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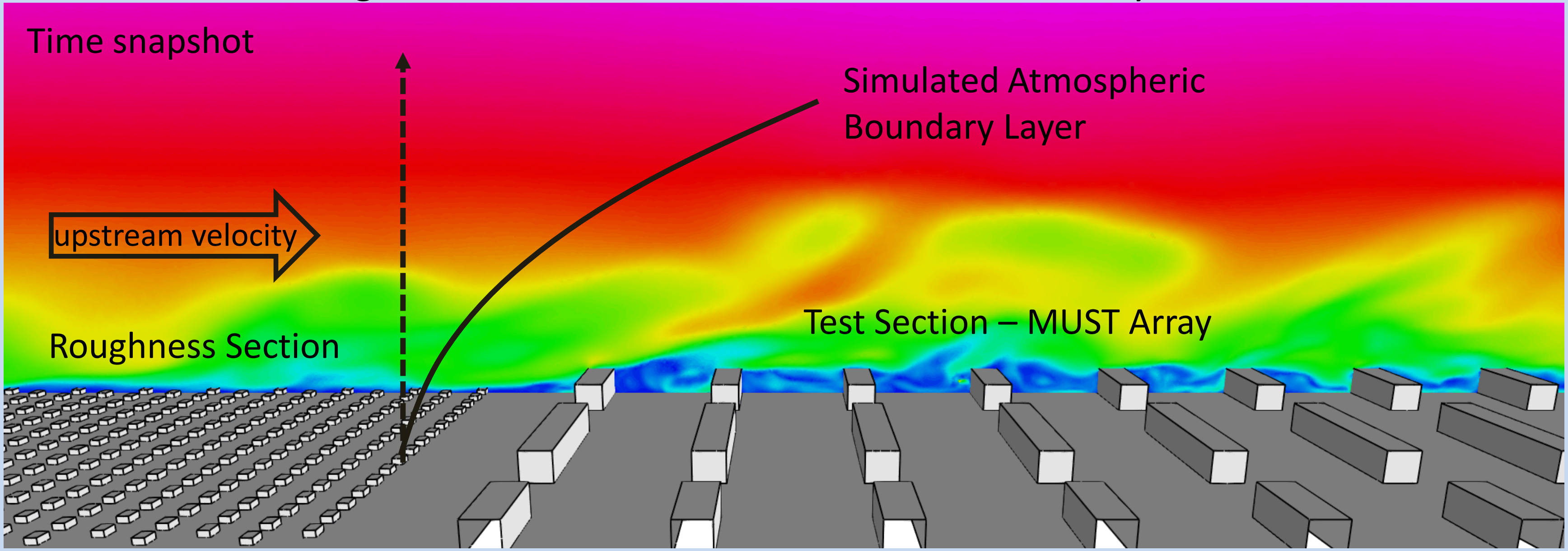
# Capturing Upstream Turbulence Information by Modeling the Turbulent Generation Region and Comparison of 0$^o$ and 30$^o$ Flow and Dispersion CFD Modeling and Macdonald's MUST Experiment

John P. Keady[1], Pablo Huq[2], W.G.K. Bradbury[1], P.E. Price[1] and Fernando E. Camelli[1]

[1]SPACS, Center for Computational Fluid Dynamics, George Mason University
[2]College of Earth, Ocean & Environment, University of Delaware



## Objectives:

•Simulate the Laboratory MUST Experiment

•More accurately model pre-test section turbulent structure of velocity flow by modeling the roughness section of the experimental tunnel

•Comparison of Simulation and Experimental parameters

Parameters Examined:

Velocity in x and z-direction

Turbulent Kinetic Energy

Normalized Temperature profile of injected plume

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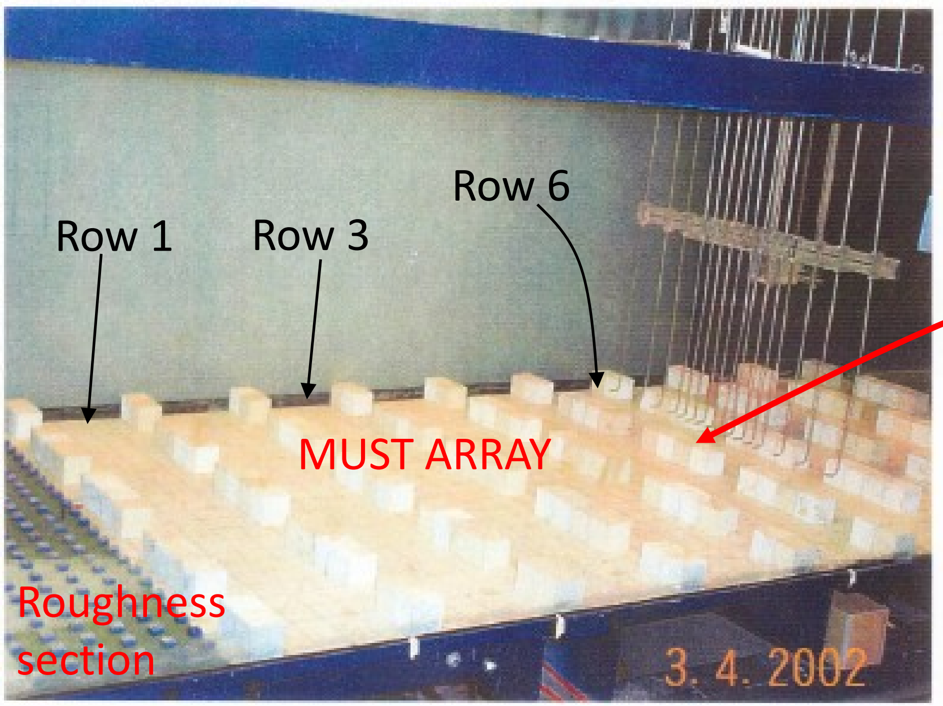
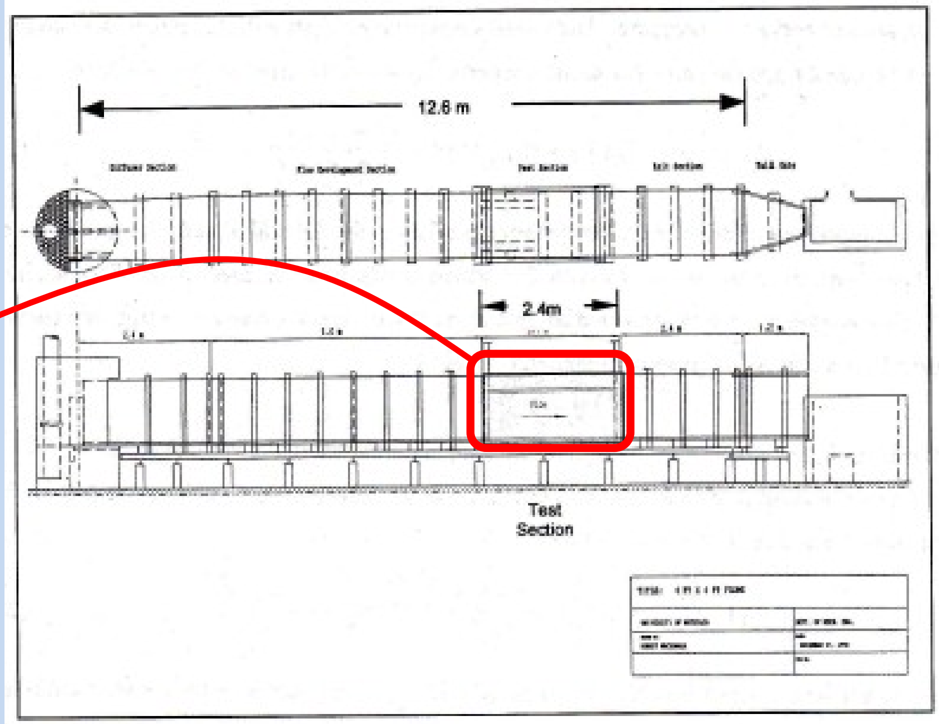
# Macdonald Lab MUST Experiment

**( 2002/2003)**
**( 0 and 30 degree angle)**

The MUST test array consisted of 50-mm high obstacles with a 4:1 (width-to-height) aspect ratio and had a packing density of 13.3% in a 12.8-m long hydraulic flume at the University of Waterloo, which has a 1.2-m x 1.2-m x 2.4-m long test section enclosed in tempered glass.

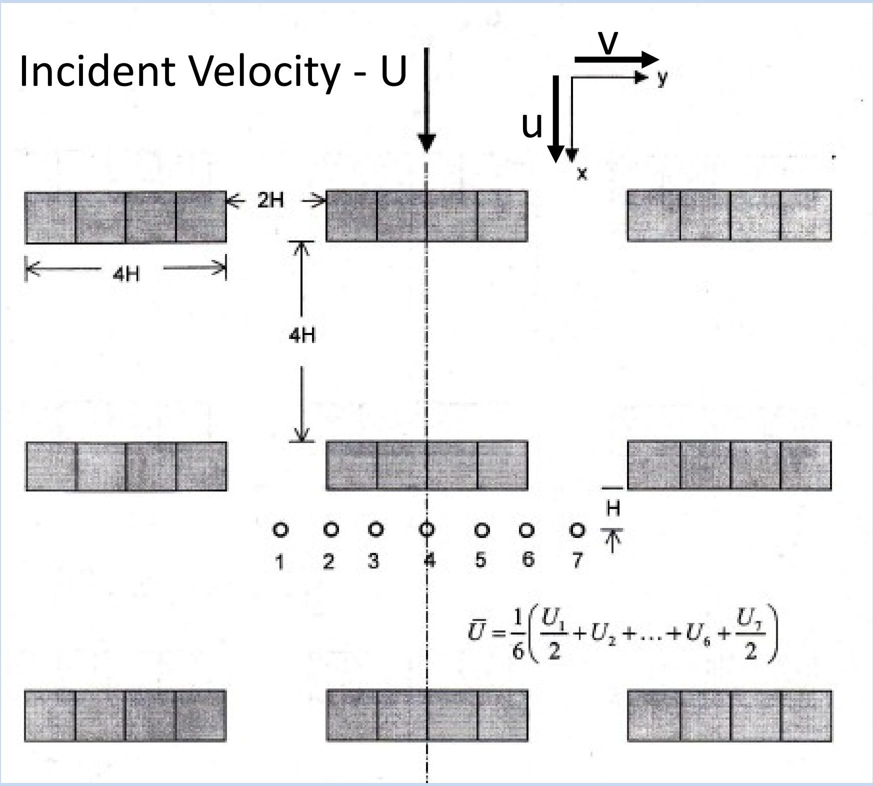


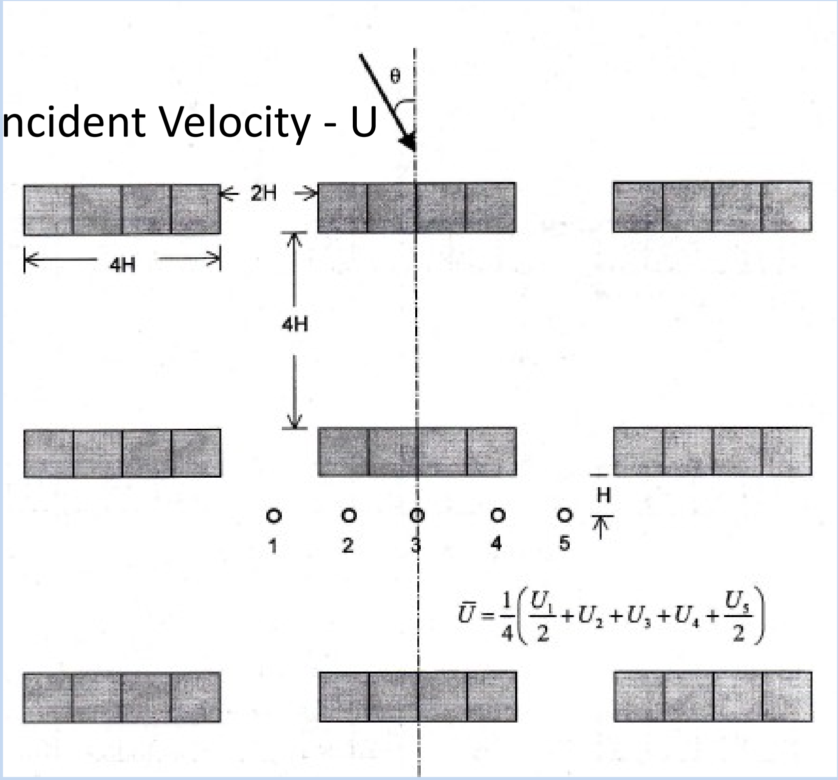



# Macdonald Lab MUST Experiment

**( 2002/2003)**

**( 0 and 30 degree angle)**




The experiment measured the flow characteristics of three incident angles 0, 30 and 45 degrees, where experimentally the velocity vector was kept constant and the array rotated.

Simulations were performed for two angles 0 and 30 degrees.

# Macdonald Lab MUST Experiment

## ( Flume Injection – Temperature Measurement)

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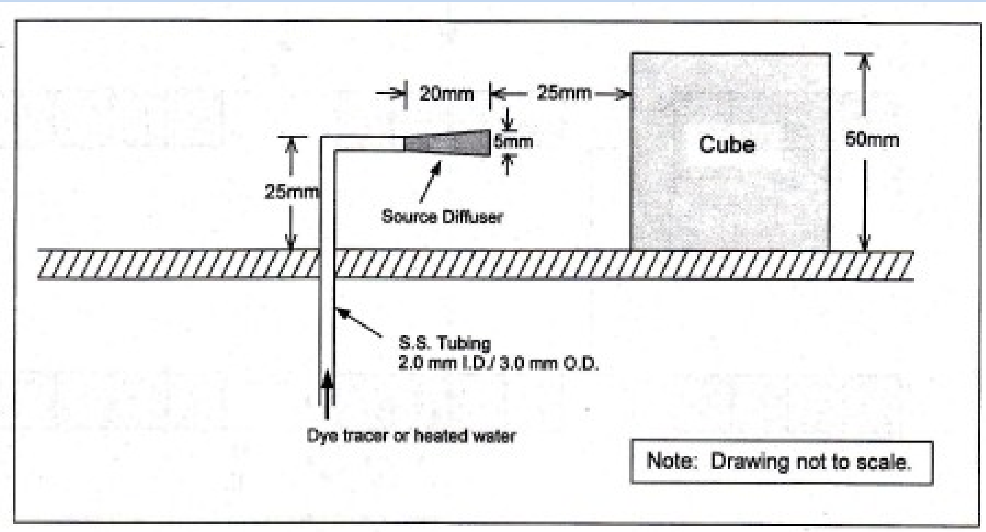


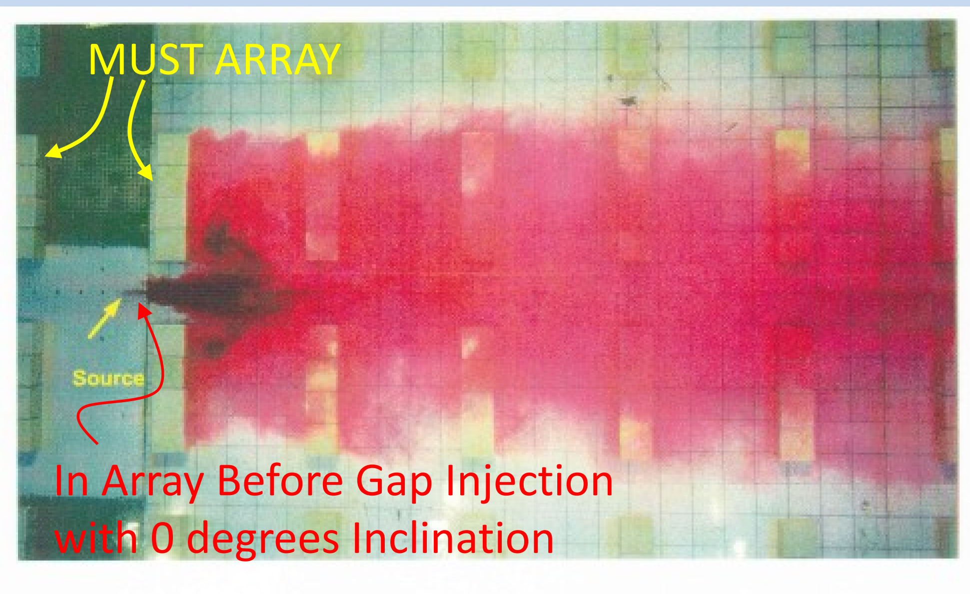

Flume injections were compared for two experimental cases of flue injection:

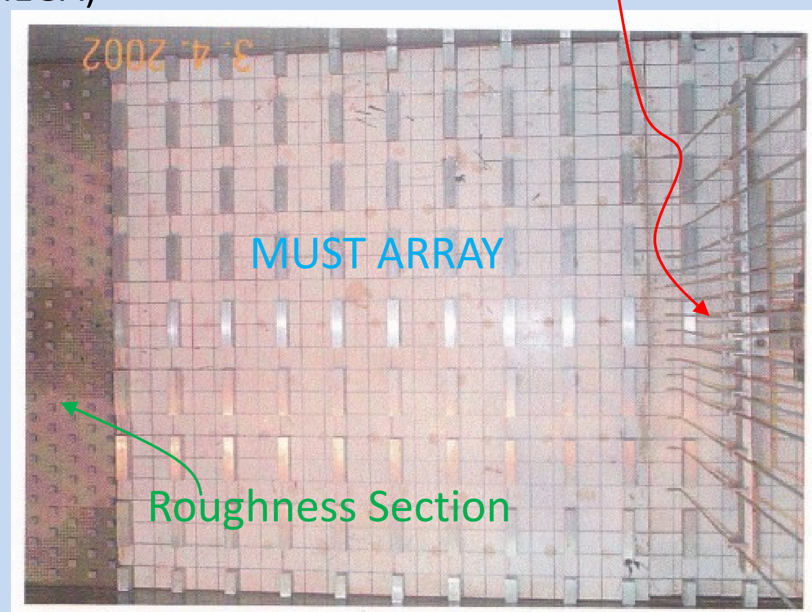
**In Array Before Gap – IABG**

**In Array Before Object - IABO**

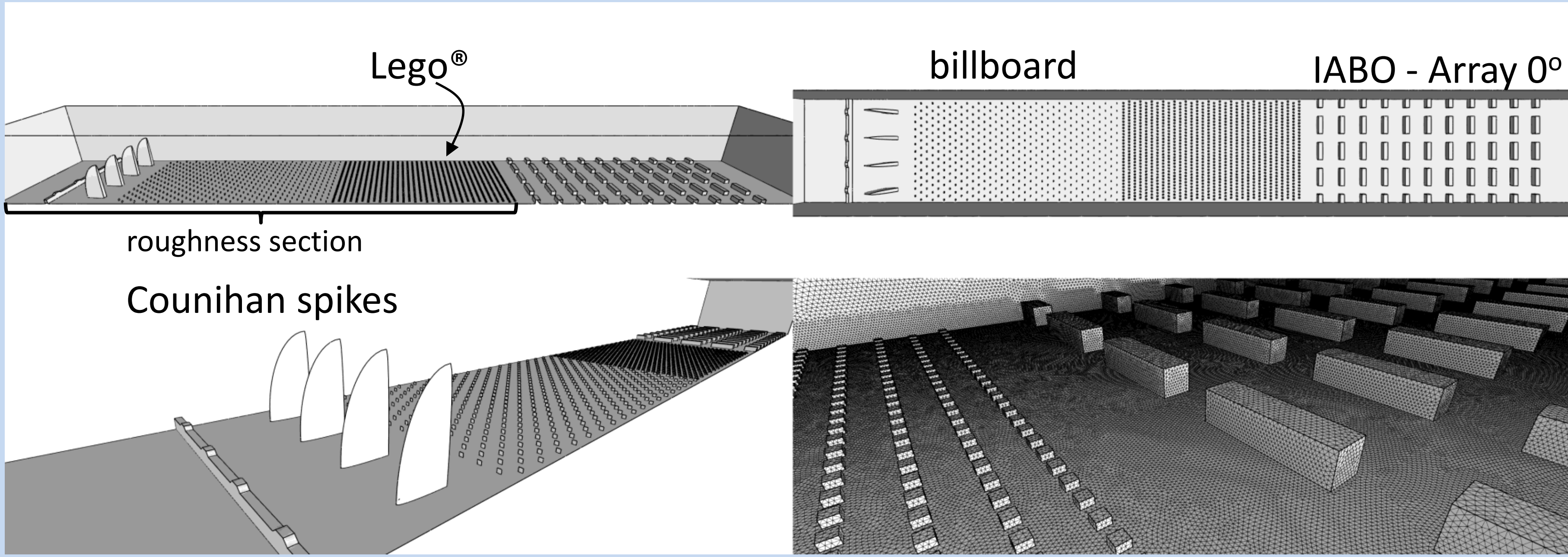
Temperature Measurements

The Plume Injection Temperature was 65°C while the ambient fluid before injection was 20°C. Temperature was measured using Resistance Temperature Detectors (RTD) (a thin film platinum detector type manufactured by OMEGA)



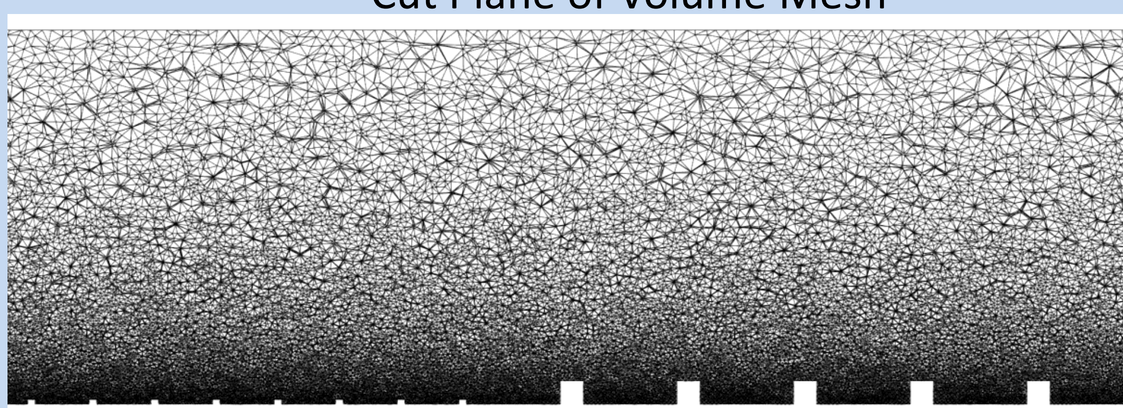
# CFD Geometry Representation – IABO




Surface Mesh

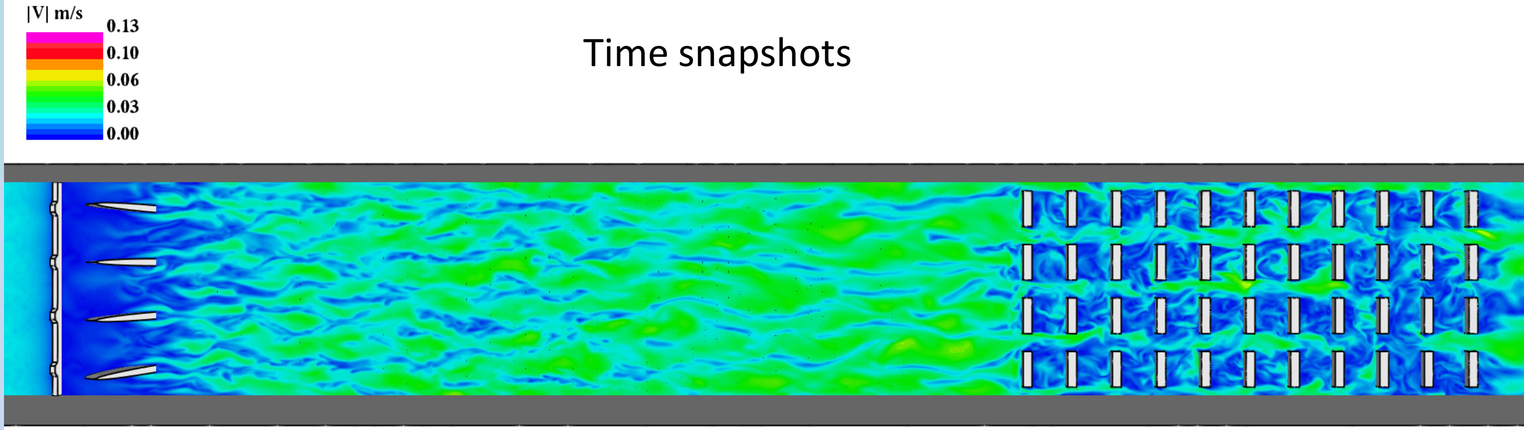
- Mesh: 39 Million tetrahedra
- Counihan spikes
- Short barrier wall
- Billboard
- Lego®

