Drag Reduction Using Superhydrophobic Surfaces

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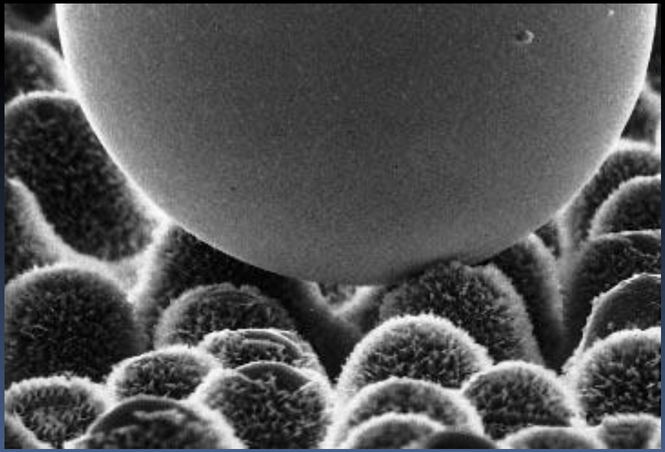
Superhydrophobicity

Hydrophobic surface = water hating

- Result of surface/liquid chemistry.
- Contact angles up to 120 degrees.

Superhydrophobic surface = really water hating

- Result of surface structures and some chemistry.
- Contact angles up to 178 degrees.
- Ultrahydrophobic means the same thing.



Drag

Droplets roll VERY easily off of superhydrophobic surfaces…

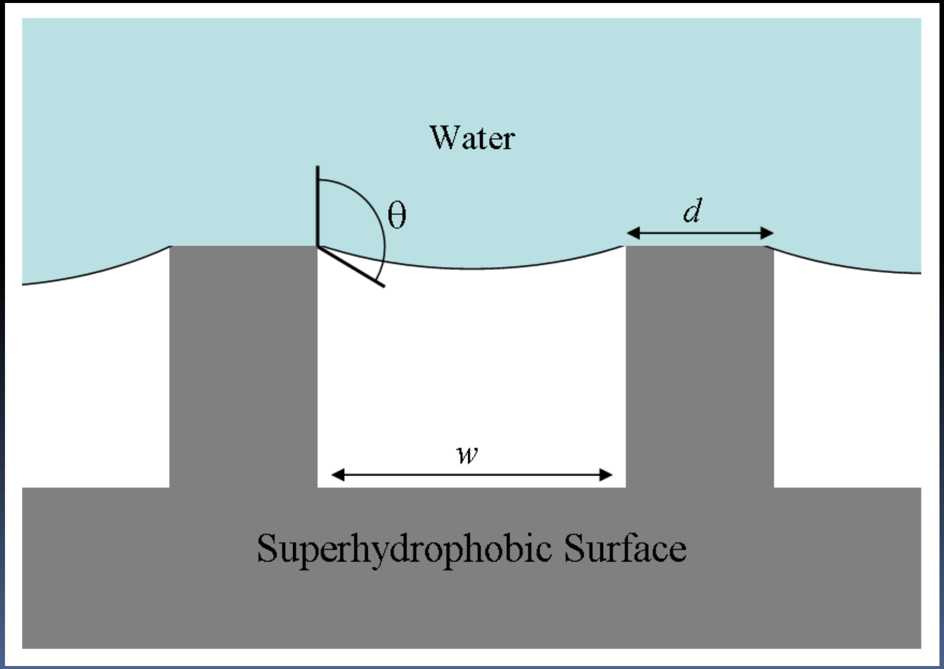
Does everything slide off superhydrophobic surfaces easily?

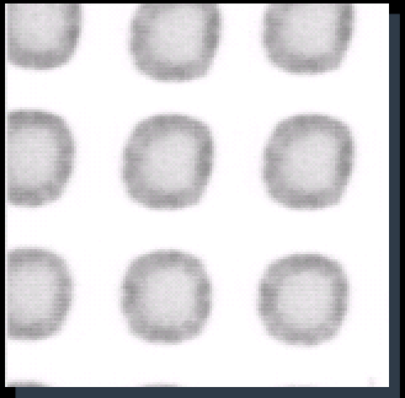
Suezmax Crude Carrier
25% drag reduction
= $5500 per day

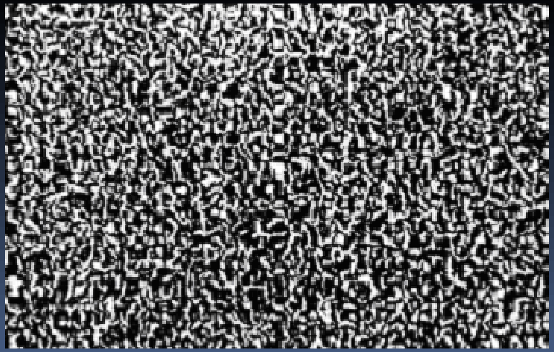
How it Works

(1) Take a rough surface.
(2) Chemically treat it to hate water.

Now the water will make vapor pockets on the surface.

