Computational Fluid Dynamics Modeling of the NASA Titan Wind Tunnel (TWT)

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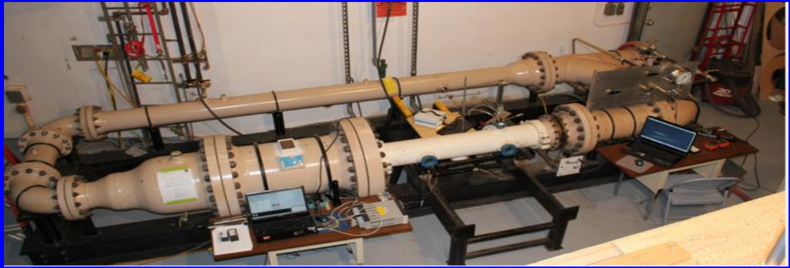
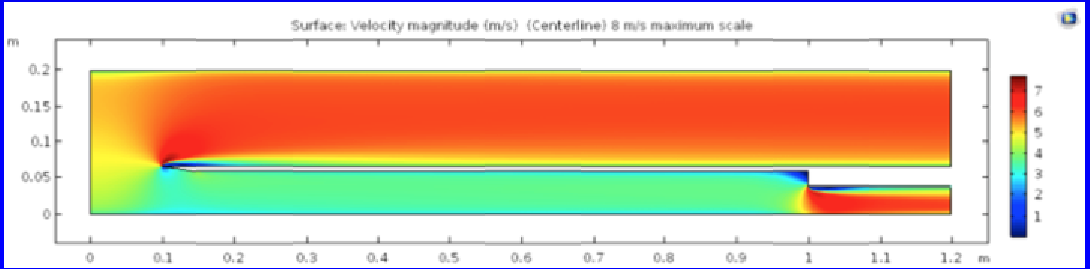
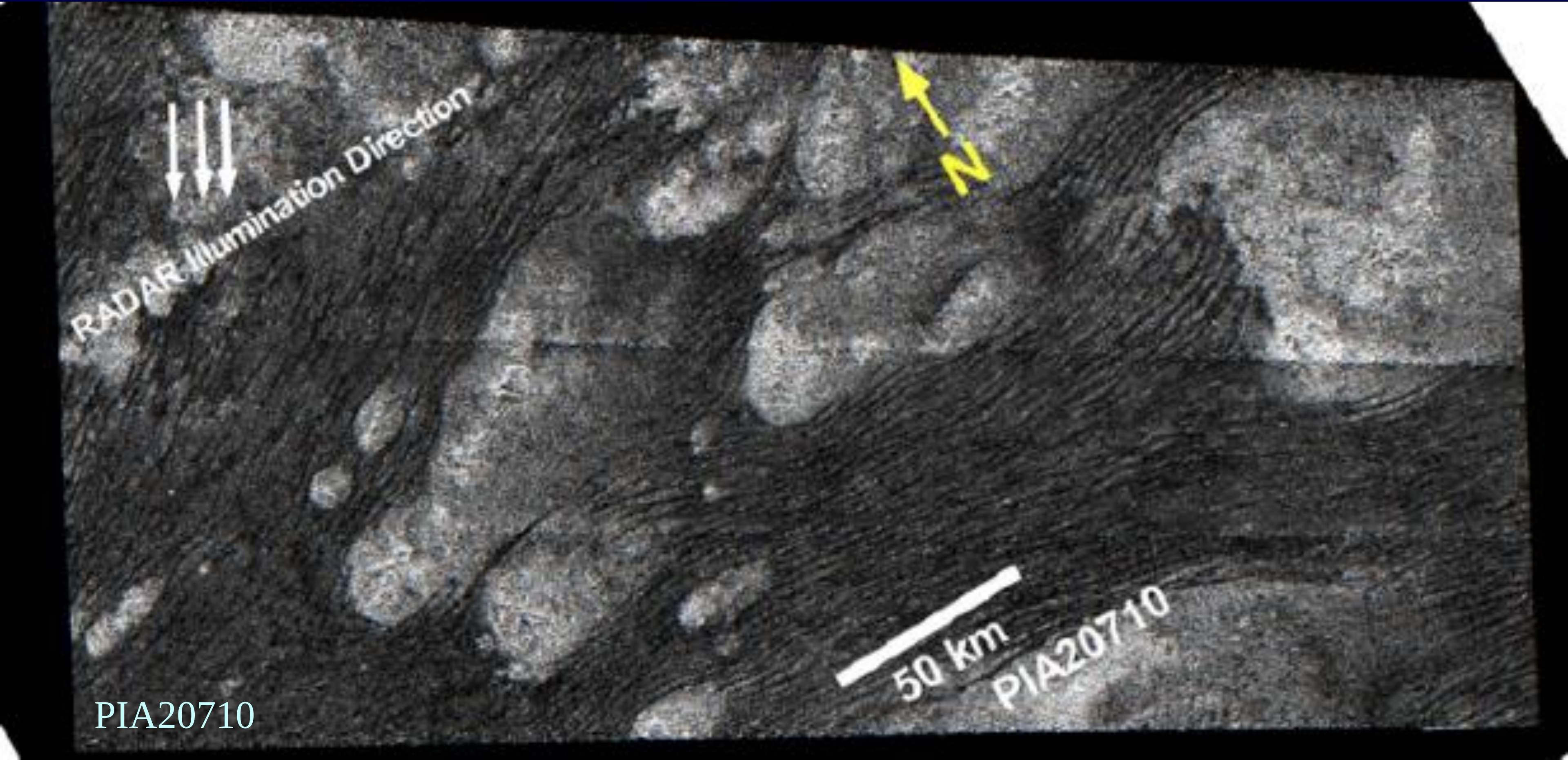