Cut Plane of Volume Mesh

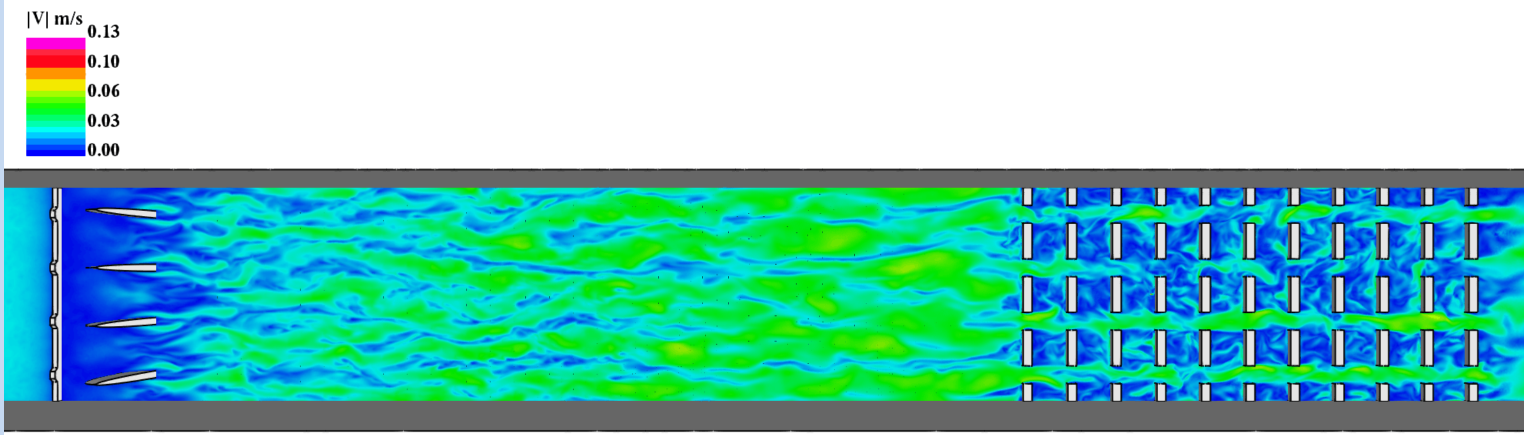


# Time snapshots

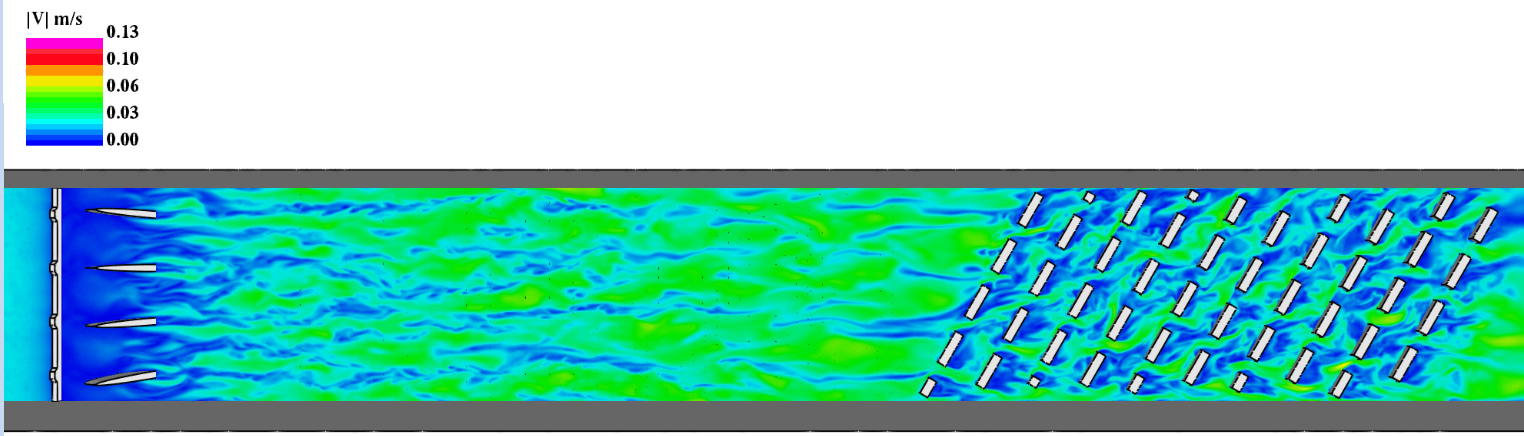
0 deg - IABG Simulation

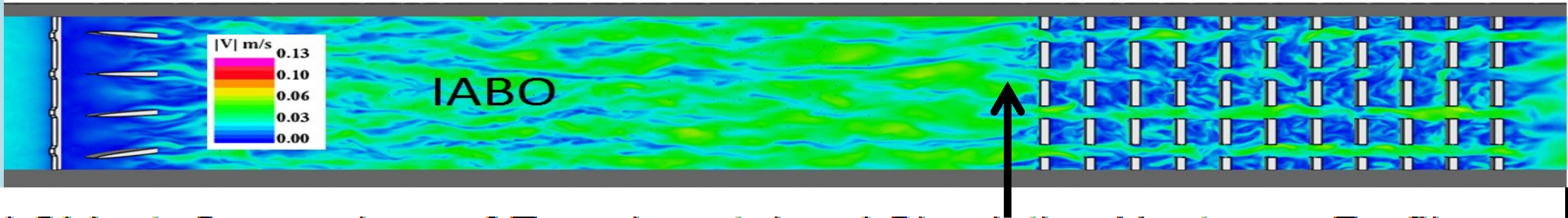



0deg - IABO Simulation

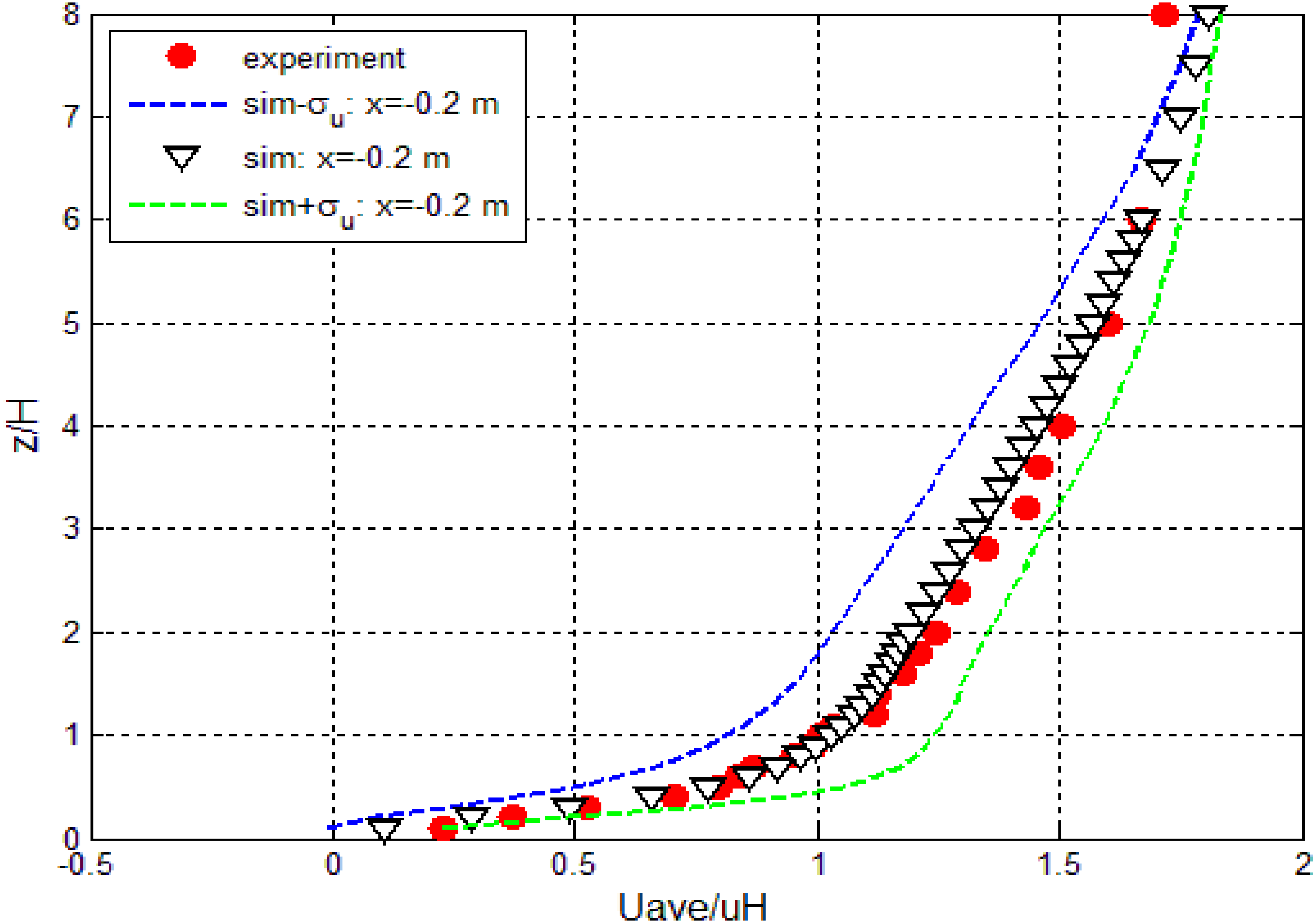



30deg - IABO Simulation






## Behind Object: Comparison of Experimental and Simulation Upstream Profiles



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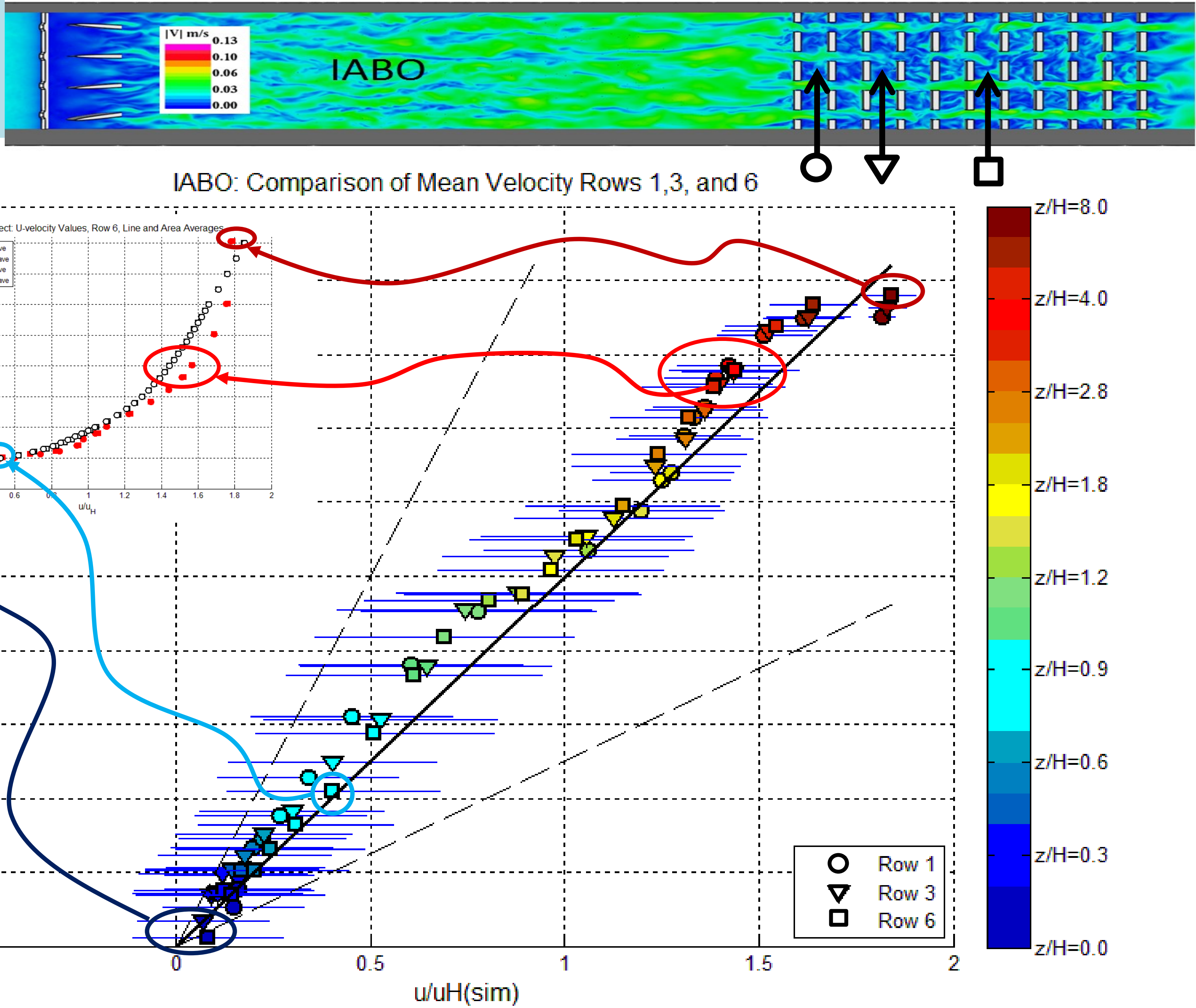
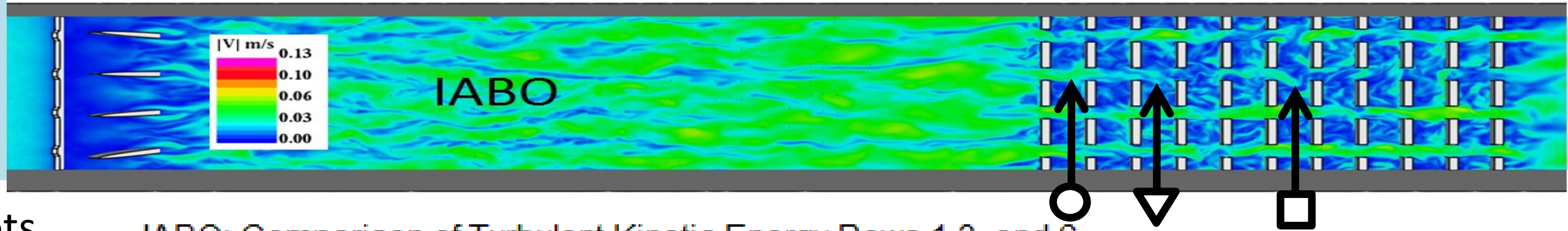
# u -velocity and Turbulent Kinetic Energy Comparison
# IABO – 0 Degrees

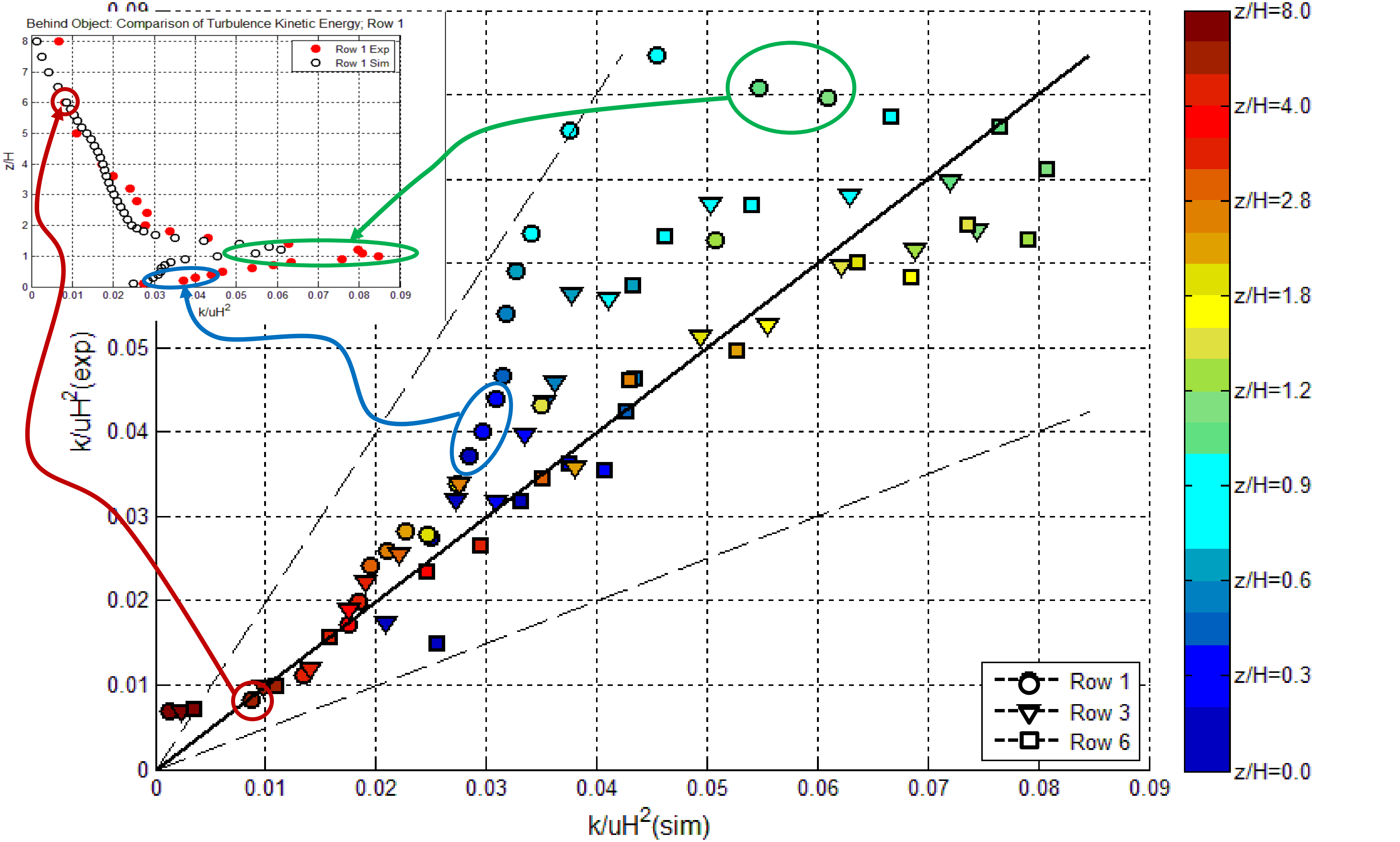


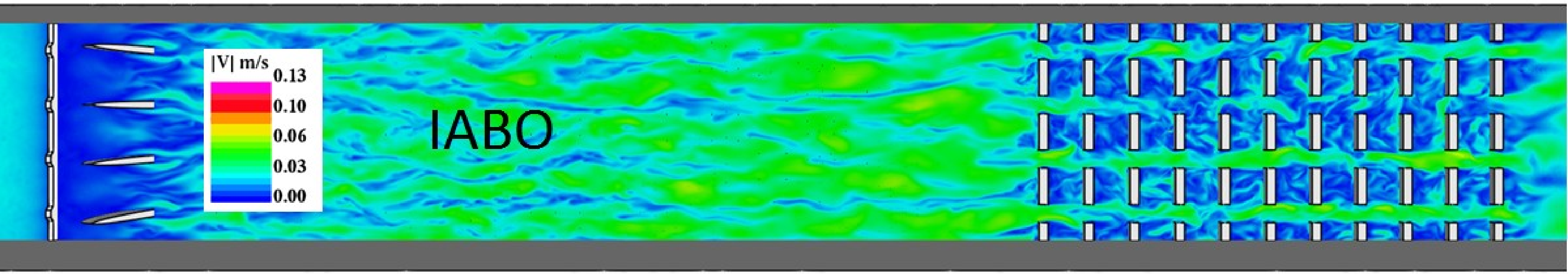
|V| m/s
0.13
0.10
0.06
0.03
0.00
IABO
IABO: Comparison of Mean Velocity Rows 1,3, and 6
Behind Object: U-velocity Values, Row 6, Line and Area Averages
Row 6 Exp line ave
Row 6 Exp area ave
Row 6 Sim line ave
Row 6 Sim area ave
z/H
u/u_H
u/uH(exp)
u/uH(sim)
Row 1
Row 3
Row 6
z/H=8.0
z/H=4.0
z/H=2.8
z/H=1.8
z/H=1.2
z/H=0.9
z/H=0.6
z/H=0.3
z/H=0.0

