
Medium Grid
Free Air
Wind Tunnel / Sting-Mast
Fine Grid
Free Air
Wind Tunnel / Sting-Mast
Extrafine Grid

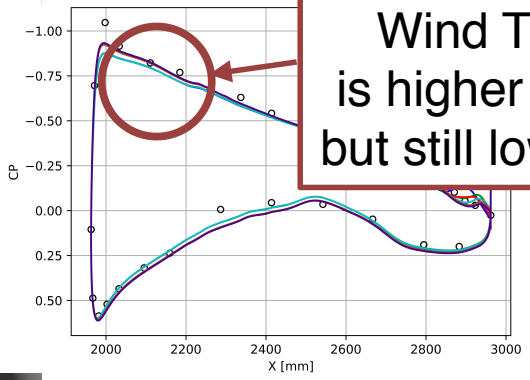

Length [mm]
300
250
200
150
100
50
0
0
5E-06
1E-05
1.5E-05
2E-05
Near Body Grid Points-2/3


Width [mm]
60
40
20
0
0
5E-06
1E-05
1.5E-05
2E-05
Near Body Grid Points-2/3
FD Air SARC-QCR
FD Air SARC
FD Air SSTRC-QCR
FD WT SARC-QCR

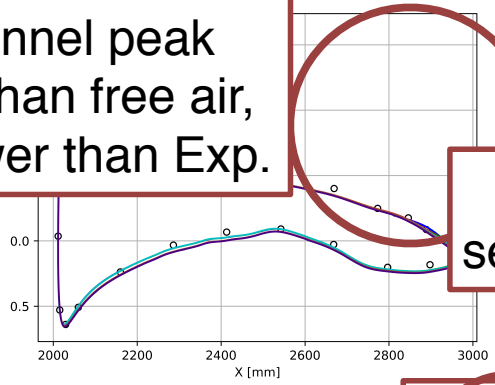
Wing Pressures, AOA = 5.0 deg



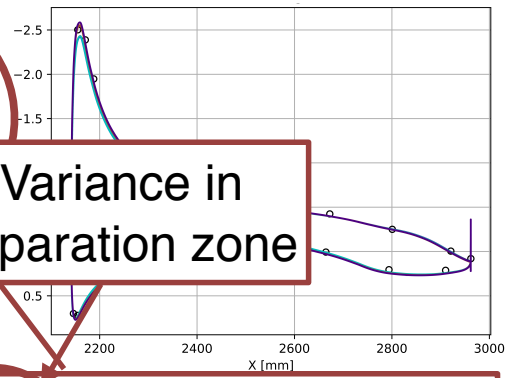
y=254.0 mm



y=290.83 mm



y=482.6 mm

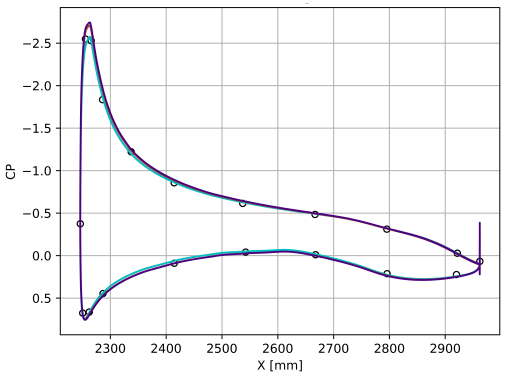


Wind Tunnel peak is higher than free air, but still lower than Exp.

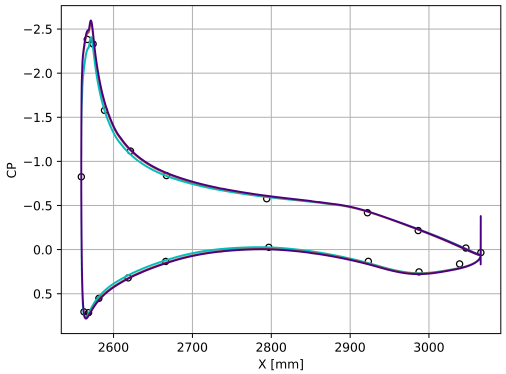
Variance in separation zone

Differences in tip pressure due to grid resolution

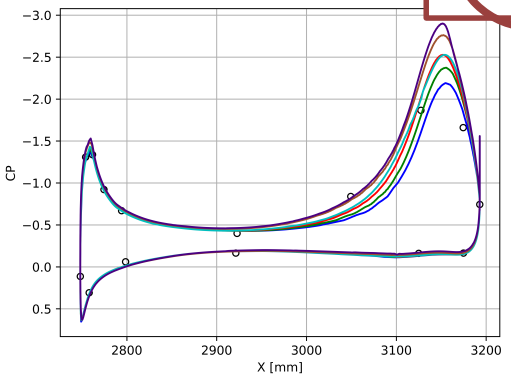
y=685.8 mm

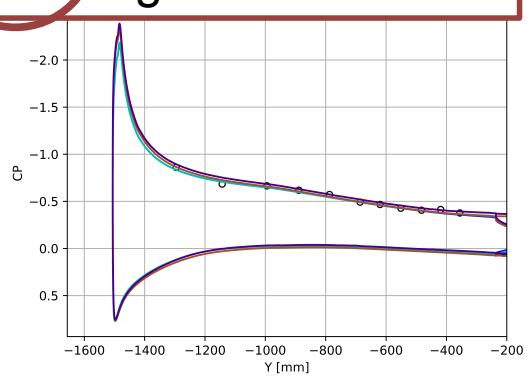


y=1295.4 mm



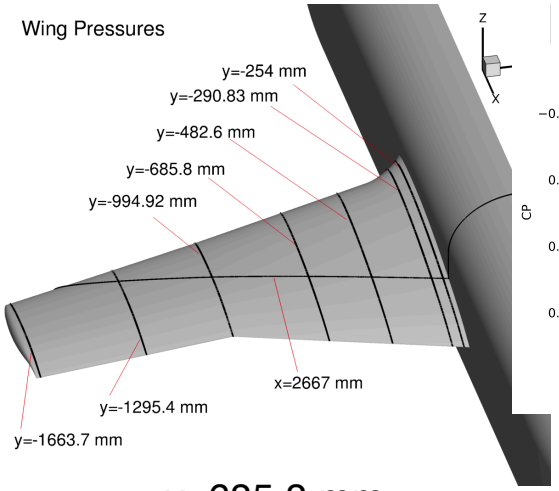
y=1663.7 mm



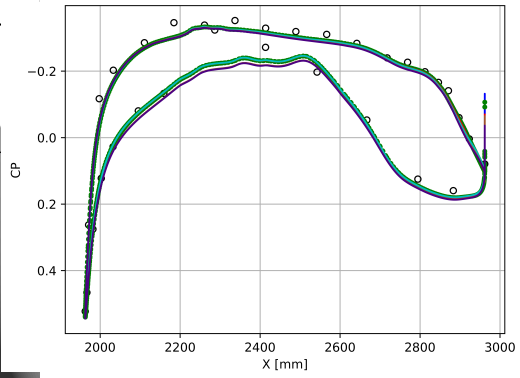


Experiment
CFD Coarse
CFD Medium
CFD Fine
CFD ExtraFine
CFD-WT+SM Medium
CFD-WT+SM Fine