Shangri-La Sand Sea, Titan



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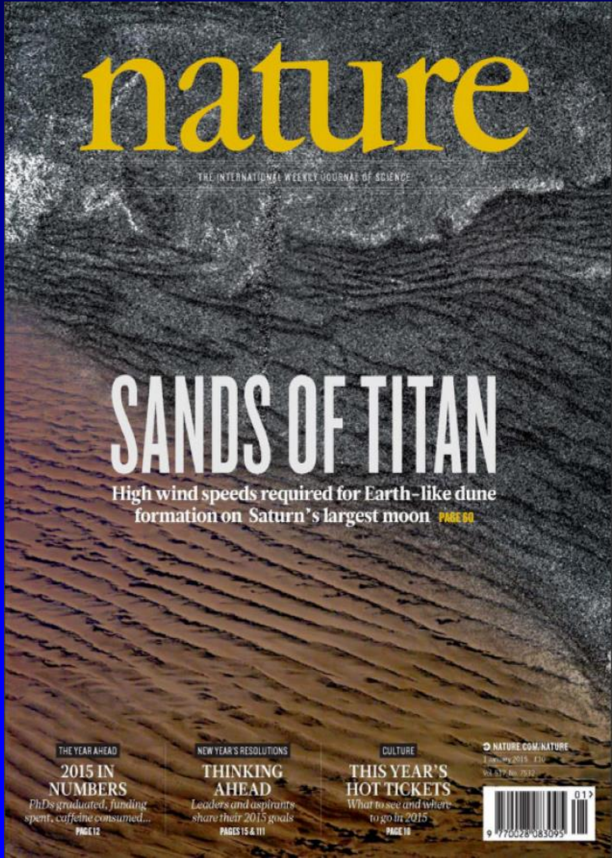
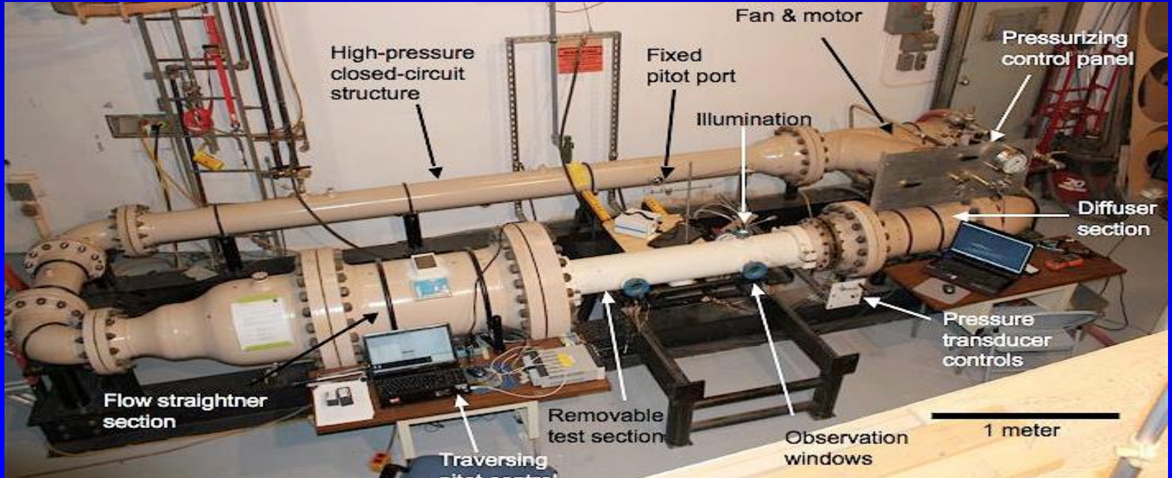
Titan Saltation Thresholds

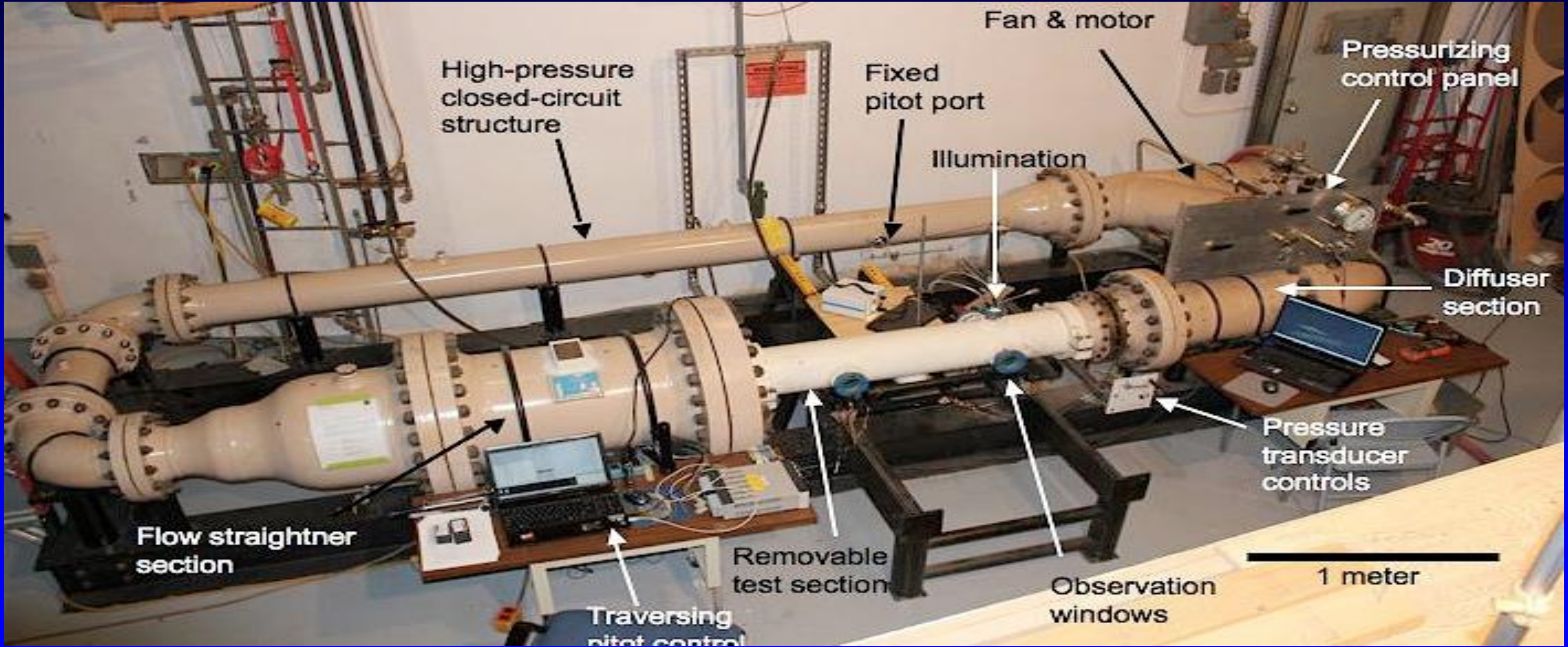
- The Titan Wind Tunnel has provided data for higher-than-predicted saltation threshold wind speeds on Titan. (*Burr et al., Nature, 2015)*
- This would have a significant effect on wind transport of particles
- Suggests that particle-fluid density ratio is more important for Titan regimes
- New environments reveal new processes we must consider *(Burr et al. Aeolian Research 2015)*