# Summary Plots

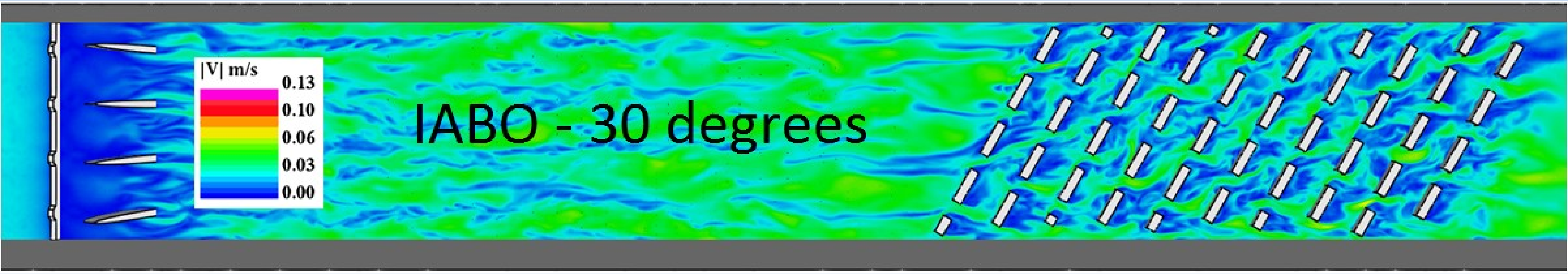


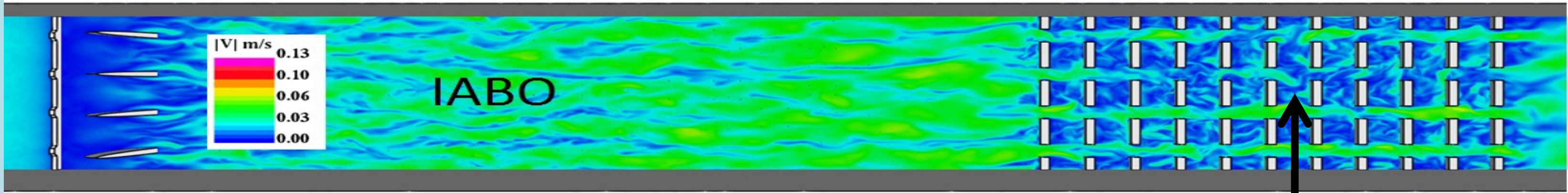

IABO: Comparison of Turbulent Kinetic Energy Rows 1,3, and 6



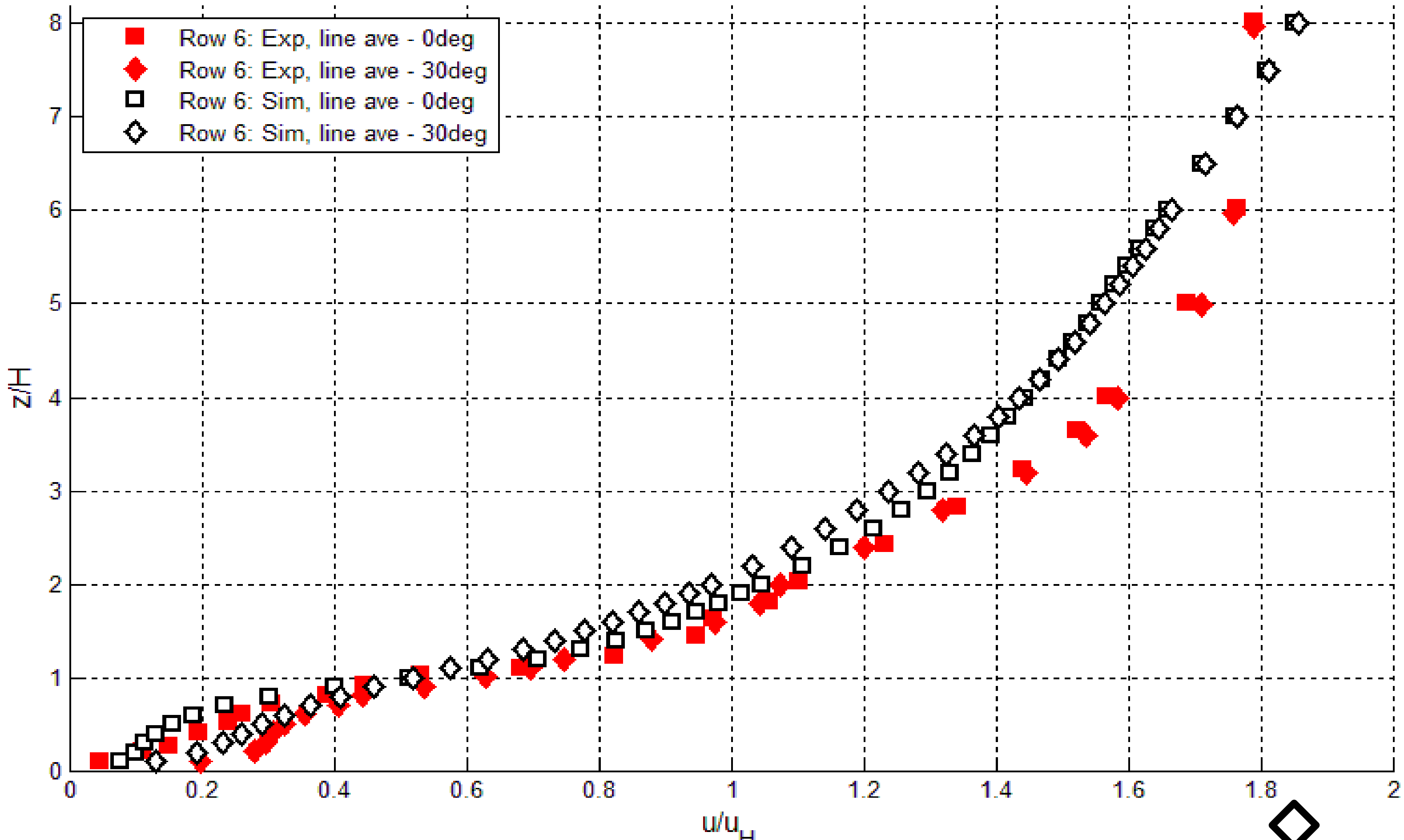


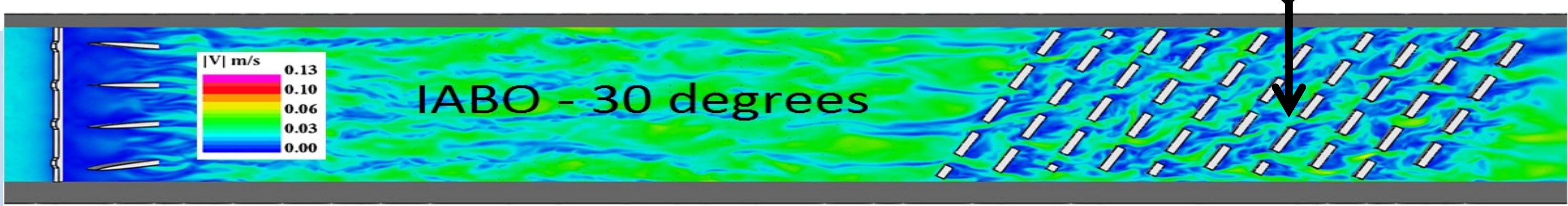

# u and v-velocity and Turbulent Kinetic Energy
# 0 and 30 degrees
# IABO – In Array Before Object
## Row 6 Value Comparisons






IABO: U-velocity Values, Row 6, Line Averages, 0 and 30 degrees

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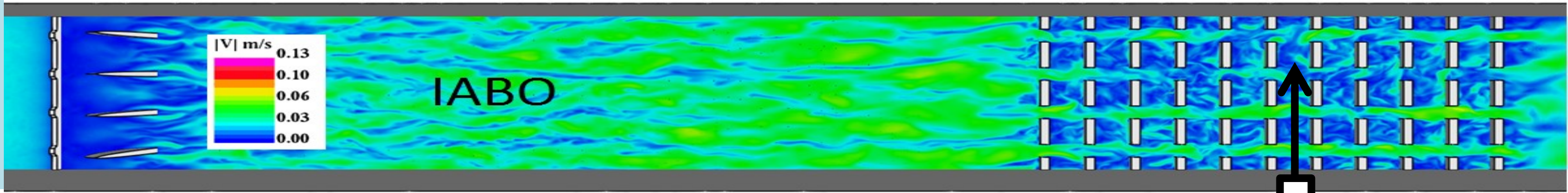
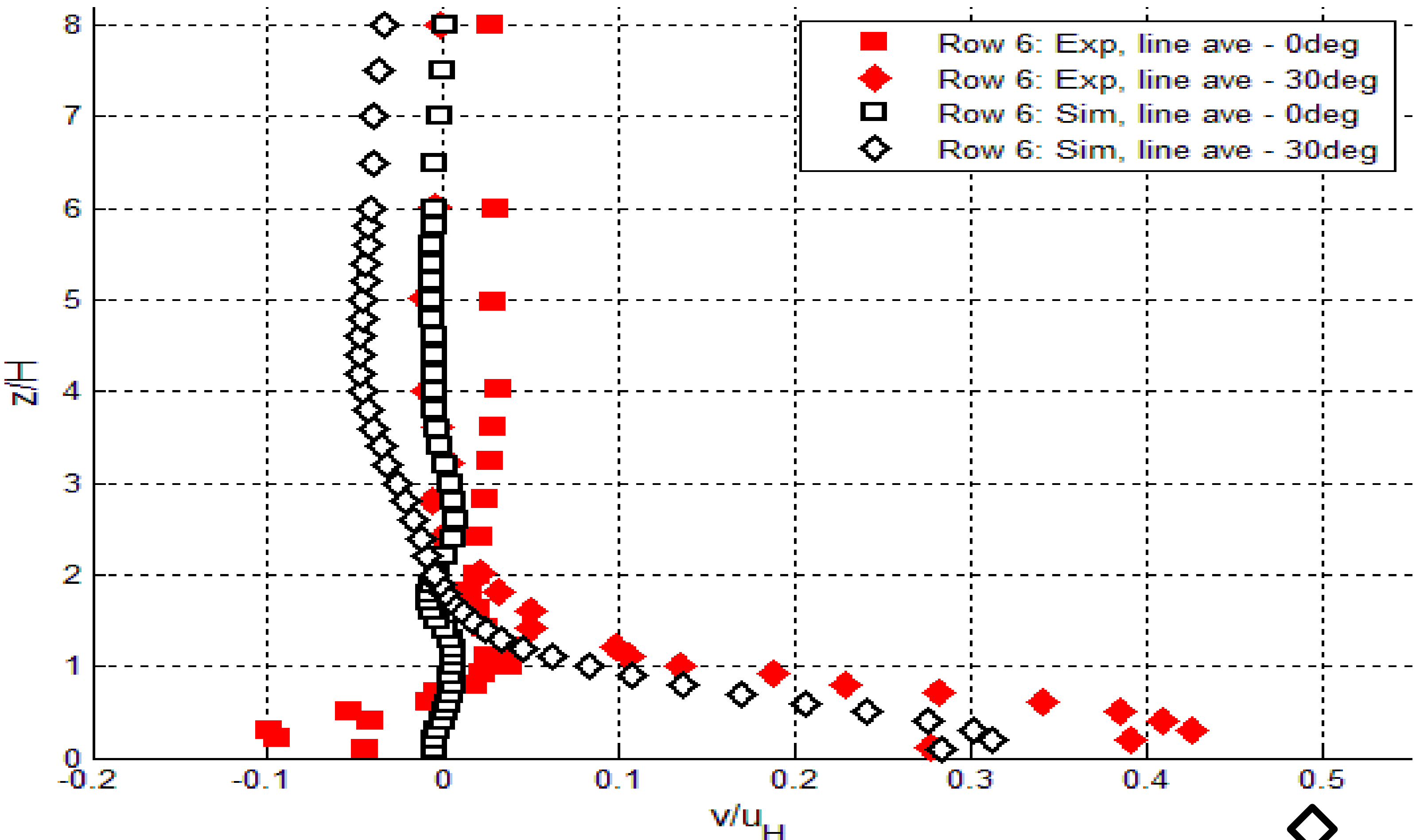
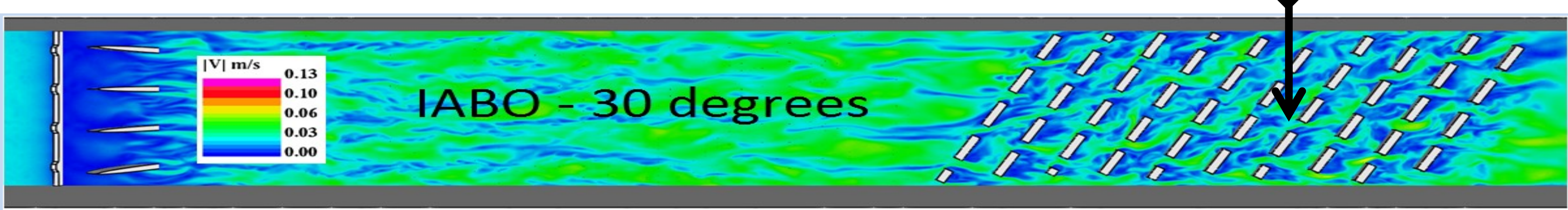



IABO: V-velocity Values, Row 6, Line Averages, 0 and 30 degrees

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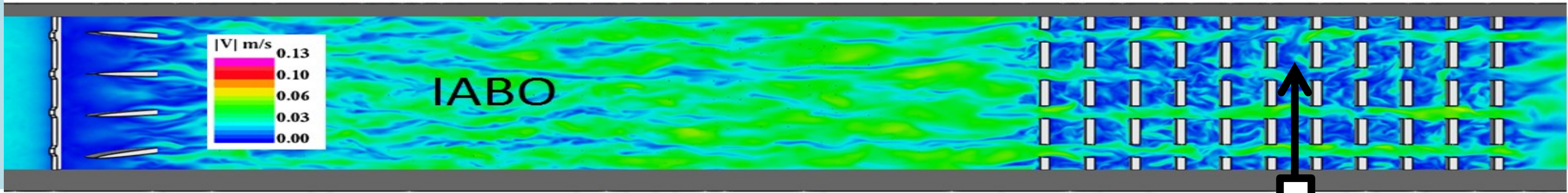
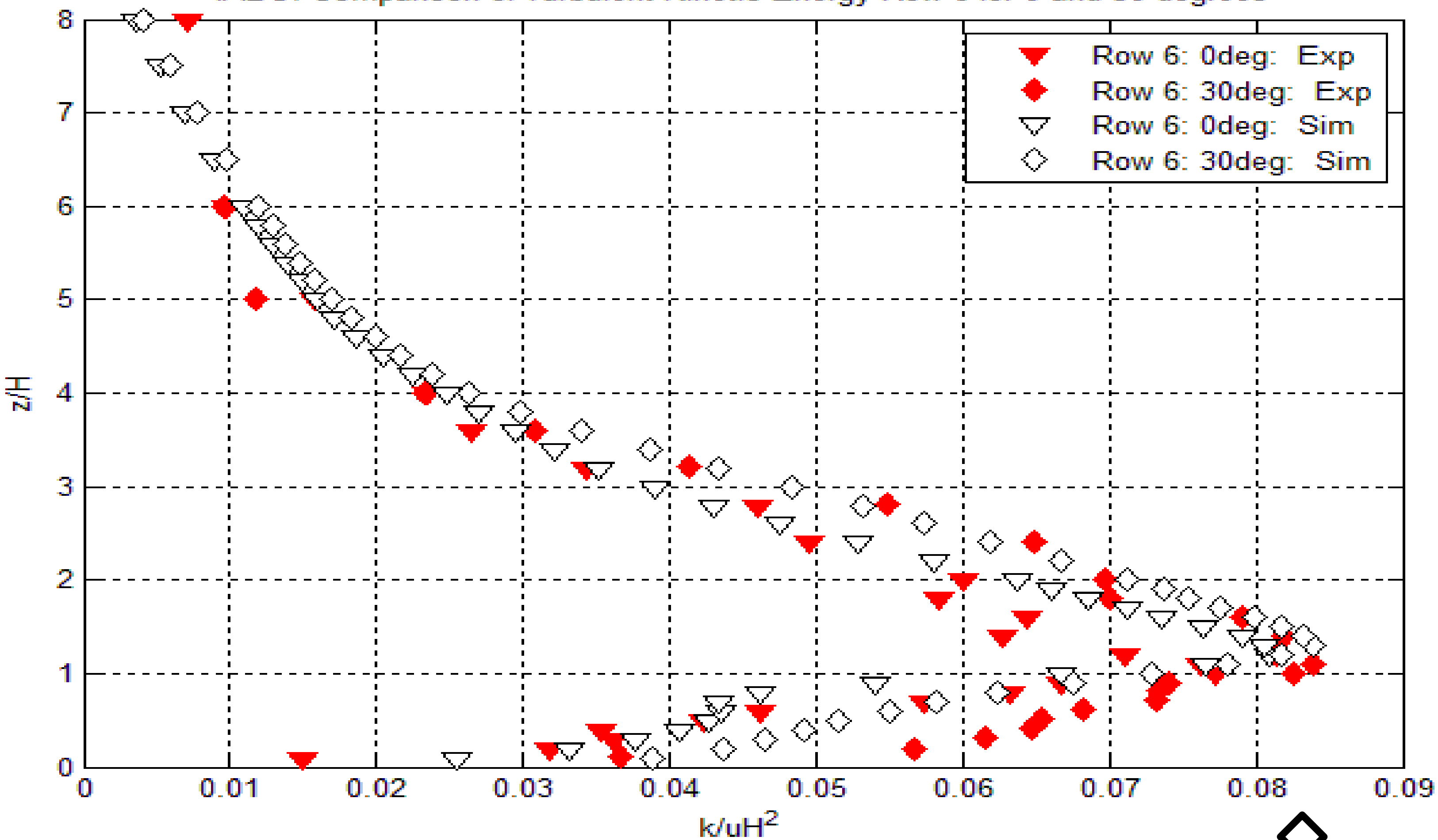
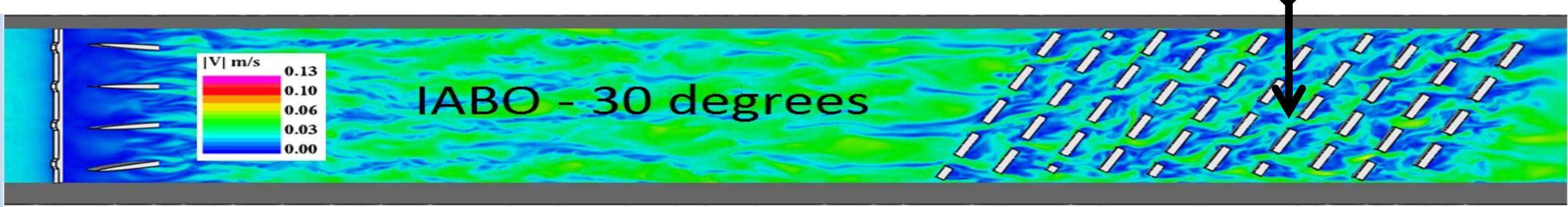



IABO: Comparison of Turbulent Kinetic Energy Row 6 for 0 and 30 degrees

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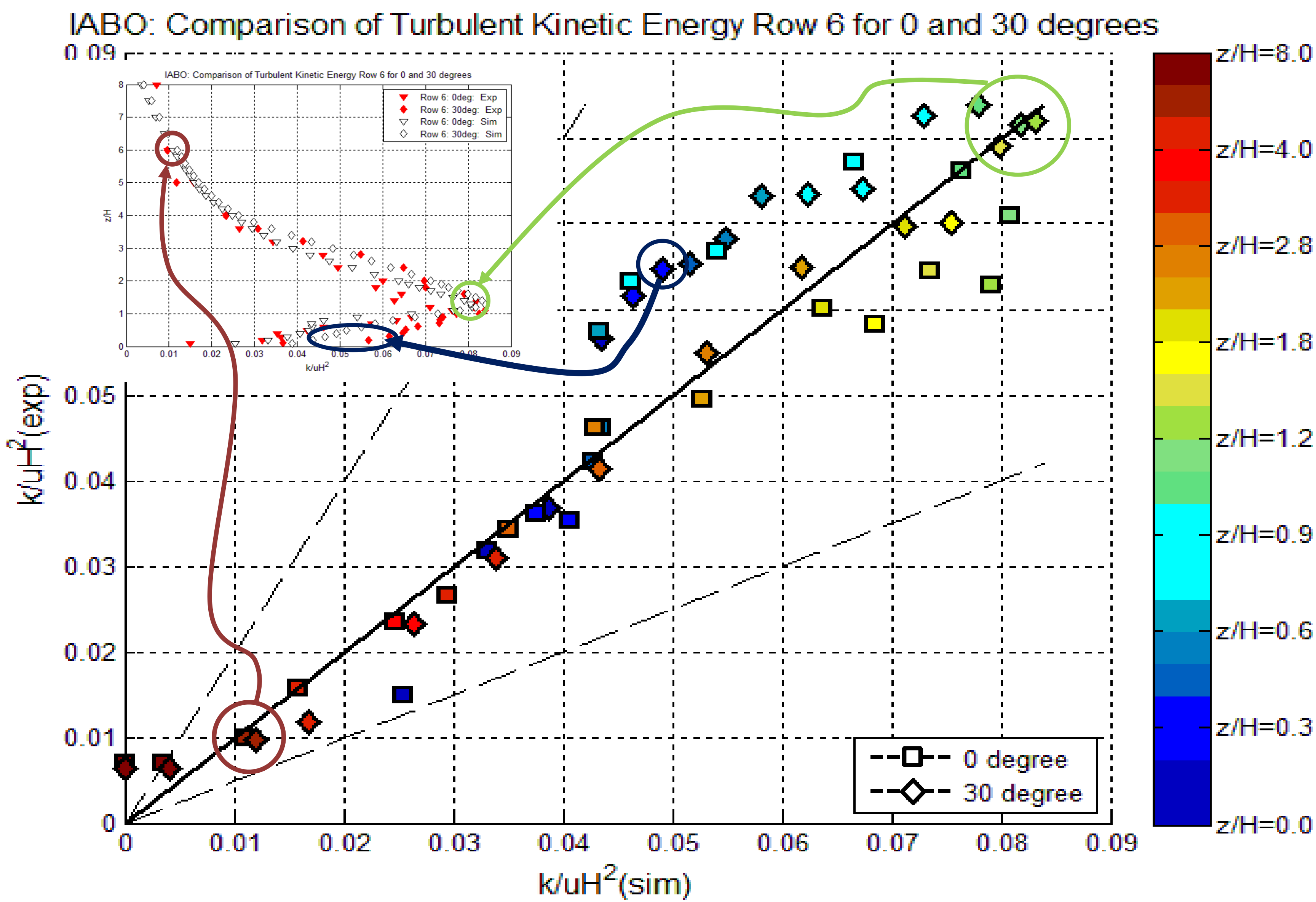
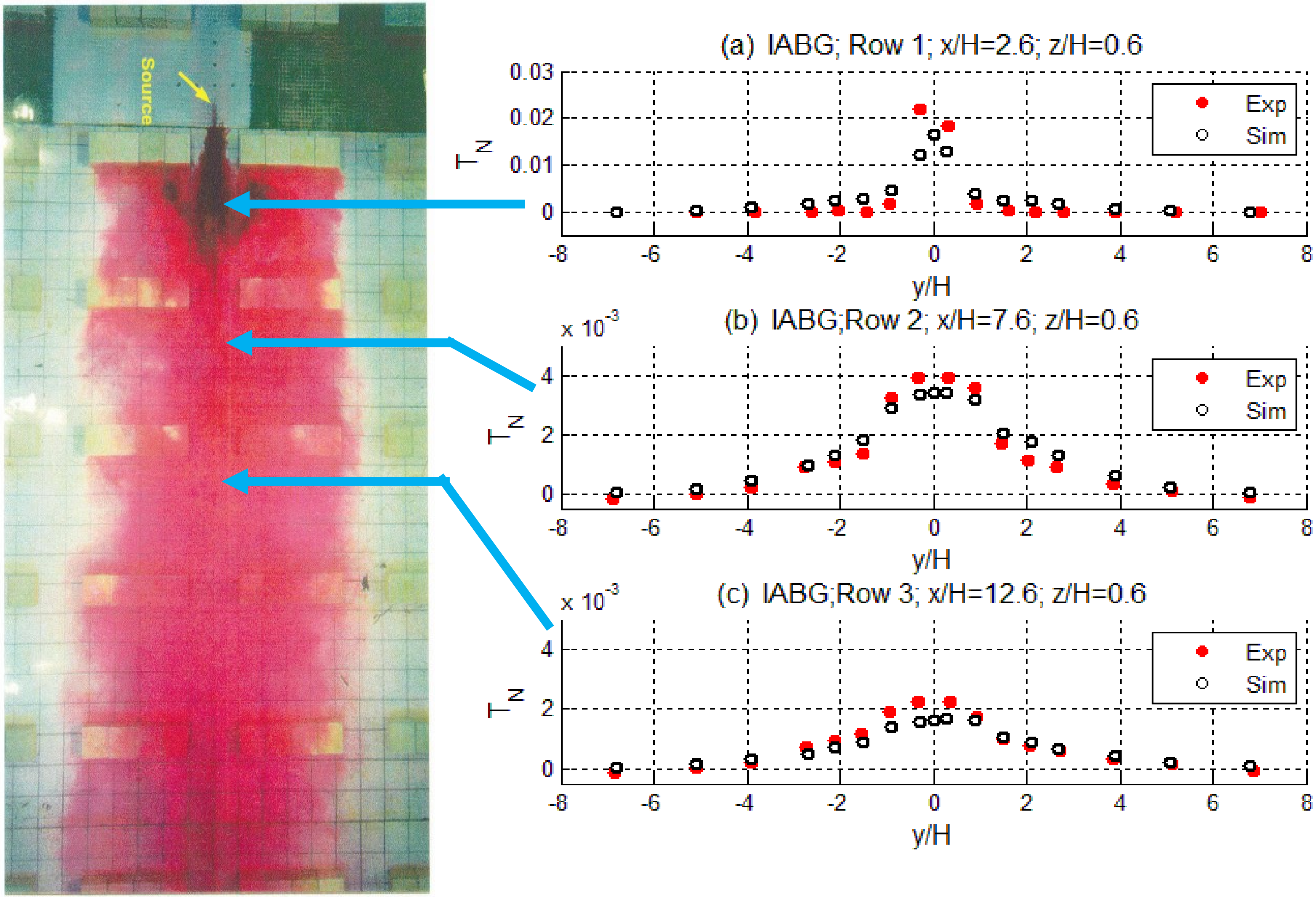
# Summary Plots
## Row 6, Turbulent Kinetic Energy



