COLLEGE OF ENGINEERING
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VIRGINIA TECH

CENTER FOR RESEARCH AND ENGINEERING IN AERO/HYDRODYNAMIC TECHNOLOGIES

Measurement and Modeling of Non-Equilibrium Turbulent Boundary Layer Flows

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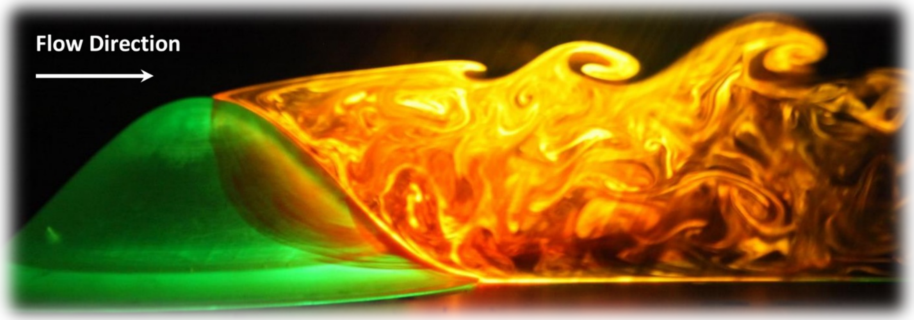
NASA 2022 Symposium on Turbulence Modeling: Roadblocks and the Potential for Machine Learning

27 July 2022

VIRGINIA TECH

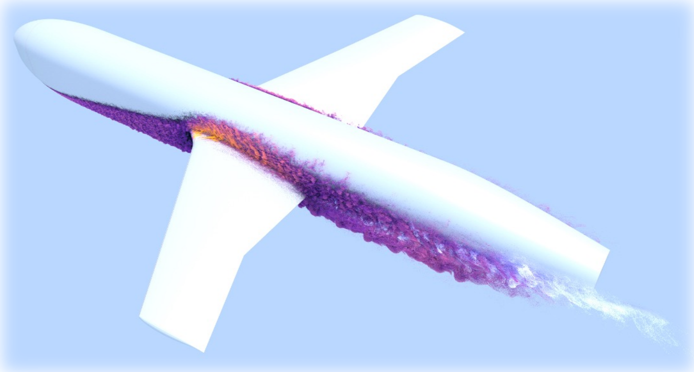
Motivation

Separation

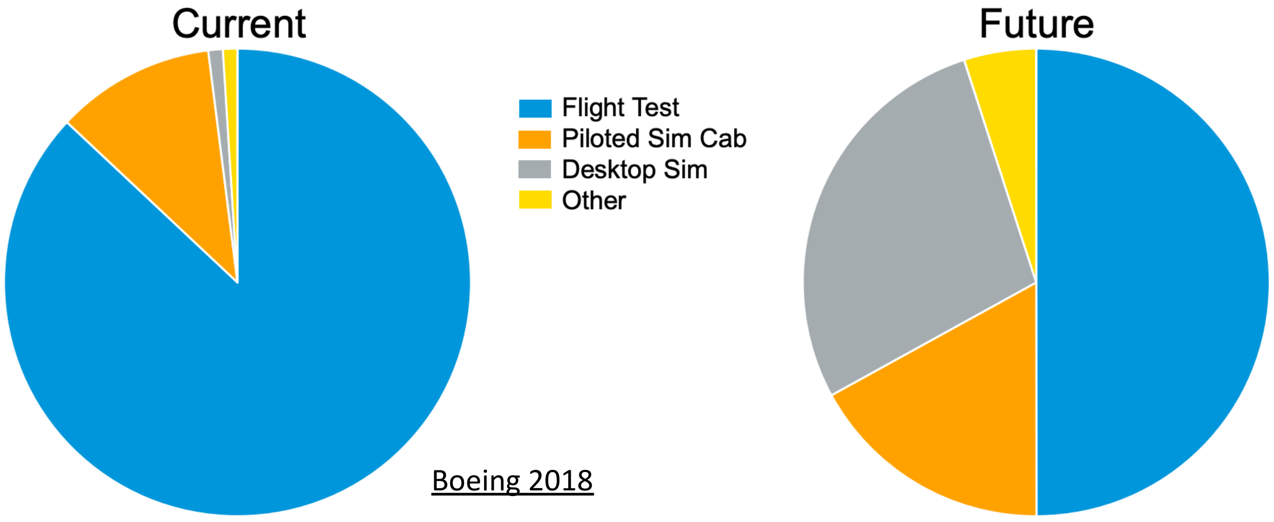


NASA FAITH Hill, Bell *et al.* 2012

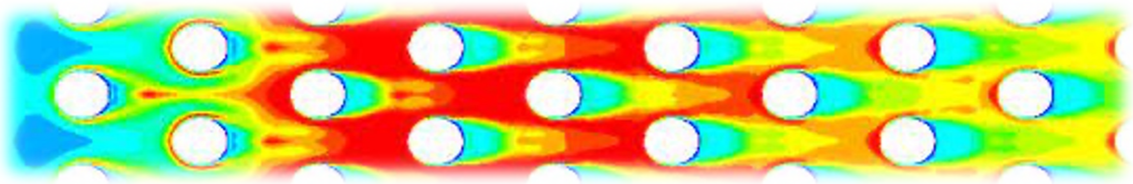
Juncture Flows



NASA Juncture Flow, Ghate *et al.* 2020



Roughness



Narato *et al.* 2021

Required: industry faith in CFD prediction of all relevant flow physics:
Improved Turbulence Modeling