Wind Tunnel Challenges

- Experimental methodology requires successive empirical fits
  - Calibration runs may not match experimental runs
- Tunnel configuration changes can be problematic
  - Documentation sparse, measurements sparse
- Some regimes are outside tunnel capabilities... But not COMSOL’s



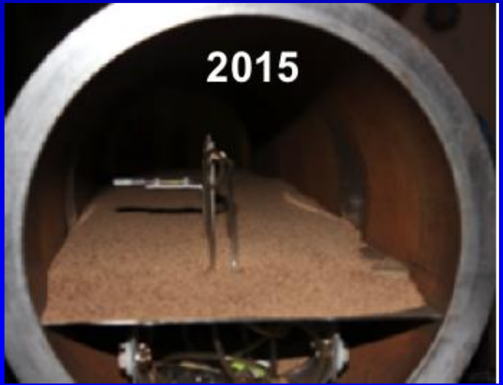


The NASA Titan Wind Tunnel is a legacy instrument, with an 8 inch/ 20 cm steel test section

Titan Wind Tunnel:
Test Section Configuration Changes

- Increasing instrumentation
- Multiple test bed plate changes with varying flow effects

More obstructions over time

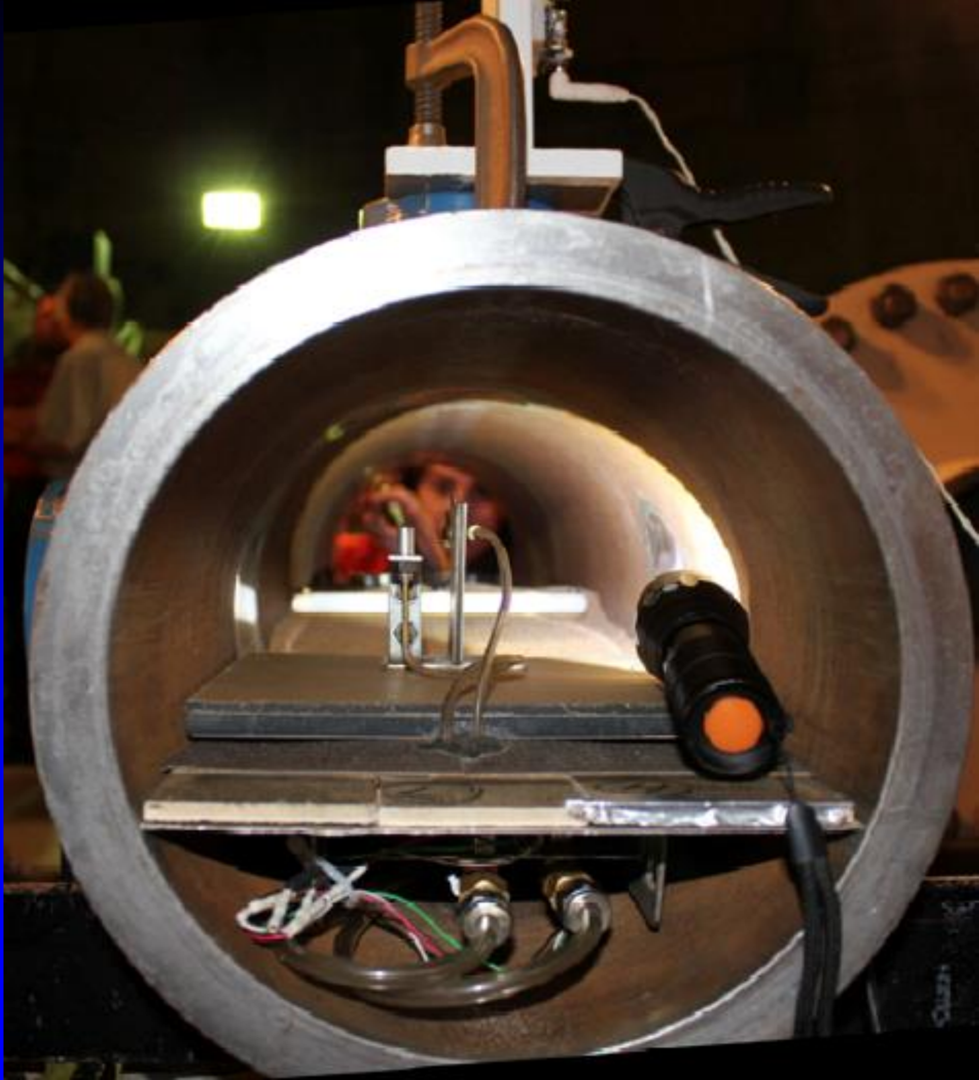


20 cm

Flow Obstruction Examples

- Thicker test plate
  - Varying roughness, connectors
- Equipment below test plate
  - Flexible tubing location varies
- Platform on top of test plate
- Instruments above test plate and platform

Emily Nield for scale



Flow Obstruction

- Recent question…

Does blocking the sub-test plate flow entirely “fix” the obstruction problem?