# Dispersion Comparison
# IABG

# Comparison of lateral normalized temperature profiles of a plume IABG, 0 degrees, rows 1, 2, and 3



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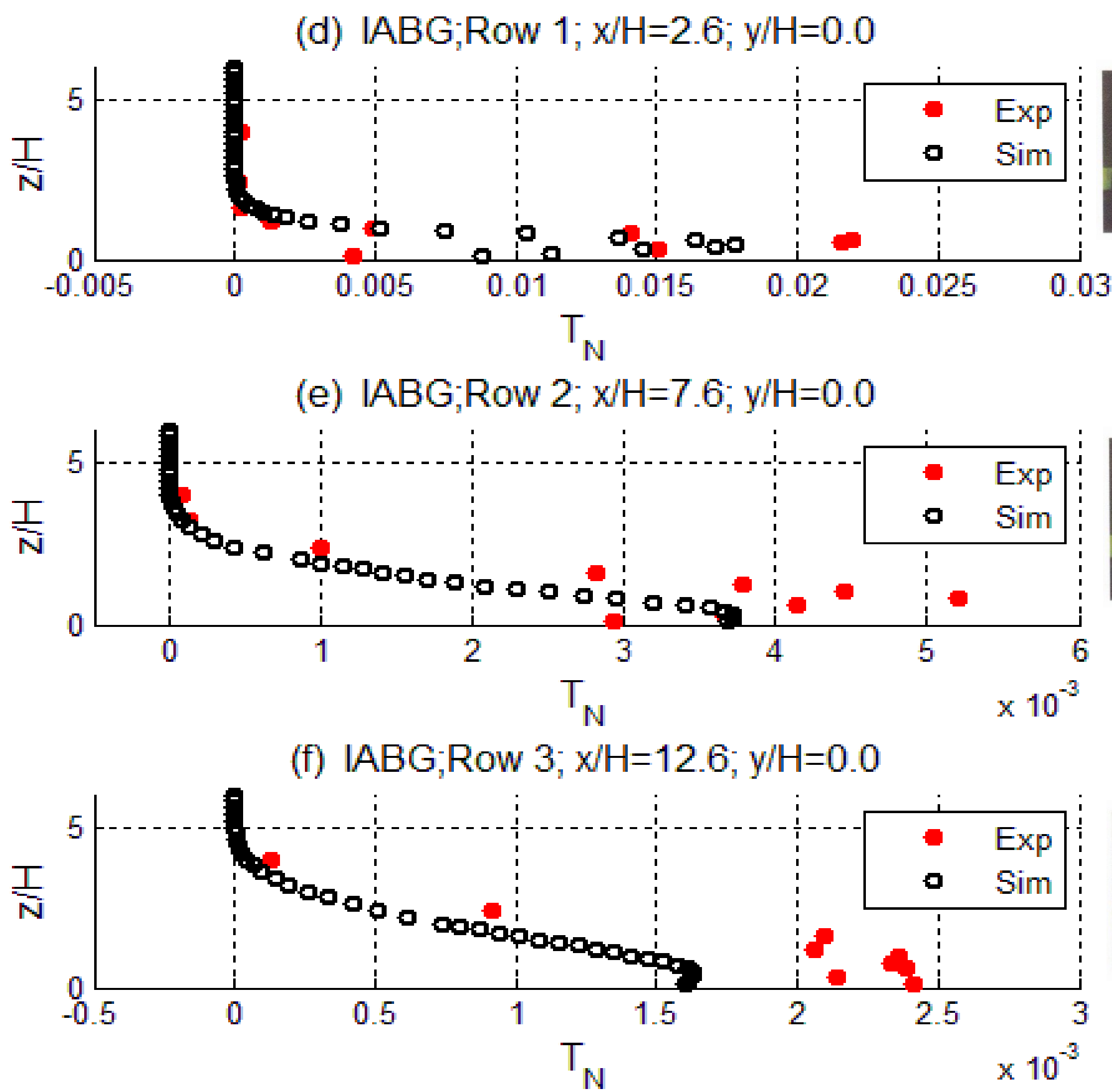
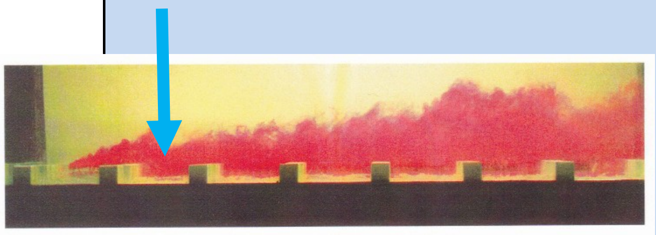
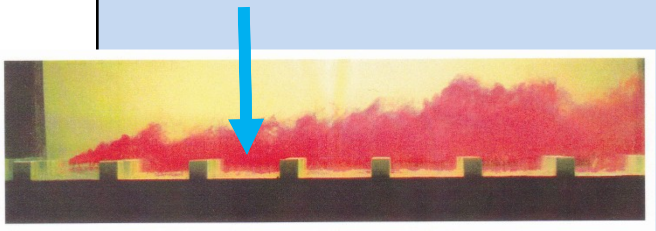
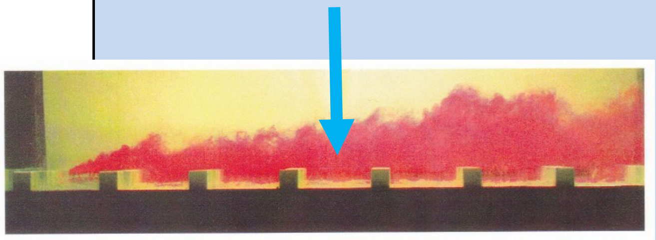
# Comparison of vertical normalized temperature profiles of a plume IABG, 0 degrees, rows 1, 2, and 3







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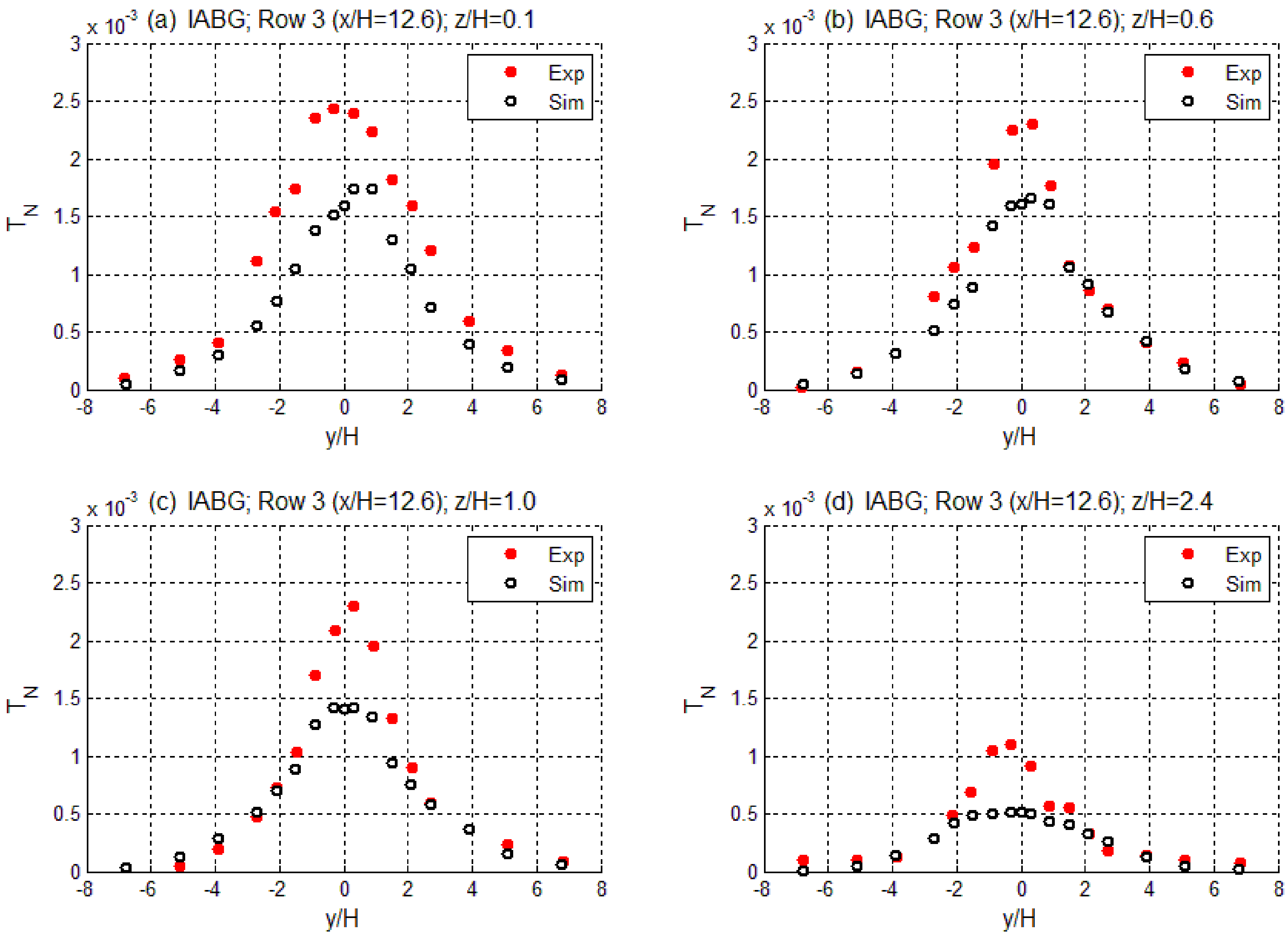
# Comparison of lateral normalized temperature profiles of a plume IABG, 0 degrees, row 3, for heights z/H =0.1, 0.6, 1.0, and 2.4



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# Flow Comparison
# IABG and IABO
# 0 and 30 Degrees

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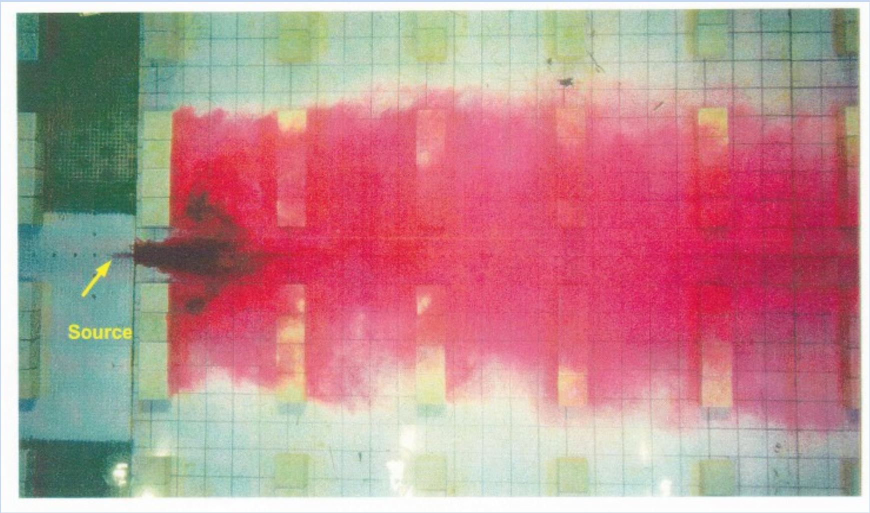
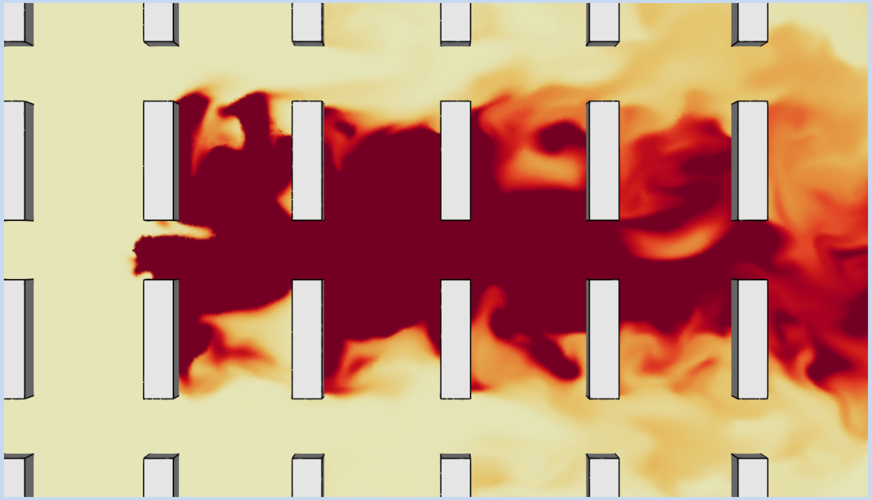
# Summary Plot: IABG vs IABO lateral Profile

## IABG Experiment

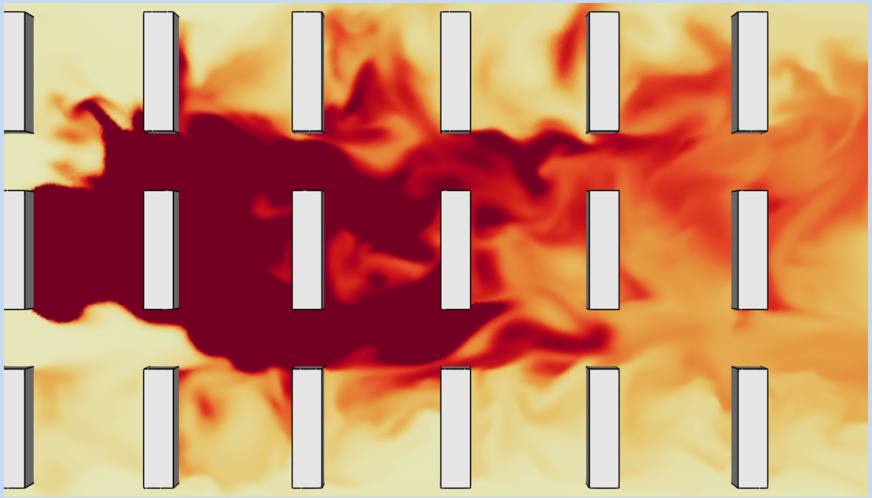



## IABO  Experiment

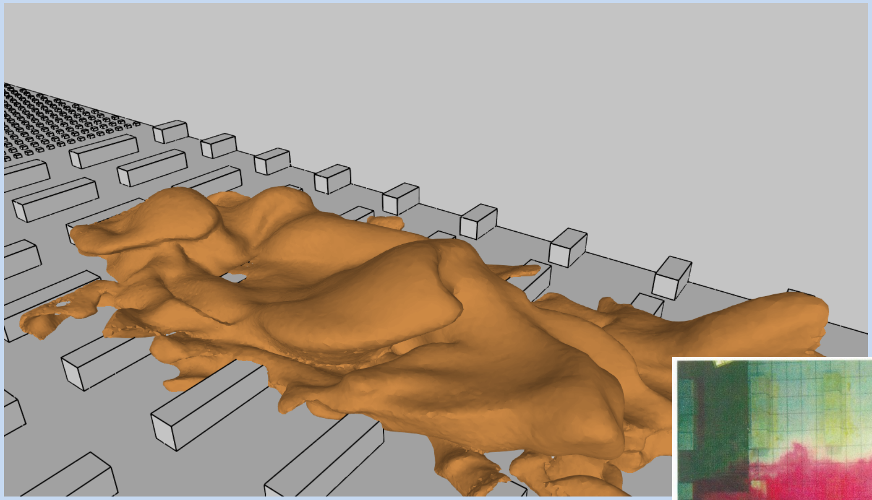

## IABG  Simulation

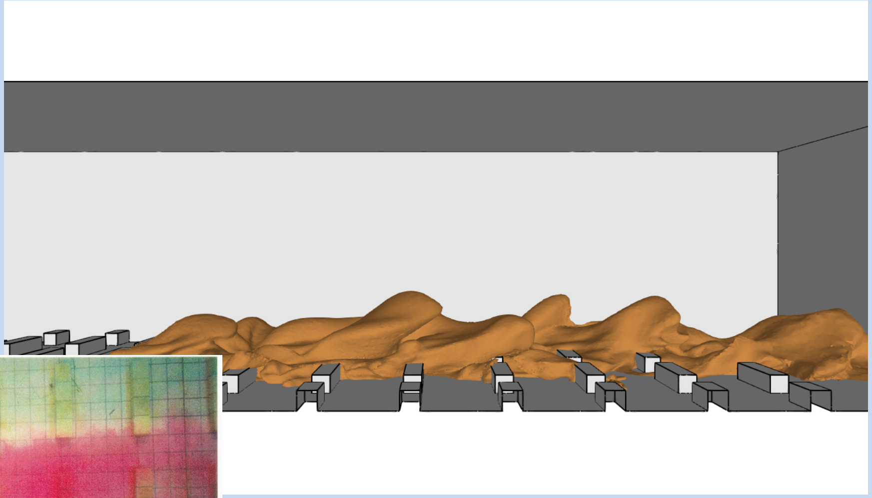


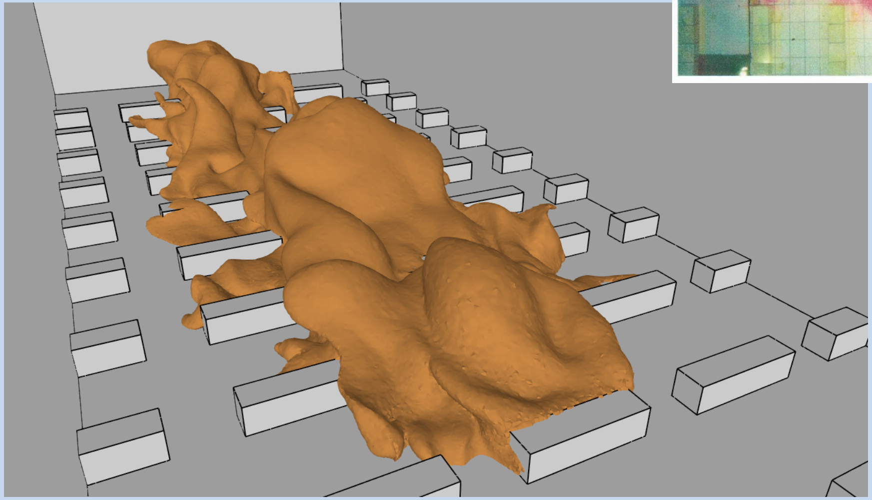
## IABO Simulation

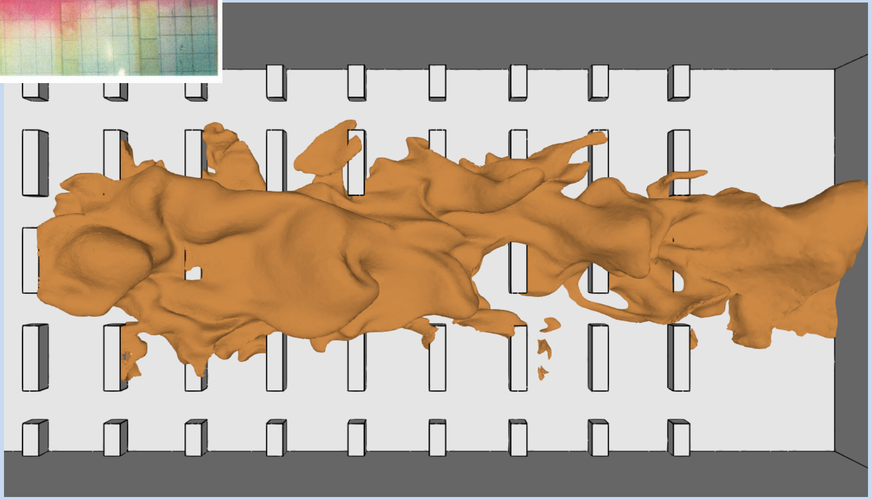


# IABO – 0 deg – Temperature Iso-surface: T= 20.01 °C

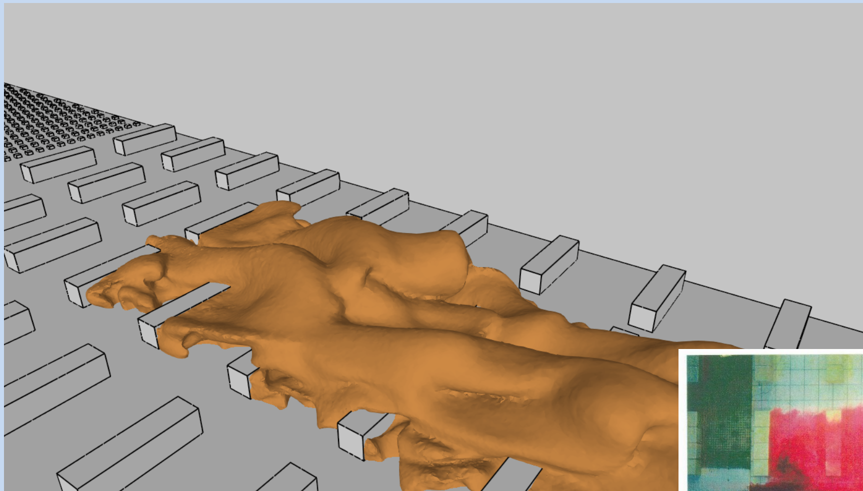


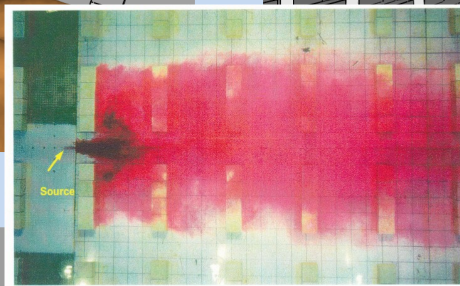


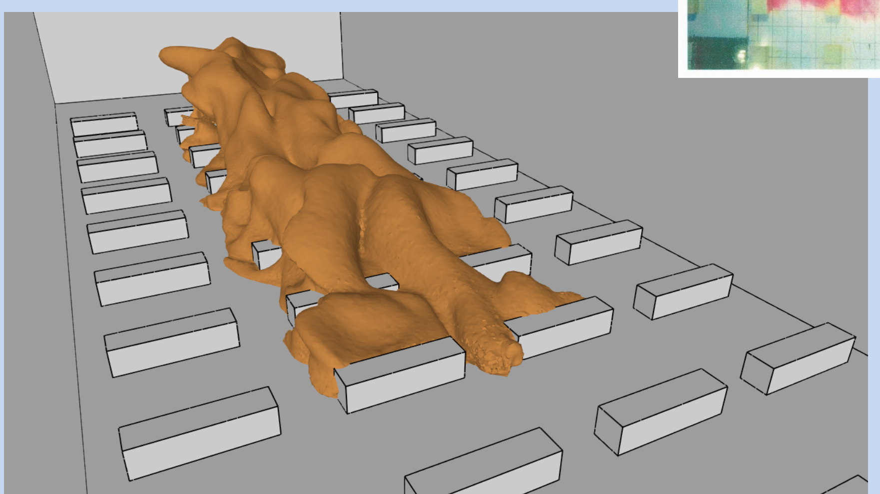
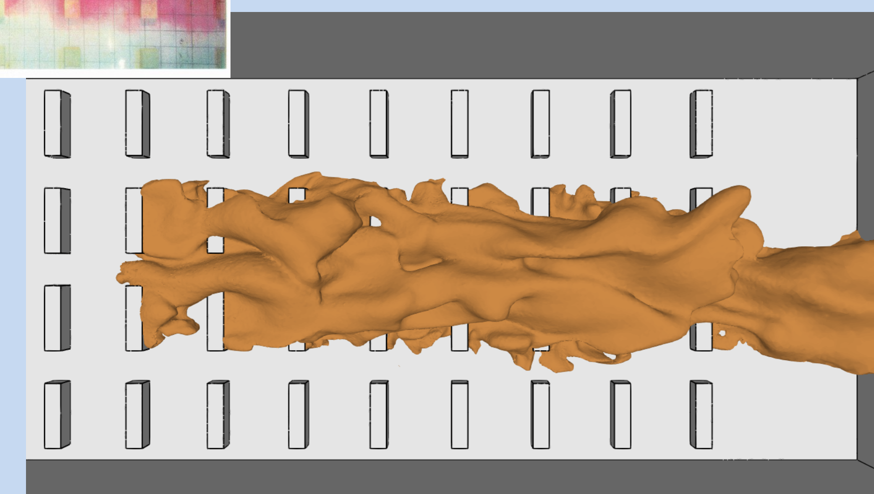