Industry Standard RANS Models:
Spalart & Allmaras (1992)
Menter (1994, 2003)

The Tripod of Science

Scientific Knowledge

- Multi-disciplinary investigators
- Multi-disciplinary teams
- Collaboration and synergy

Simulations

Theory

Experiments

Typical Model Development/Validation

1. Experimentalists design and perform experiment to study fundamental physics
2. Experimentalists document quantities of interest to experimental findings
3. Modelers make educated guesses about boundary conditions, flow behavior, etc. and simulate experiment
4. Modelers develop and validate model based on these data

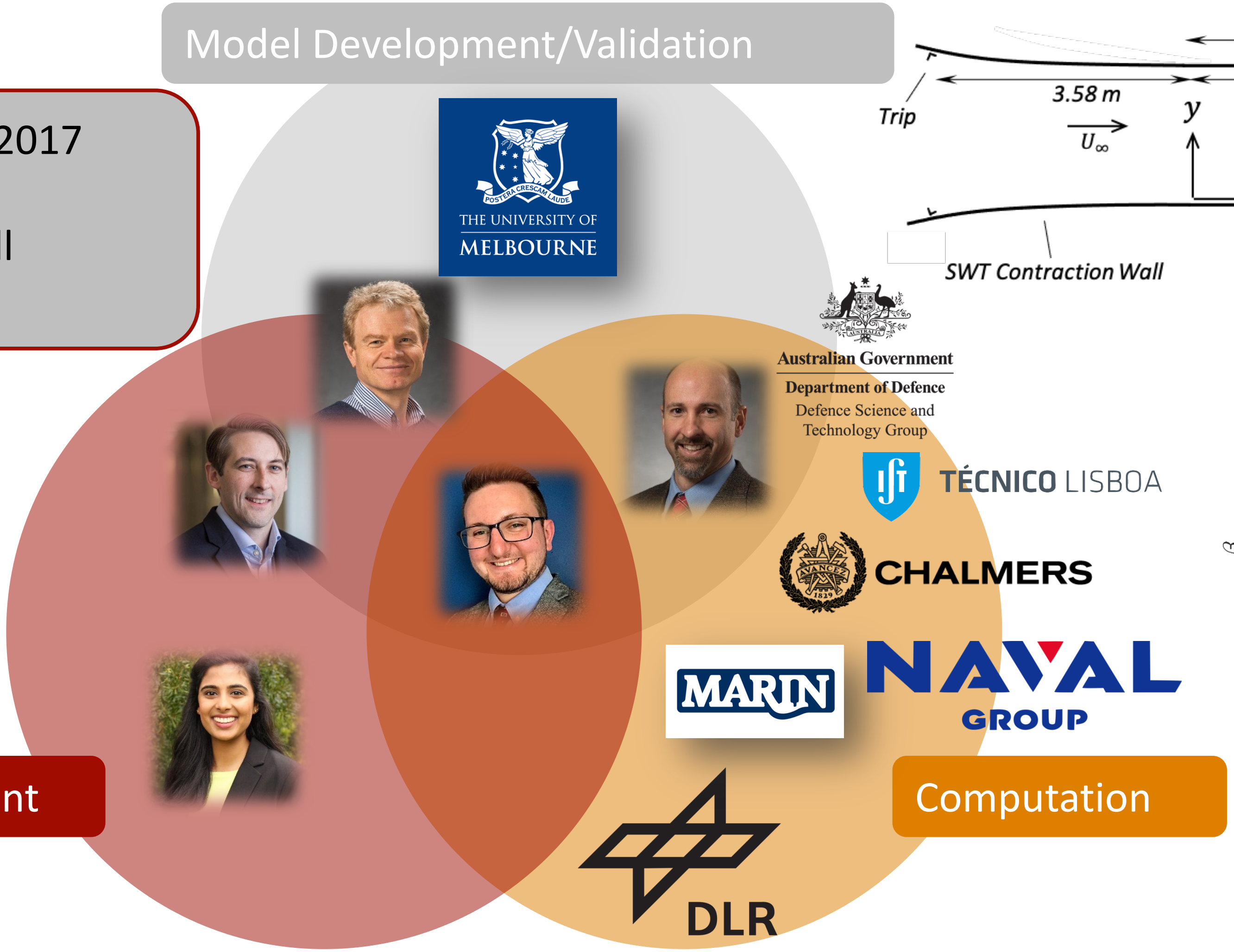
Synergistic Model Development/Validation

1. Experimentalists and modelers work together to design validation experiment
2. Risk reduction experiments and computations are performed in parallel - findings are shared and reviewed together
3. Experiment and digital twin are investigated in parallel, detailed measurements are made of quantities required for simulation setup and validation
4. Team develops and validates model based on these data

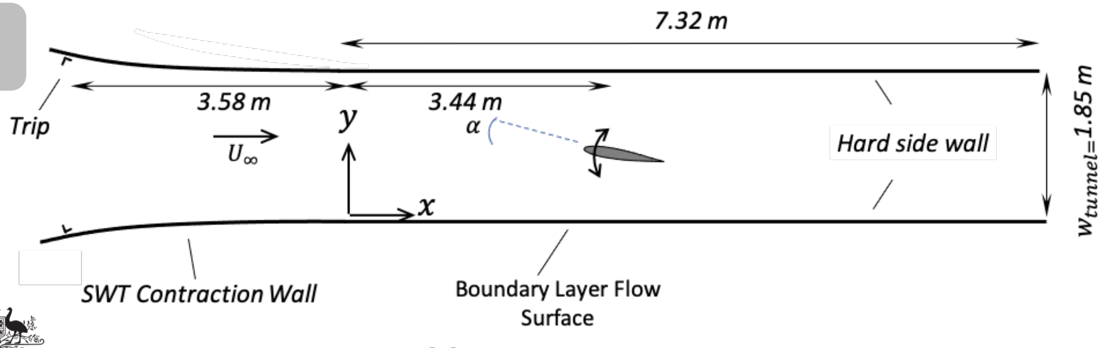
Bottom Line:
We may have reached the limit of what can be accomplished in isolation.