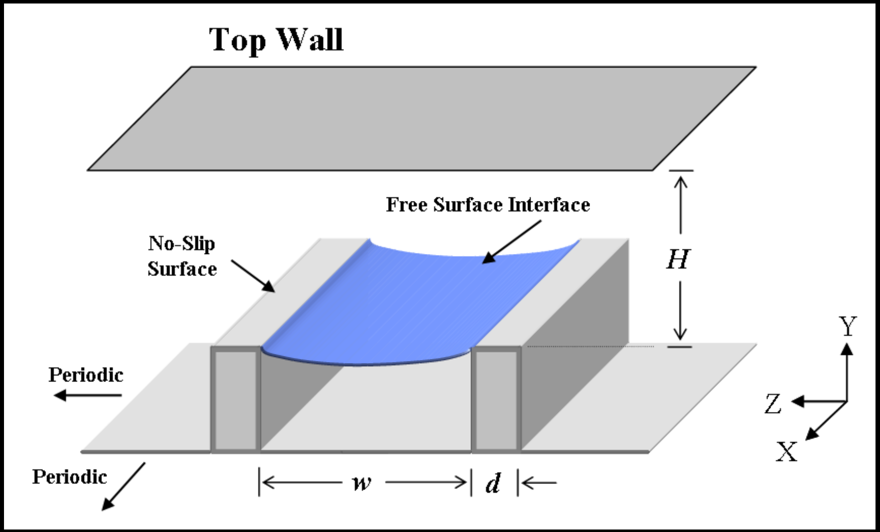




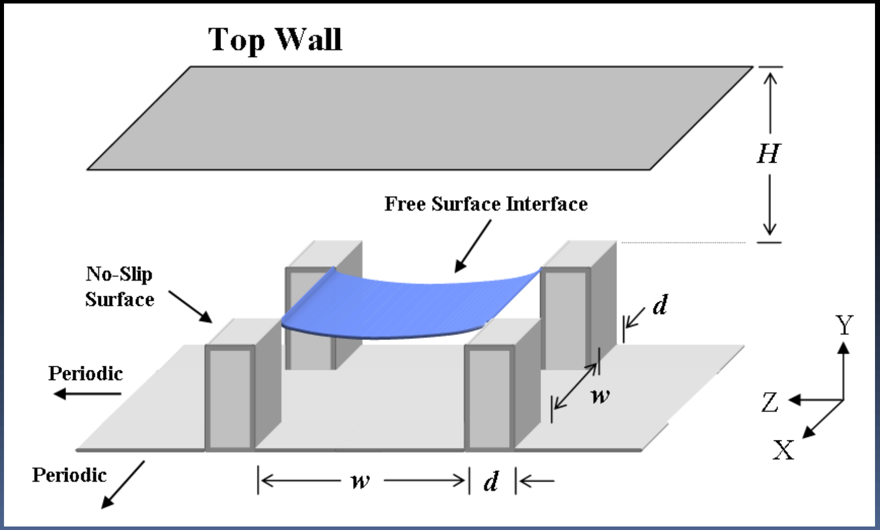


Configuration

Ridges



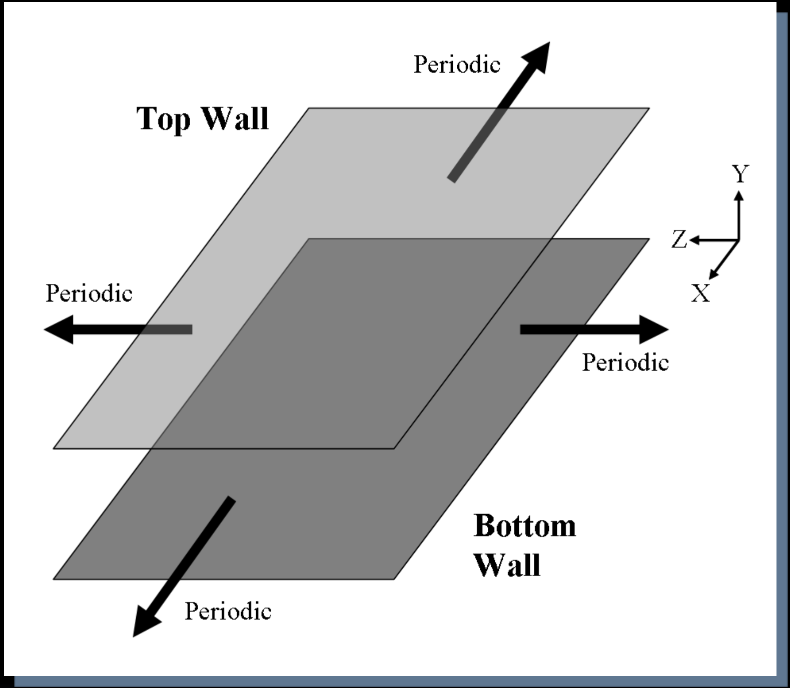
Posts

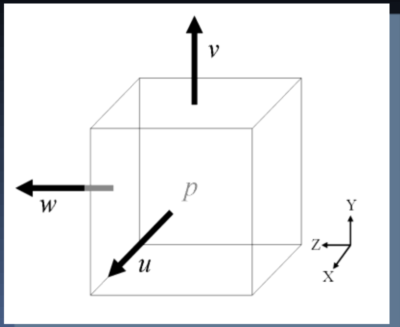


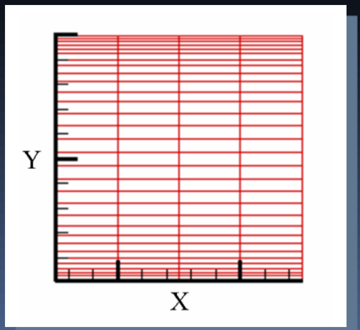
- Flat Surface
- Just Calculate the Water
- No-slip on posts/ridges
- Slip on surface
- w = spacing
- d = size

Computational Setup

- Constant pressure gradient
- Periodic in 2 directions