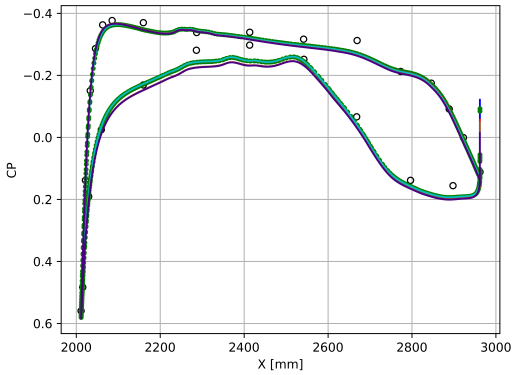
Wing Pressures, AOA = -2.5 deg



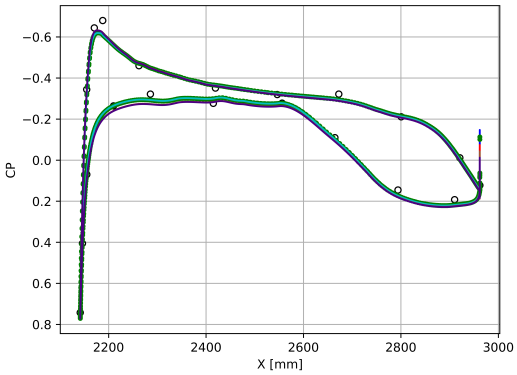
y=254.0 mm



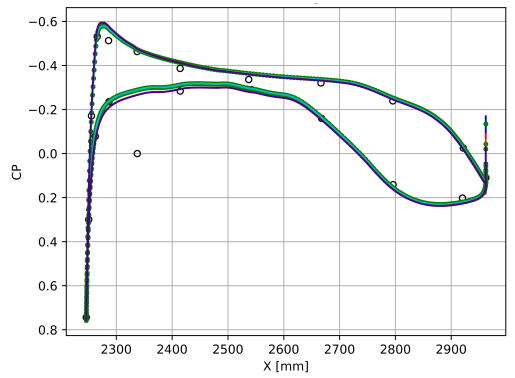
y=290.83 mm



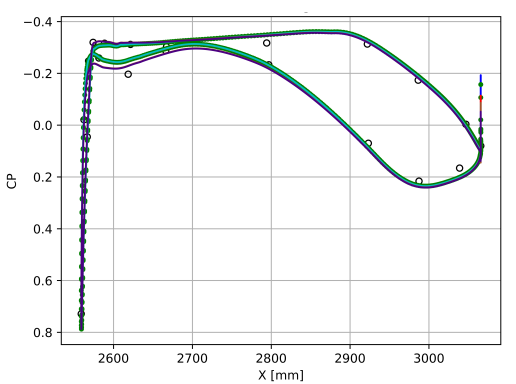
y=482.6 mm



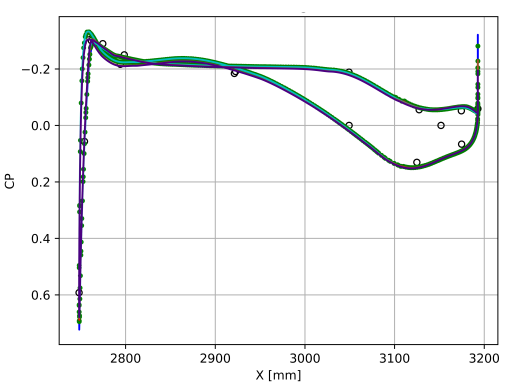
y=685.8 mm



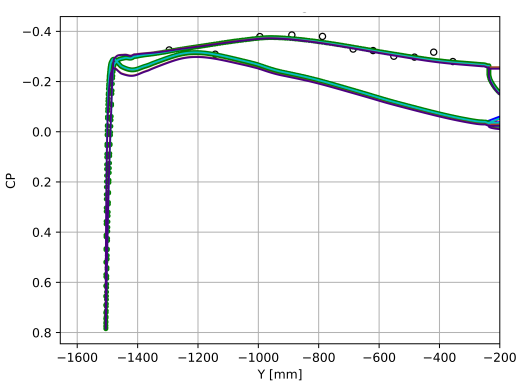
y=1295.4 mm



y=1663.7 mm



x=2667 mm

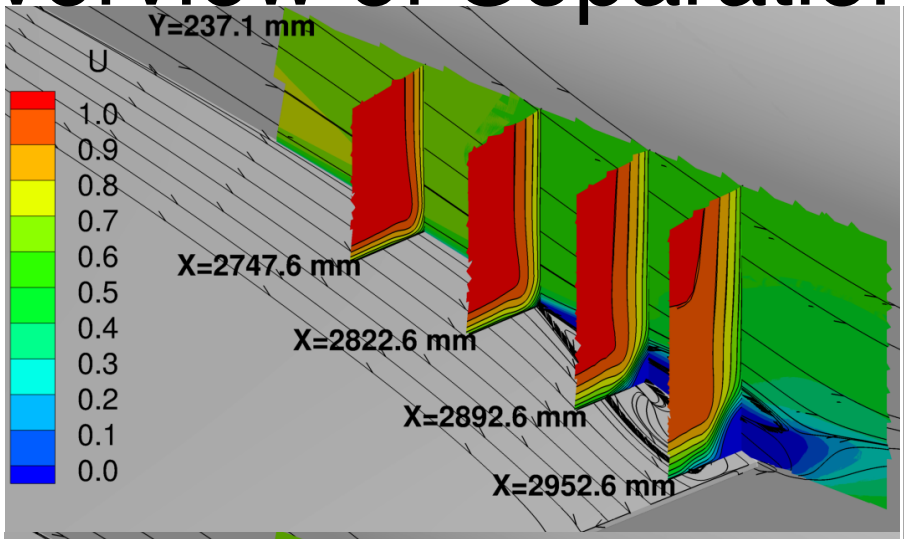


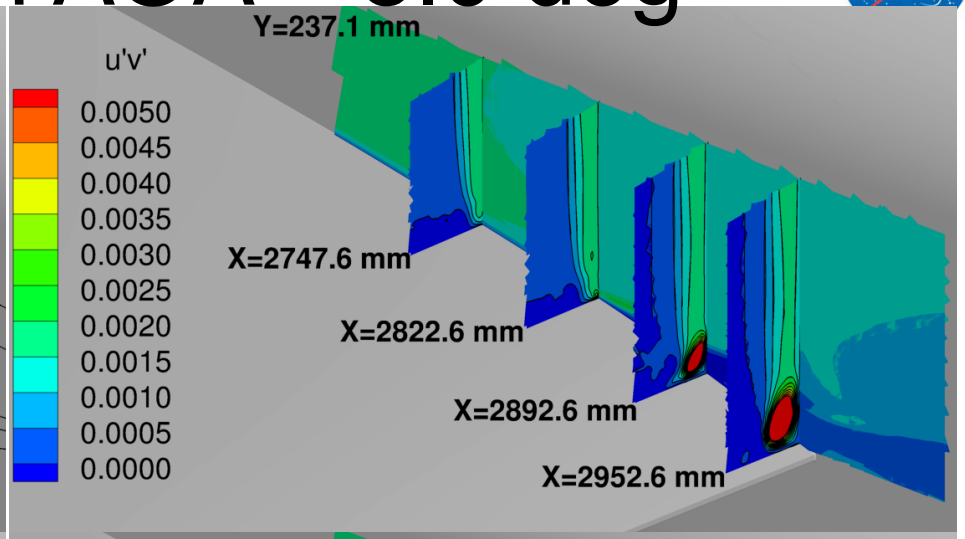
Experiment
CFD Coarse
CFD Medium
CFD Fine
CFD ExtraFine
CFD-WT+SM Medium
CFD-WT+SM Fine

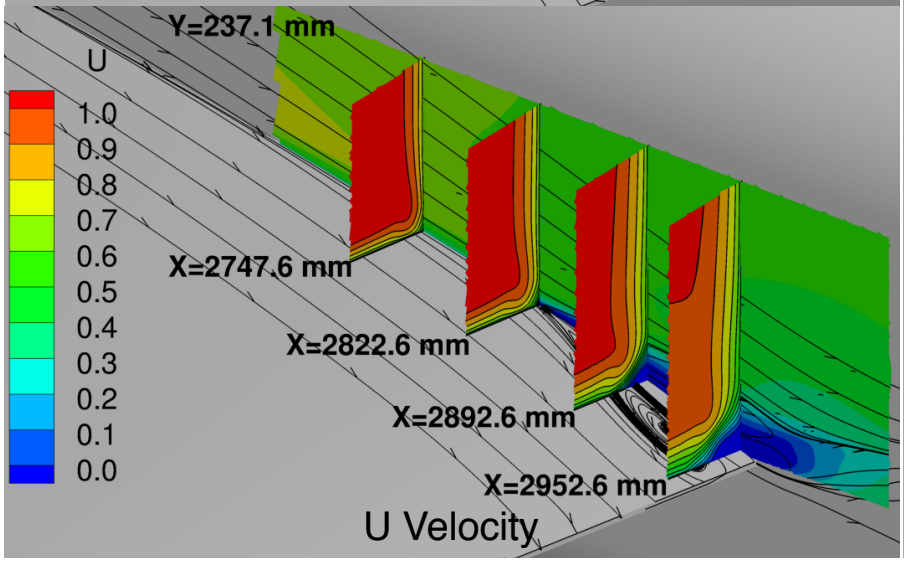
Overview of Separation AOA = 5.0 deg

Medium Grid (Air)

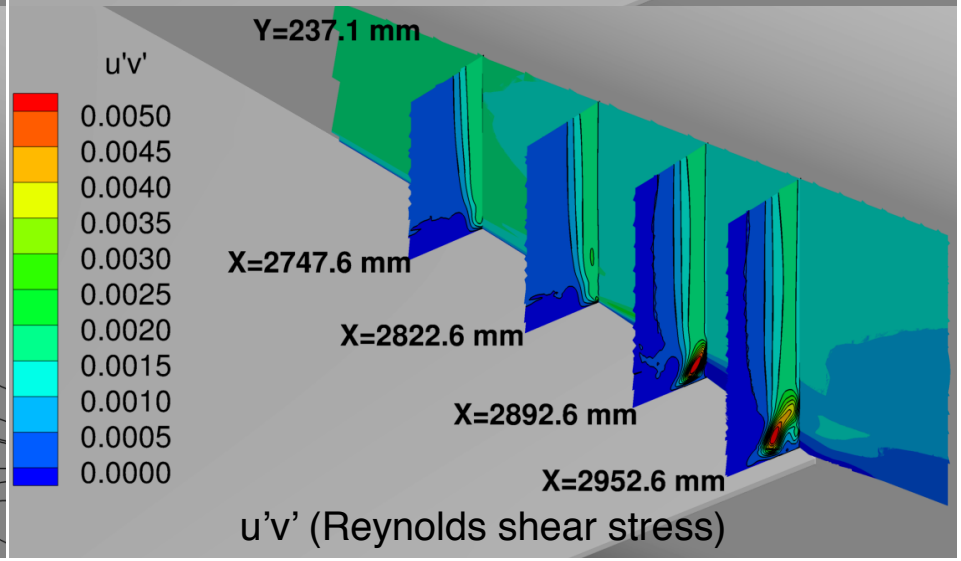
Fine Grid (Air)





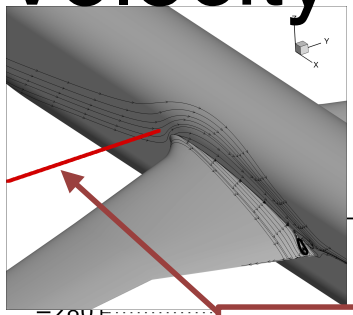


U Velocity



u'v' (Reynolds shear stress)

Velocity Profiles: Grid Resolution (Free Air)

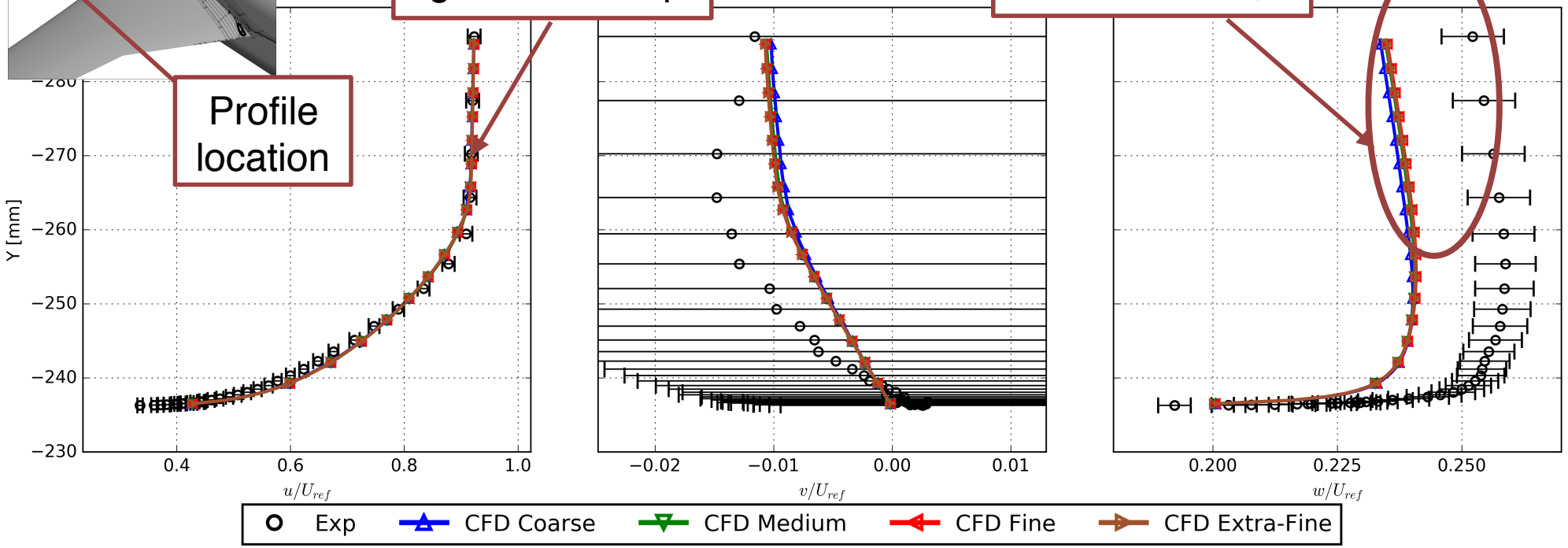


Profile location

Before LE of wing

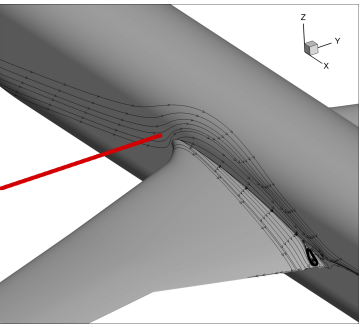
u-component agrees with Exp.

w-component is lower than Exp.