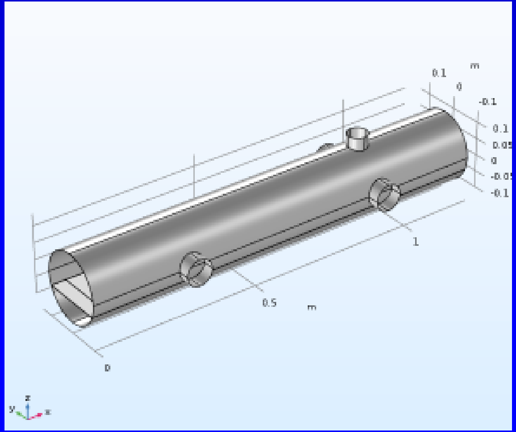
We need:

Better understanding of the tunnel to:

- Interpret results --> Boundary layer processes
- Detect/explore more of the processes
- Extend TWT analyses to additional parameter space

Approach:

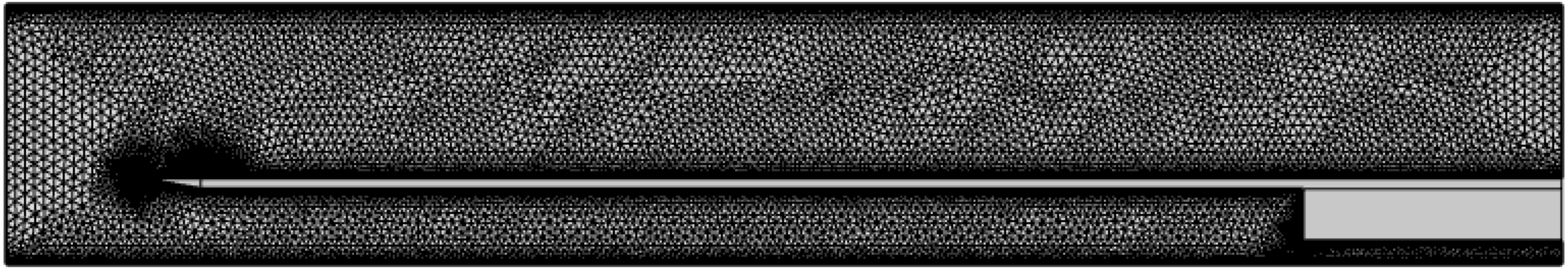
Build a COMSOL model of the Titan Wind Tunnel for comparison with experimental data and use for virtual experiments



Model Setup

- COMSOL Multiphysics
  - Turbulent (k-ε) isothermal flow matched to TWT P, T, g conditions
  - 2-D slice of tunnel test bed center w/ particle tracing and wall roughness
  - Vary test bed shape, obstructions, roughness, particle density ratio

Example of model geometry and FEM mesh with downstream below-plate blockage

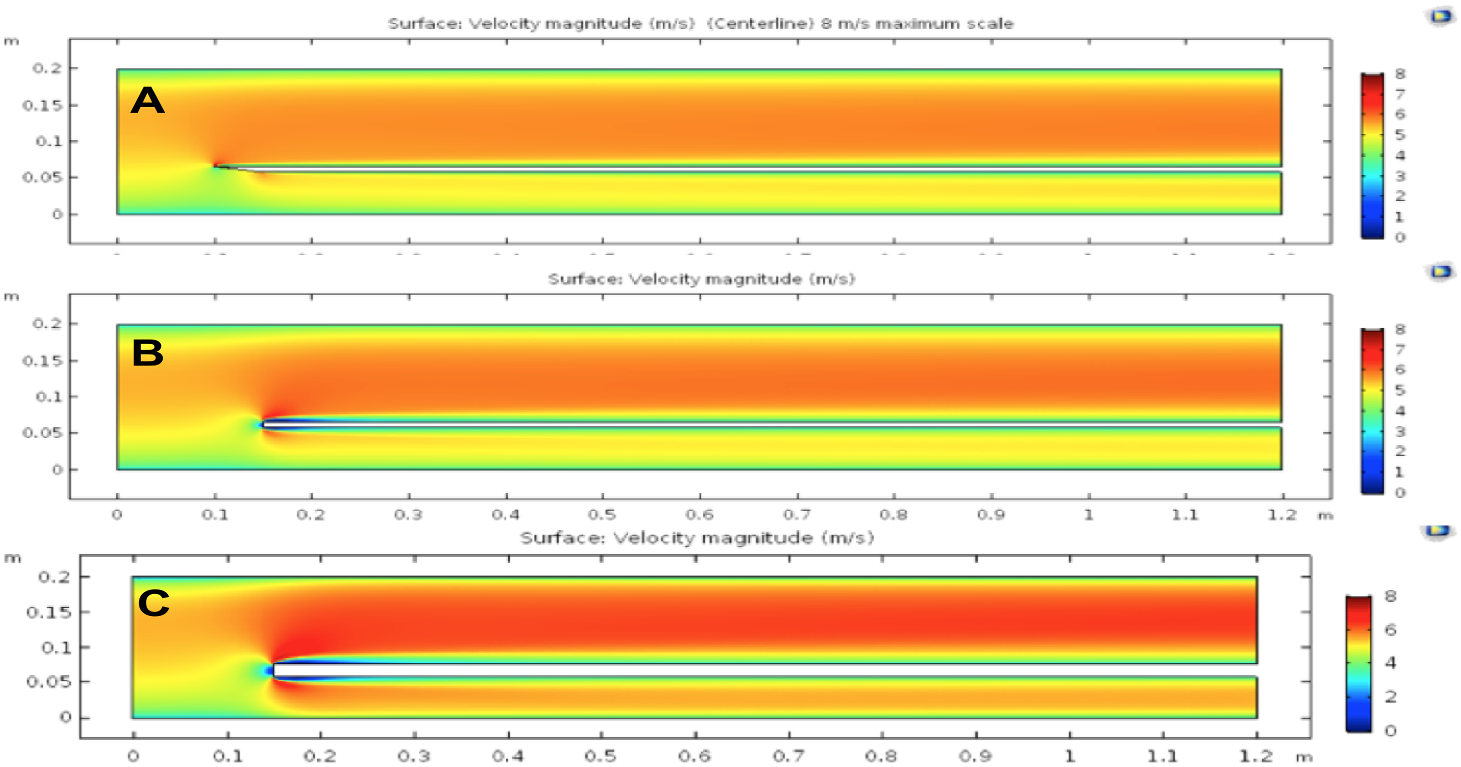


Titan Wind Tunnel CFD: Test bed effects

A: Taper end test bed (0.8 cm thickness), 5 m/s, roughness (~3µm)