- Staggered Mesh (2^{nd} order)
- Exact Fractional Step for Incompressibility/Pressure
- Locally conserves mass, momentum, vorticity, and kinetic energy
- 3-step low-storage Runge-Kutta
- Runs in Parallel and on GPUs







Hardware

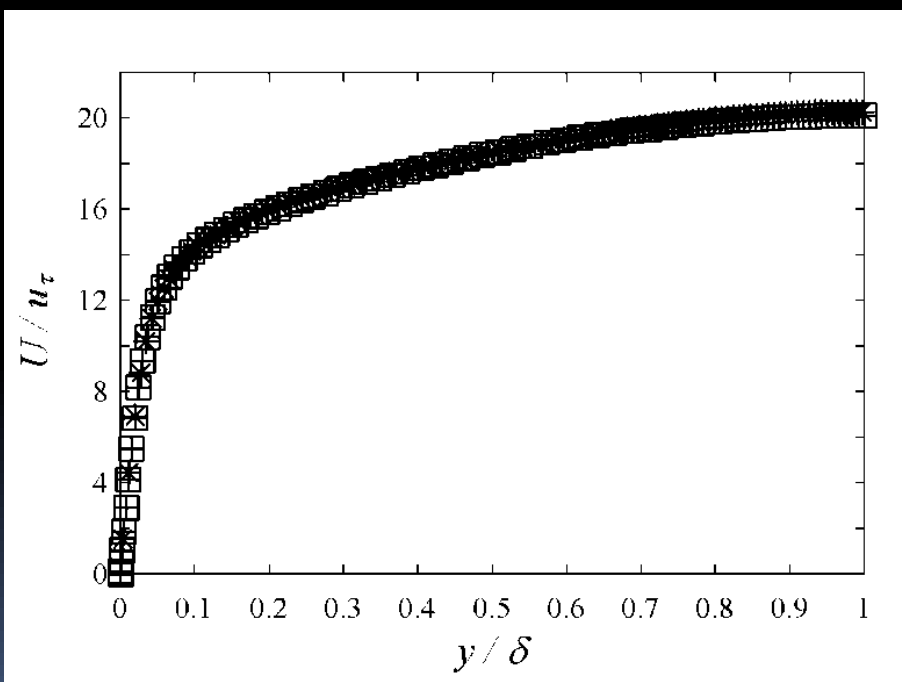
Midnight:
- Alaska
- Opteron Cluster

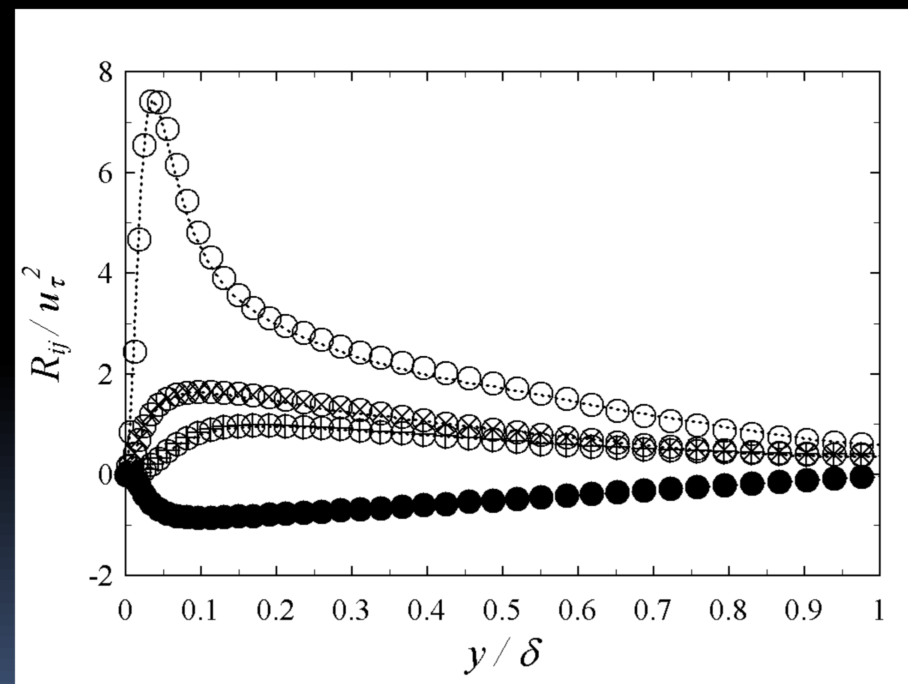
Orion:
- Local
- 8 GPUs
- 1924 Cores
- ~200x 1 CPU core
- 7.2 GB (256x256x512)
- $4000 total