# IABG – 0 deg – Temperature Iso-surface: T= 20.01 °C





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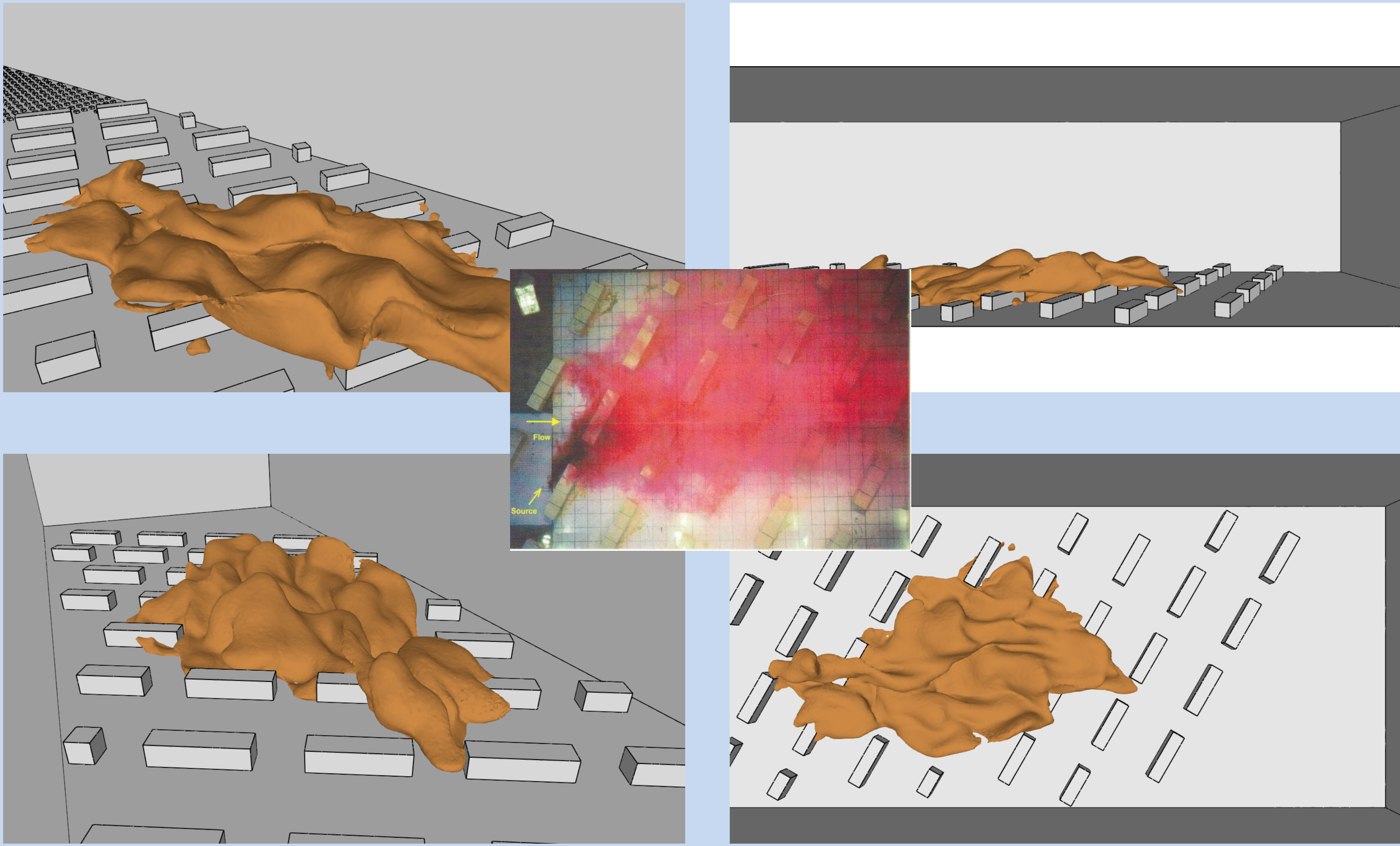
# IABO – 30 deg – Temperature Iso-surface: T= 20.01 °C



# Conclusions

• **Modeling flow development through the roughness section provides a pre-test section velocity profile that maintains turbulence information, eliminating the need for independent turbulence modeling of the pre-test section velocity**.
(Support: Modeled Uave vs. Exp Uave closely match)
(Support: Modeled TKE vs. Exp TKE closely match)

• **Modeling flow development through the roughness section provides a pre-test section velocity profile that maintains turbulence information, reproducing dispersion trends seen in experiments.**
(Support: Modeled TN vs. Exp TN (closely follow similar trends such as peaks, extent))

• NEEDS: From Experimentalist:
**For future simulation comparisons, experimental information is needed in the pre roughness section, and more details of pre-test section measurement positions are needed for simulation.**

# EXTRA SLIDES

# Upstream Flow Sensitivity

## Summary Plots

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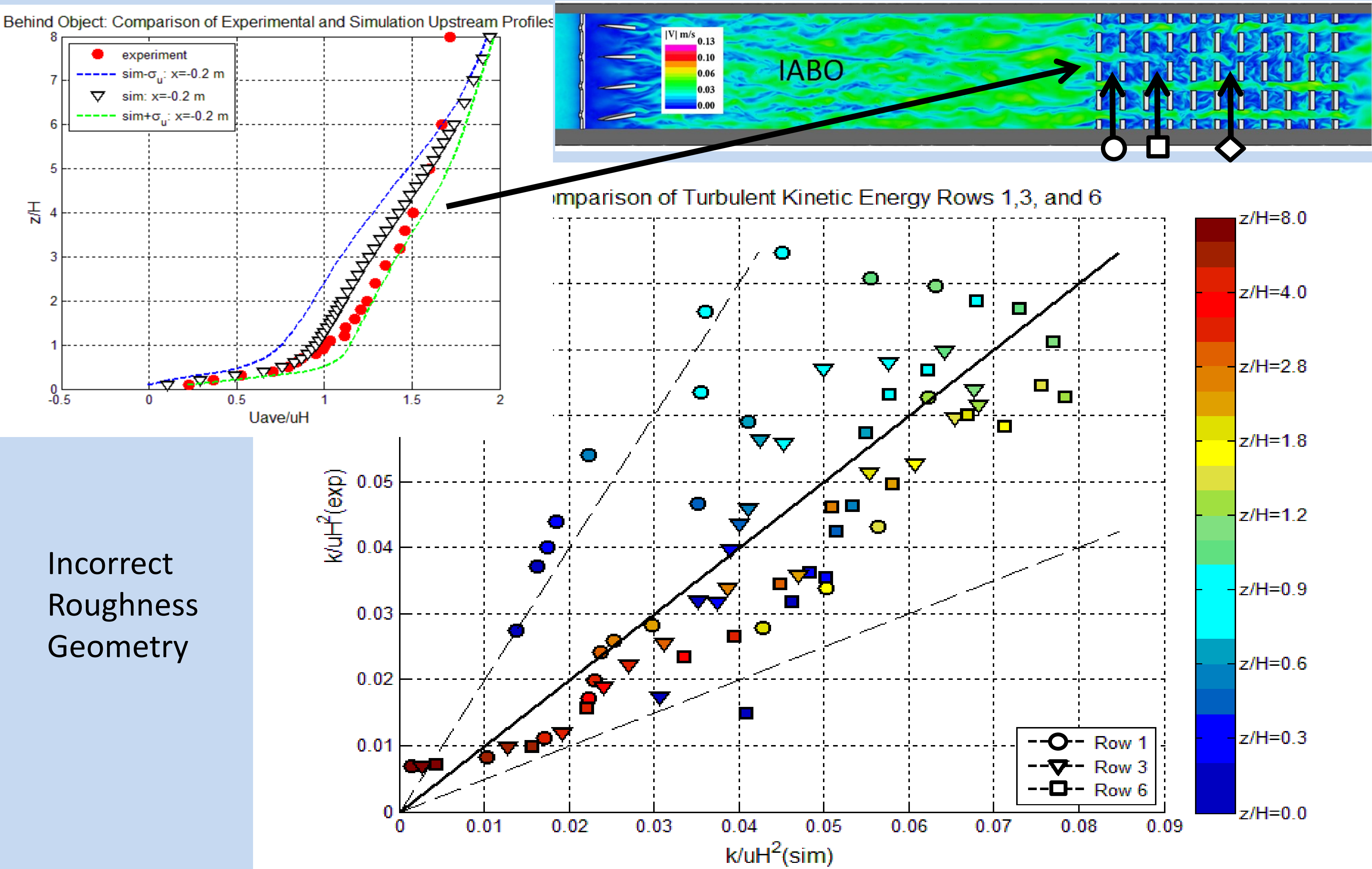


Incorrect Roughness Geometry

# Upstream Flow Sensitivity

## Summary Plots

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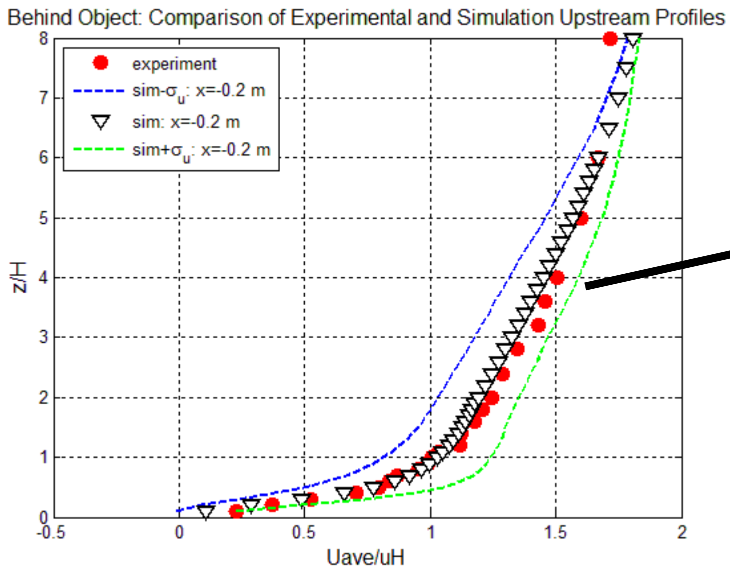


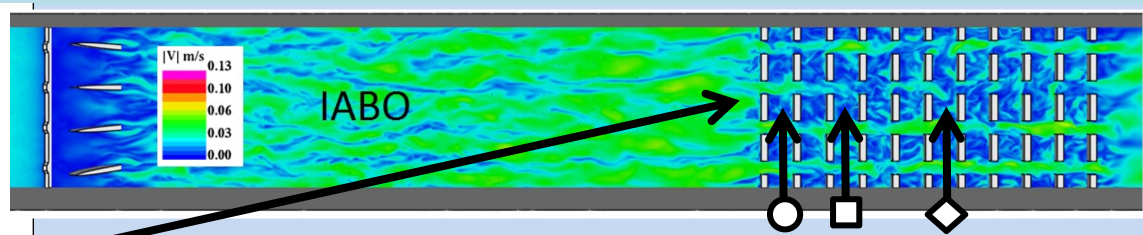


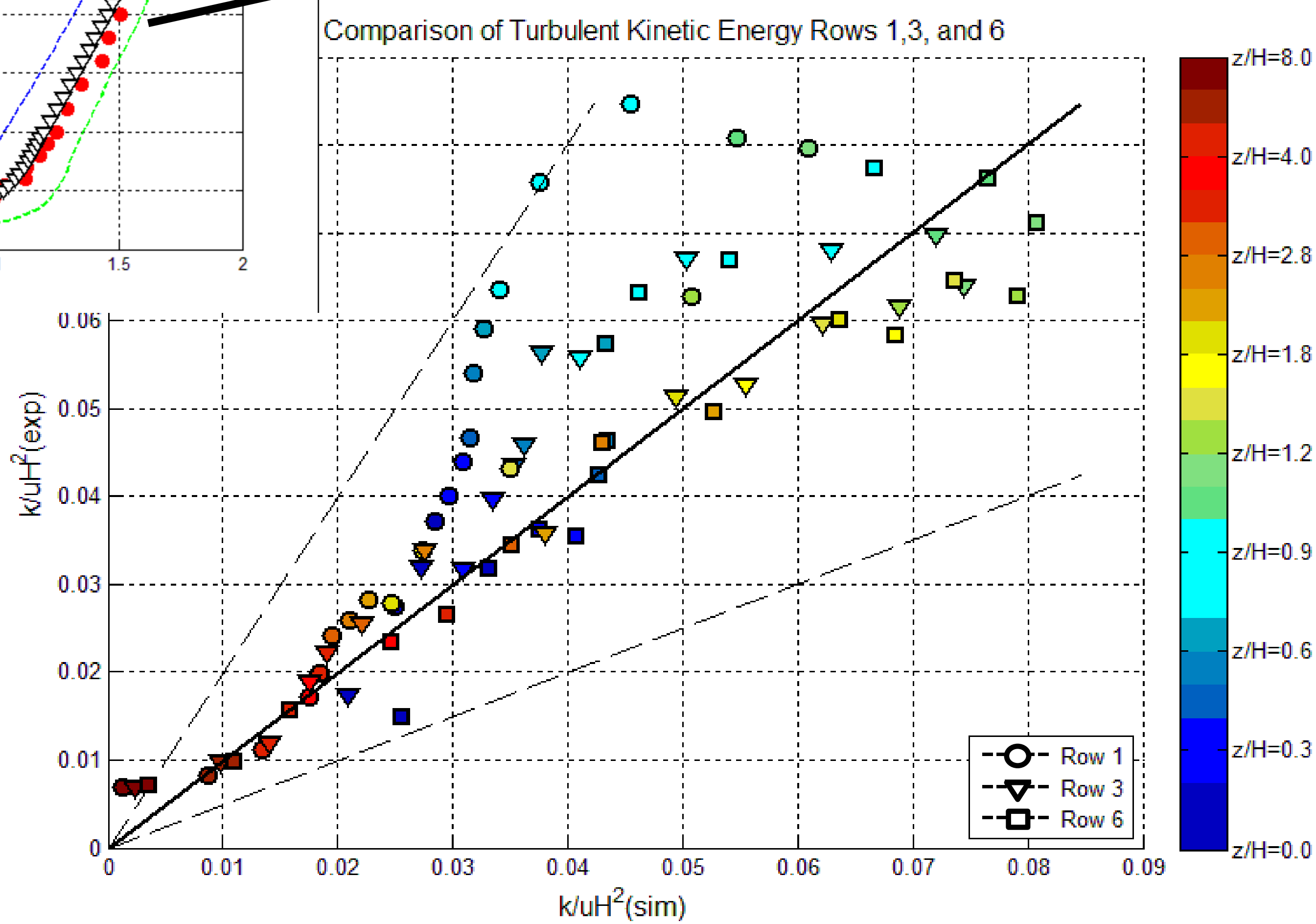


Acurate
Roughness
Geometry

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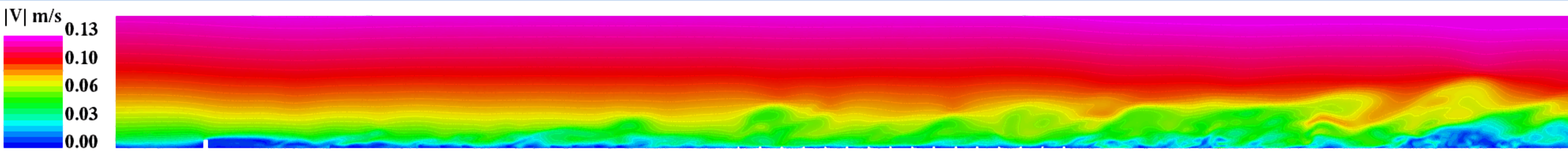
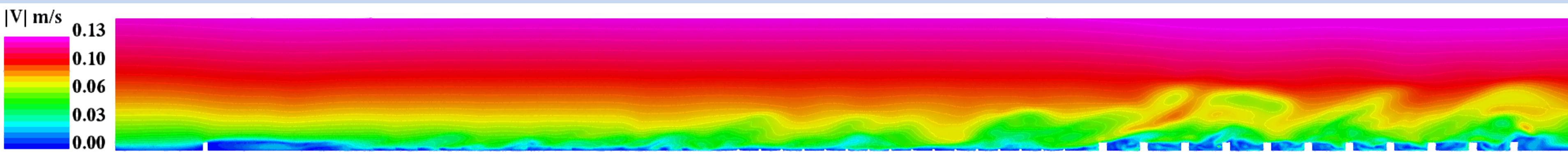
# Time snapshots