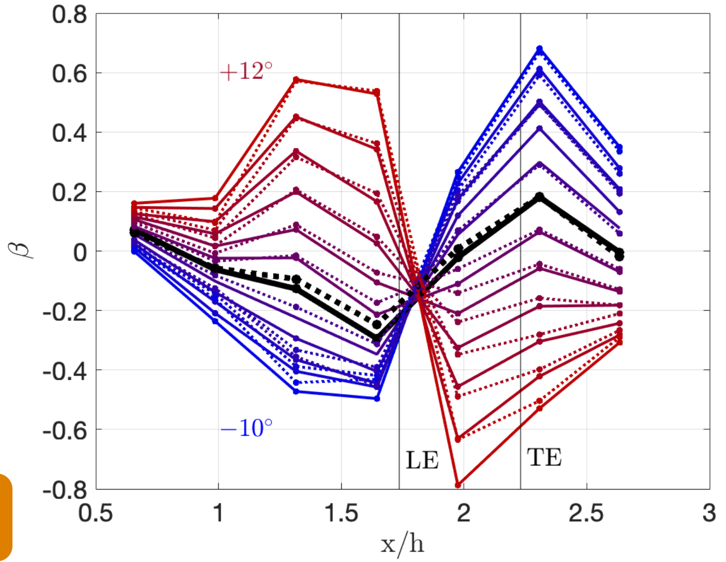
Creating Multi-Discipline Synergy

- Oberkampf & Smith 2017
- NASA Juncture Flow
- NASA/VT BEVERLI Hill
- NATO CRT



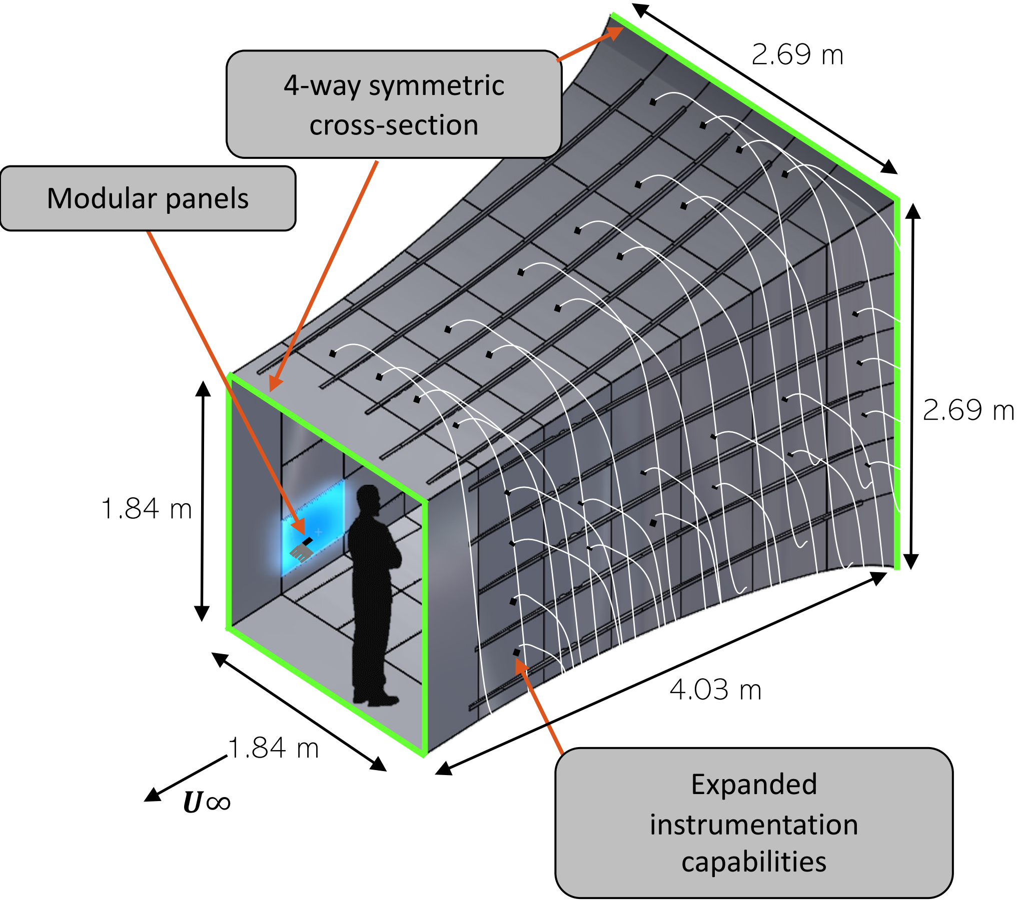
Experiment



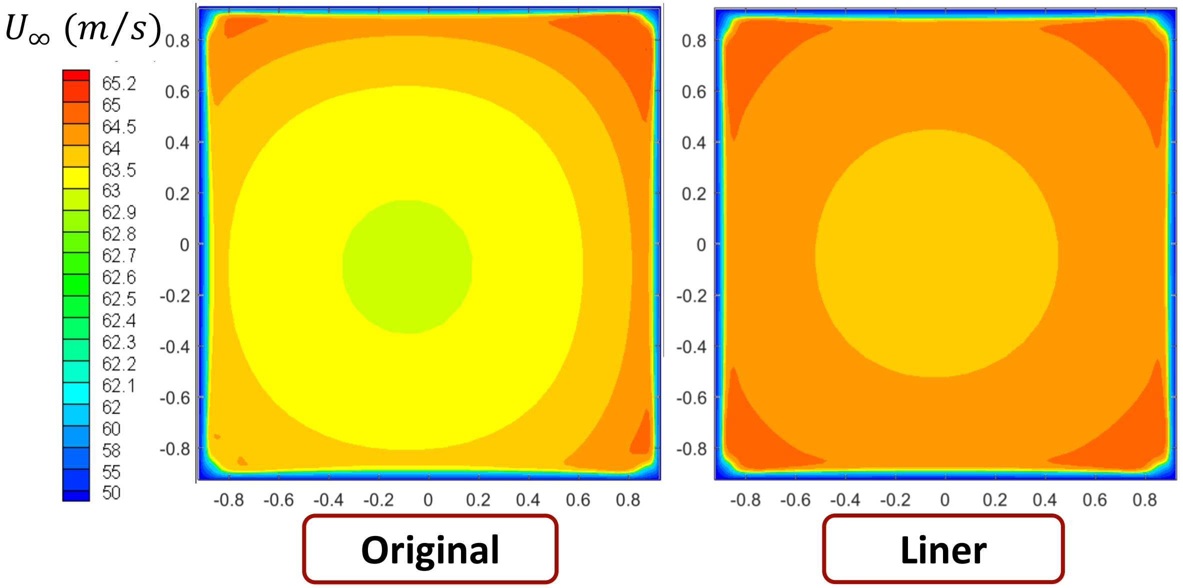