Validation

$$\mathrm{Re}_\tau = 395$$

Regular Channel
Resolution of 256^3
Symbols = Moser et al.
Lines = current simulations.

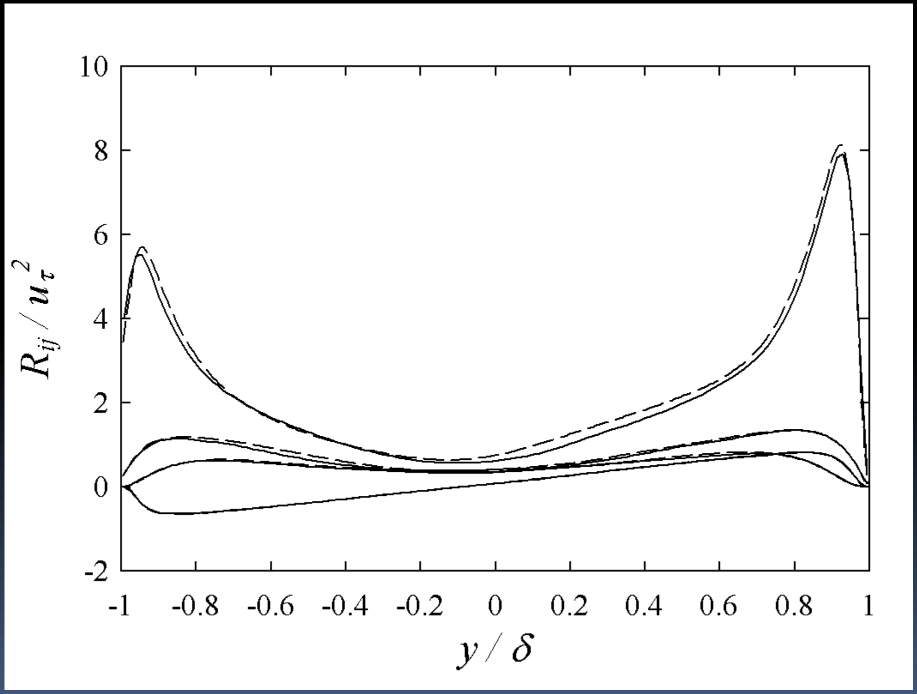


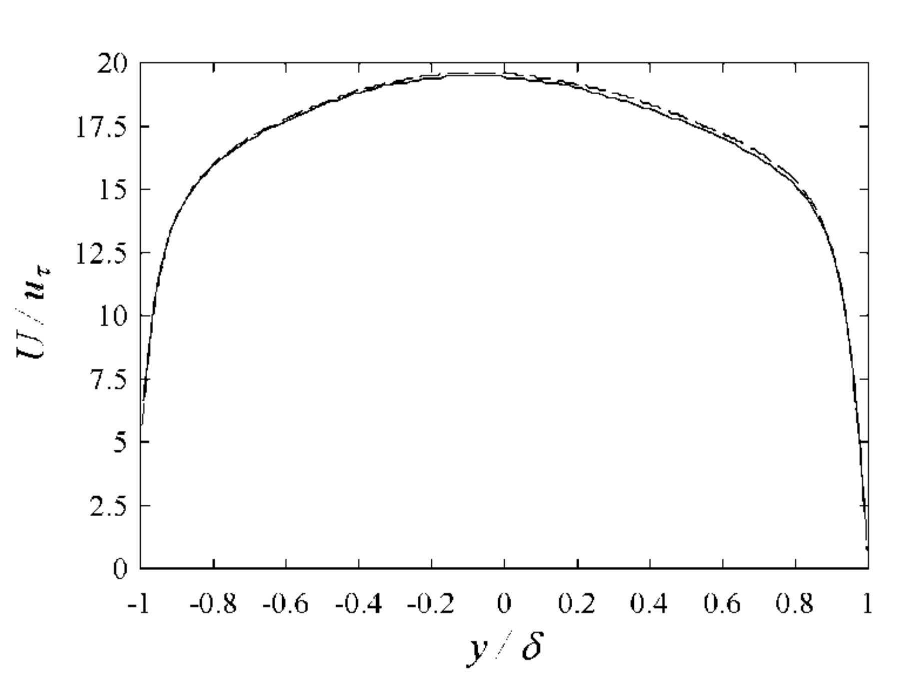


Resolution

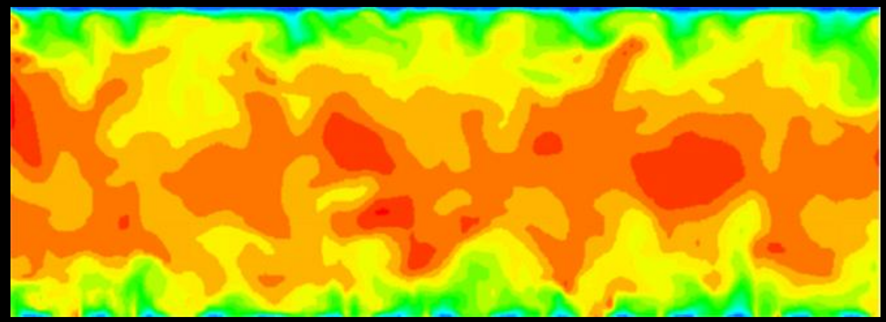
$$\mathrm{Re}_\tau = 180$$

Ridges
Resolution of 128^3 and 256^3
$d^+ = w^+ = 34$
8 (or 16) mesh points per ridge (or gap)