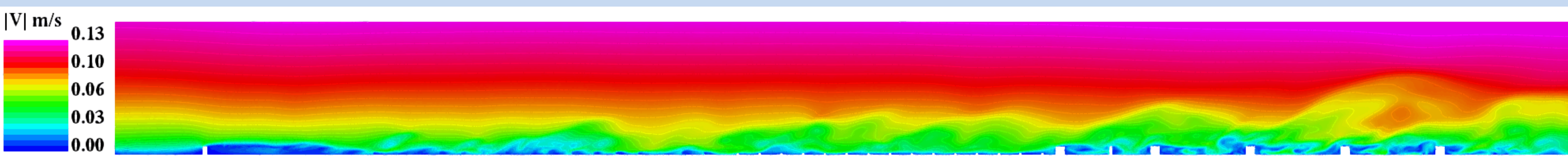
## 0 deg - IABG Simulation



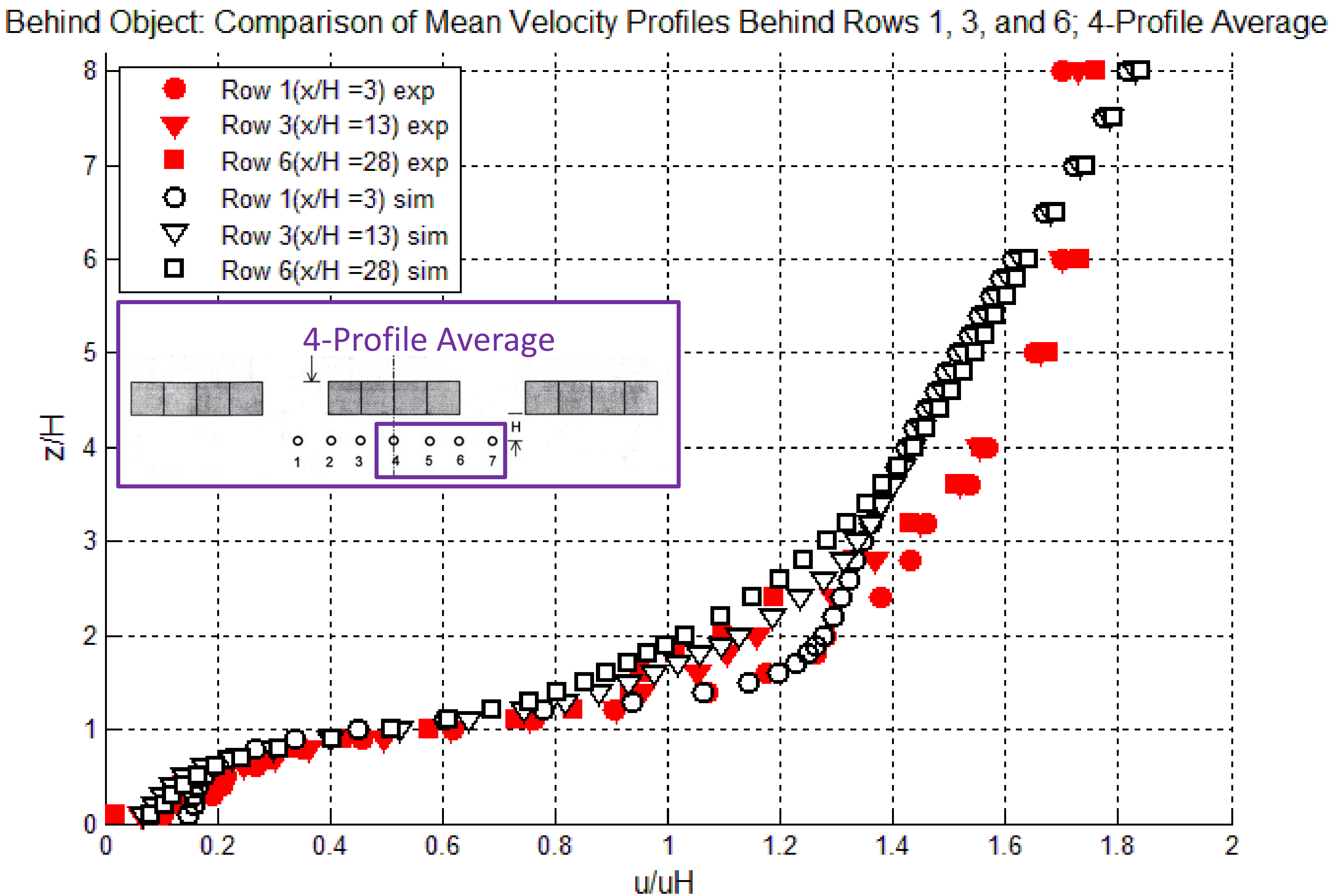

## 0 deg - IABO Simulation




## 30deg - IABO Simulation



# Comparison of normalized u-velocity behind rows 1, 3, and 6



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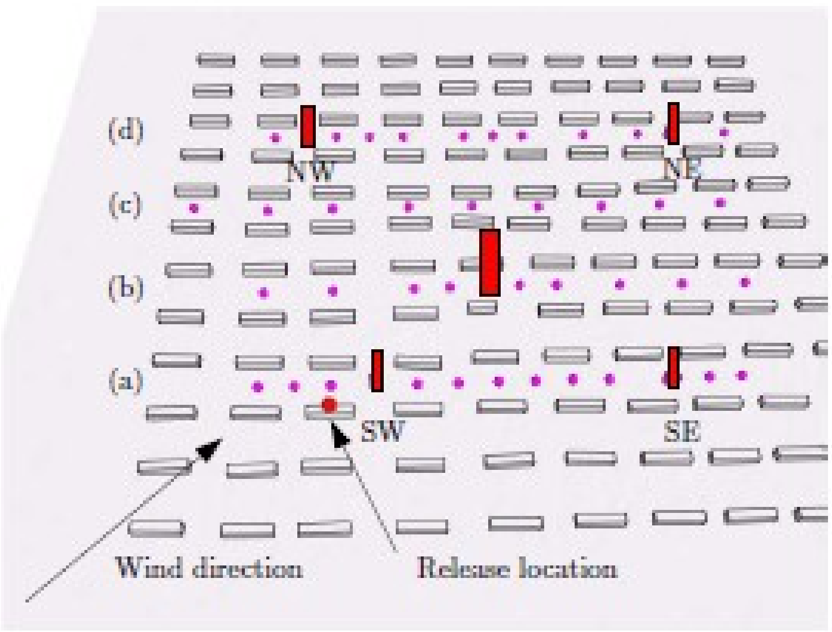
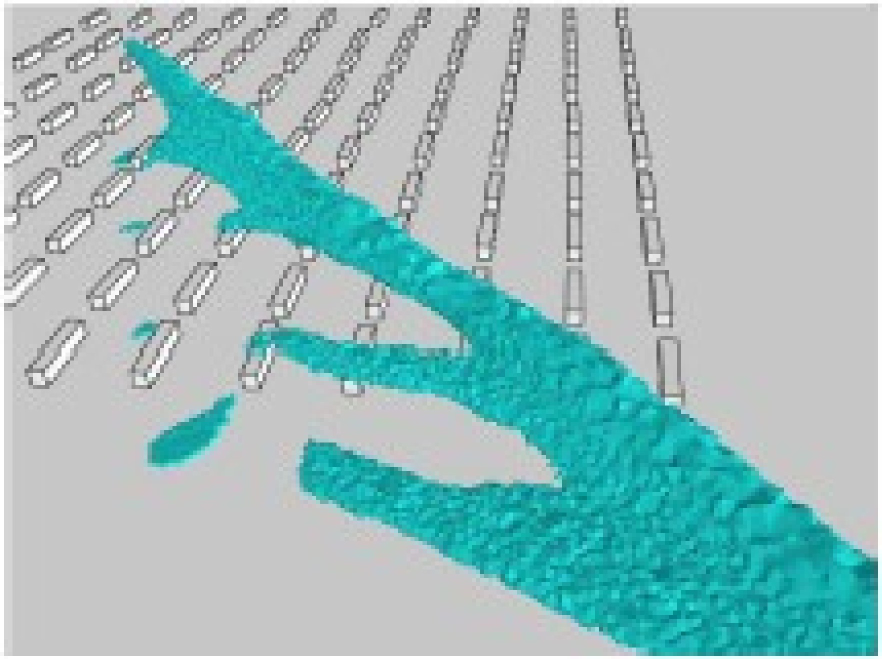
# Mock Urban Setting MUST Experiment

## Review

The MUST experiment was designed to represent an urban layout with symmetric characteristics. An array of 10 by 12 containers was placed at the U.S. Army Dugway Proving Ground Horizontal Grid test site in Utah. Each container was 12.2 m long, 2.42 m wide and 2.54 m high.
The test area encompassed 280 m in width, and 50 m in height above the ground…

." 43rd AIAA Aerospace Sciences Meeting and Exhibit, January 10-13, Reno, Nevada, Fernando E. Camelli et al. .."



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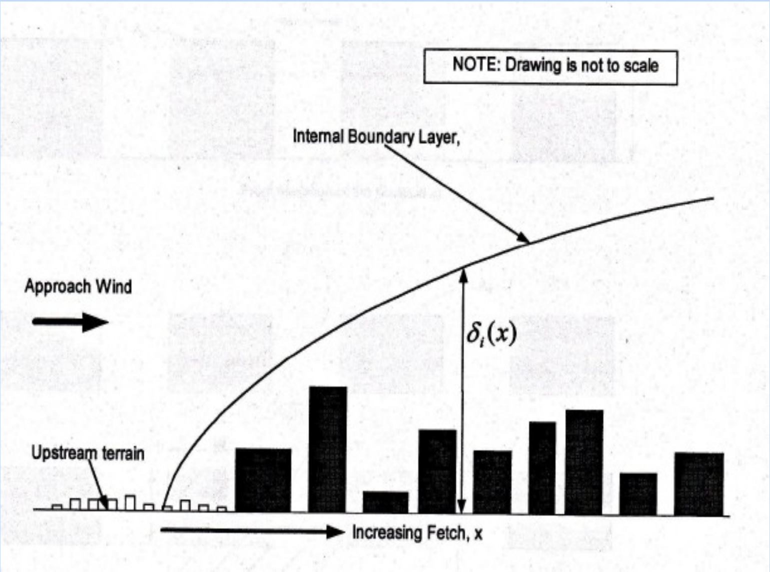
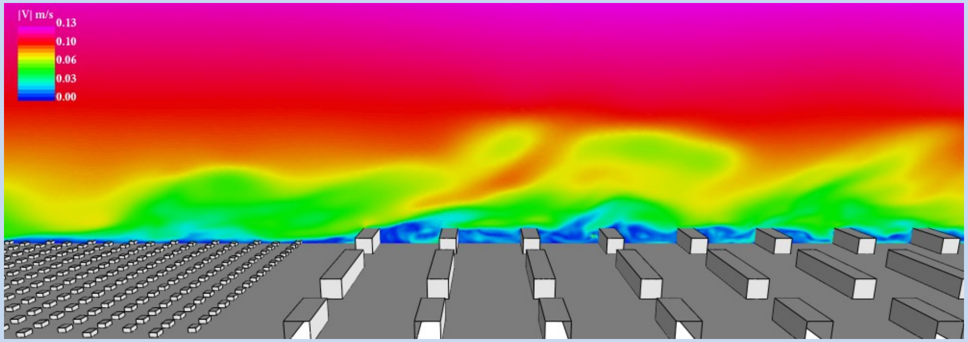
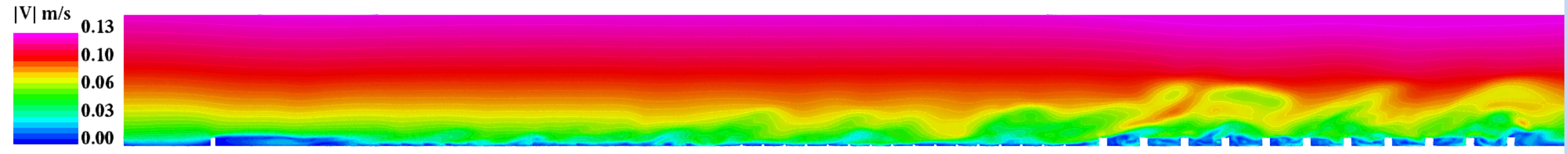
# Macdonald Lab MUST Experiment

## ( 2002/2003) ( 0 and 30 degree angle)




Scale models were placed on the floor of the test section upstream of which a 800-mm deep, fully turbulent simulated atmospheric boundary layer (ABL) flow is created using a combination of a short barrier wall, turbulence spires, and an extended fetch of surface roughness. The surface roughness has two fetches. The first consists of 2.4-m of 19-mm high aluminum plates with packing density λf=0.063. This is followed by a2.4-mfetch of 10-mm high x l6-mm wide Lego@ blocks on 48-mm centers with a packing density λf=0.069.

# Macdonald Lab MUST Experiment

## ( Velocity Measurement)

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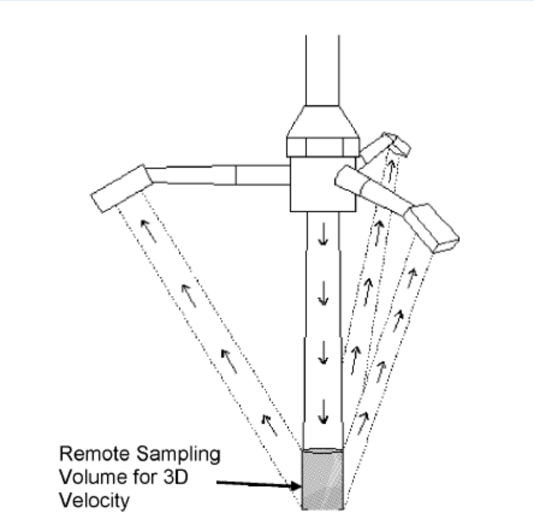
### Velocity Measurements

Velocity measurements in the flume are made with a three-dimensional SonTek micro-acoustic Doppler velocimeter (ADV) sampling at20 Hz. The ADV probe focuses a l6-MHz acoustic beam into a small control volume located 50-mm below the probe tip and uses the Doppler reflection from tiny particles in the flow to calculate the velocity.



# Navier-Stokes Equations - CFD

- Conservation of Mass

$$\nabla \cdot \vec{u} = 0$$

- Conservation of Momentum

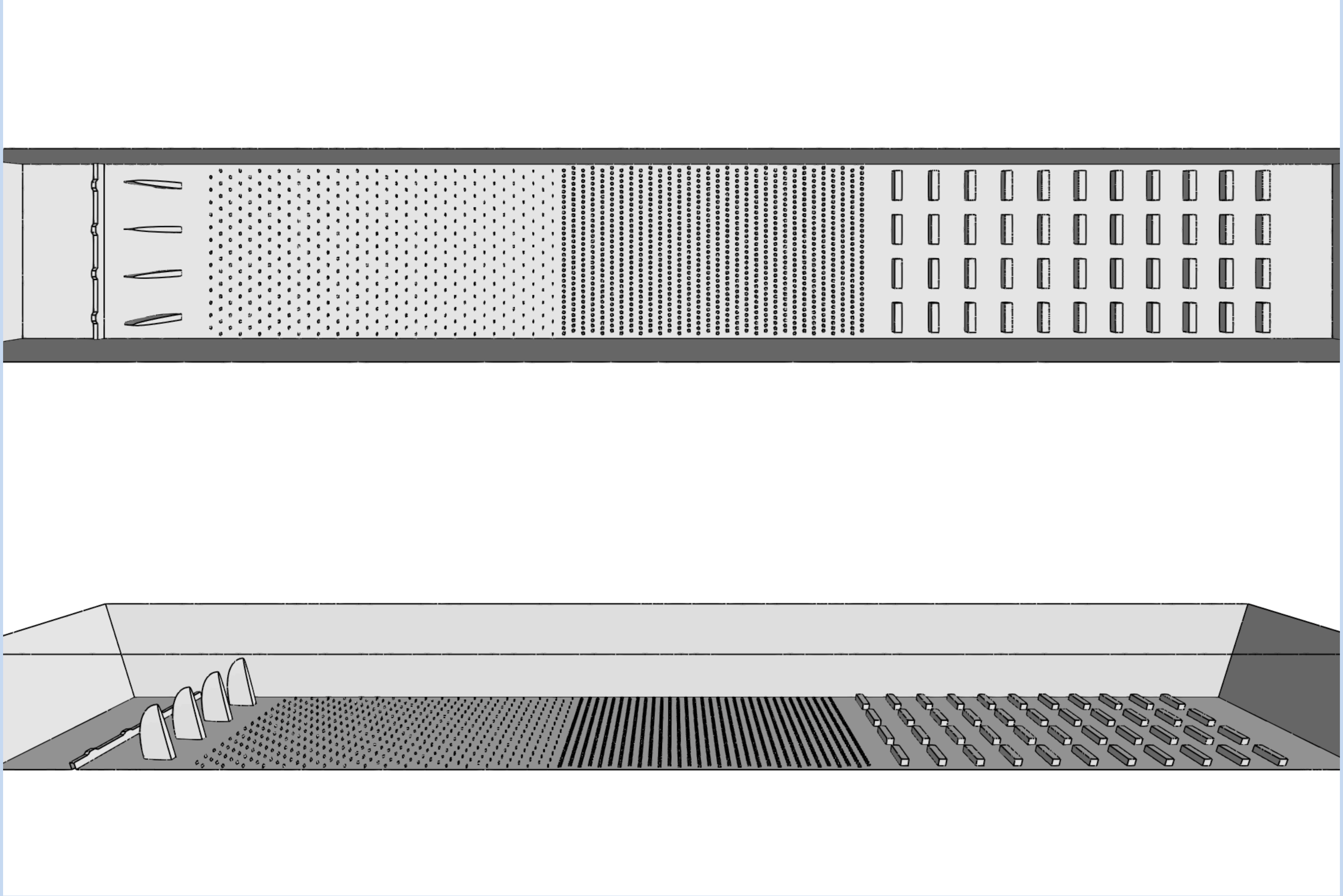
$$\rho \left[ \frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \nabla \vec{u} \right] = \rho f_e - \nabla p + \mu \nabla^2 \vec{u}$$

- Temperature

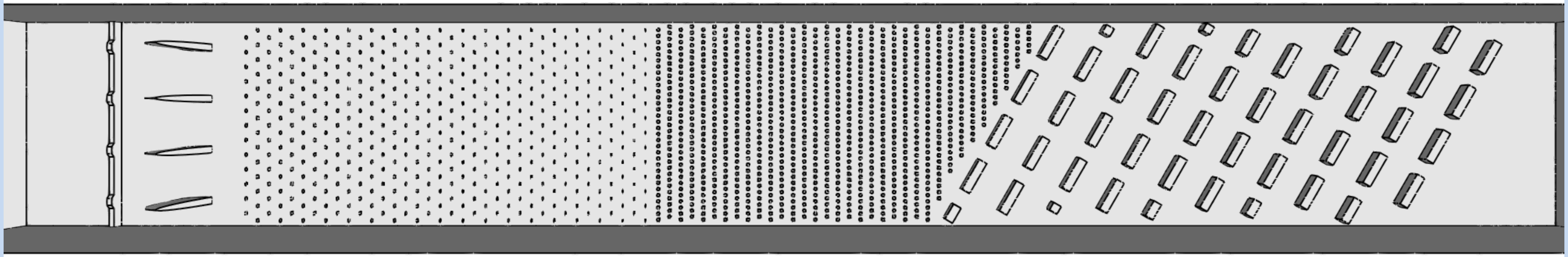
$$\rho c_p \left[ \frac{\partial T}{\partial t} + \vec{u} \cdot \nabla T \right] = \kappa \nabla^2 T$$

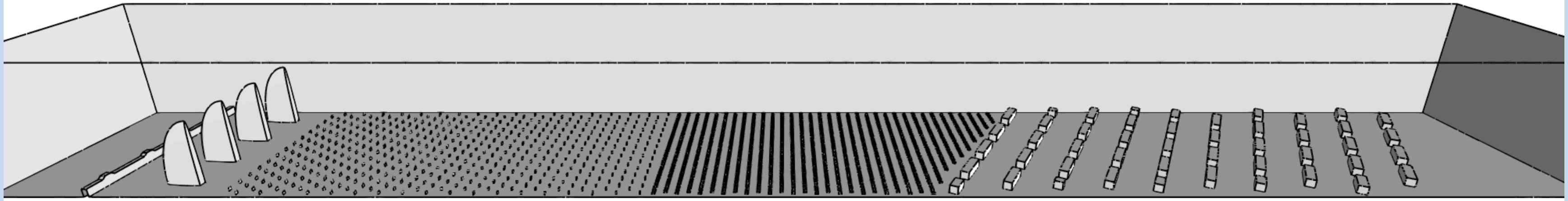
- Large Eddy Simulation
- Smagorinsky WALE Turbulence model

# CFD Geometry Representation – IABG



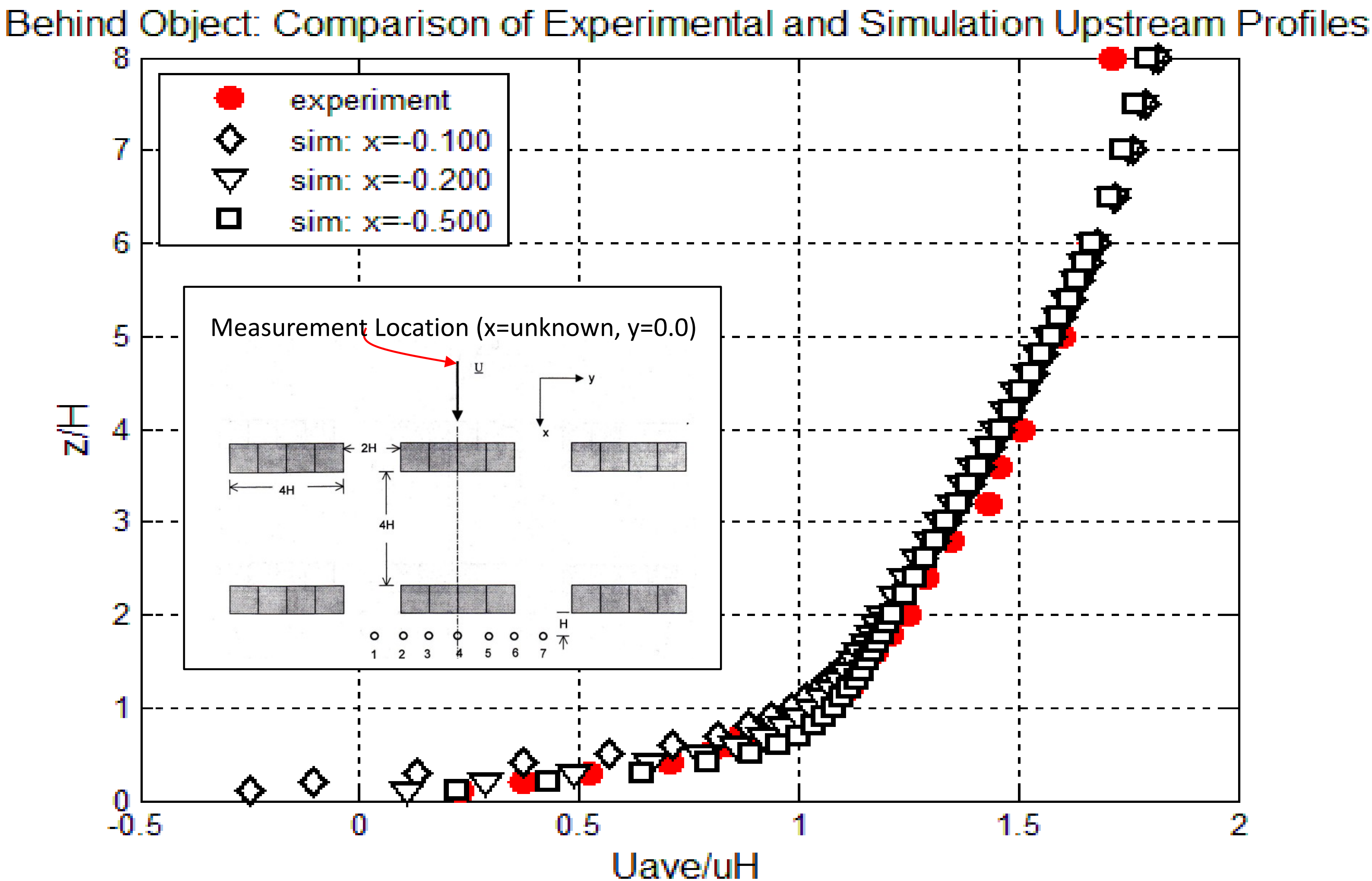
# CFD Geometry Representation – 30 deg IABO