Fritsch *et al.* 2022 *AIAAJ*

Computations Improve Experiments



Vishwanathan *et al.* 2020 *AIAA SciTech*

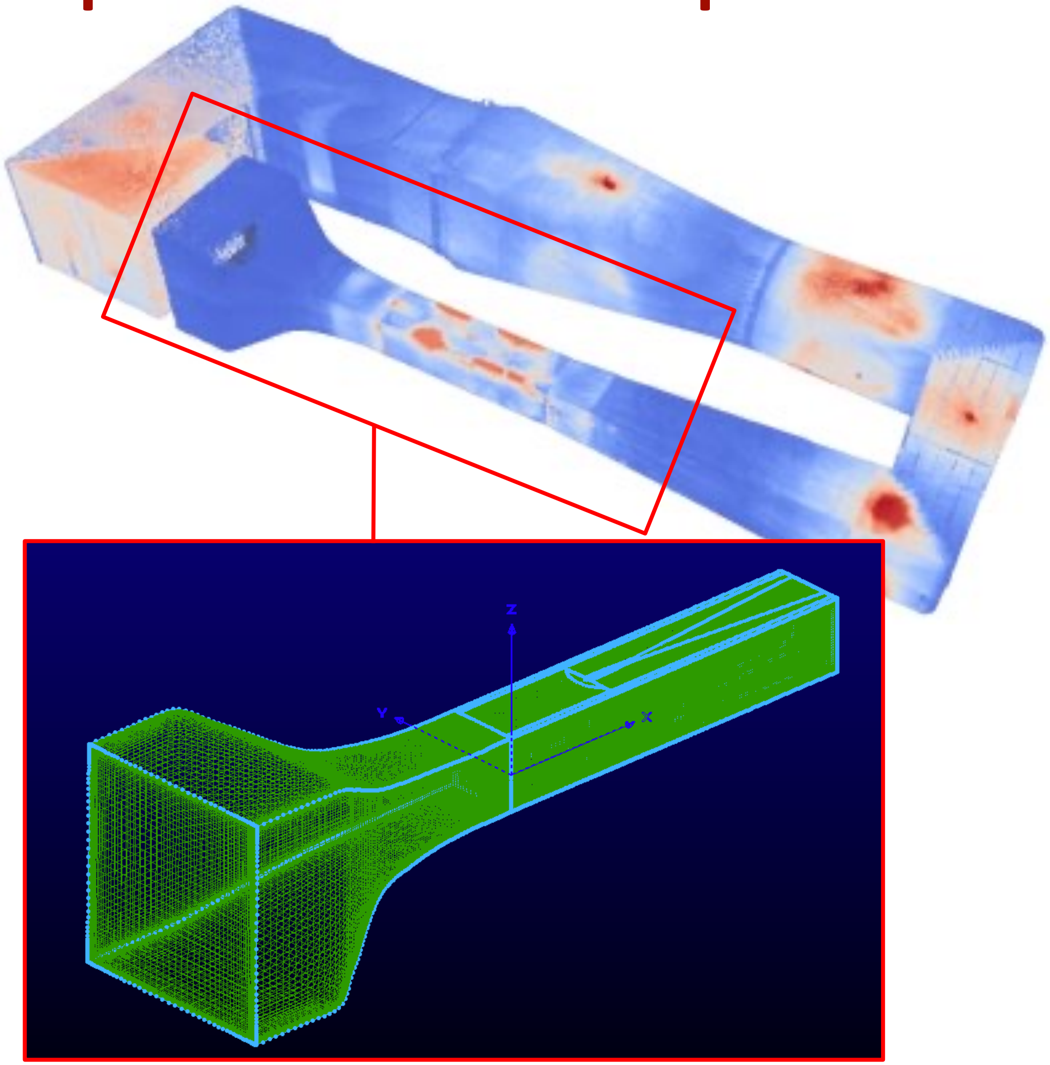


Szoke *et al.* 2020 *AIAA SciTech*

Explicit Measurements of:

- Inflow turbulence intensity and directionality
- Airfoil wake flow
- Contraction flow
- Opposing wall flow
- Spanwise boundary layer distributions
- Turbulence model parameters, k & ϵ

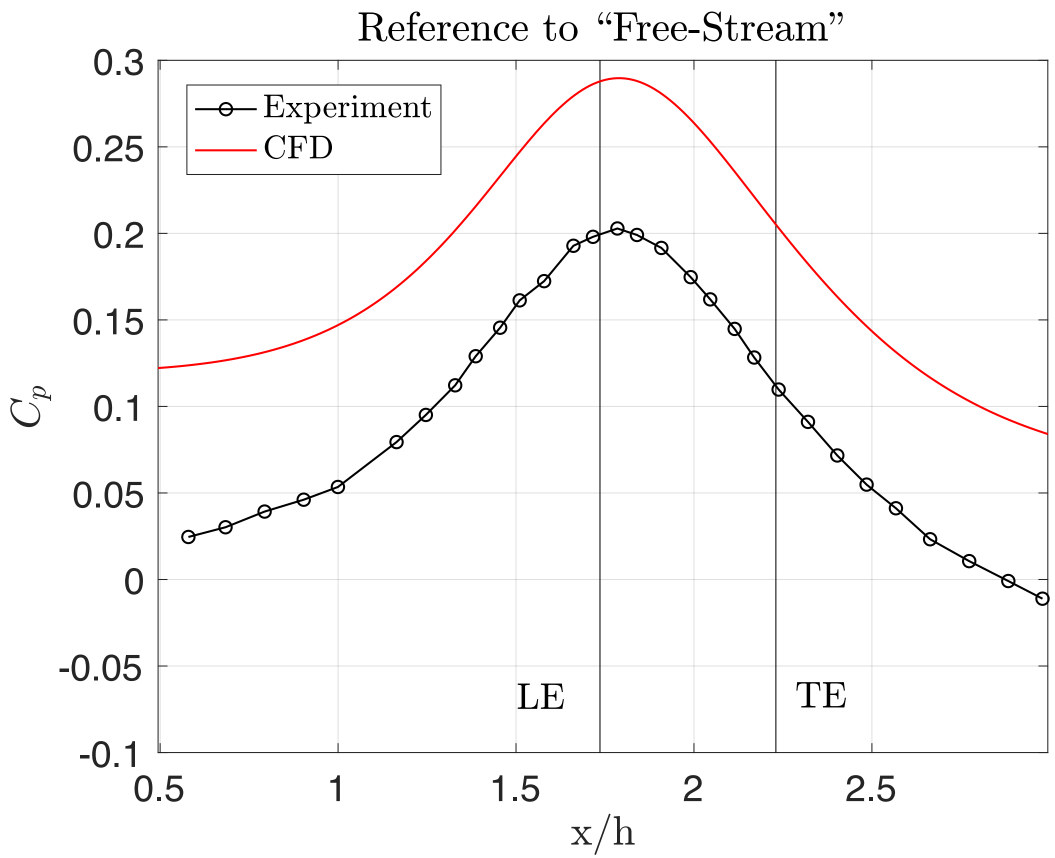
Experiments Improve Computations

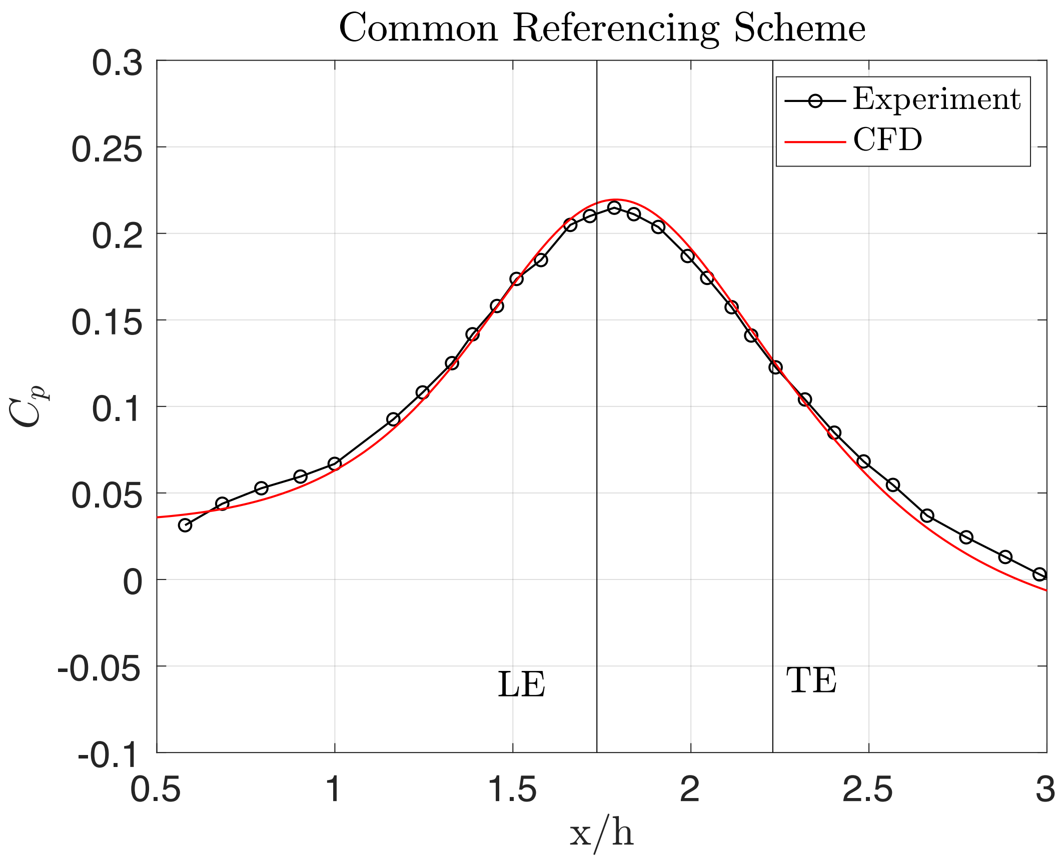


Known:

- Geometry
- Boundary conditions
- Reference conditions
- Asymmetries (geometric and flow-induced)
- Uncertainties & ranges
- Setup details
    - Trips, steps, etc.
    - Probe locations
- “Boring” data
    - Contraction flow
    - Off-span flow
    - Corners
    - Wakes

