COLLEGE OF ENGINEERING
KEVIN T. CROFTON DEPARTMENT OF AEROSPACE AND OCEAN ENGINEERING
VIRGINIA TECH

CENTER FOR RENEWABLE ENERGY AND AERO/HYDRODYNAMIC TECHNOLOGY

A Blind Validation CFD Challenge Case for 3D Smooth-Body Turbulent Separation

Center for Research and Engineering in Aero/Hydrodynamic Technologies

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Background

- Virginia Tech has acquired turbulence model validation data for 3D smooth-body flow separation
- The BeVERLI Hill (Benchmark Validation Experiments for RANS and LES Investigations) has been studied at Reynolds numbers of 250k to 650k
- Experimental data obtained for the hill at 0° and 45° orientations
- Data includes: oil flow visualizations, surface pressures, skin friction via OFI & LDV, and mean and fluctuating velocities using PIV, LDV, & BL rakes
- Uncertainty estimates in data (random and bias)
- Extensive BCs and oncoming BL data measured
- However, there were some issues with the 0° and 45° orientations

Background

- Virginia Tech has acquired turbulence model validation data for 3D smooth-body flow separation
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Blind CFD Turbulence Model Challenge*

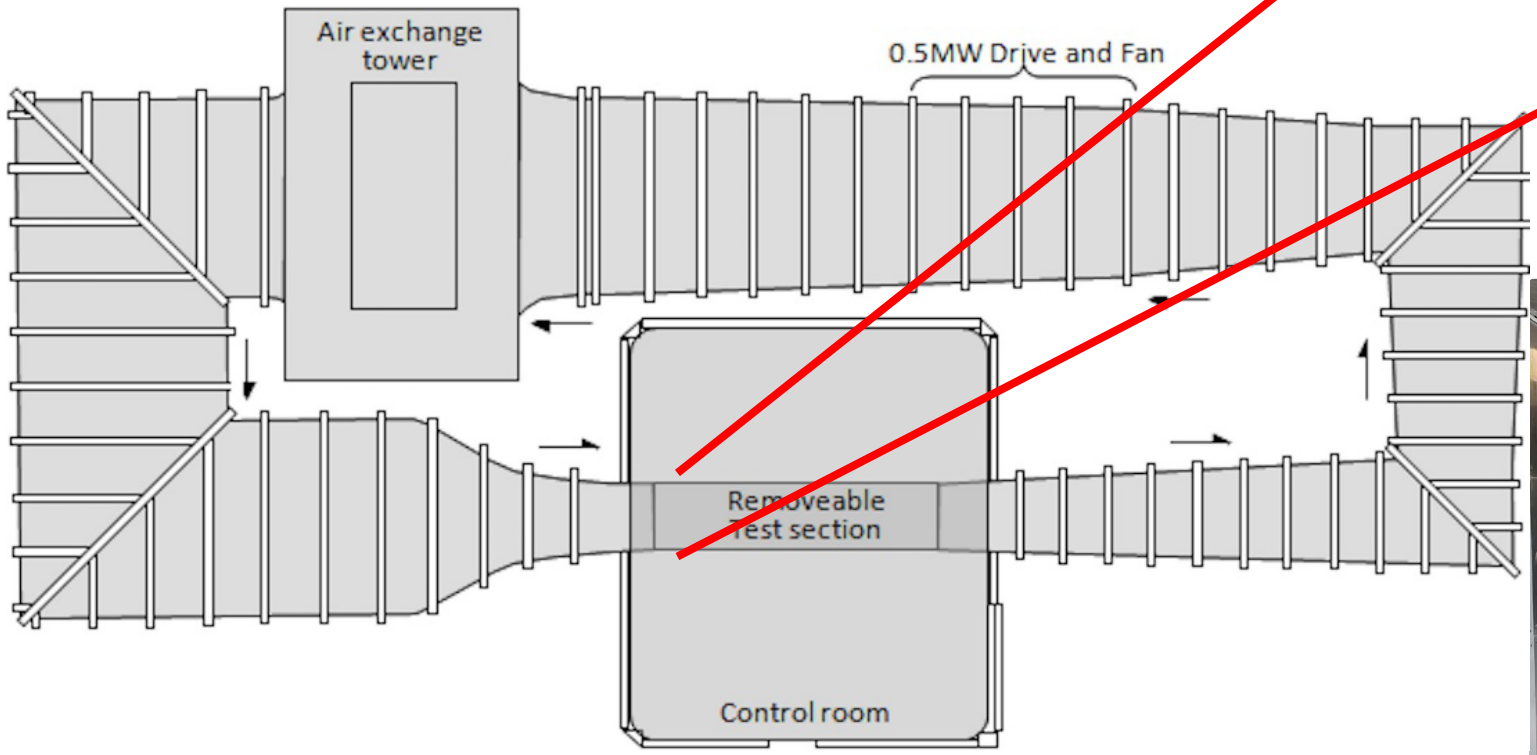
- Goal: find a case that is steady in the mean (unlike 0°) and unique in the mean (unlike 45°): required Re_H=250k case and optional Re_H=650k case
- Initial wind tunnel entry confirmed the 30° yaw meets this goal
- Systematic family of grids available for as-designed geometries
- Grids (and CAD) soon to be available for as-built hill geometry (via scan)
- Detailed boundary conditions with uncertainties available
- Compare: separation zone, C_f, C_p, mean velocities, TKE, Reynolds stresses
- Challenge includes a 2D subsonic bump code verification case**