B: Blunt end test bed (0.8 cm thickness), 5 m/s, , roughness (~3µm)

C: Blunt thicker test bed (1.8 cm thickness), 5 m/s, roughness (~3µm)



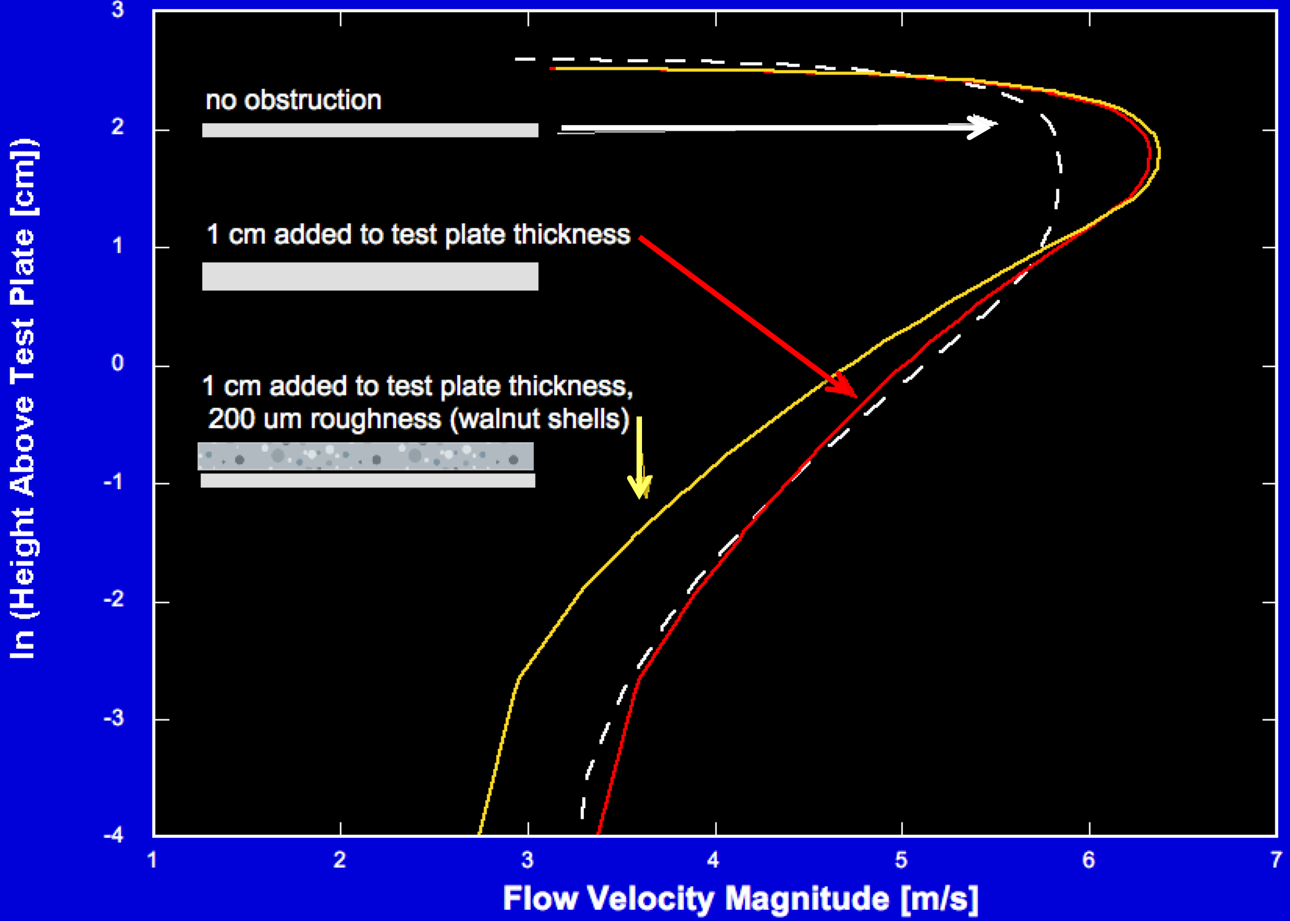
COMSOL Model Results: Plate Variations

Natural log height version…

Thicker or rougher plates will:

- Increase maximum flow velocity
- Change the boundary layer shape

Effects of test bed plate thickness or roughness (In height version)