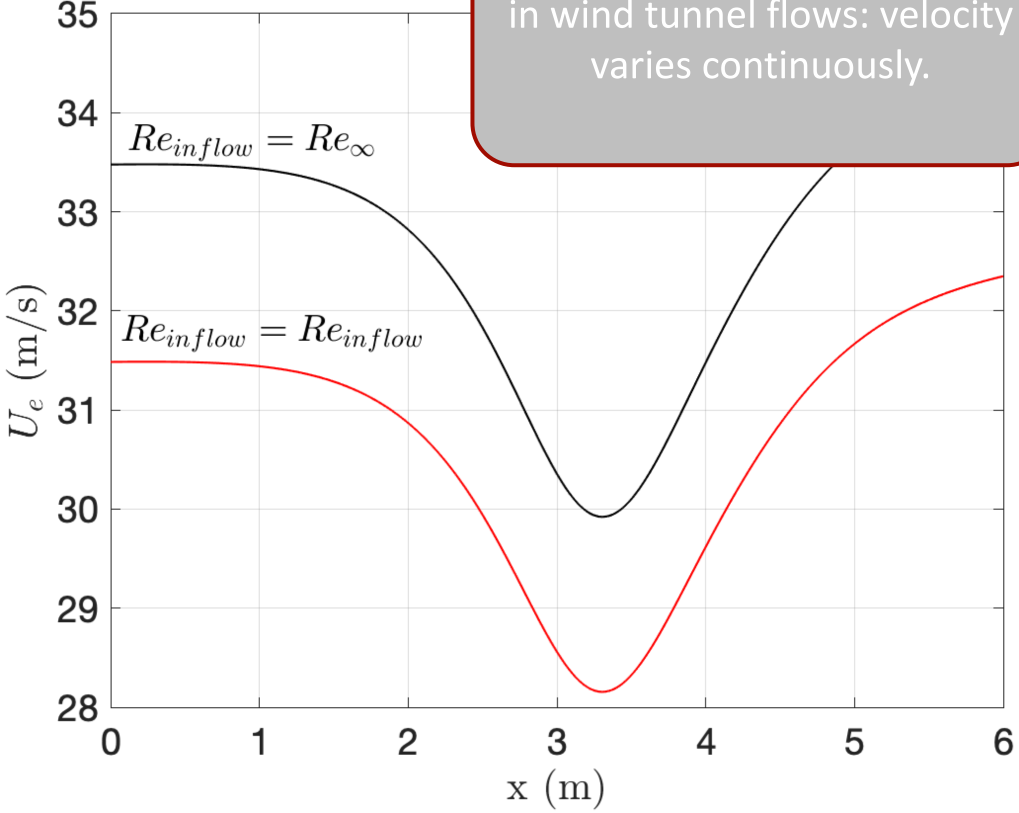
Referencing Schemes

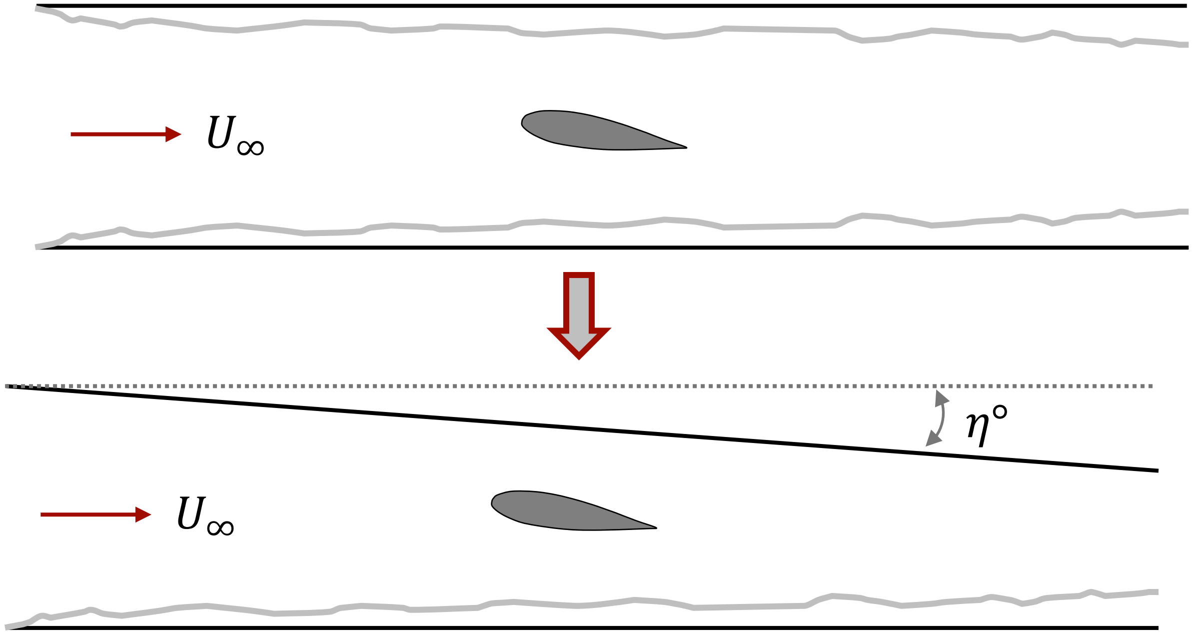




Blockage Effects