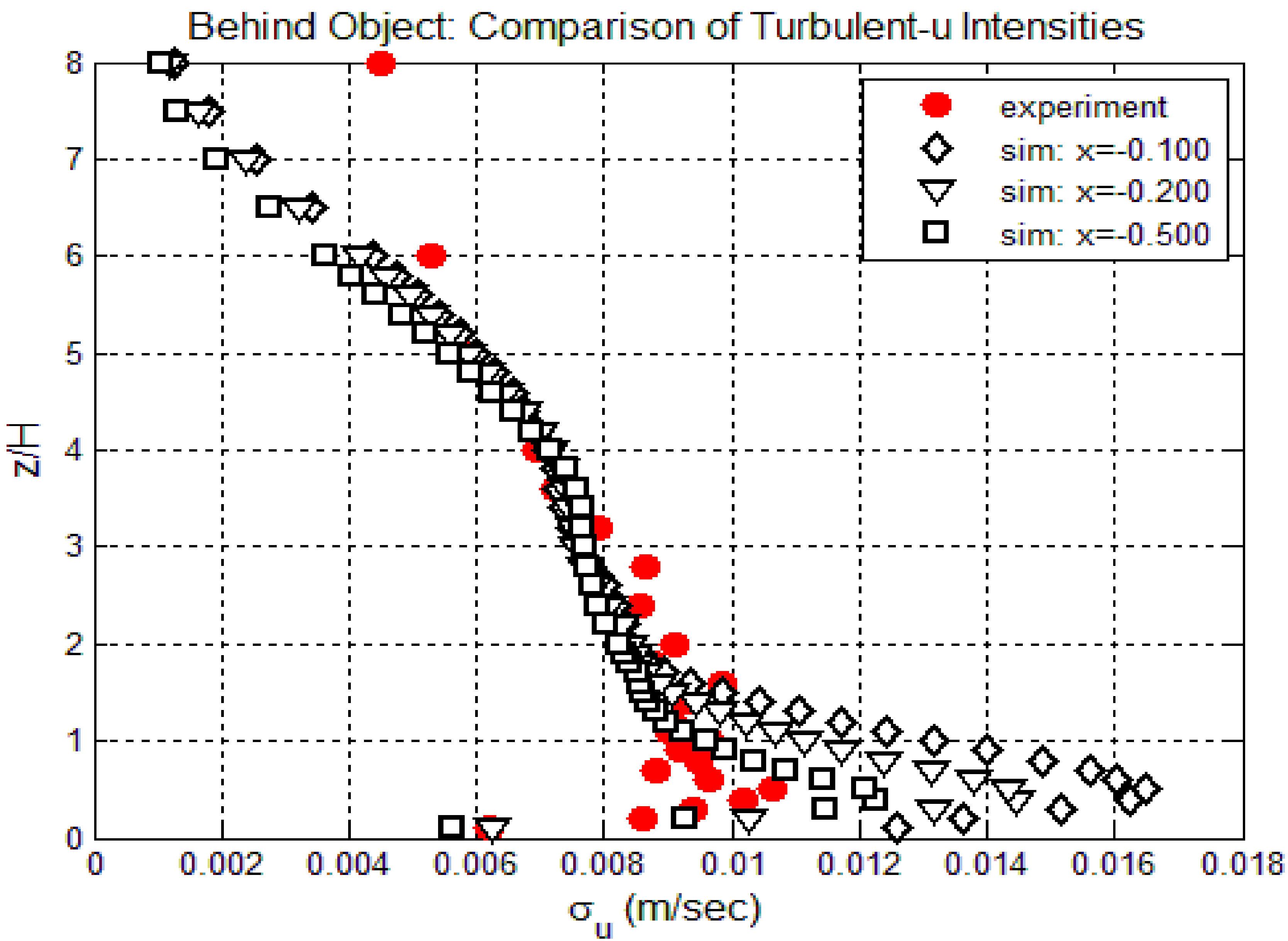


# Velocity and Structure Upstream of Test Section

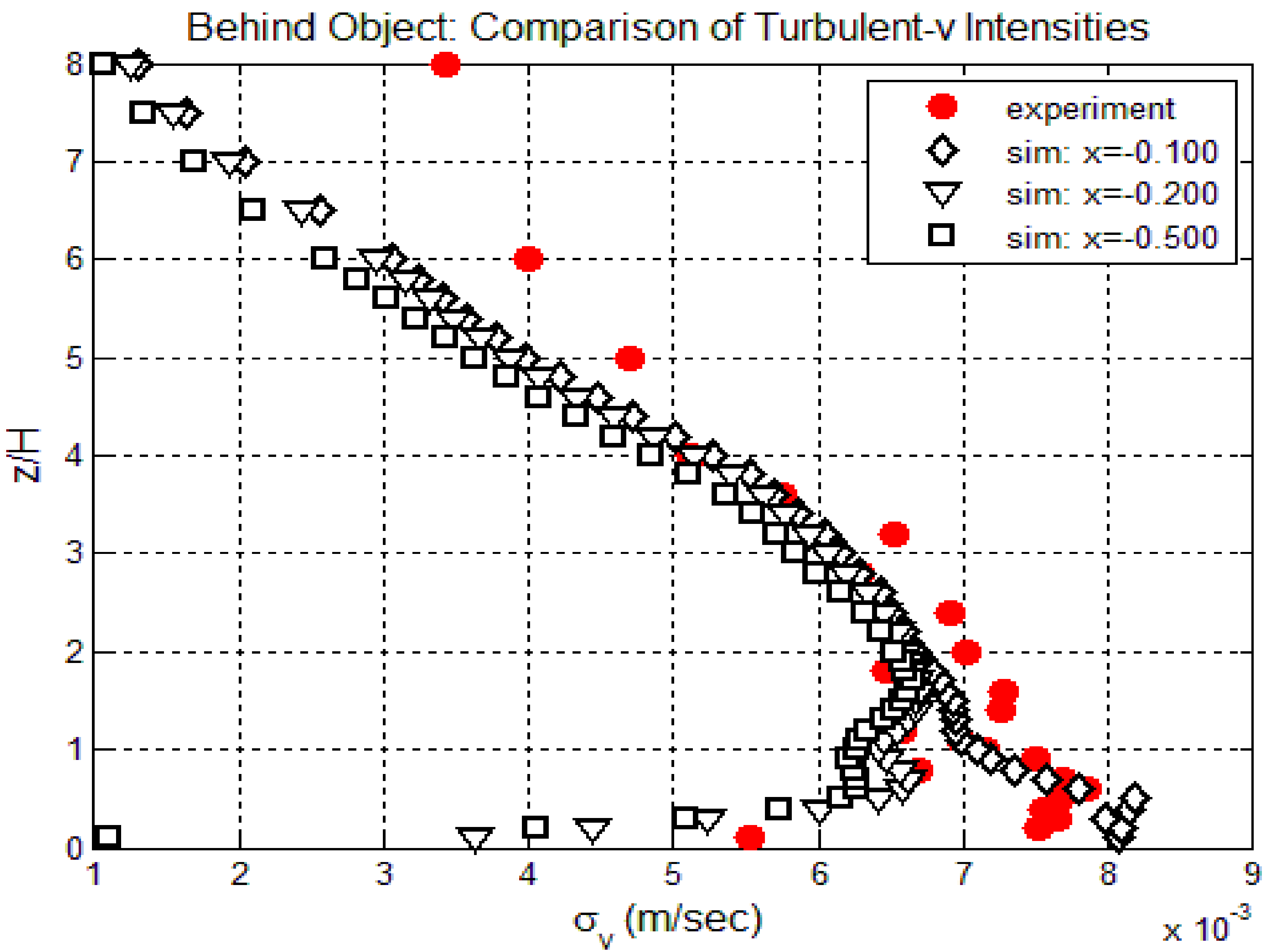
# Comparison of Uave velocity at Entrance of Test Section



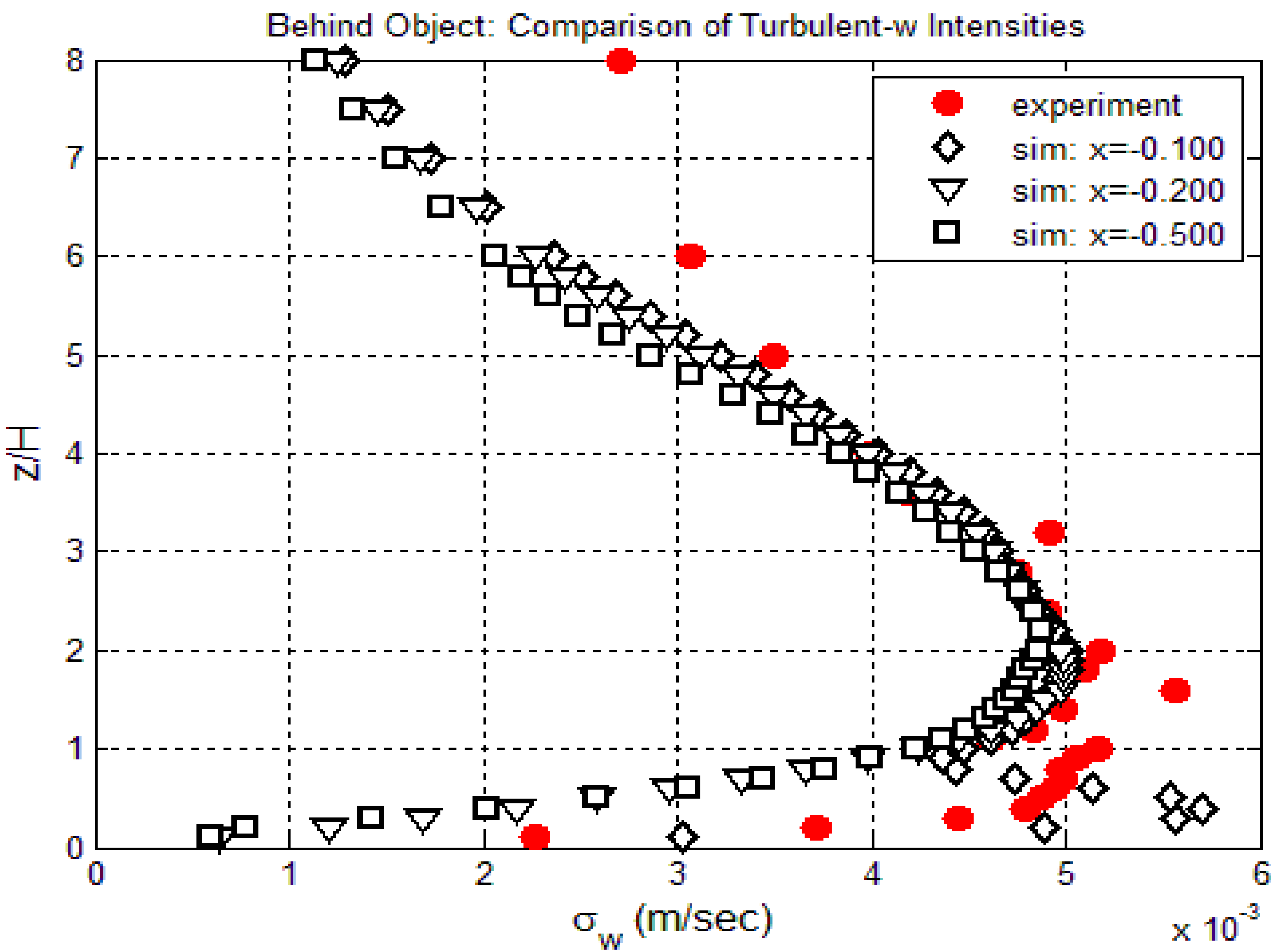
# Comparison of Turbulent u-Intensities at Entrance of Test Section



# Comparison of Turbulent v-Intensities at Entrance of Test Section

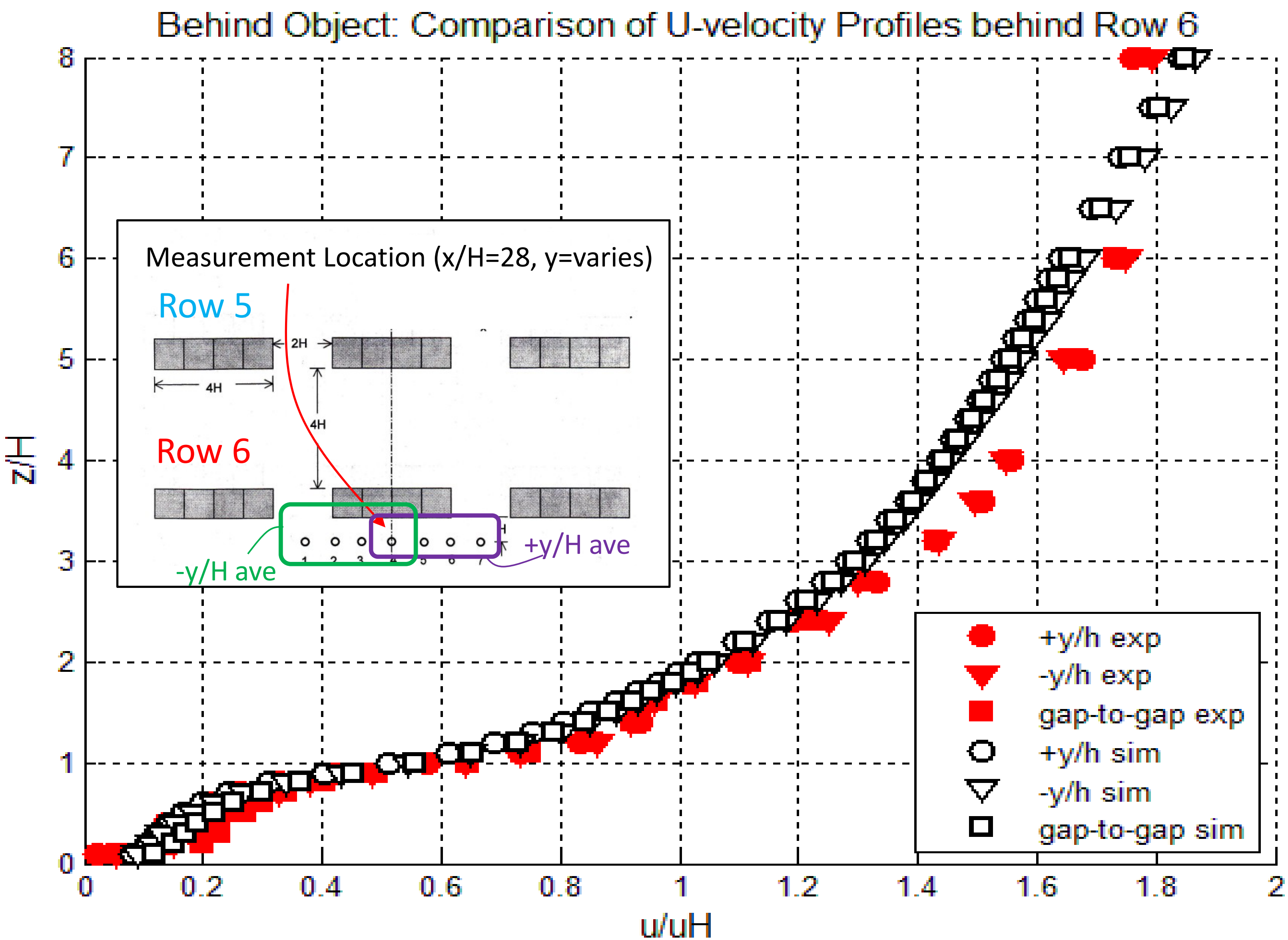


# Comparison of Turbulent w-Intensities at Entrance of Test Section

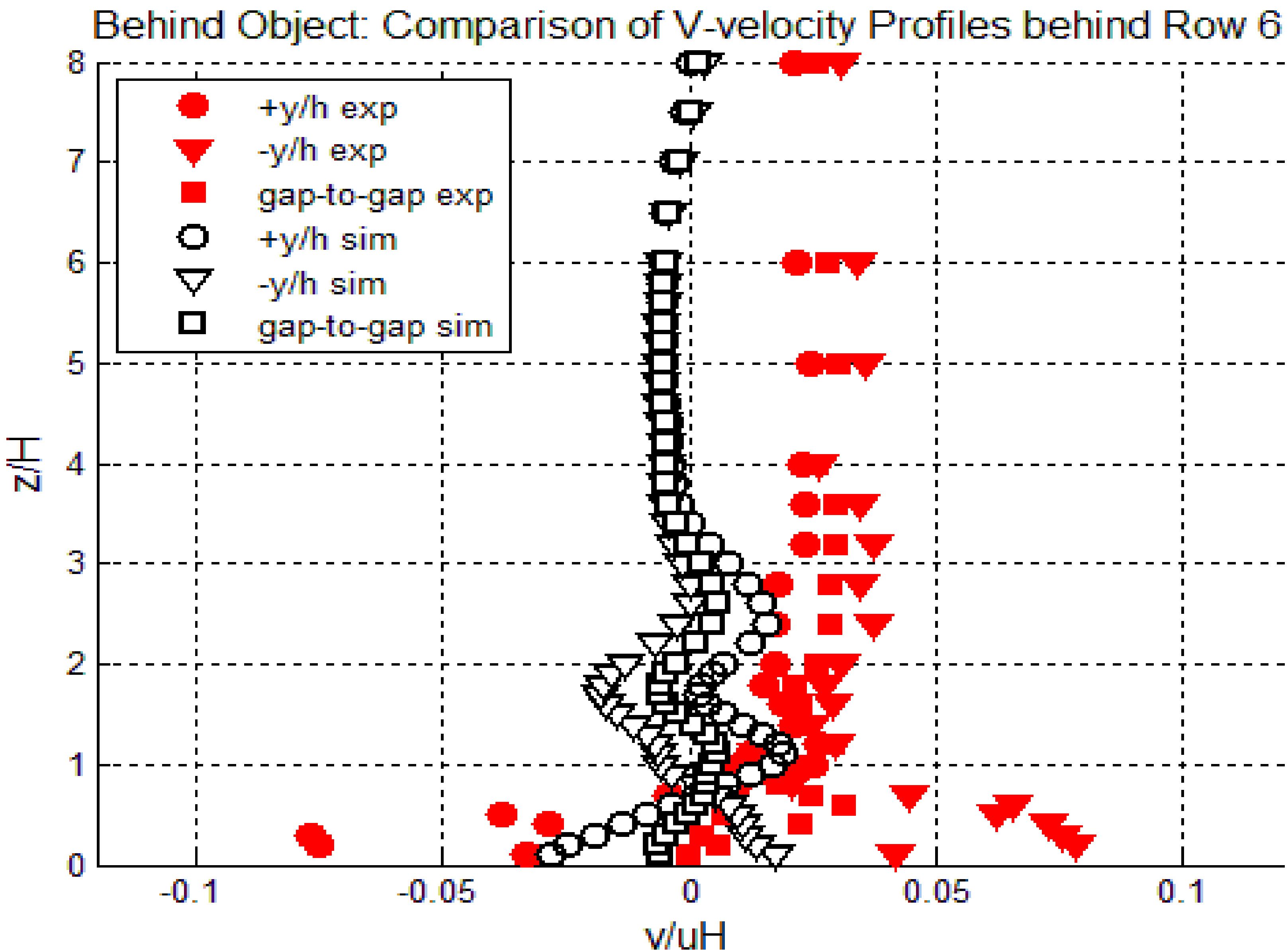


# Row 6 Velocity
# Symmetry and Averaging Comparisons

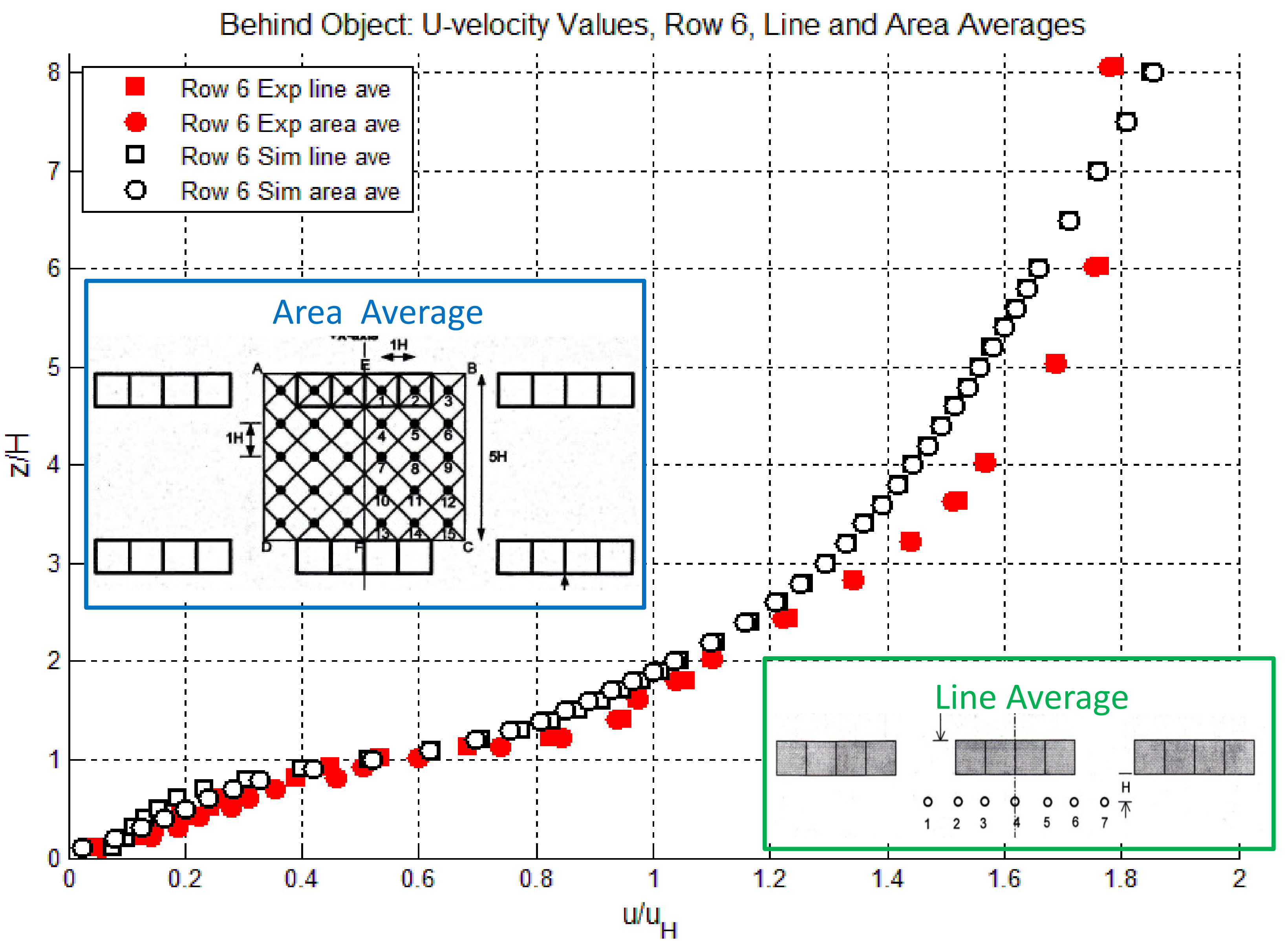
# Comparison of normalized u-velocity behind row 6



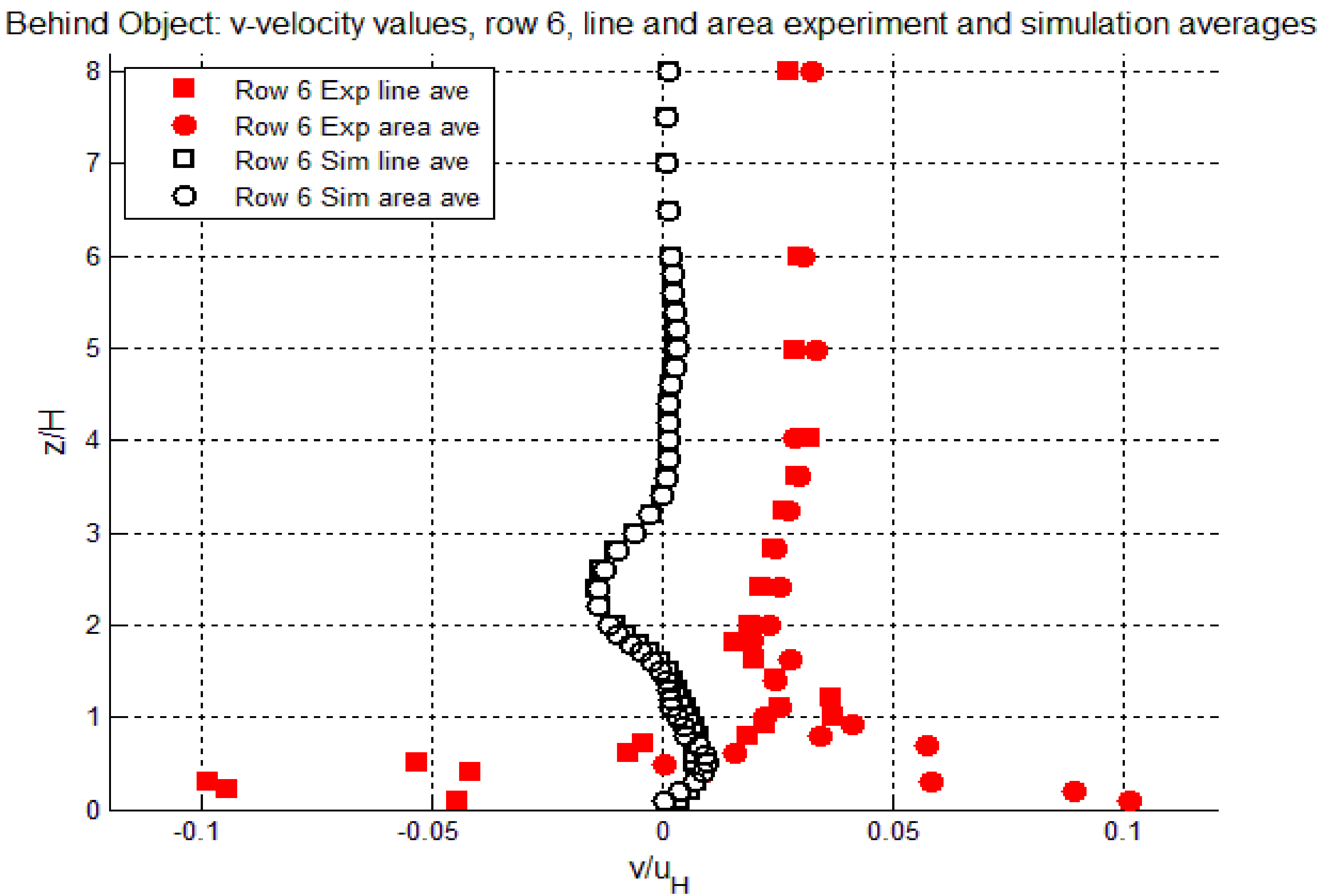
# Comparison of normalized v-velocity behind row 6