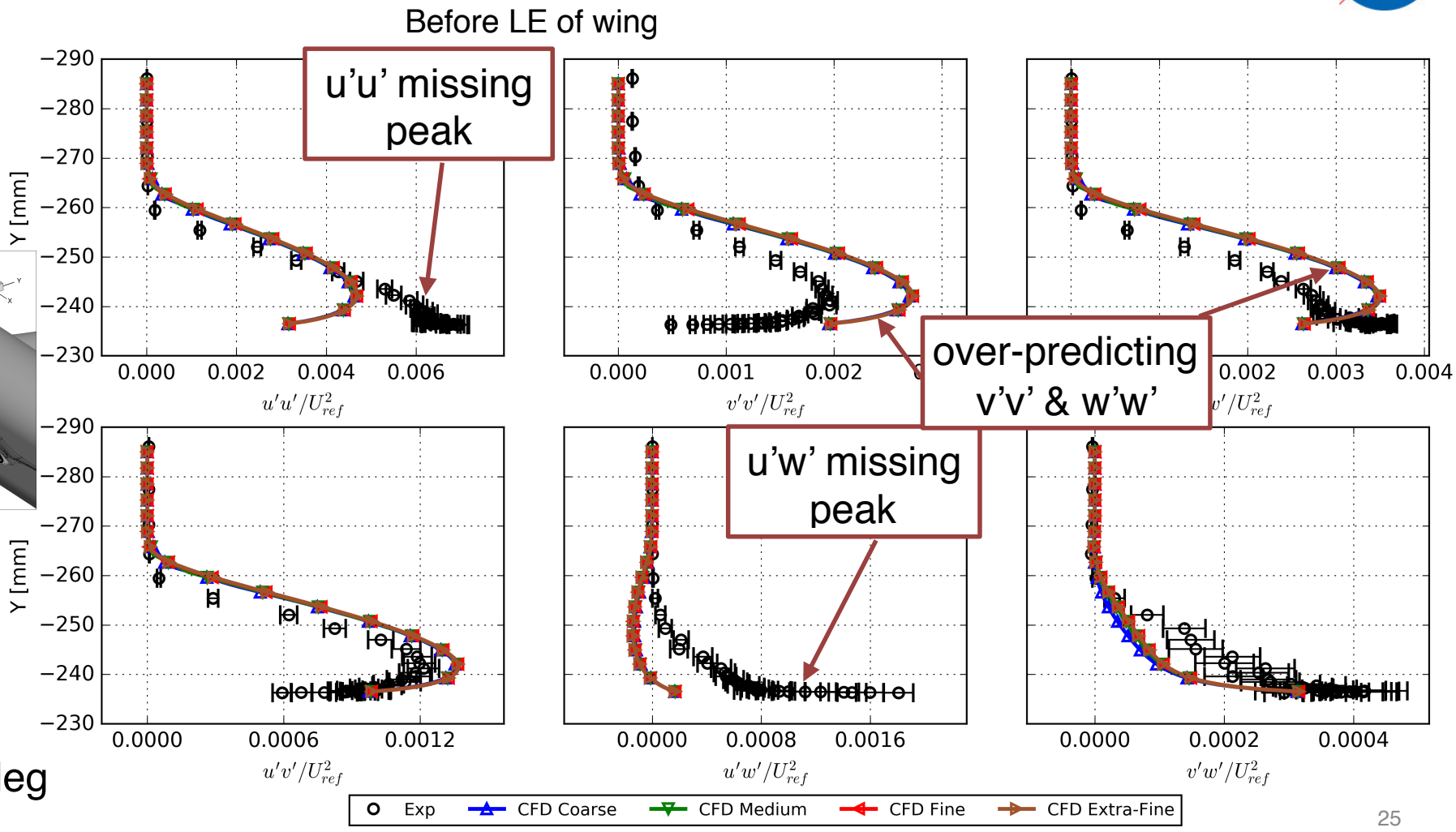


AOA = 5 deg

Reynolds Stress Profiles: Grid Resolution (Free Air)