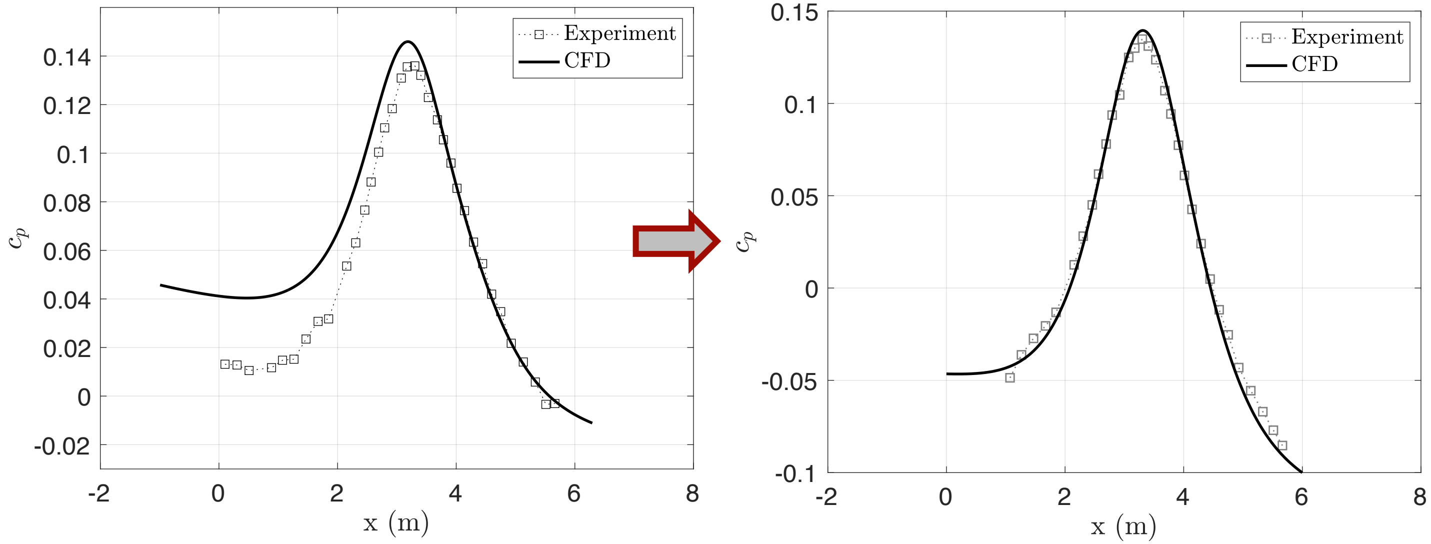
“Free-stream” is a misnomer in wind tunnel flows: velocity varies continuously.