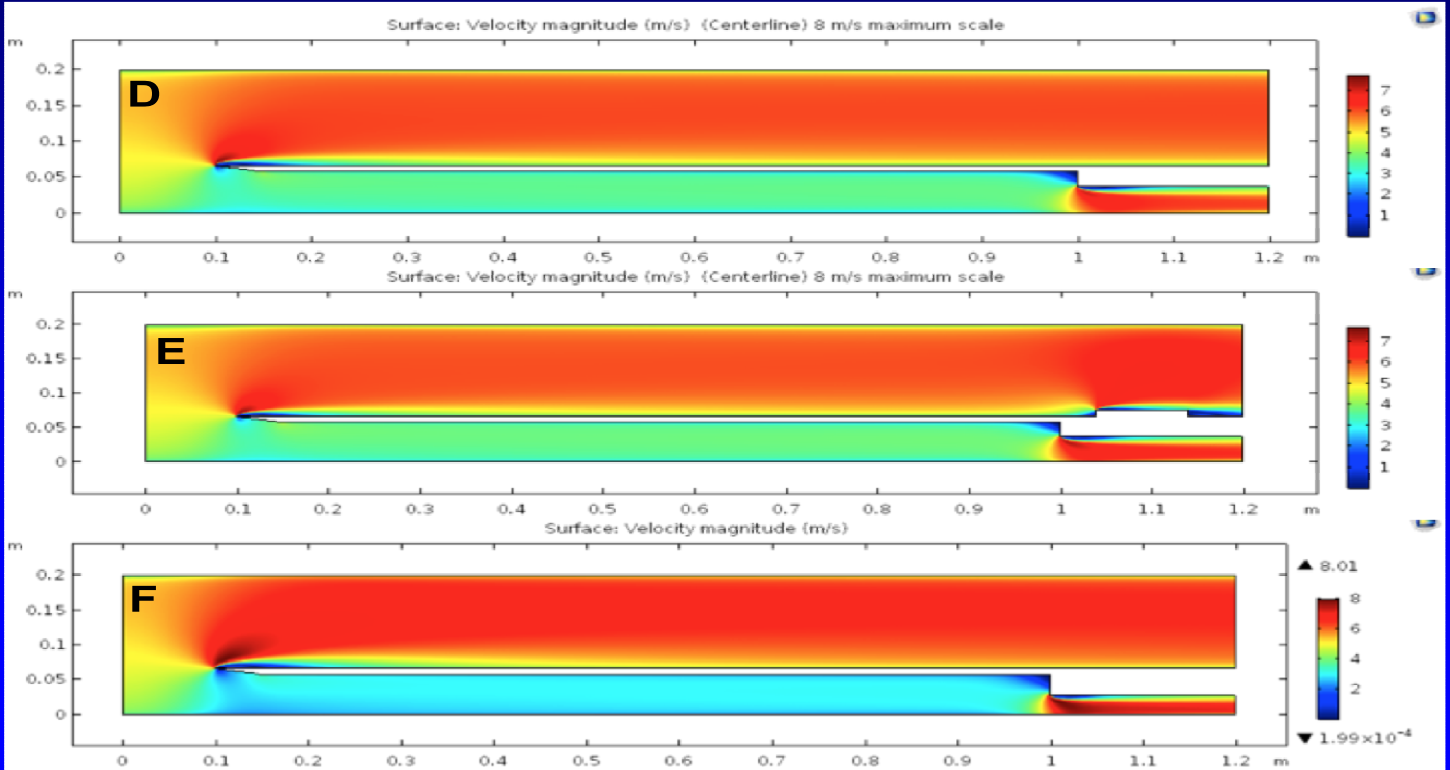


Titan Wind Tunnel CFD: Obstruction effects

D: Taper end test bed (0.8 cm), 2 cm obstructed below

E: Taper end test bed (0.8 cm), 2 cm obstructed below + pitot tube base on top

F: Taper end test bed (0.8 cm), 3 cm obstructed below (more tubing)

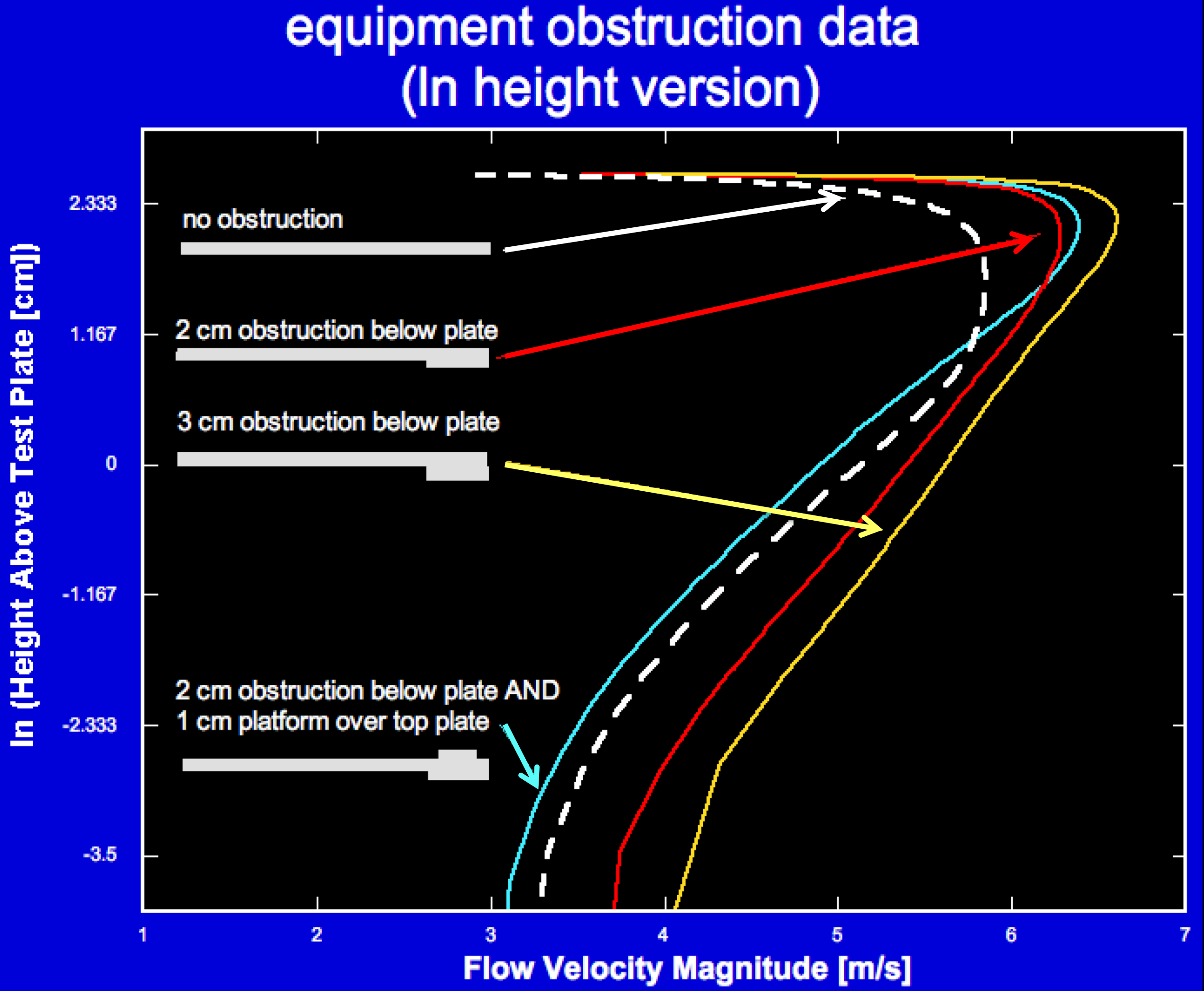


COMSOL Model Results: Obstructions

Natural Log height version

Flow obstructions will:

- Increase maximum flow velocity
- Change the boundary layer shape

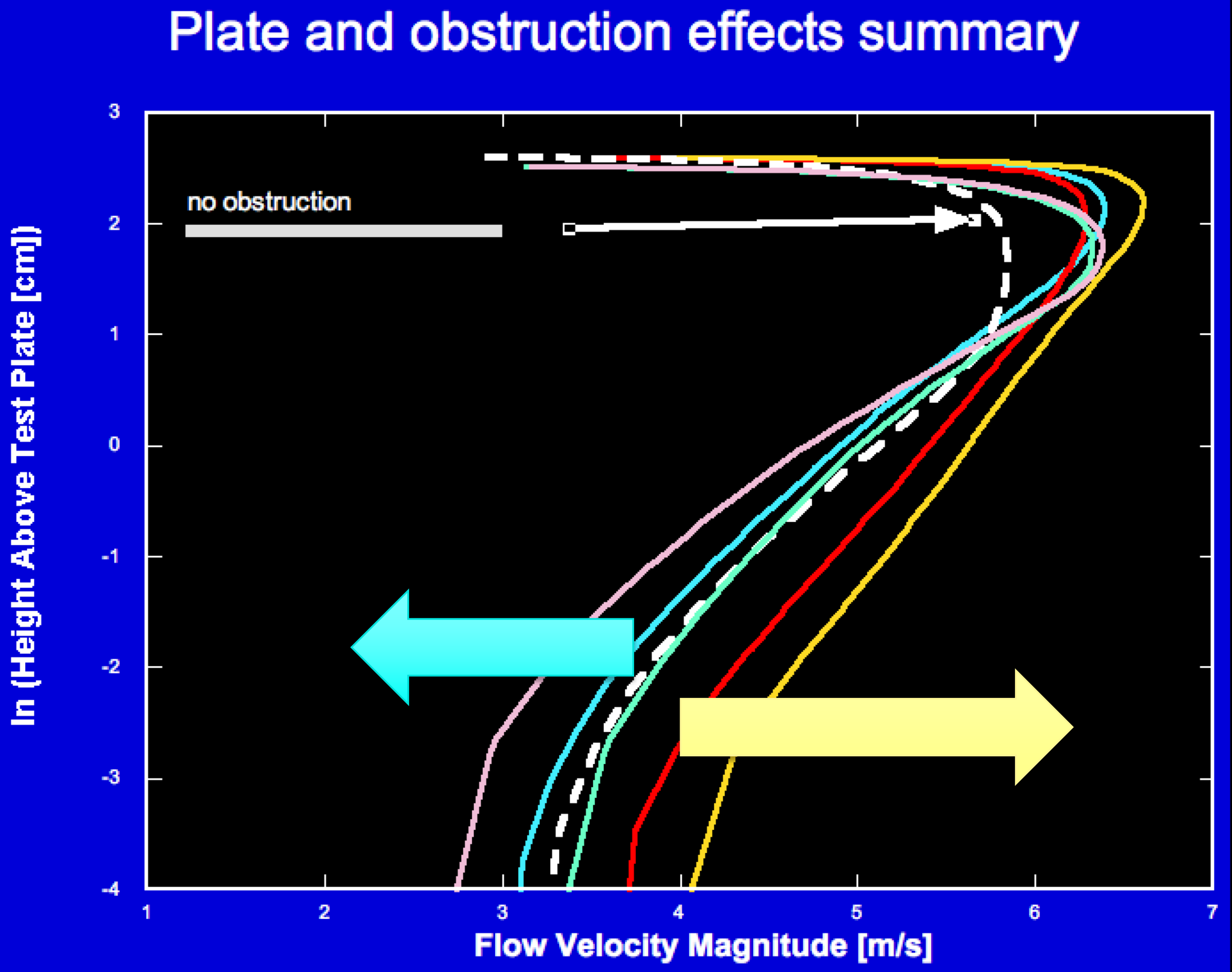


COMSOL Model Results: Summary

Lower Boundary Layer moves left for:
- -above-plate obstruction
- -thicker plates (some)
- -rougher plates

Lower Boundary Layer moves right for:
- -below-plate obstructions

Curvature from thick test bed AND large roughness



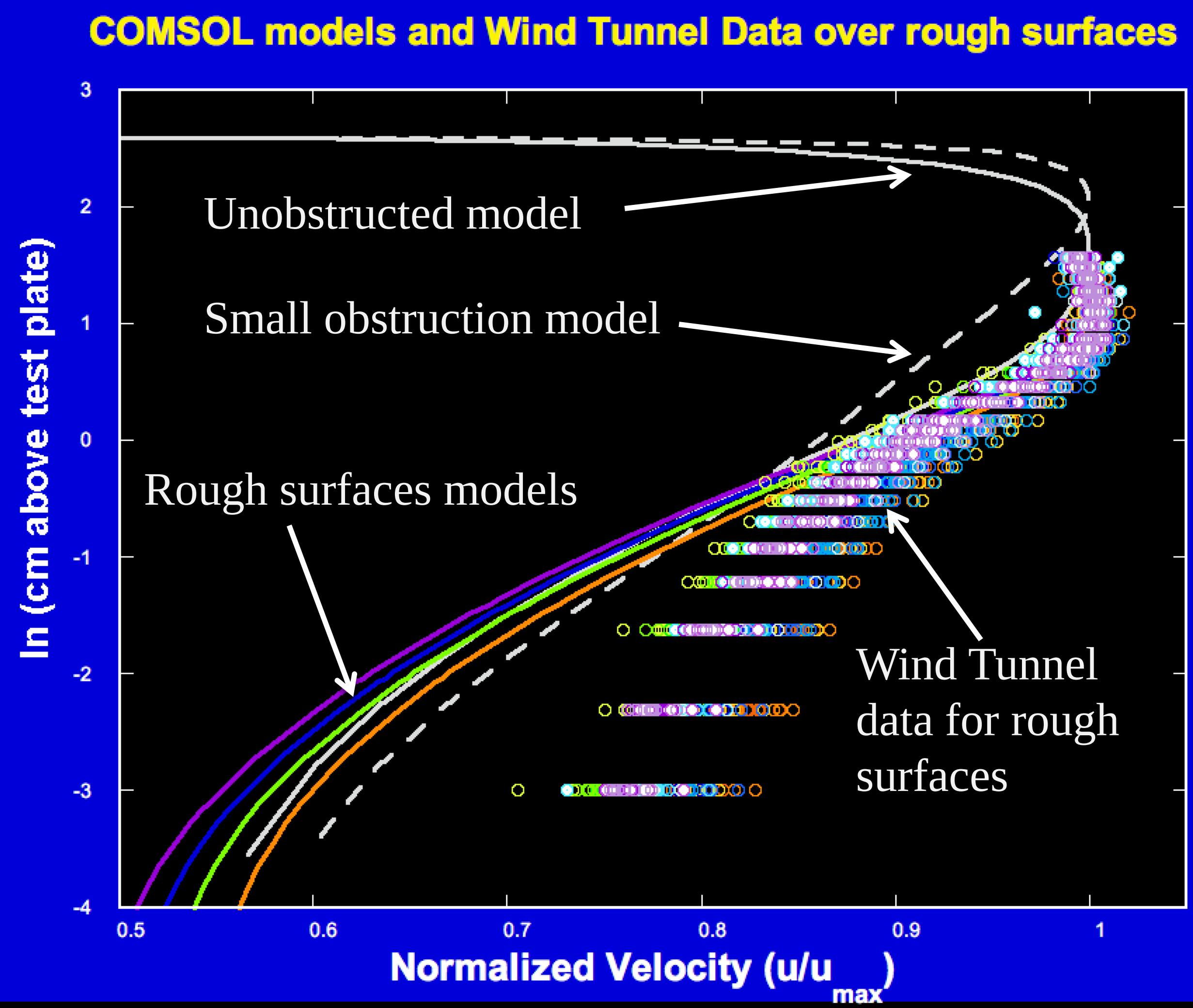
COMSOL Model Results and Wind Tunnel Data