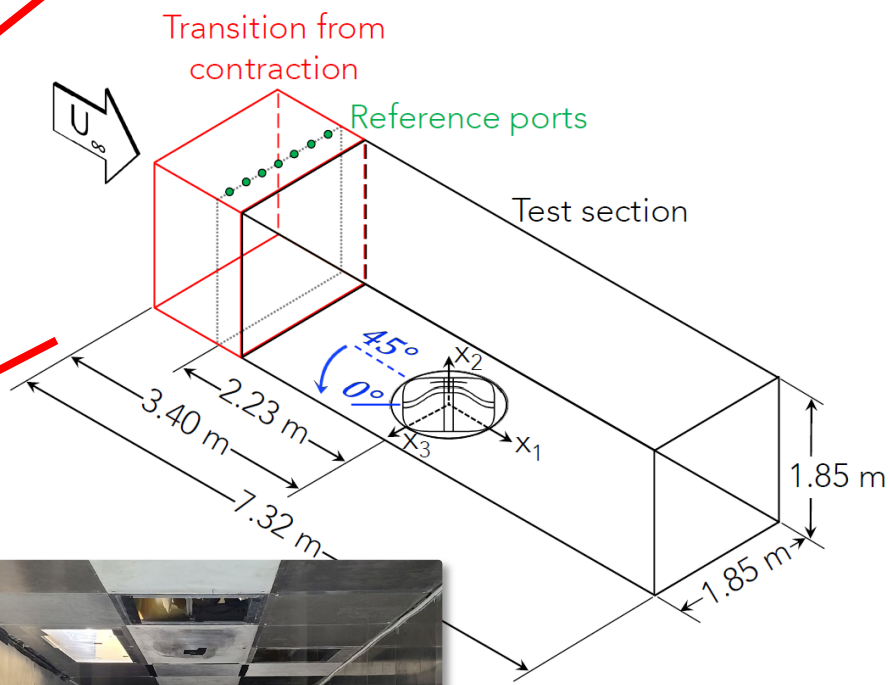
*Challenge web site: https://roy.aoe.vt.edu/vt-nasa-validation-challenge/

**2D code verification case: https://turbmodels.larc.nasa.gov/bump.html

Experimental Facilities

Virginia Tech Stability Wind Tunnel





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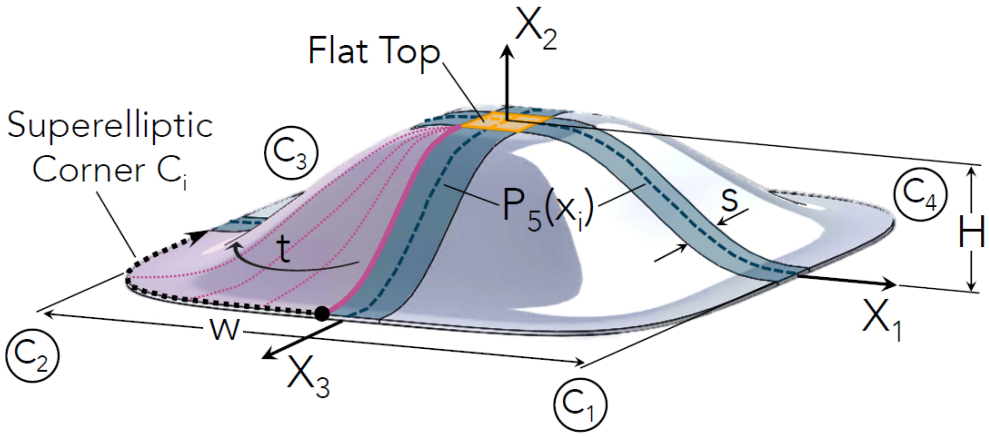
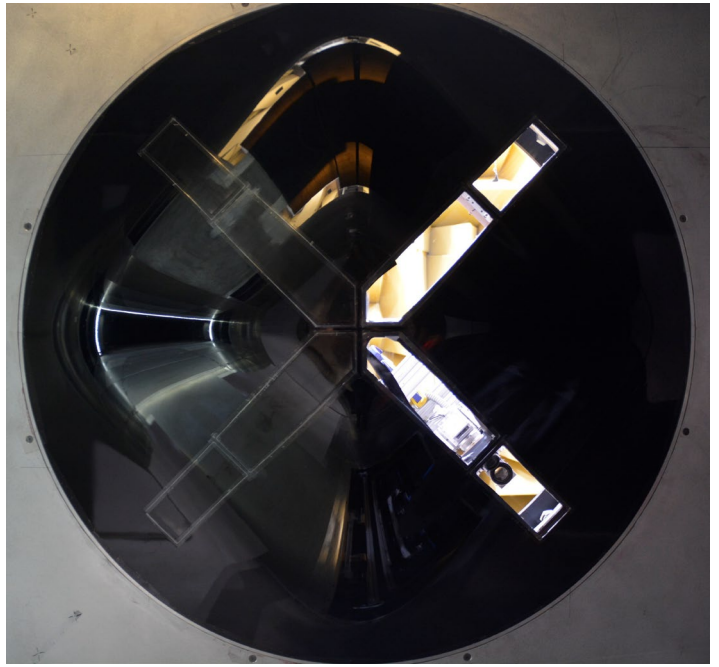
BeVERLI Hill