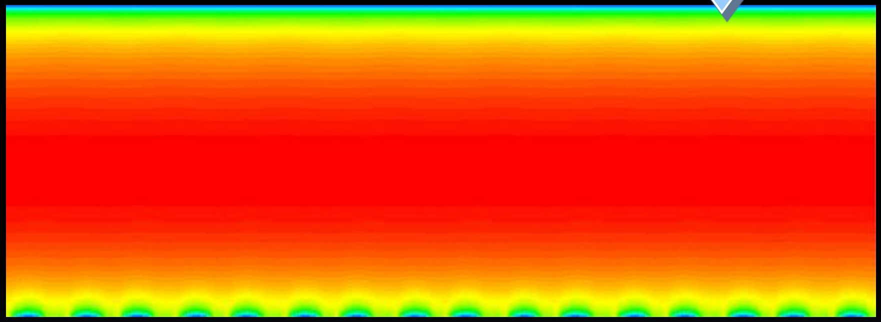




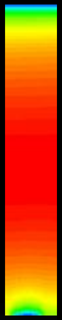
Averaging



time average

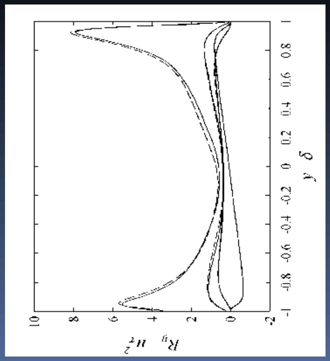


ensemble average

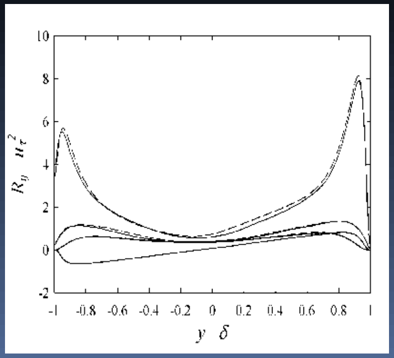


Statistic Here

planar average



rotate



Cases

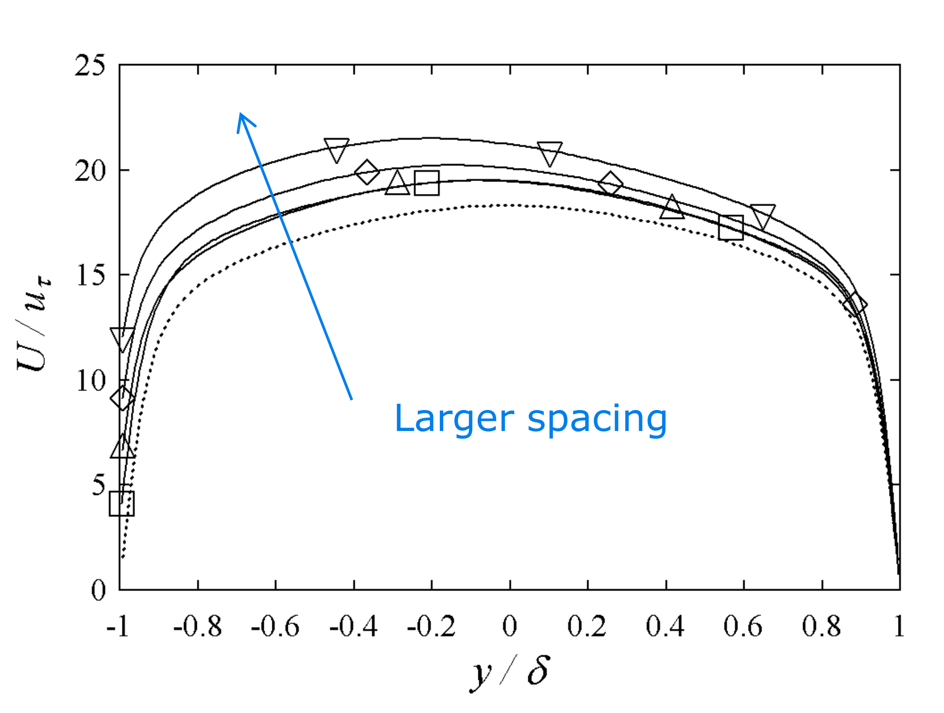
Shape
Size
Spacing
Re

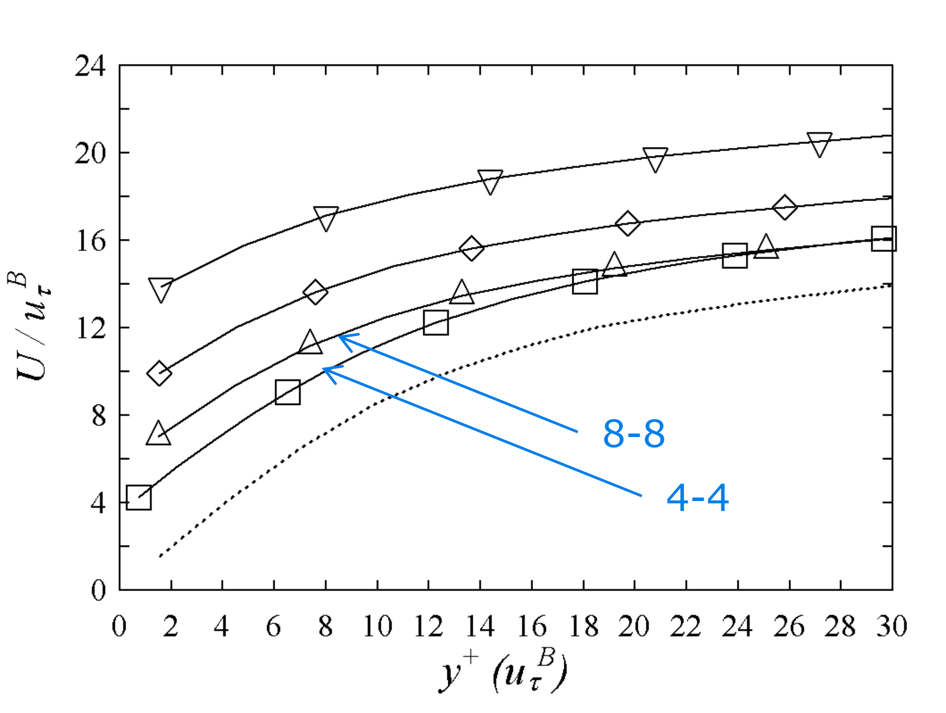
Line Types	
$Re_\tau \sim 180$	