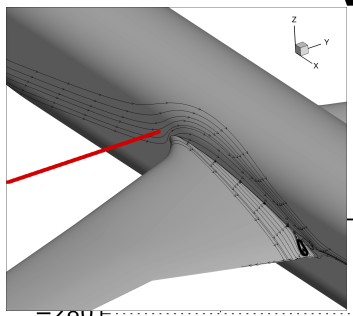


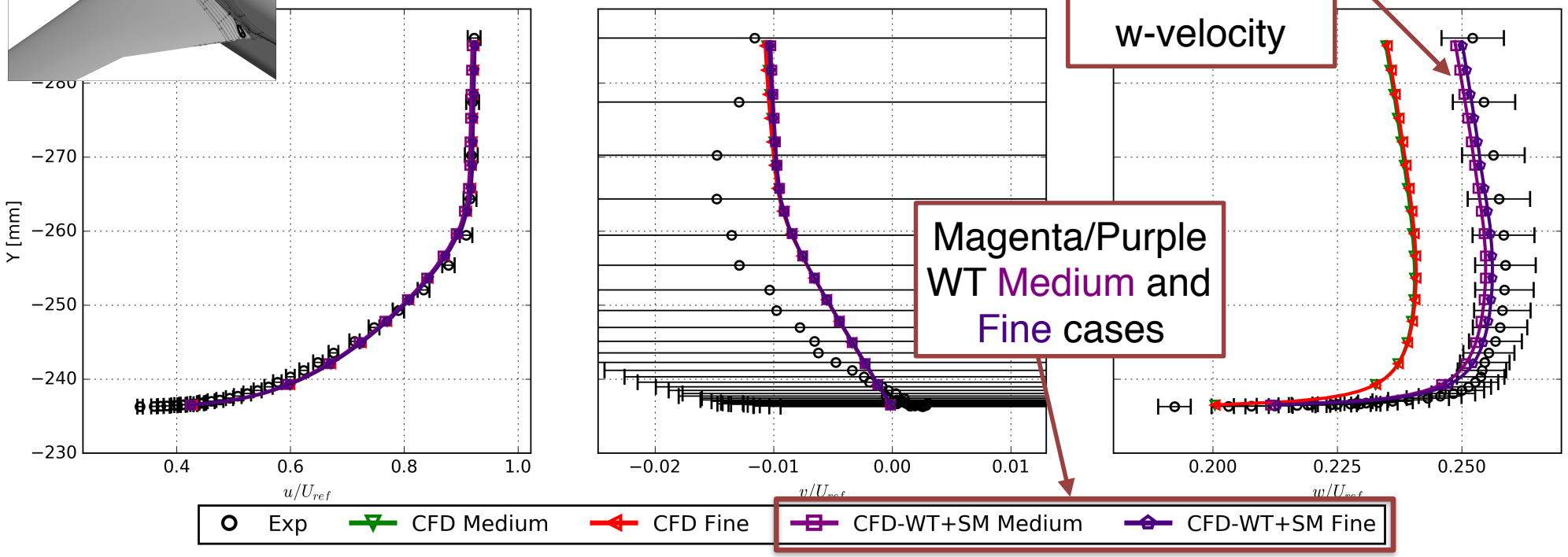
AOA = 5 deg



Velocity Profiles: Wall Effect

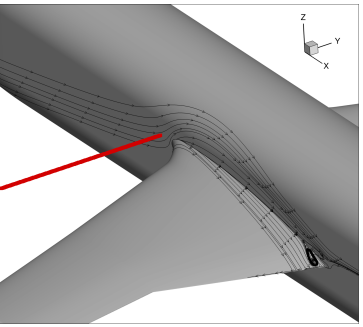
Before LE of wing



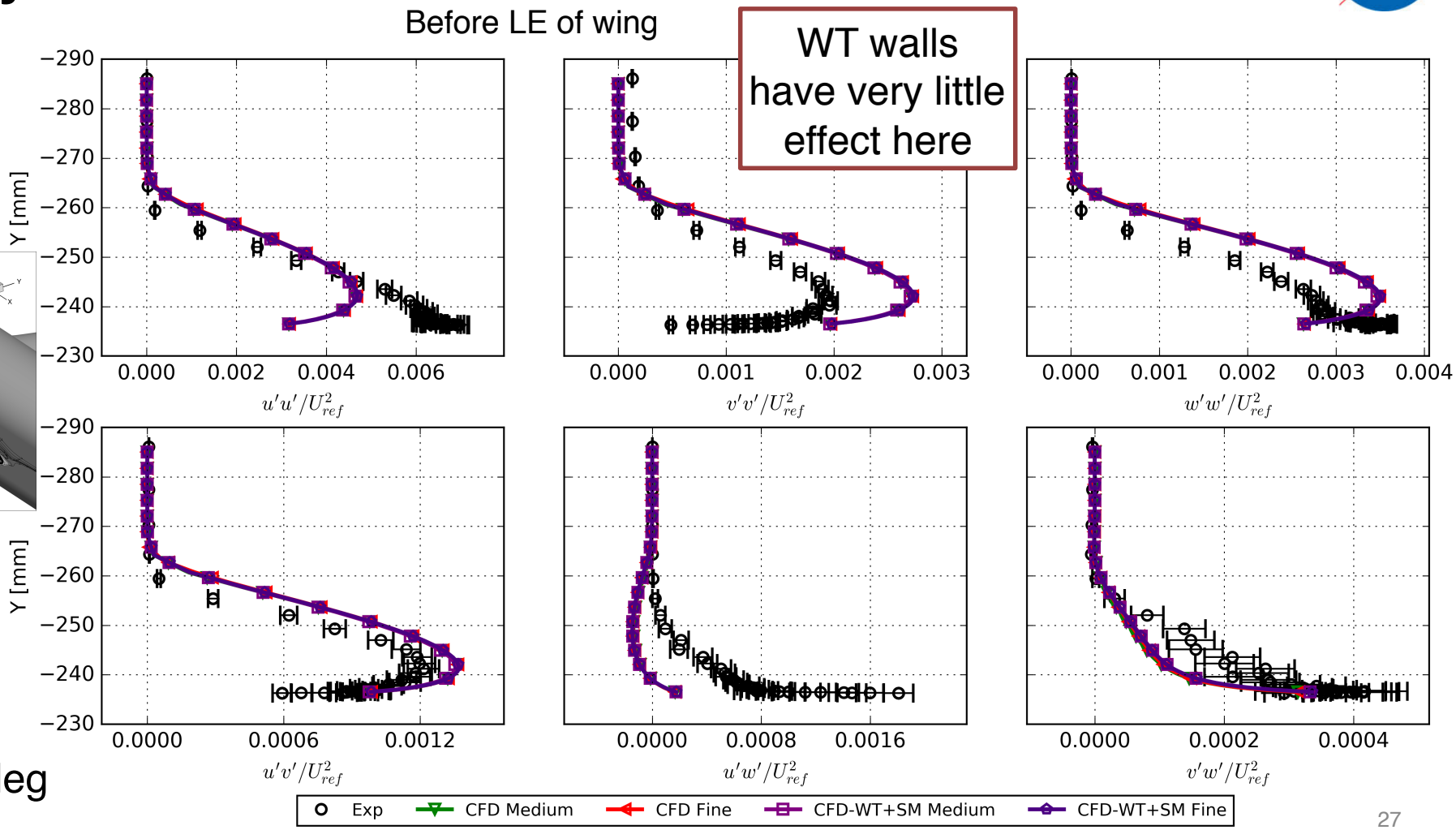


AOA = 5 deg

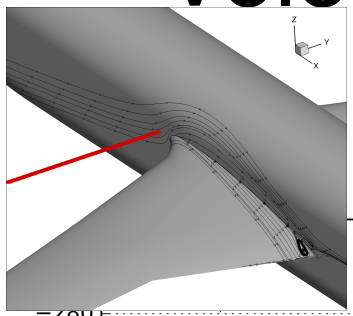
Reynolds Stress Profiles: Wall Effect



AOA = 5 deg



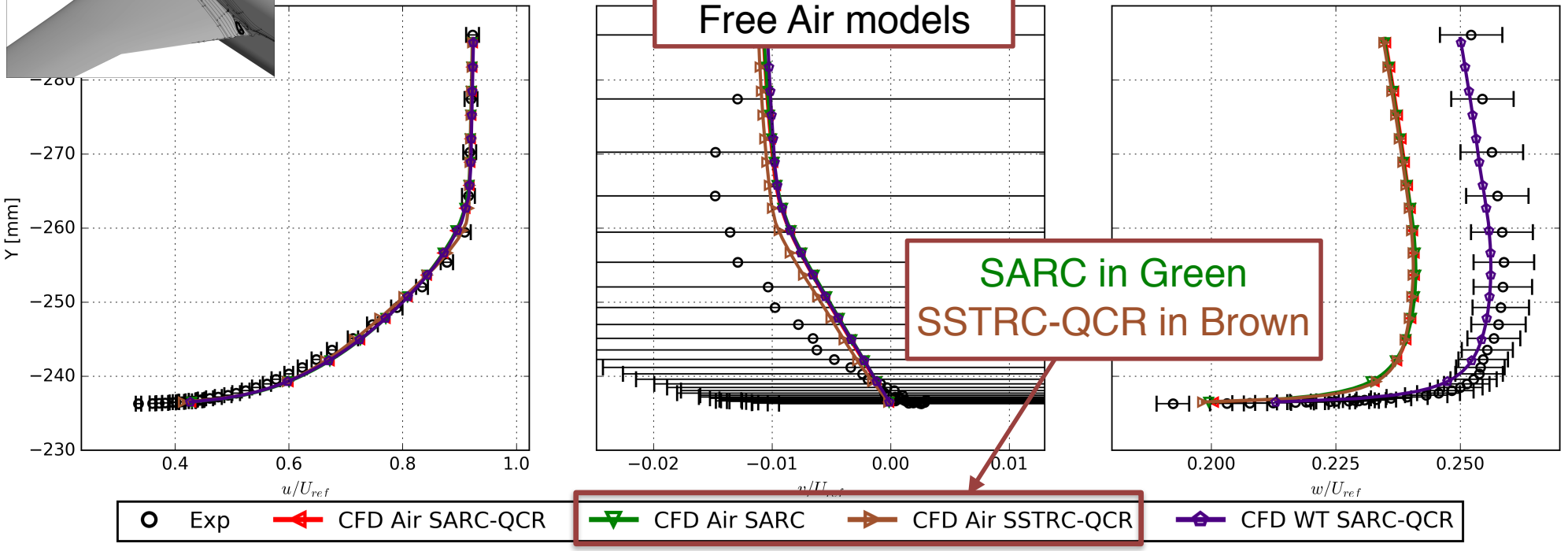
Velocity Profiles: Turbulence Model



Before LE of wing, Fine Grid

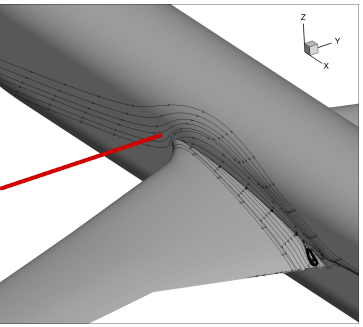
Profiles look similar between all Turb. Free Air models

SARC in Green
SSTRC-QCR in Brown

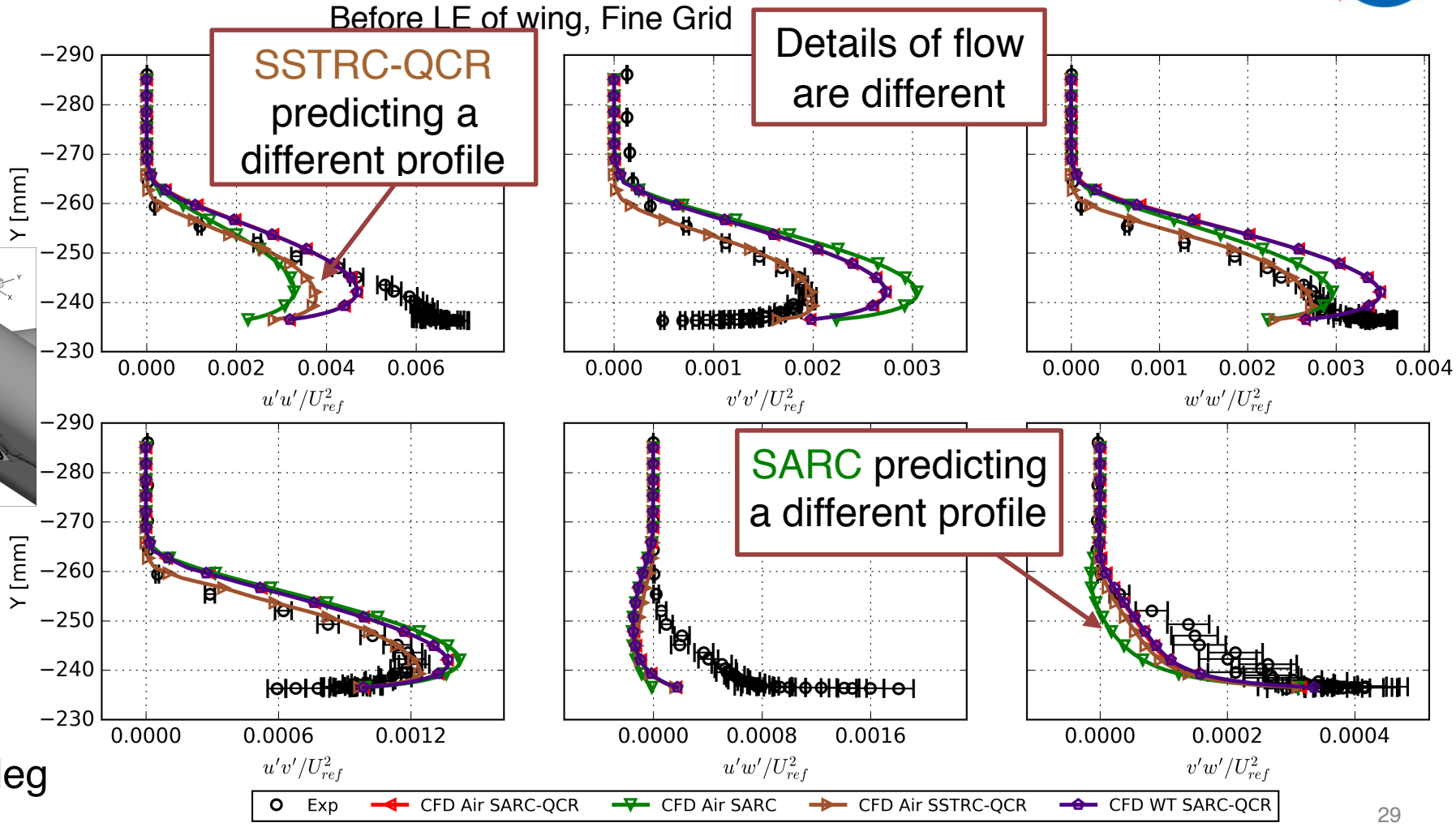


AOA = 5 deg

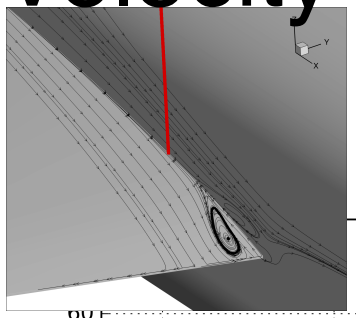
Reynolds Stress Profiles: Turbulence Model



AOA = 5 deg



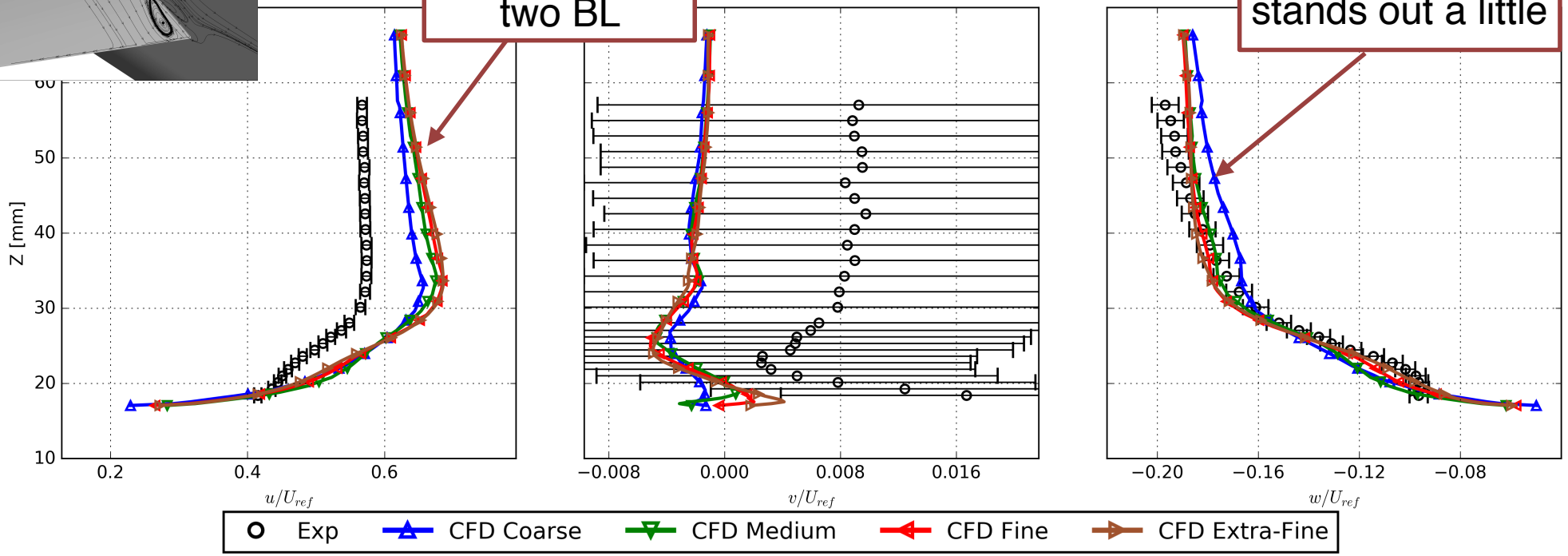
Velocity Profiles: Grid Resolution (Free Air)