Analytic Geometry

Pressure Hill



LDV Hill

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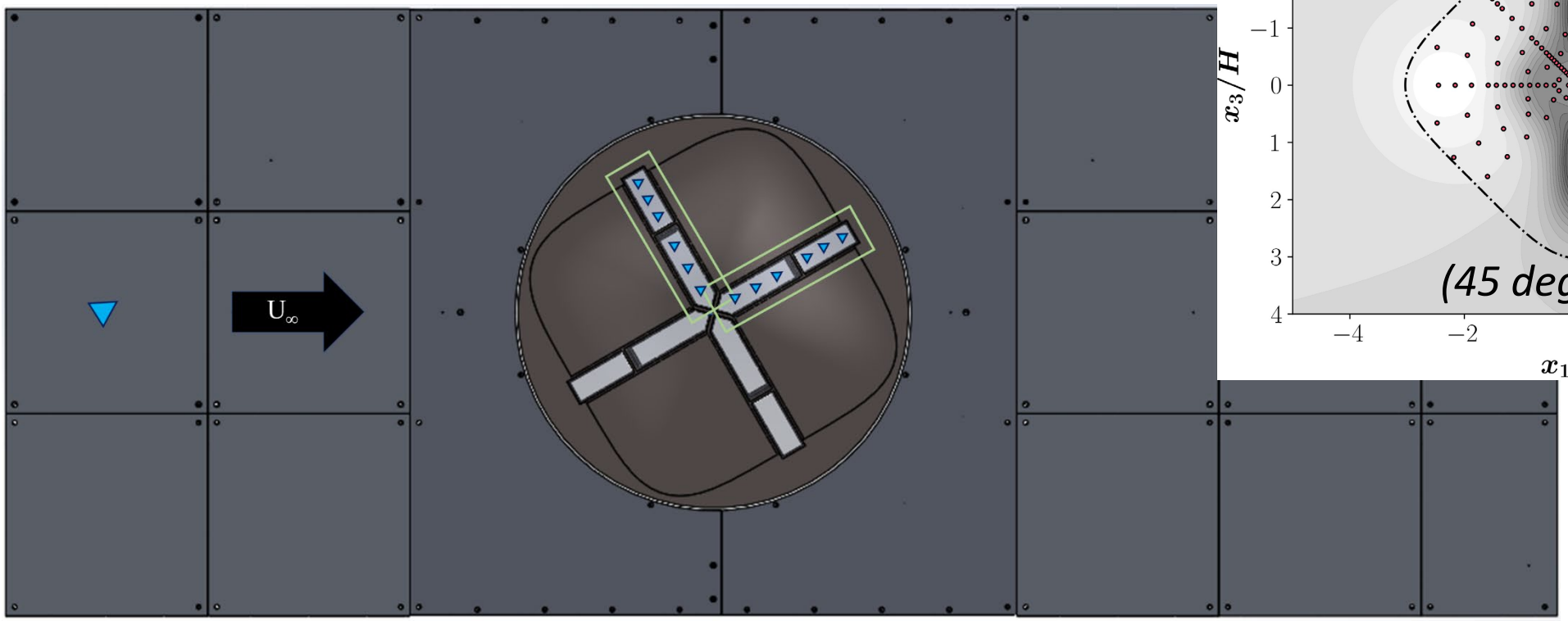
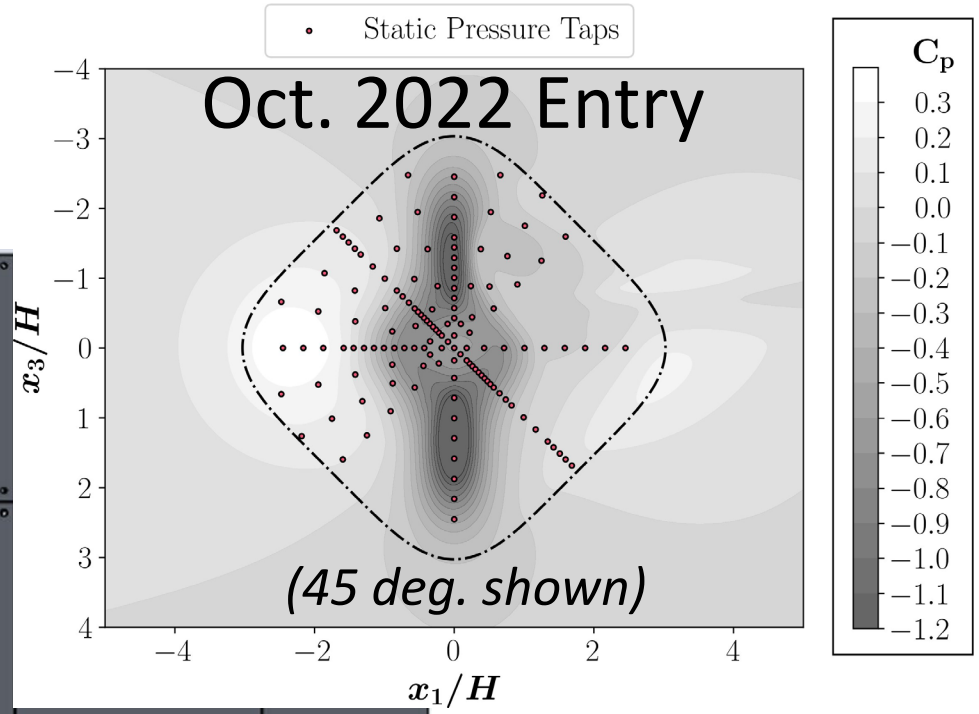
Proposed Experimental Data