# Comparison of normalized u-velocity behind row 6, line and area average

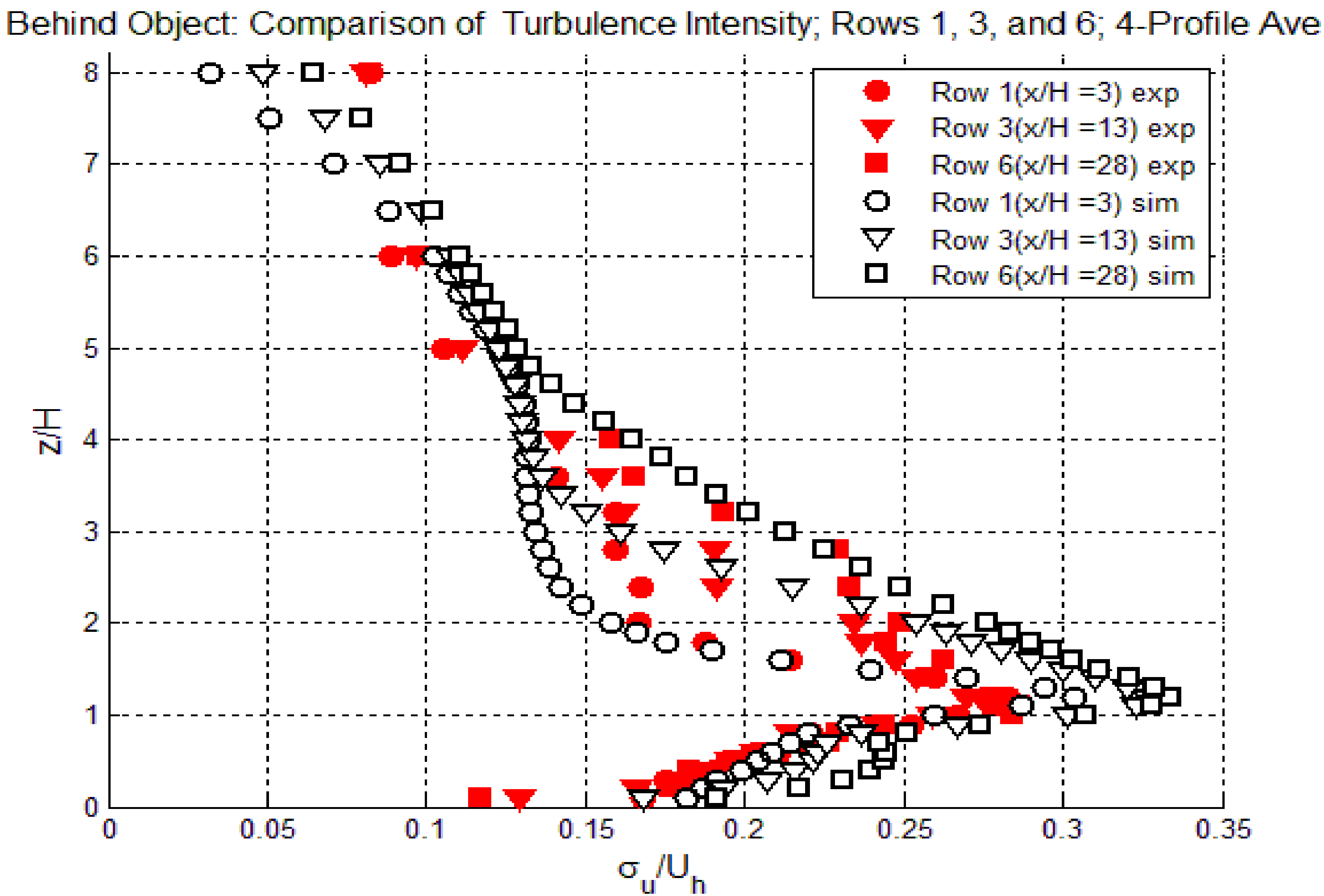


# Comparison of normalized v-velocity behind row 6, line and area average

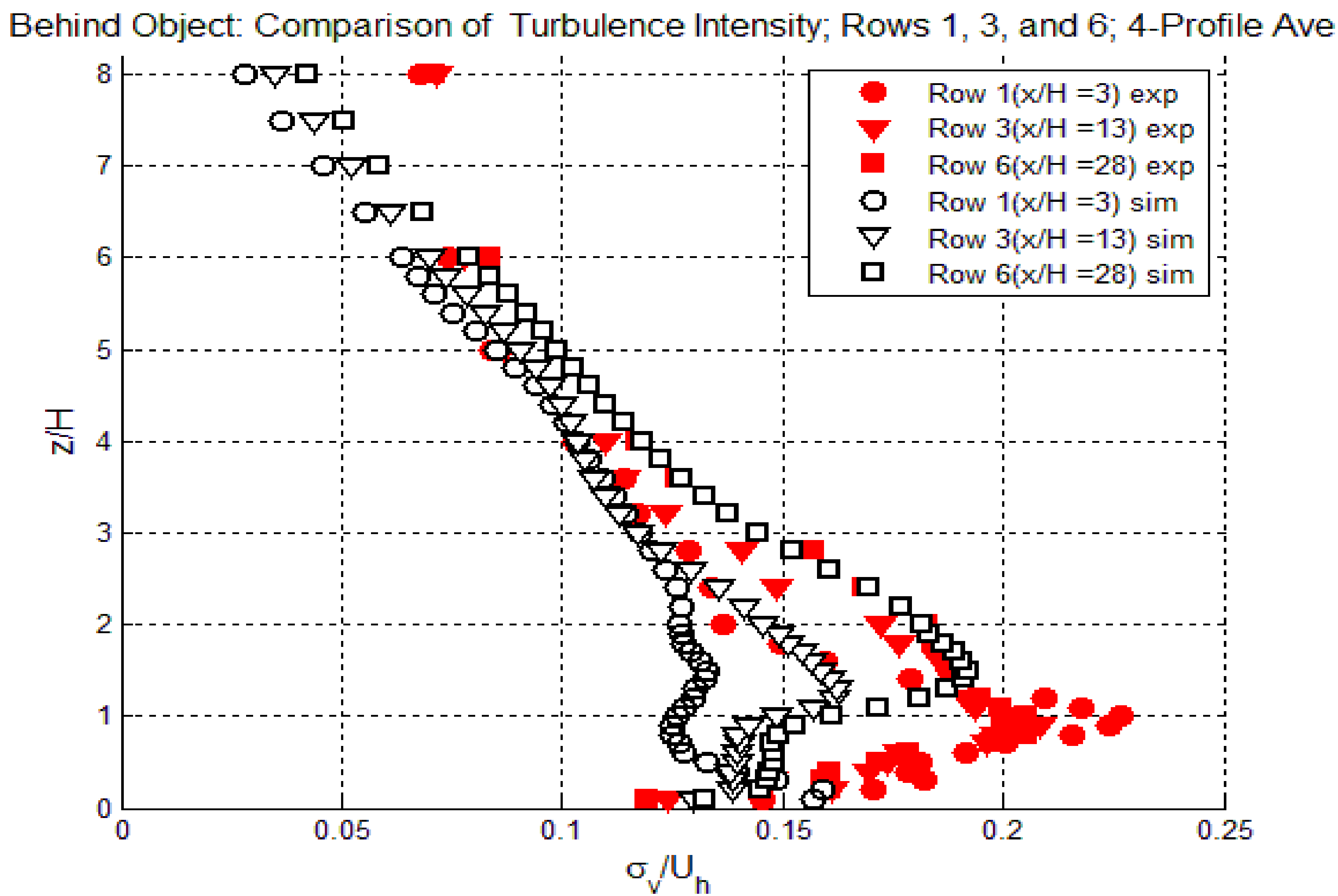


# IABO
# Rows 1, 3, and 6
# Velocity and Turbulence

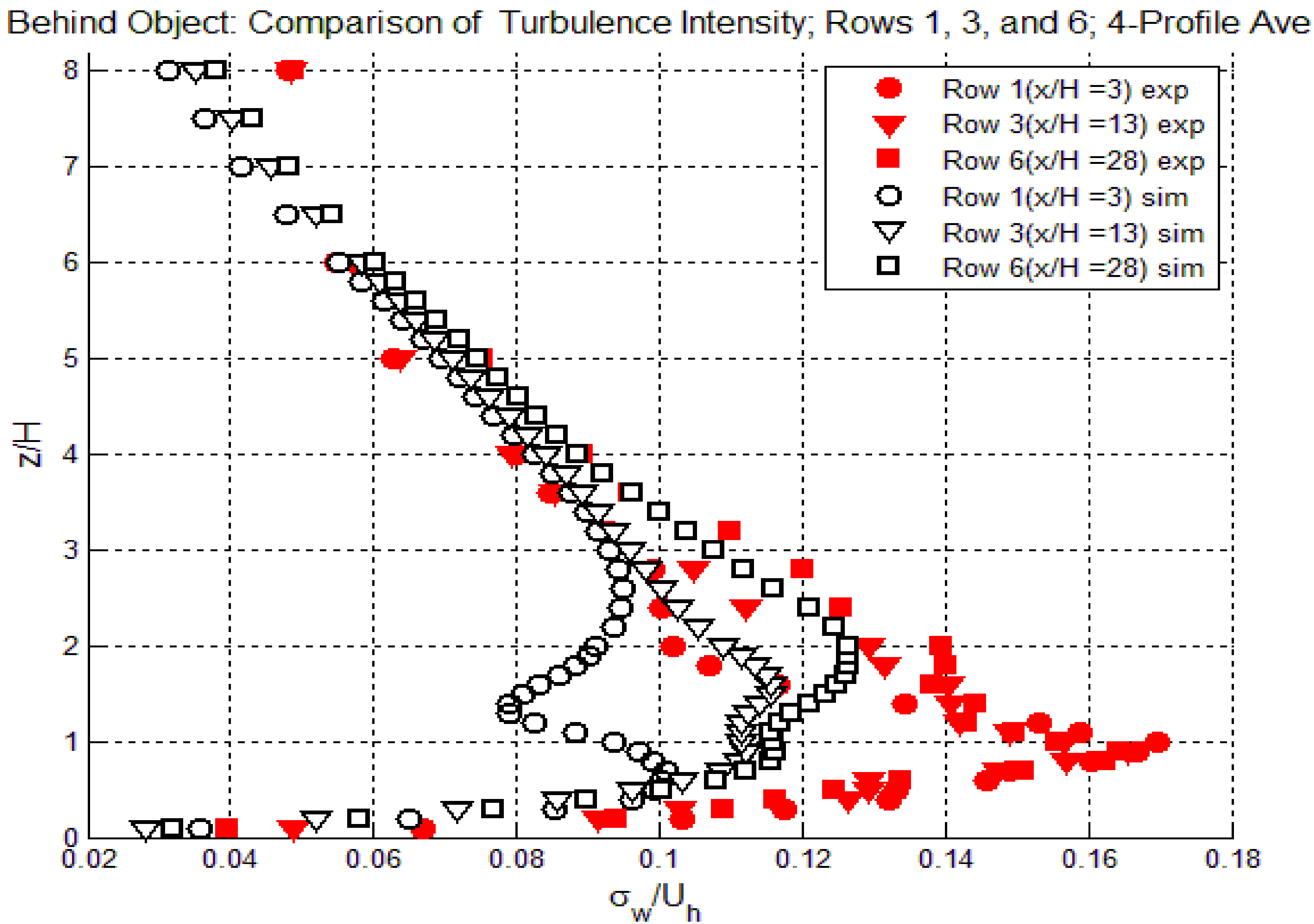
# Comparison of normalized u-turbulent intensity behind rows 1, 3, and 6



# Comparison of normalized v-turbulent intensity behind rows 1, 3, and 6



# Comparison of normalized w-turbulent intensity behind rows 1, 3, and 6



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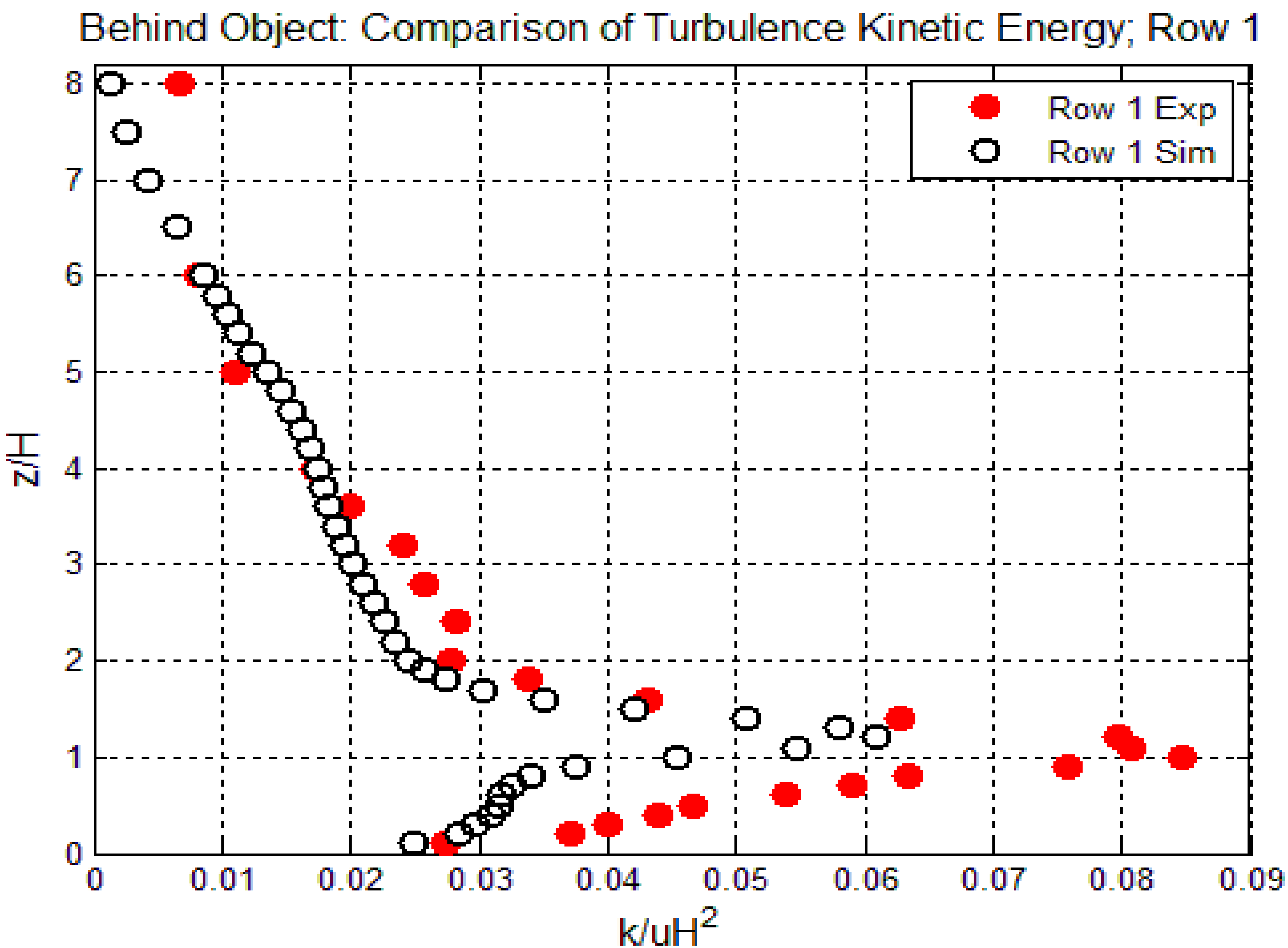
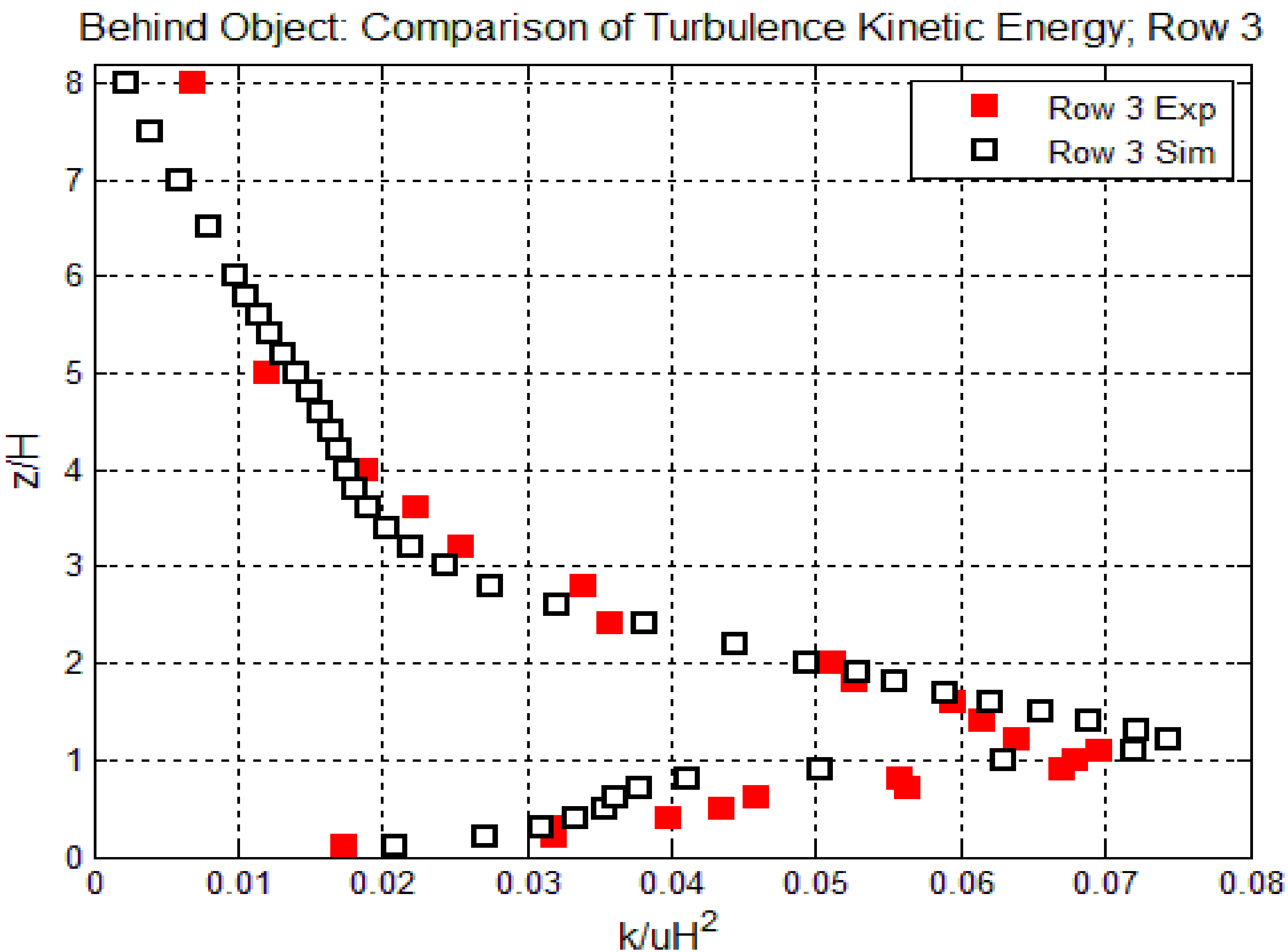
# IABO
# Rows 1, 3, and 6
# Turbulent Kinetic Energy

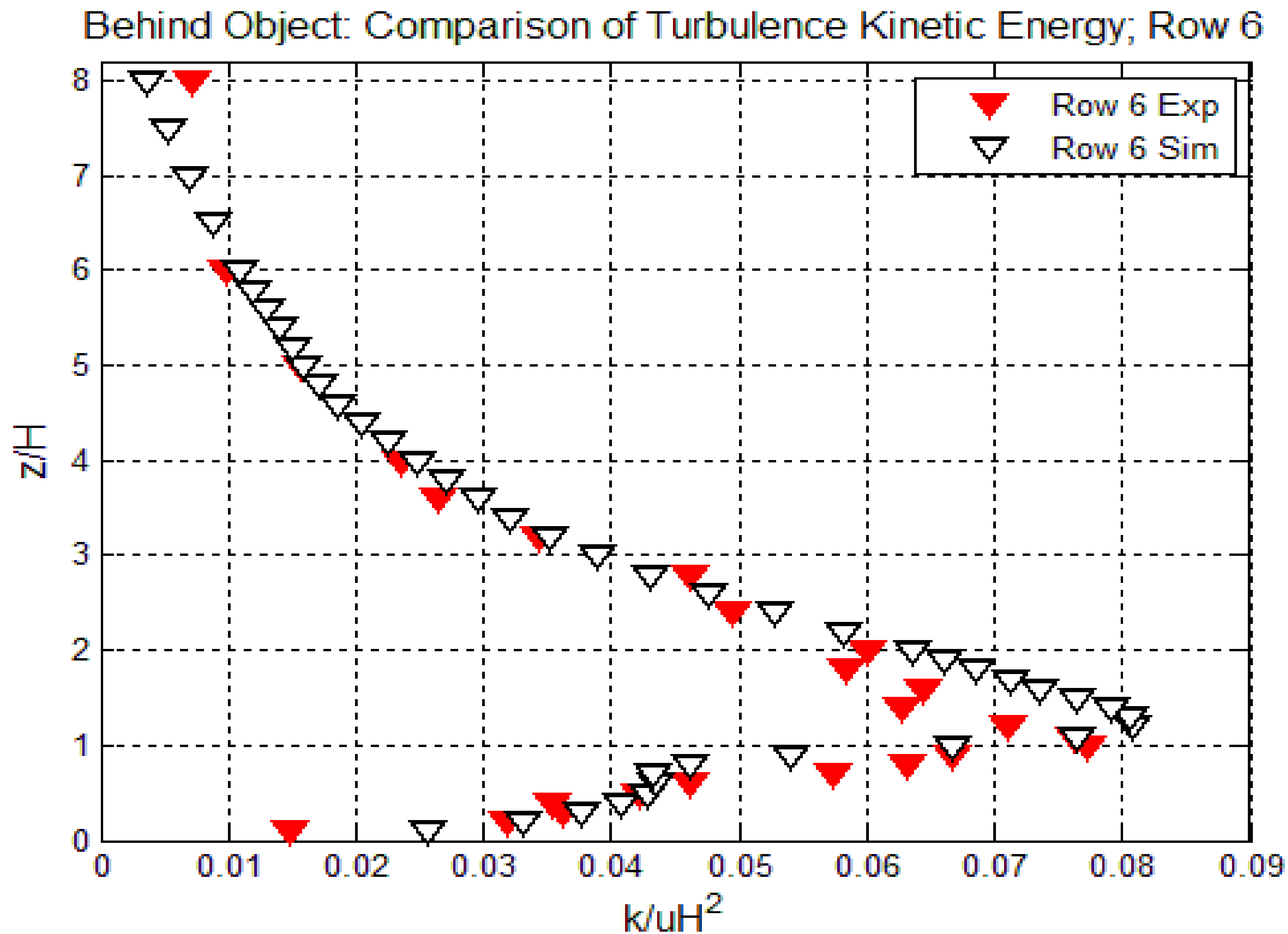
# Comparison of normalized turbulence kinetic energy profiles behind row 1



# Comparison of normalized turbulence kinetic energy profiles behind row 3



# Comparison of normalized turbulence kinetic energy profiles behind 6



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# Dispersion Comparison
# IABO

# Comparison of lateral normalized temperature profiles of a plume IABO, 0 degrees, row 3, for heights z/H =0.1, 0.6, 1.0, and 2.4