Upstream of Separation, 1 mm from fuselage

Shift may be caused by the two BL

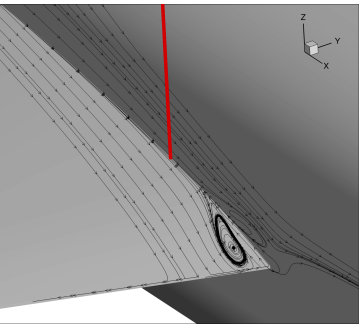
Coarse grid stands out a little



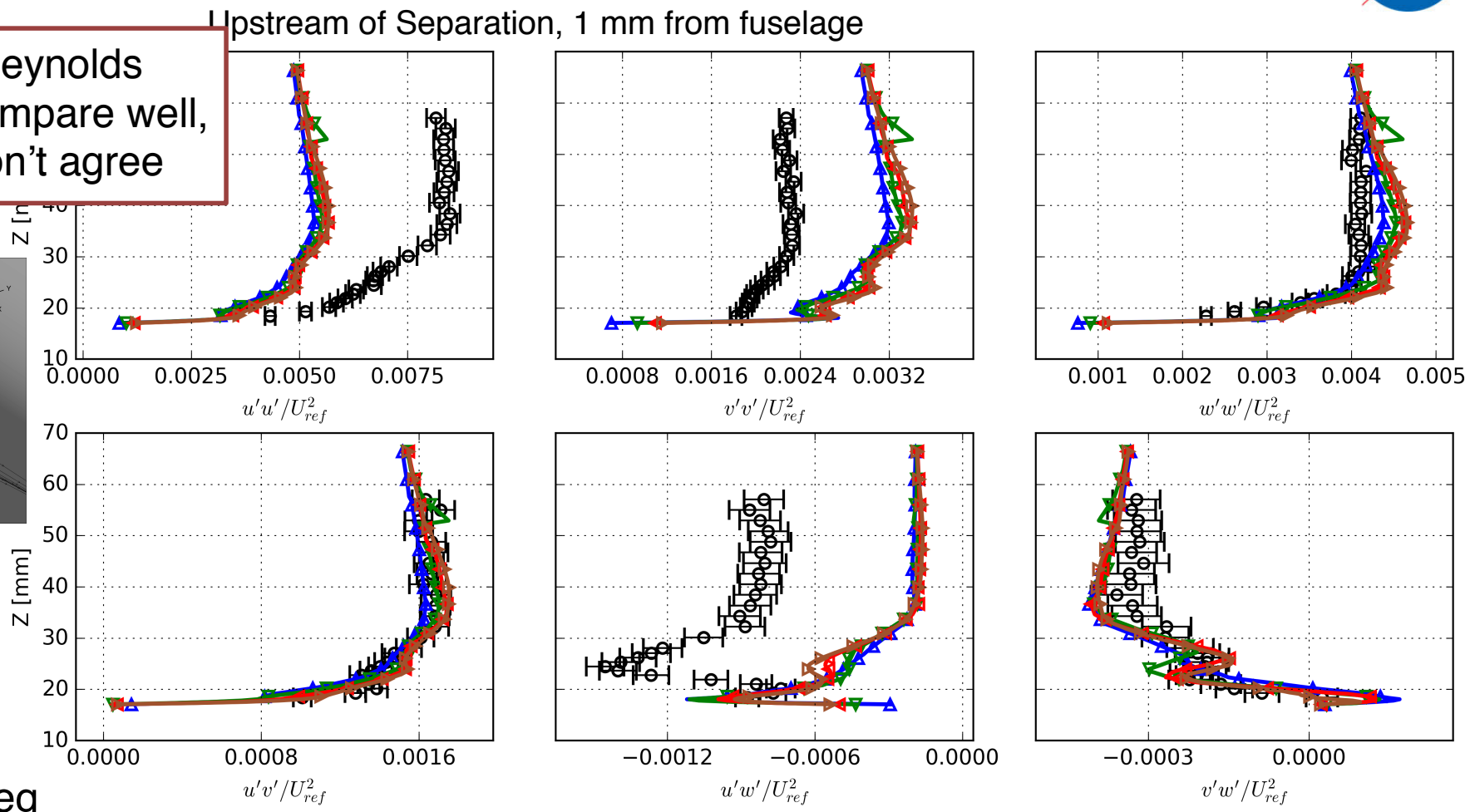
AOA = 5 deg

Reynolds Stress Profiles: Grid Resolution (Free Air)