Wind tunnel entries in July and Oct. 2023



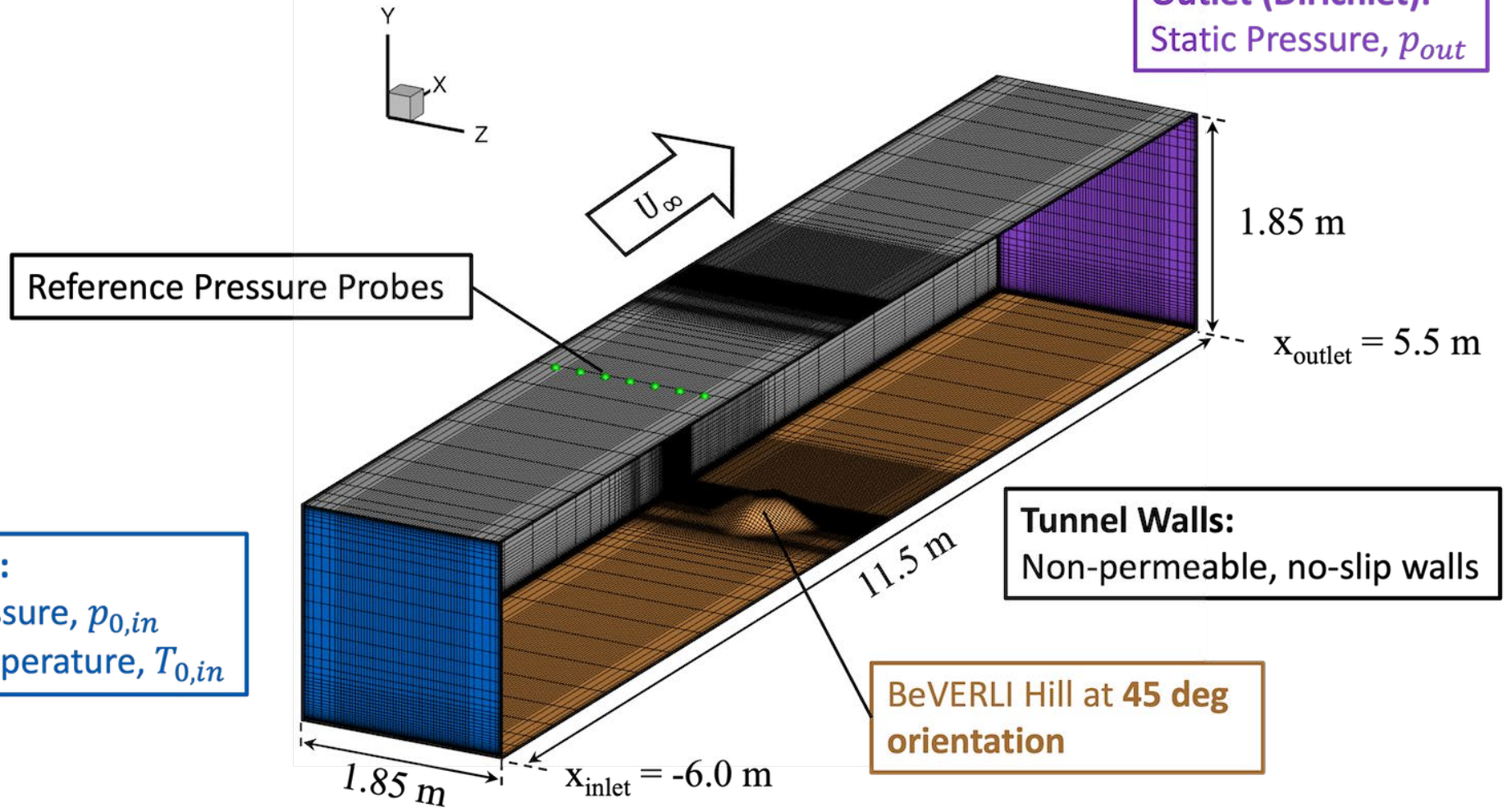


LDV & OFI

PTV Window

Boundary & Reference Conditions 1

Outlet (Dirichlet):
Static Pressure, p_{out}



Inlet (Dirichlet):
Stagnation Pressure, $p_{0,in}$
Stagnation Temperature, $T_{0,in}$

Tunnel Walls:
Non-permeable, no-slip walls

BeVERLI Hill at **45 deg orientation**

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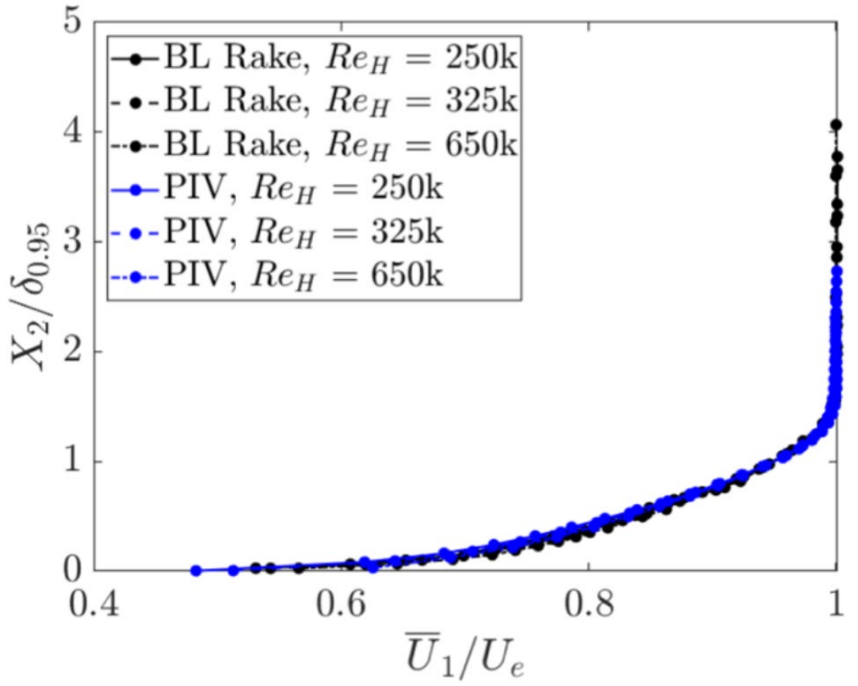
Boundary & Reference Conditions 2