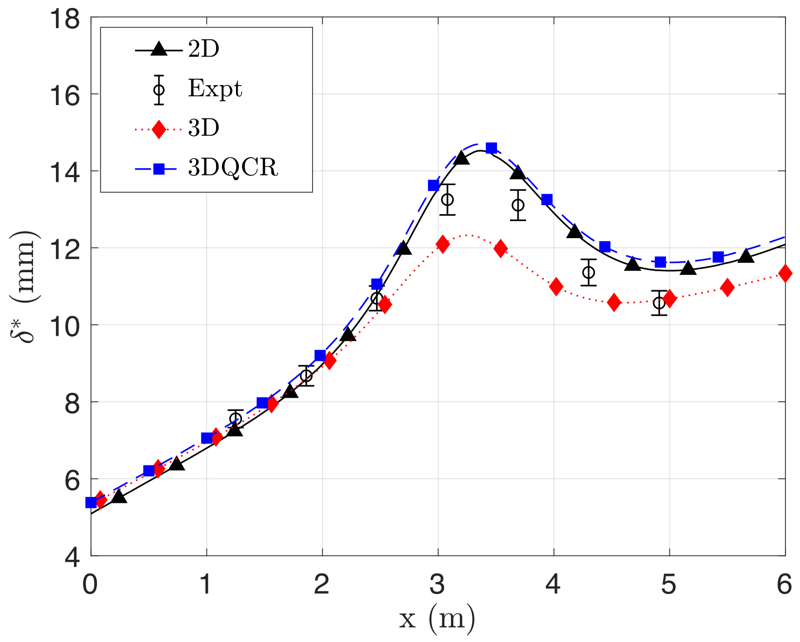


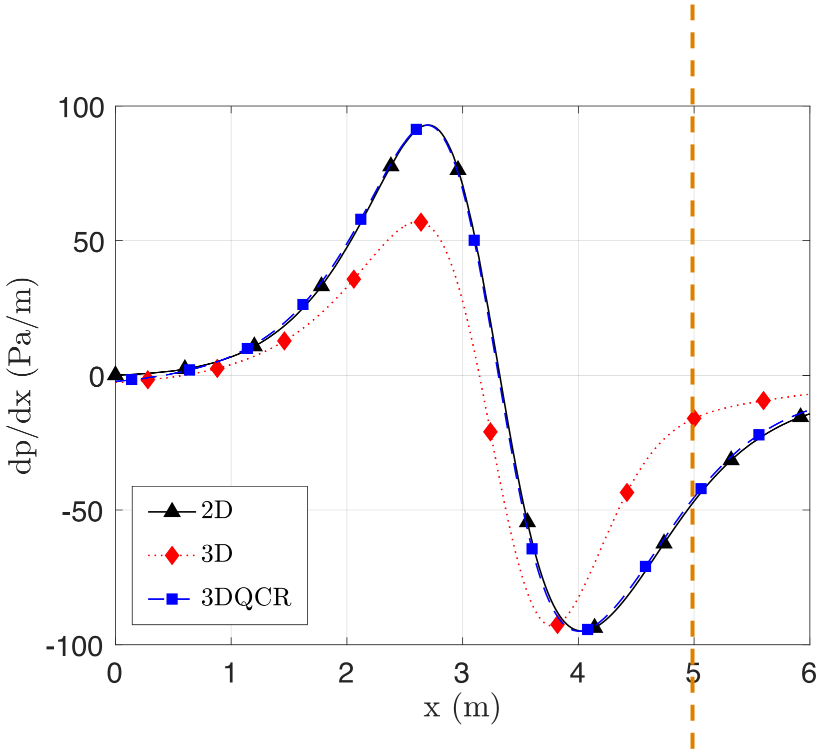
Straight Wall

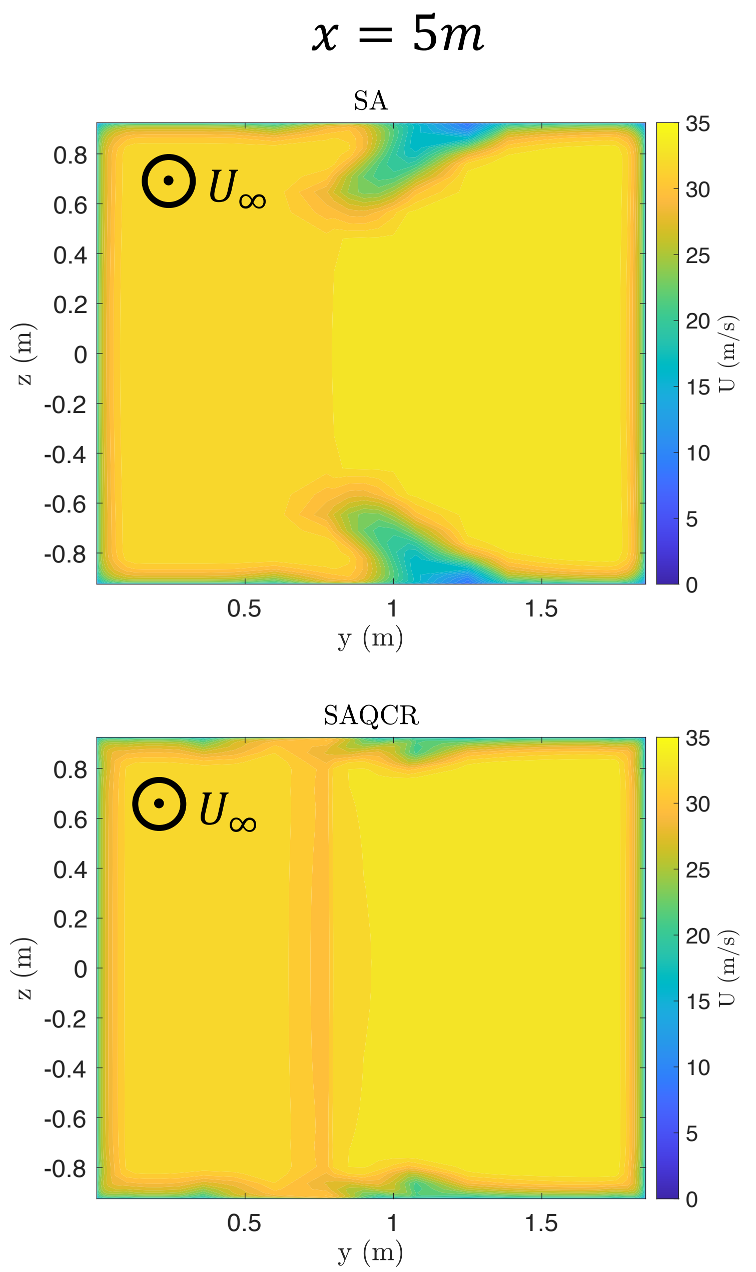
Angled Wall



3D Wind Tunnel Flows







Inclusion of more details is not always more accurate if those details cannot be correctly modeled.

Final Points

Cross-discipline collaboration enabled higher quality, more complete experiments and more robust and accurate simulations.

Wind tunnels are internal, 3D problems.

Next generation turbulence models will come from well documented, fully complete* collaborative studies.

*Oberkampf & Smith 2017 *JVVUQ*

Acknowledgements

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