Some Reynolds stresses compare well, others don't agree

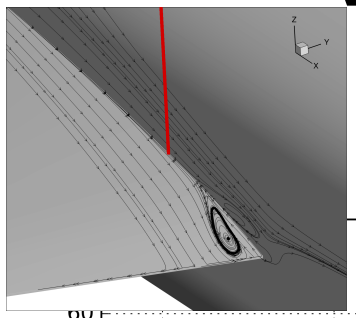


AOA = 5 deg

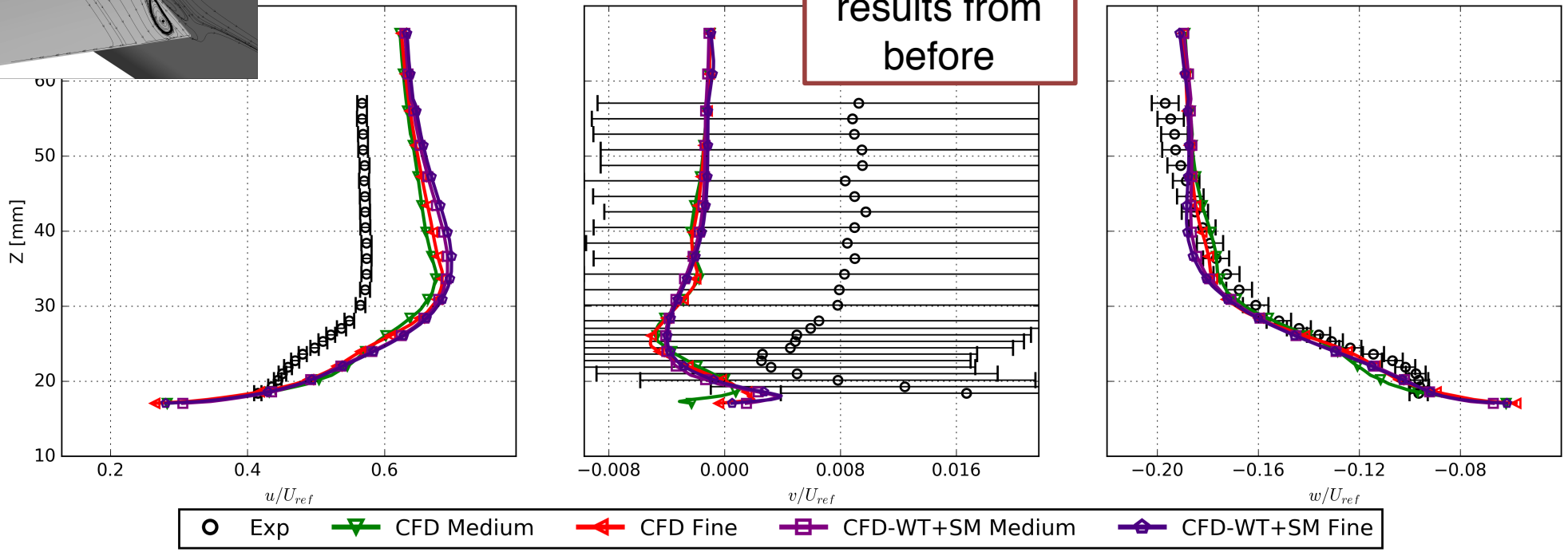


Velocity Profiles: Wall Effect

Upstream of Separation, 1 mm from fuselage

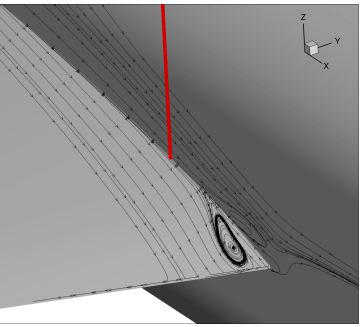


Very similar results from before

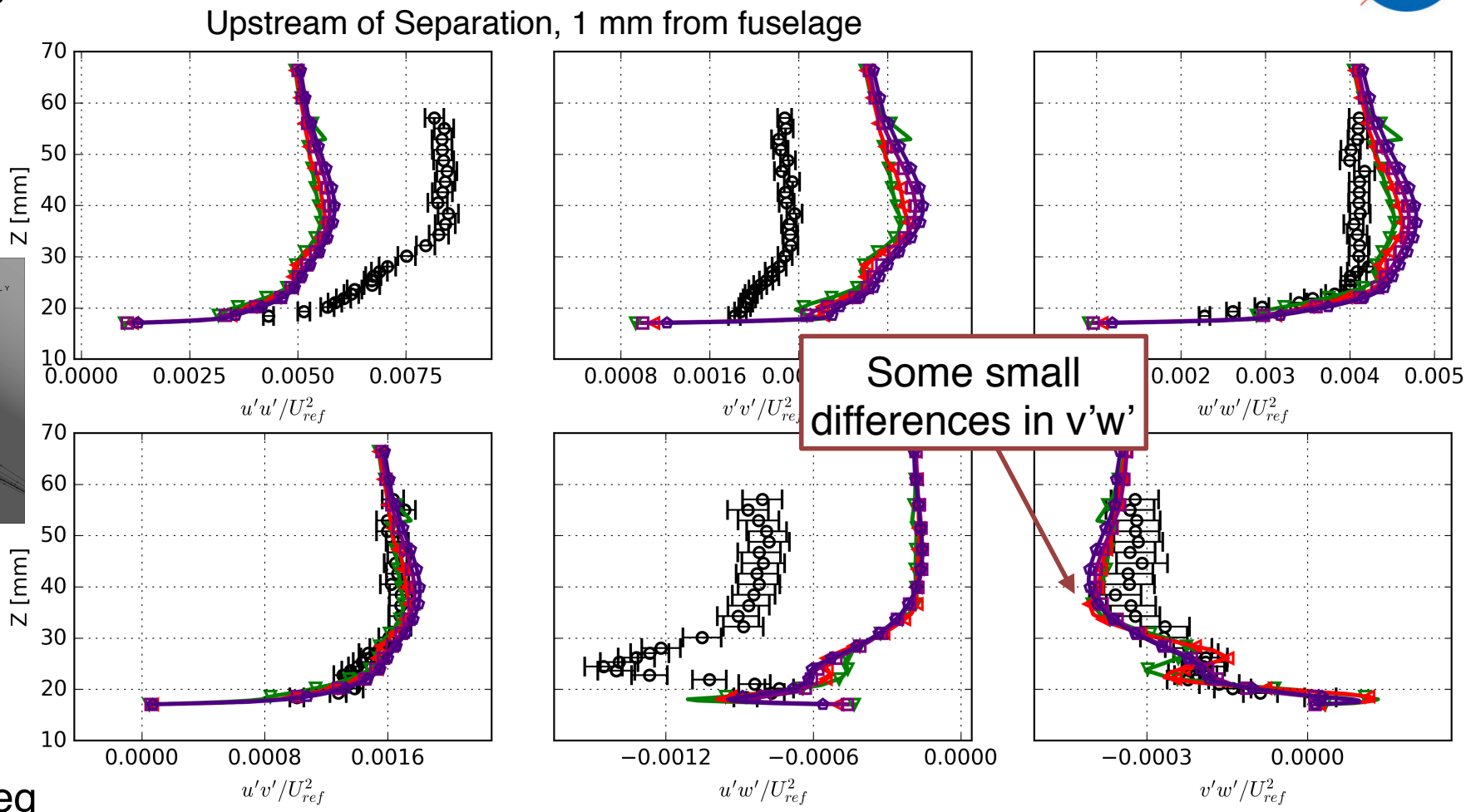


AOA = 5 deg

Reynolds Stress Profiles: Wall Effect

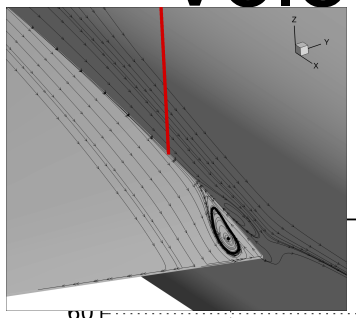


AOA = 5 deg



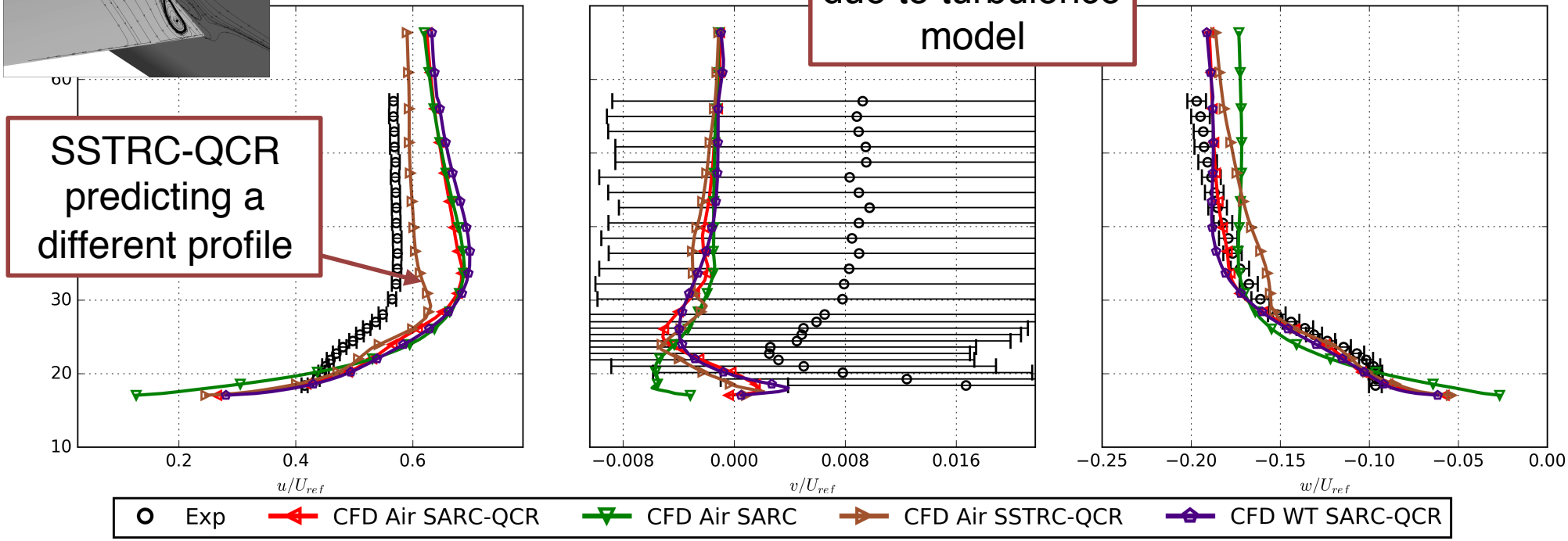
Velocity Profiles: Turbulence Model

Upstream of Separation, 1 mm from fuselage, Fine Grid



More variation due to turbulence model

SSTRC-QCR predicting a different profile

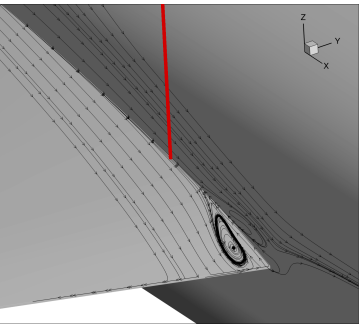


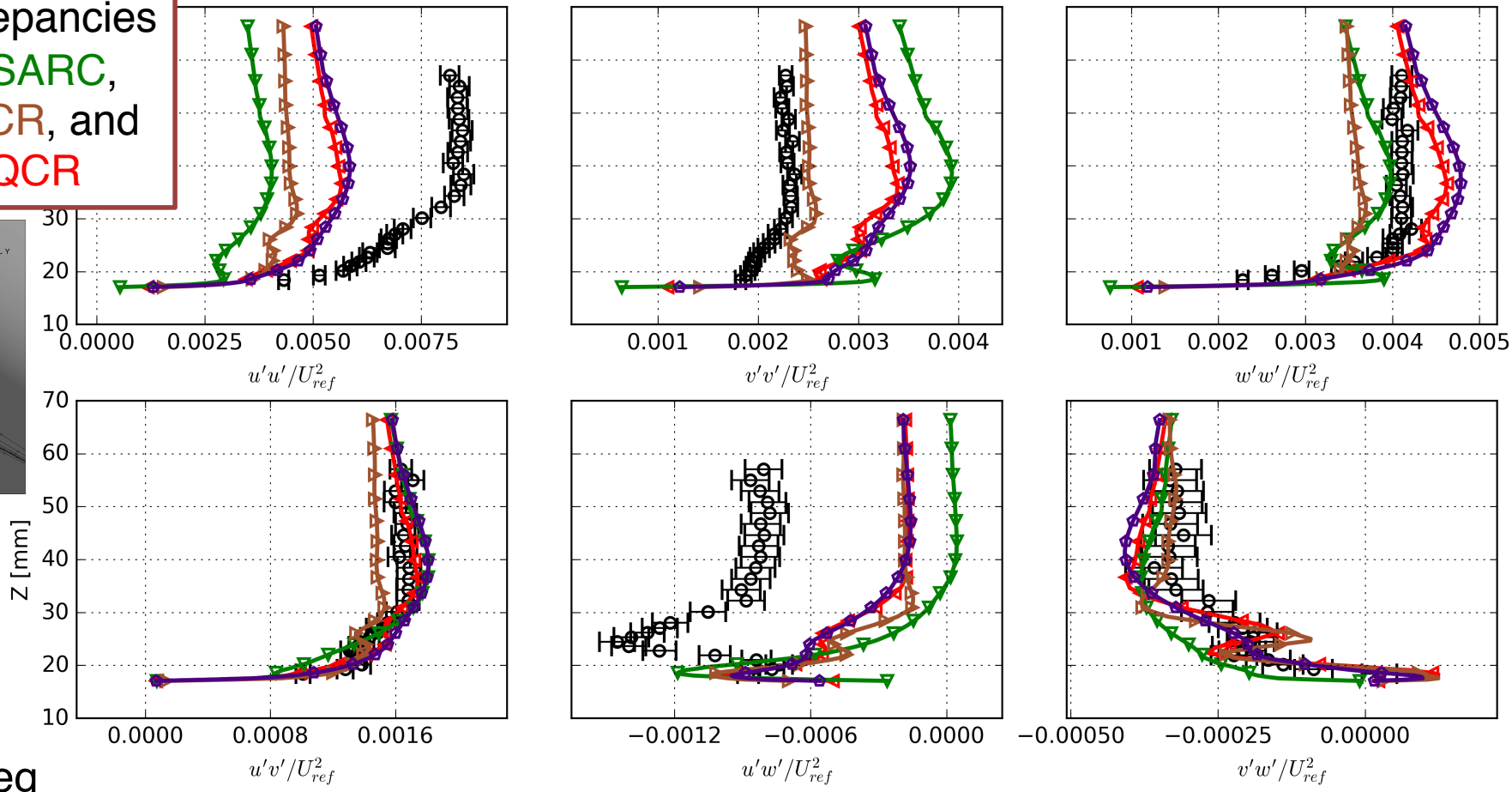
AOA = 5 deg

Reynolds Stress Profiles: Turbulence Model

Upstream of Separation, 1 mm from fuselage, Fine Grid

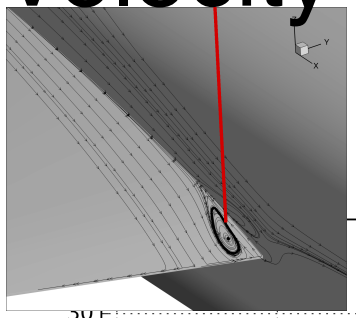
Large discrepancies between SARC, SSTRC-QCR, and SARC-QCR





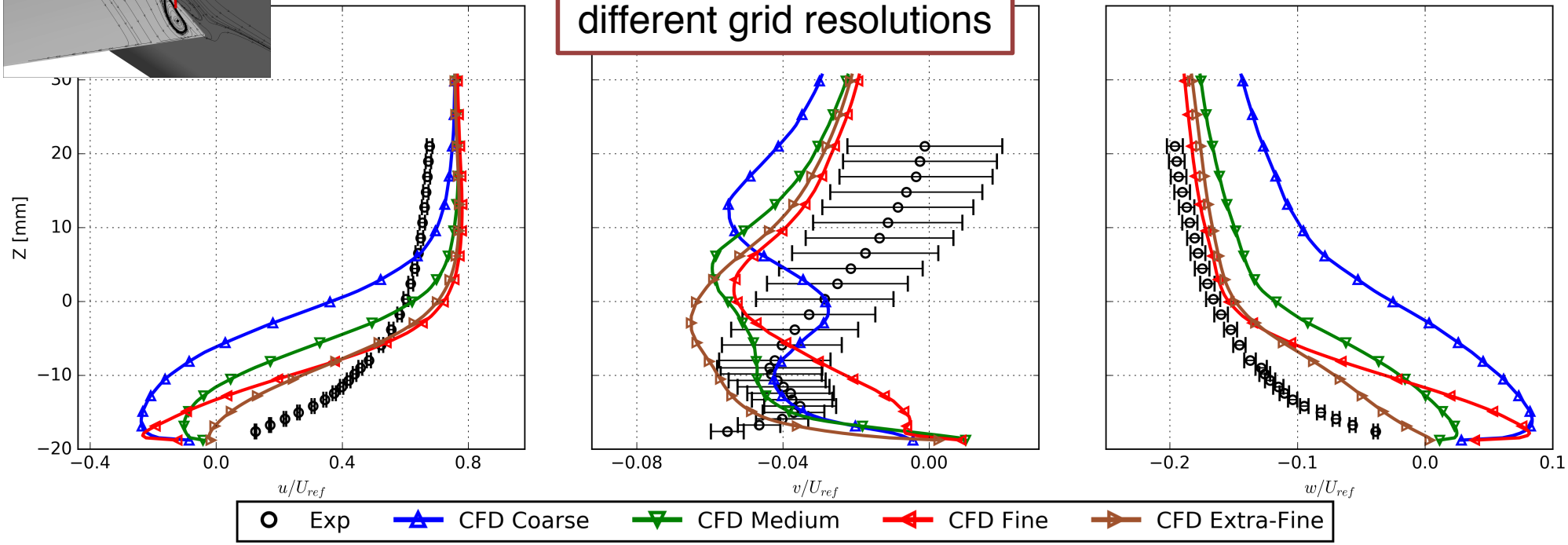
AOA = 5 deg

Velocity Profiles: Grid Resolution (Free Air)