Re_H	250,000	650,000
$P_{0,\text{in}}$ (Pa)	94,220	94,450
$T_{0,\text{in}}$ (K)	297	297
P_{out} (Pa)	93,961	92,692
P_{ref} (Pa)	93,974	92,771
M_{ref} $(-)$	0.06	0.16
U_{ref} (m/s)	21.11	55.22
ρ_{ref} (kg/m^3)	1.103	1.093
I_{in} (%)	0.021	0.030
$(\mu_t/\mu)_{\text{in}}$ $(-)$	1.5	3
k_{in} (m^2/s^2)	2.9e-5	4.0e-4
ω_{in} (s^{-1})	1.17	8.12
$\tilde{\nu}_{\text{in}}$ (m^2/s)	4.5e-5	9.2e-5

Profile is at $(x_1, x_2, x_3) = (-1.93\text{ m}, 0, 0)$

Re_H	250,000	650,000
$\delta_{0.95}$ (mm)	43.0 ± 1.5	38.5 ± 1.3
δ^* (mm)	8.3 ± 0.2	6.8 ± 0.2
θ (mm)	6.1 ± 0.2	5.2 ± 0.2



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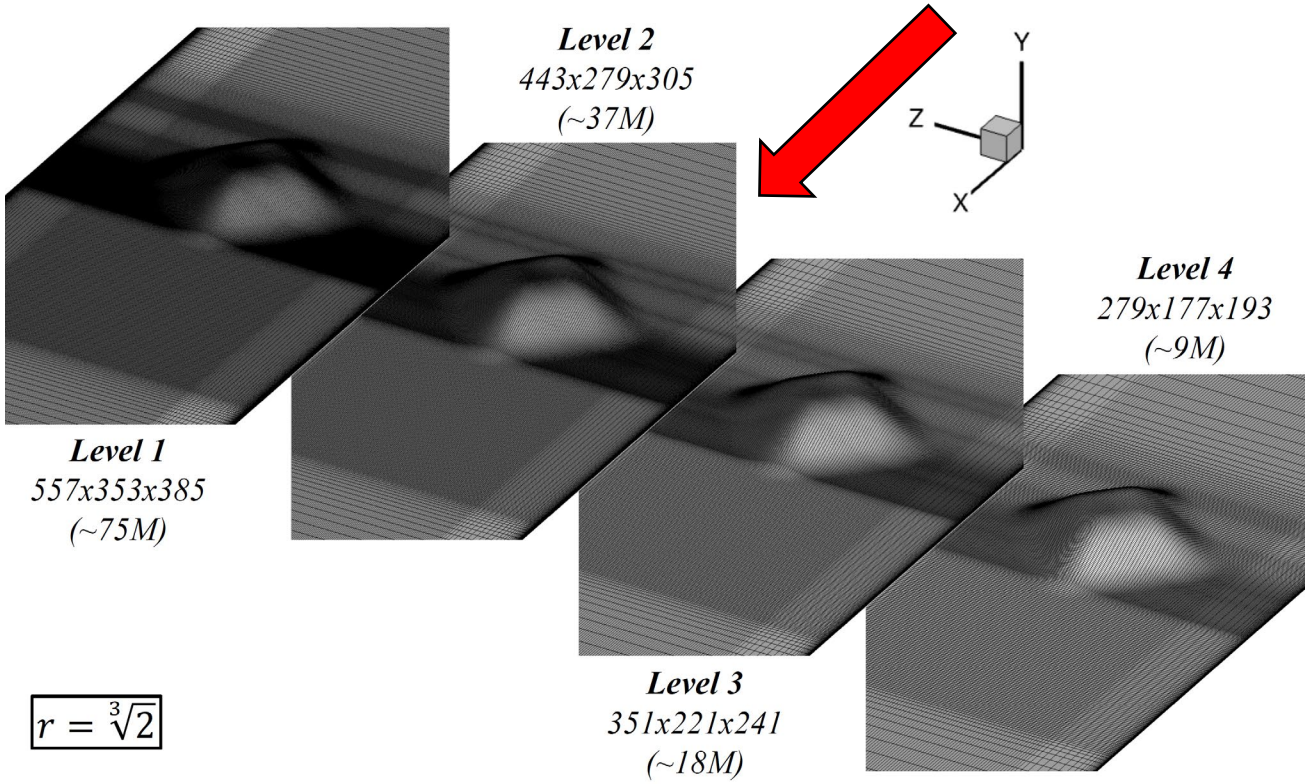
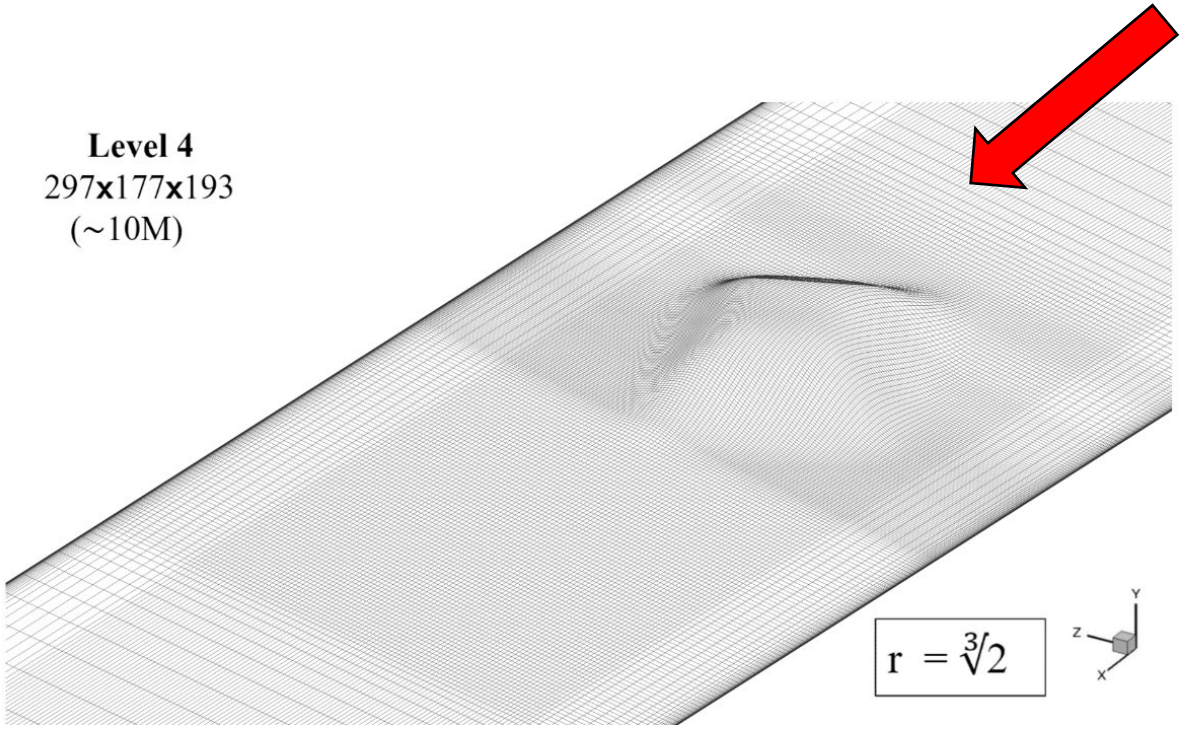
Family of Systematically-Refined Grids