$Re_\tau \sim 395$	
$Re_\tau \sim 590$	
Smooth (all)	

Geometries, Symbols, and Reynolds Numbers				
Case	**Symbol**	$Re_\tau \sim 180$	$Re_\tau \sim 395$	$Re_\tau \sim 590$
4 - 4 ridges	□	✓	✓	
8 - 8 ridges	△	✓	✓	✓
8 - 13 ridges	◇	✓		
8 - 24 ridges	▽	✓		
8 - 8 posts	▲	✓		
8 - 13 posts	◆	✓		
8 - 24 posts	▼	✓	✓	✓

Spacing

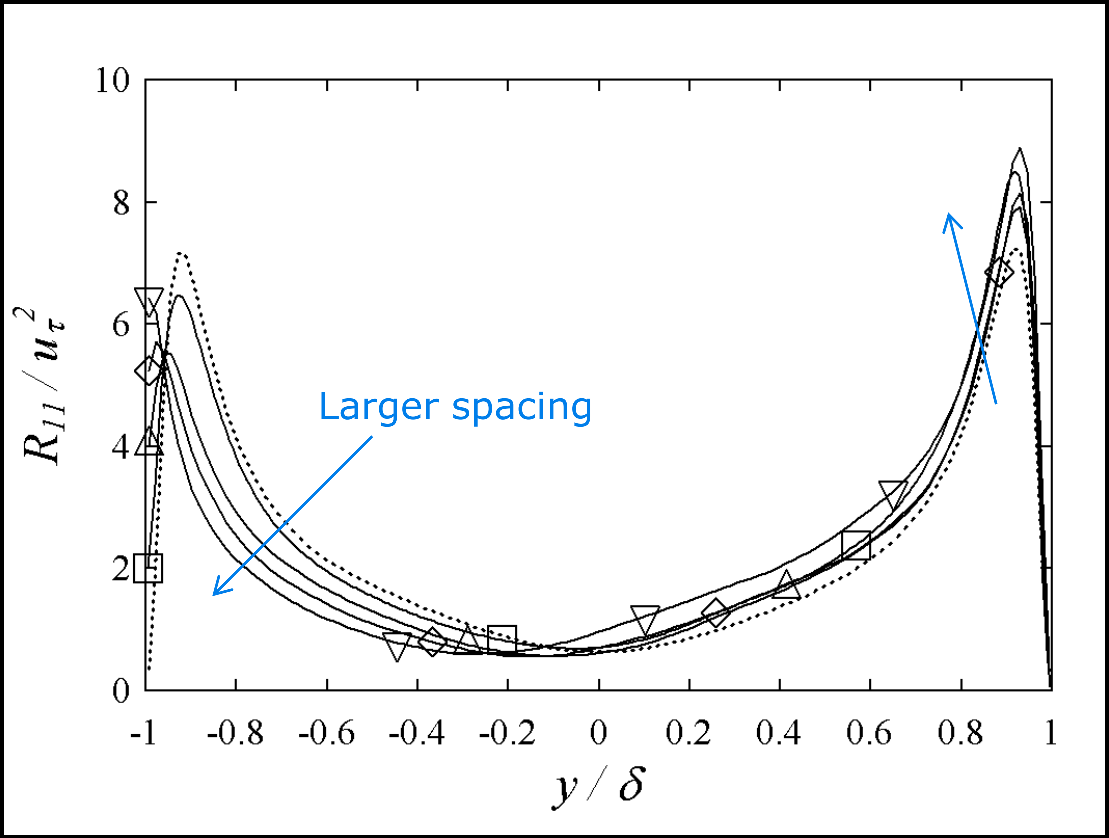
Ridges $\mathrm{Re}_\tau = 180$
Velocity