In the Separated Region, 10 mm from fuselage

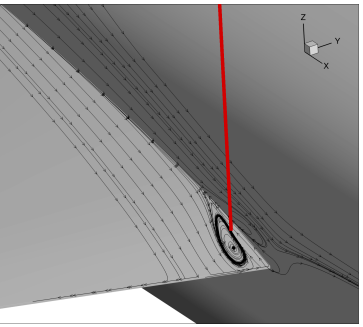
Large variation in velocity profiles across different grid resolutions



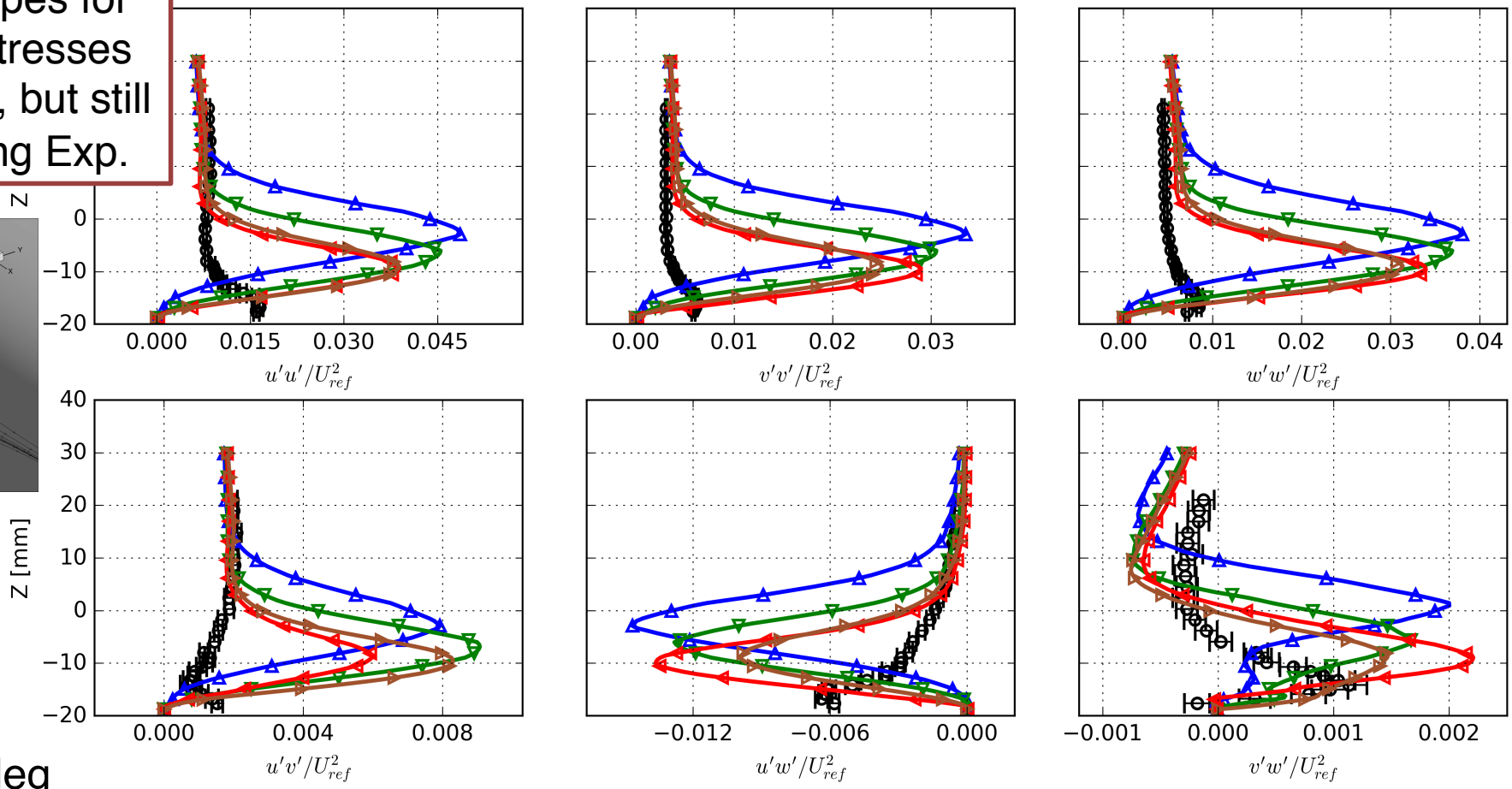
AOA = 5 deg

Reynolds Stress Profiles: Grid Resolution (Free Air)

Similar shapes for Reynolds stresses across grids, but still not matching Exp.



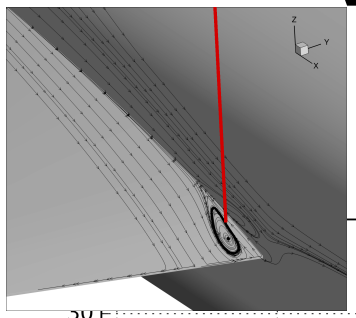
In the Separated Region, 10 mm from fuselage



AOA = 5 deg

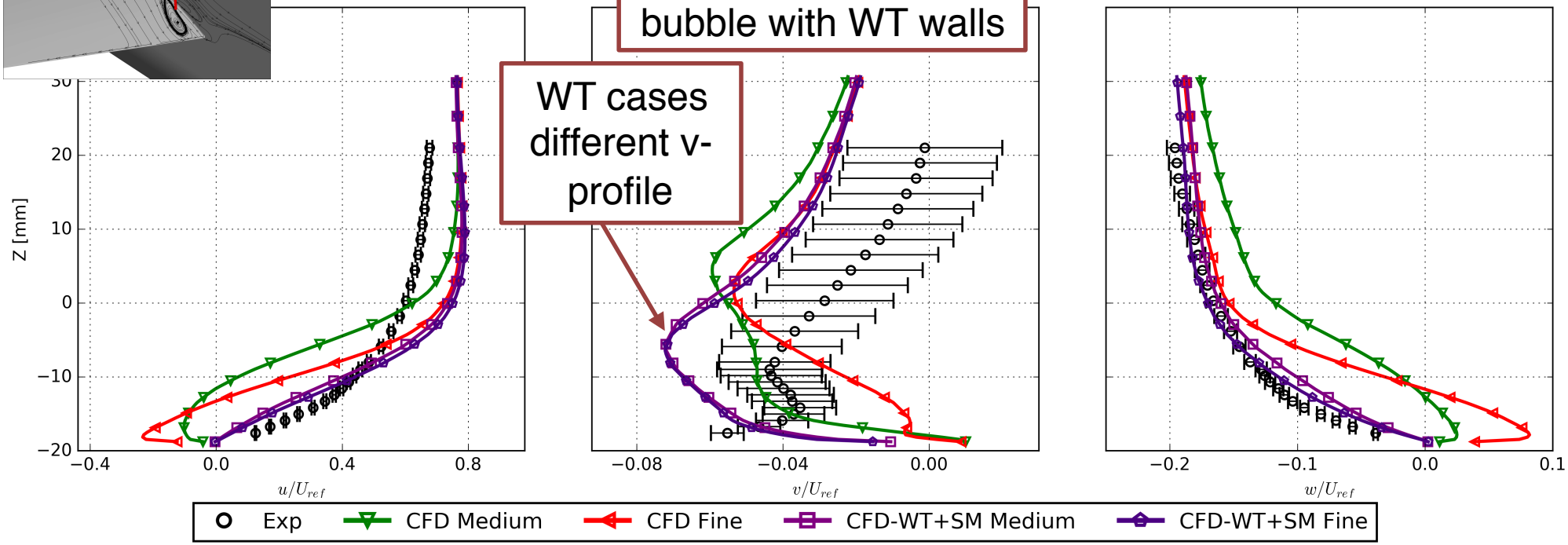
Velocity Profiles: Wall Effect

In the Separated Region, 10 mm from fuselage



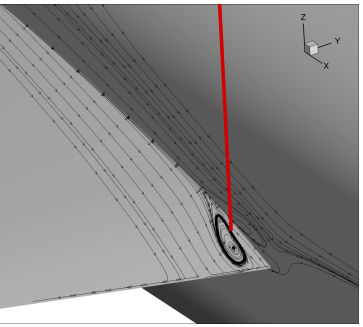
Separated flow predictions different in bubble with WT walls