45 Deg.



30 Deg.

As-Designed Grids

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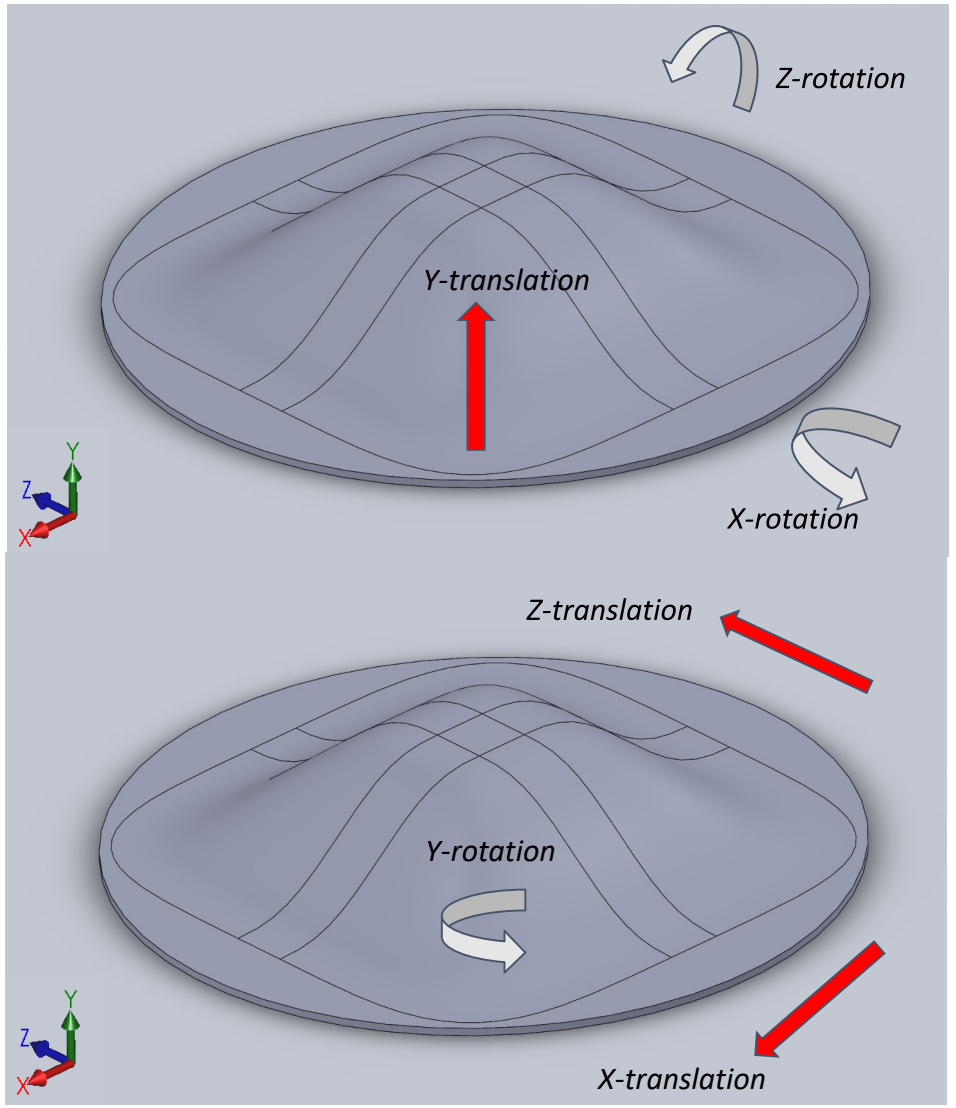
As-Built Hill Geometry