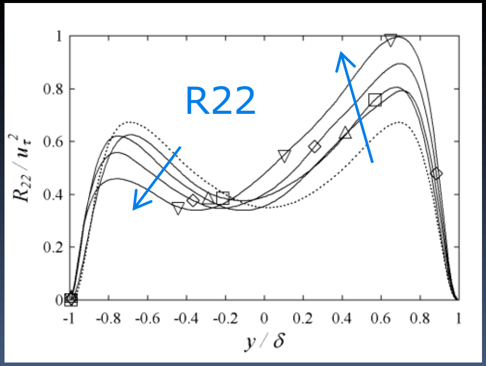


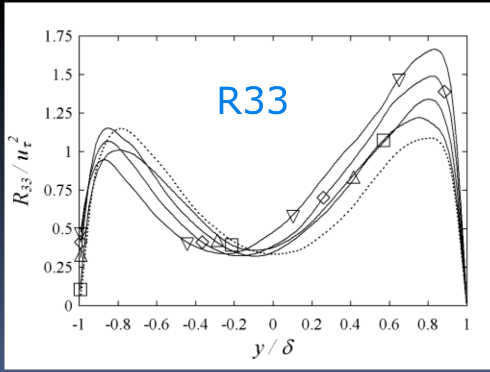


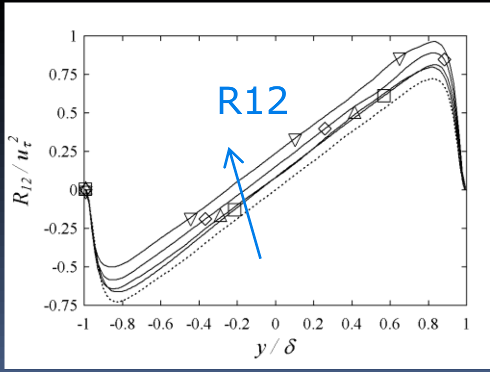
Spacing

Ridges $\mathrm{Re}_\tau = 180$
Turbulence