ln(height) vs.
normalized velocity space

Model and data diverge close to the test plate (within 1 cm)

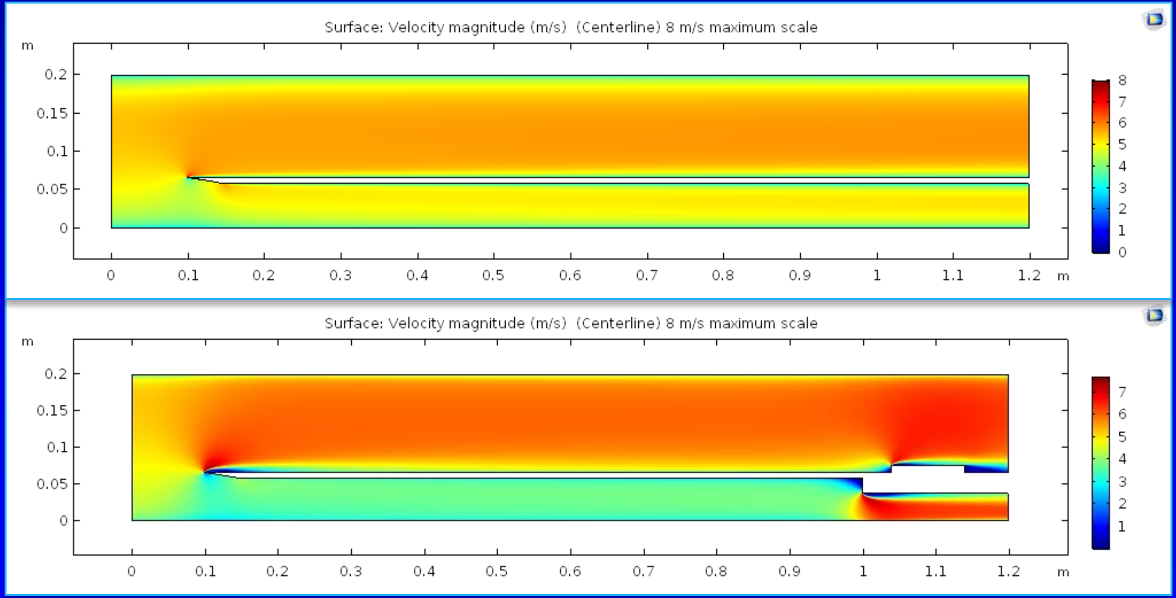
Need better obstruction model

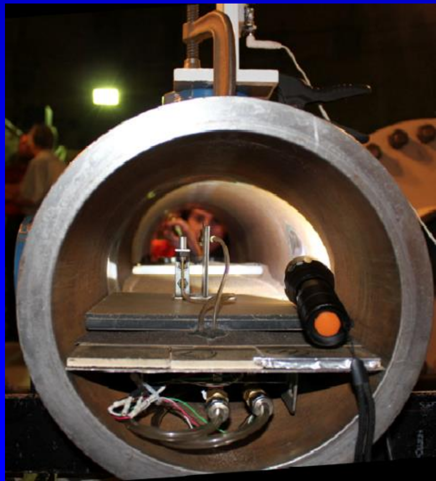
Investigate different turbulence and wall model effects



Science Lessons Learned for Titan Wind Tunnel Investigations: I

- Be certain that the configuration for the calibration runs **exactly** matches the data collection runs





Other preliminary model results…

- Density ratio behavior may vary in ways not yet captured in the experimentally derived correction
- Triboelectric particle modeling suggests that this mucks up everything

  +/- charge = !*$%

- Sediment-flow interaction modeling can also adjust the boundary layer curve shape…this is a big issue for ongoing boundary layer derivations
  - We empirically define boundary layers without sediment, and apply them to flows with sediment

Conclusions

- COMSOL modeling shows that Titan Wind Tunnel flow conditions are very sensitive to experimental setup
  - This was clearly understood prior to COMSOL modeling
  - Tunnel setup has evolved over time and is inadequately documented
- We need more discussion to match experimental and modeling results for flow closest to the plate (better obstruction model)
  - Consider low Re approaches, as slower speeds may be transitional flow
- Particle/fluid density ratios ARE important for Titan
- Sediments in the boundary layer change its behavior
- Gathering measurements for 3-D flow model and instrument tower modeling.