1. Rough adjustment of scanned Hill point cloud to model location in ideal tunnel
2. Hill translated in y and rotated about x and z to minimize L2 norm height (y) between outer flat region of scan points and idealized tunnel wall plane
3. Hill translated in x and z and rotated about y to minimize L2 norm height (y) between Hill scan points and as-designed Hill CAD
4. Hill will be rotated to the 300 deg. orientation (nominal 30 deg.), geometry files created (CAD and IGES), grid family created, and CFD run to ensure smoothness



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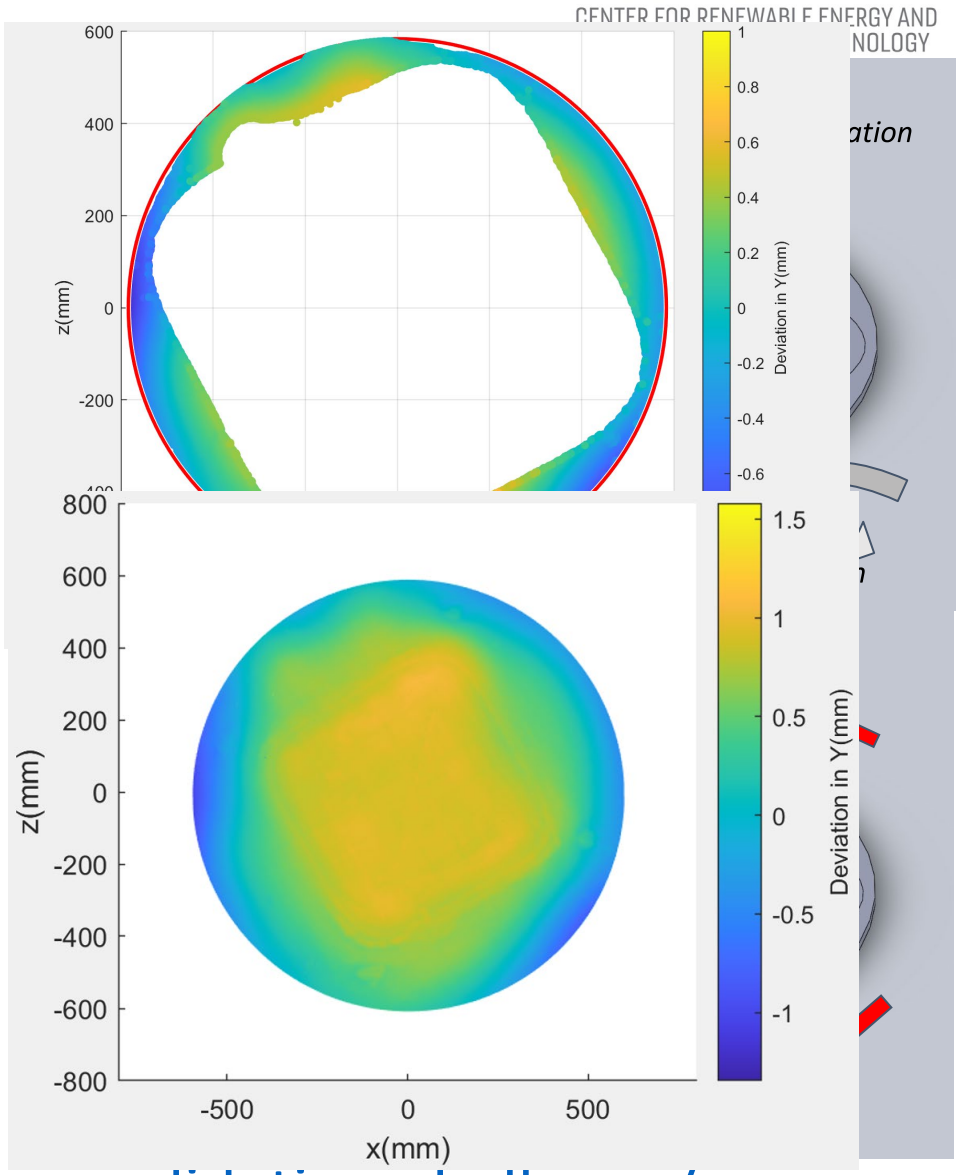