WT cases different v-profile

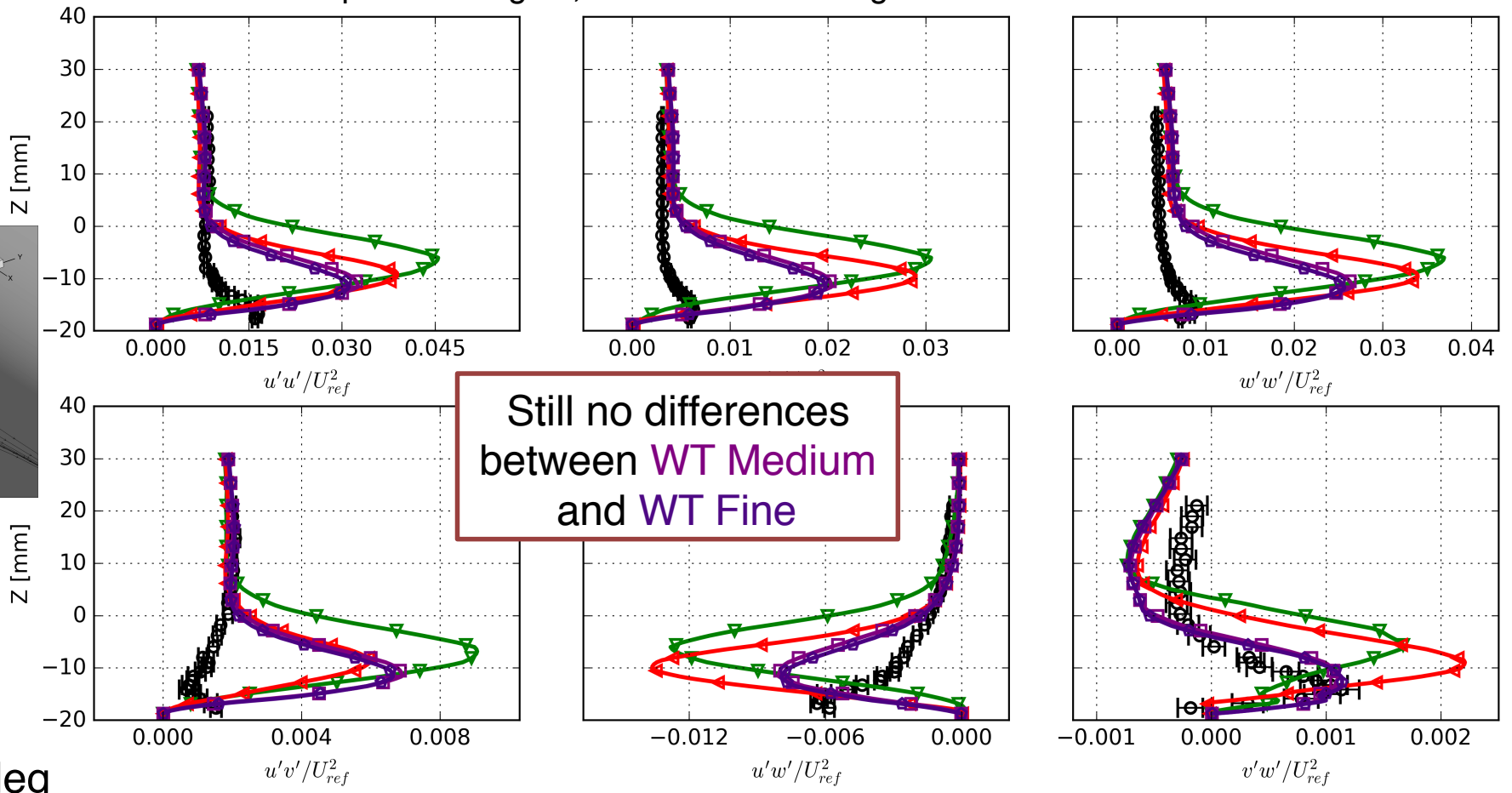


AOA = 5 deg

Reynolds Stress Profiles: Wall Effect



In the Separated Region, 10 mm from fuselage

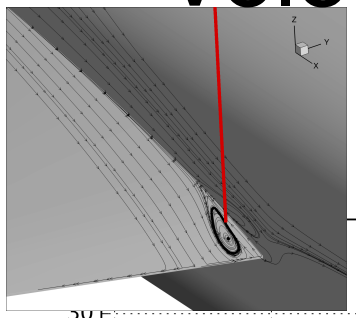


Still no differences between WT Medium and WT Fine

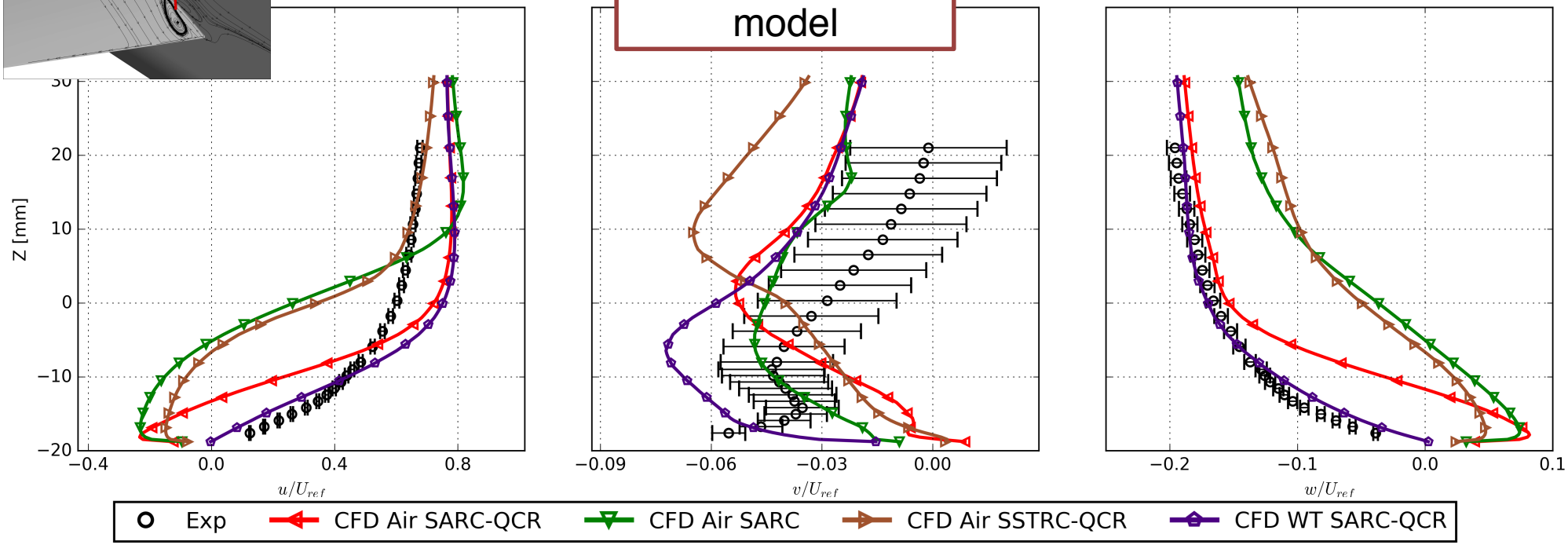
AOA = 5 deg

Velocity Profiles: Turbulence Model

In the Separated Region, 10 mm from fuselage, Fine Grid



Large variation for each turbulence model

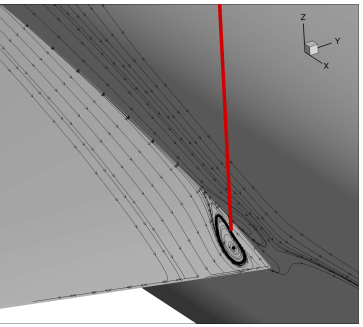


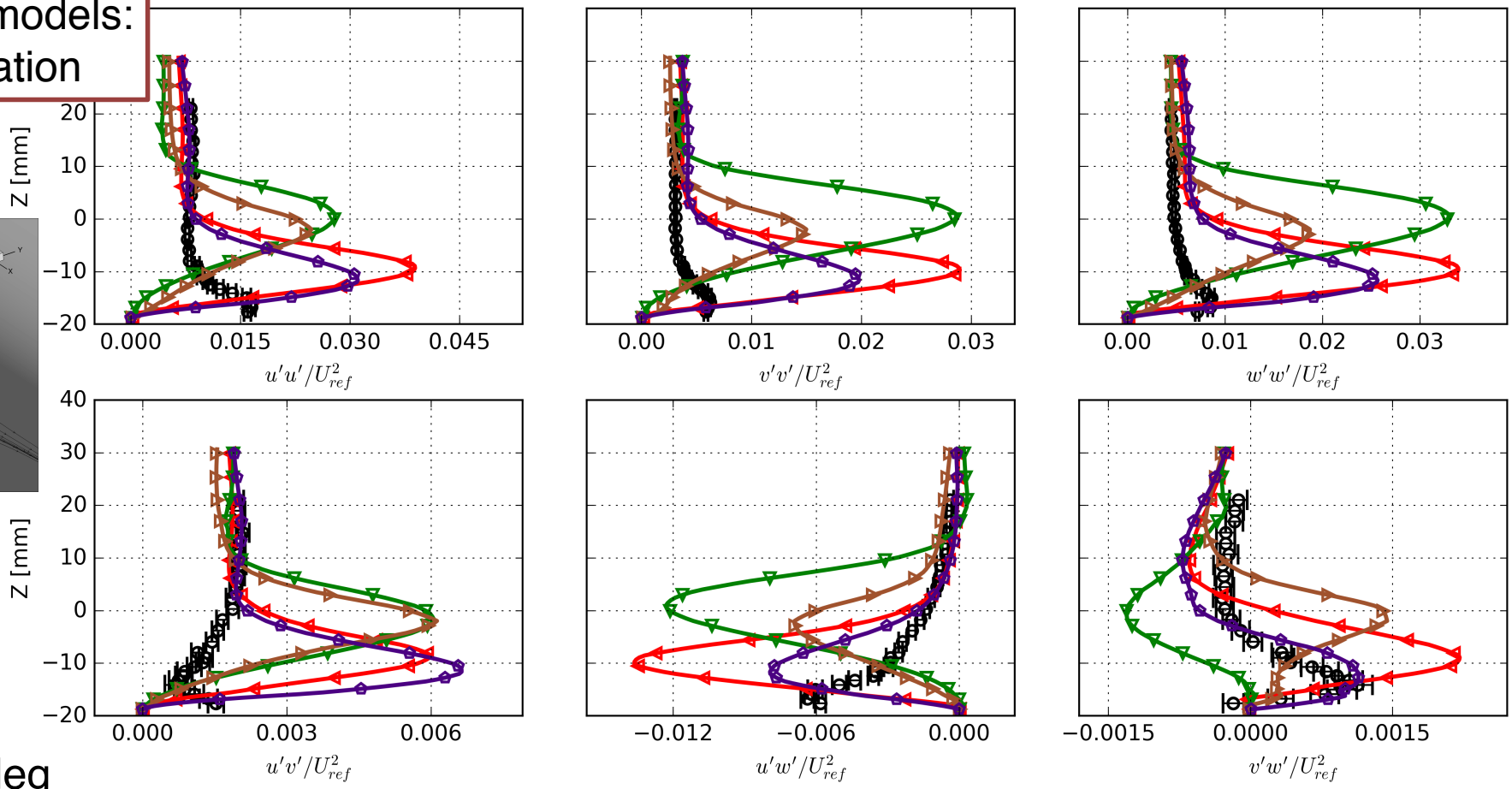
AOA = 5 deg

Reynolds Stress Profiles: Turbulence Model

In the Separated Region, 10 mm from fuselage, Fine Grid

Turbulence models: large variation





AOA = 5 deg

Summary



- Preliminary evaluations of OVERFLOW CFD “RANS” on Juncture Flow region
  - Solutions compare well before separation
  - Some sensitivity to grid resolution in free air
  - Less sensitive to grid resolution with wind tunnel walls
  - CFD in tunnel simulations predicted smaller separations
  - Turbulence Model variations the largest

- Turbulence Model predicted largest differences
  - No “trend” on which model matches the best
  - Wide variation across models

- CFD is doing a decent job at the broader quantities (pressures, velocities), but predictions break down in the separated regions.

Future Work



- No significant indication in the computation of unsteady nature to the flow
  - Preliminary time accurate computations do not show any major effects of unsteadiness
  - Need a bit more guidance about the time scales
- Possible corrections for AOA?
- Website: https://turbmodels.larc.nasa.gov/Other_exp_Data/junctureflow_exp.html

Acknowledgements



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Questions?