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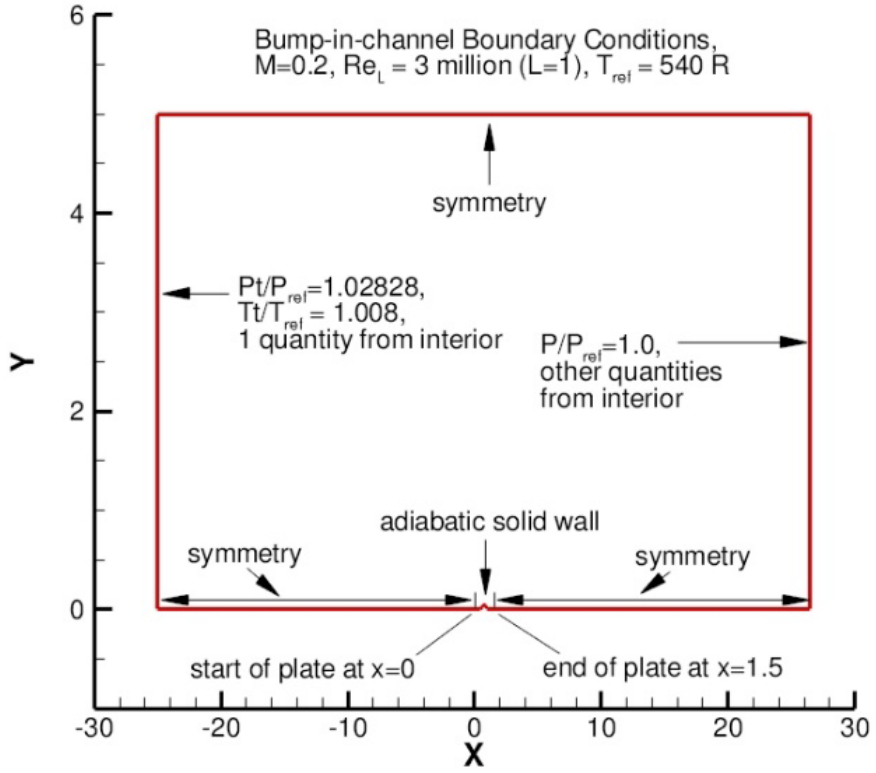
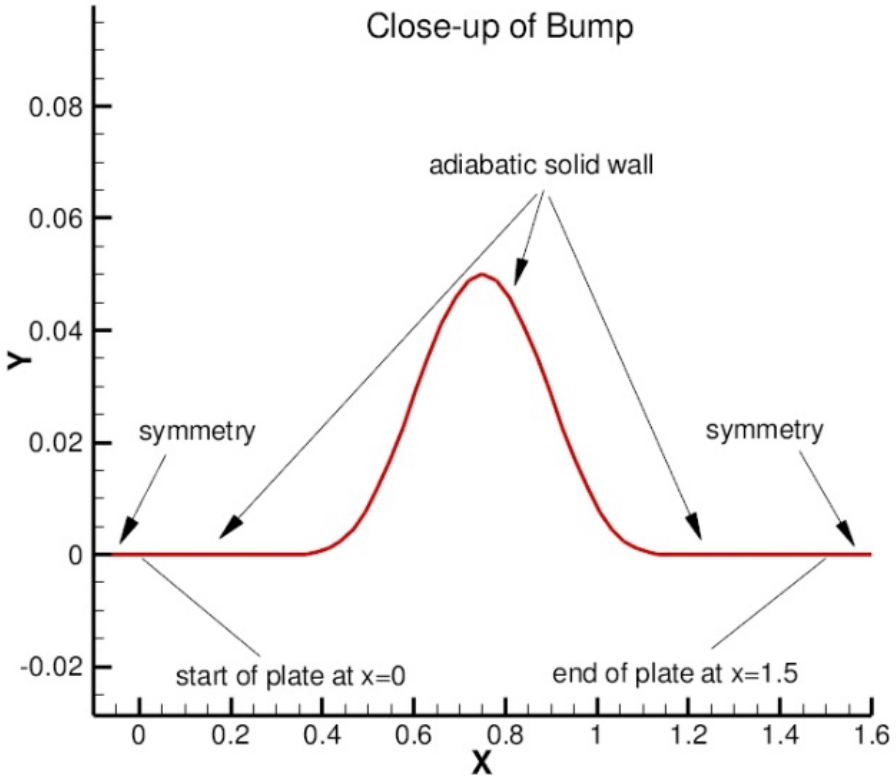
Code Verification Case*

2D Turbulent Bump-In-Channel





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*2D code verification case: https://turbmodels.larc.nasa.gov/bump.html

Challenge Case Information

- Specific data submission formats will be provided by October 2023 (after the final wind tunnel entry)
- Two hill height-based Reynolds numbers are required: Re_H = 250,000 and 650,000
- Results with two turbulence models are strongly recommended: the standard Spalart-Allmaras one-equation model and the Menter k-ω SST two-equation model
- Results for other turbulence models are also encouraged, especially nonlinear models (e.g., QCR)
- Results on at least three systematically-refined grids are required
- Relative iterative convergence levels must be reported for each governing equation
- Parties interested in participating in the challenge and/or the special session at the 2024 AIAA Aviation meeting should email Dr. Chris Roy: cjroy@vt.edu

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Timeline

- 2022 Oct. Wind tunnel entry #1: surface pressure, BL rake, & surface oil flow viz (done)
- 2023 Jan. AIAA SciTech: announcement of blind validation challenge; as-designed geometries, grids, BCs available; challenge web site available (done)
- 2023 June AIAA Aviation: AIAA Paper on validation challenge; as-built geometry/grids available
- 2023 July Wind tunnel entry #2: inflow LDV, windward PIV/PTV, and OFI
- 2023 Oct. Wind tunnel entry #3: hill LDV, wake PIV/PTV, & any additional measurements
- 2023 Nov. Abstracts submitted by contributors to AIAA Aviation 2024 special session
- 2024 April Deadline for contributors to submit data for blind validation challenge
- 2024 June AIAA Aviation: special session w/ papers by contributors, experimental data paper, & summary paper; data released to public after conference
- 2024 Sept. Invite papers for a special journal issue

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Acknowledgements

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If You Are Interested in Participating…

PLEASE send me an email at cjroy@vt.edu

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Challenge QR Code