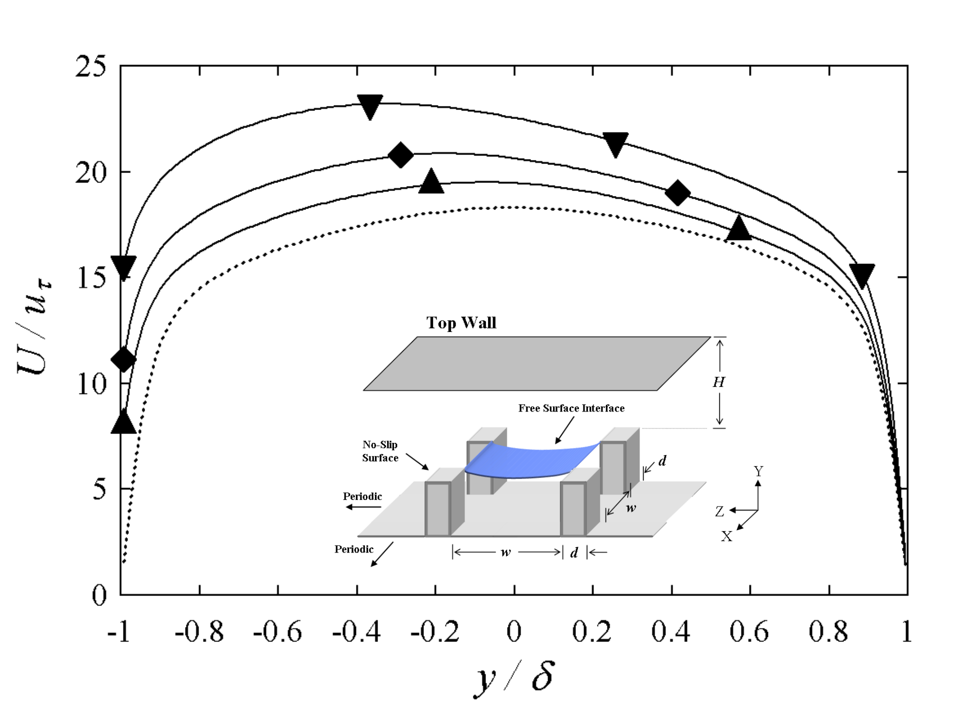


Shape

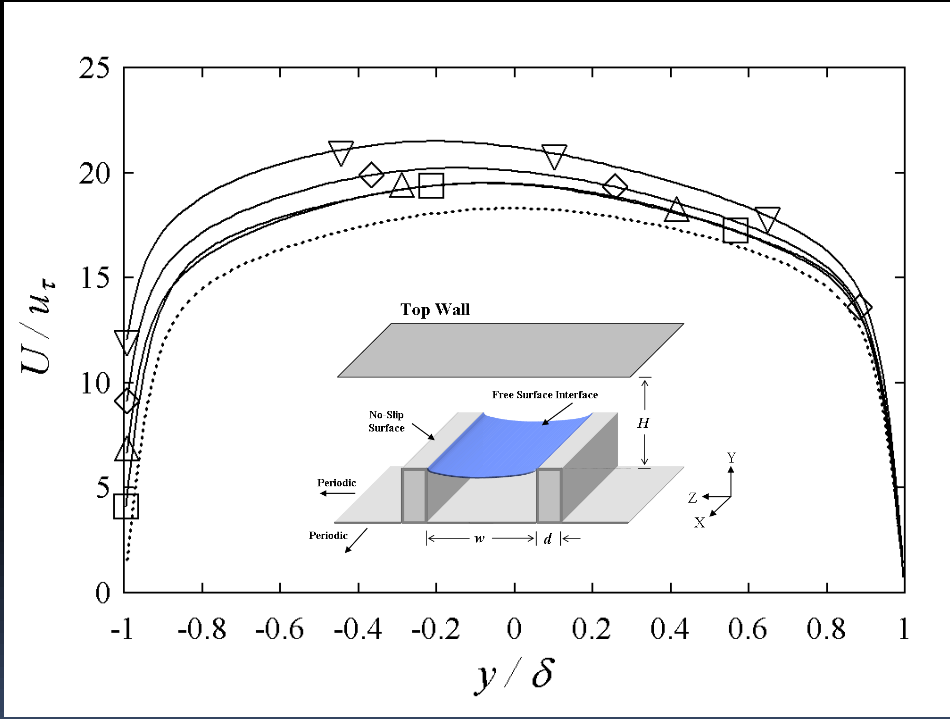
$$\mathrm{Re}_\tau = 180$$

Velocity

Posts

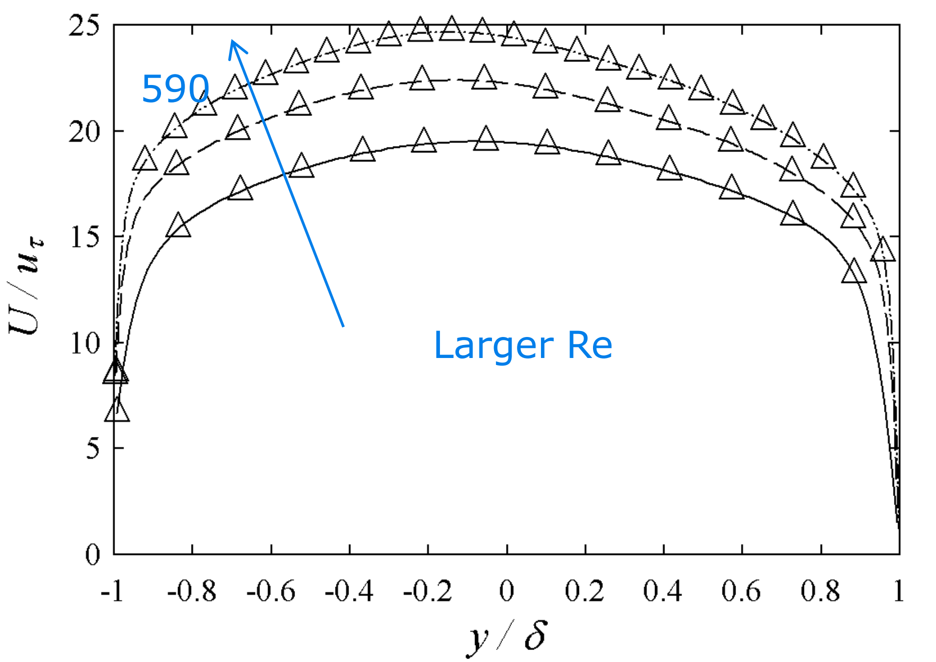


Ridges

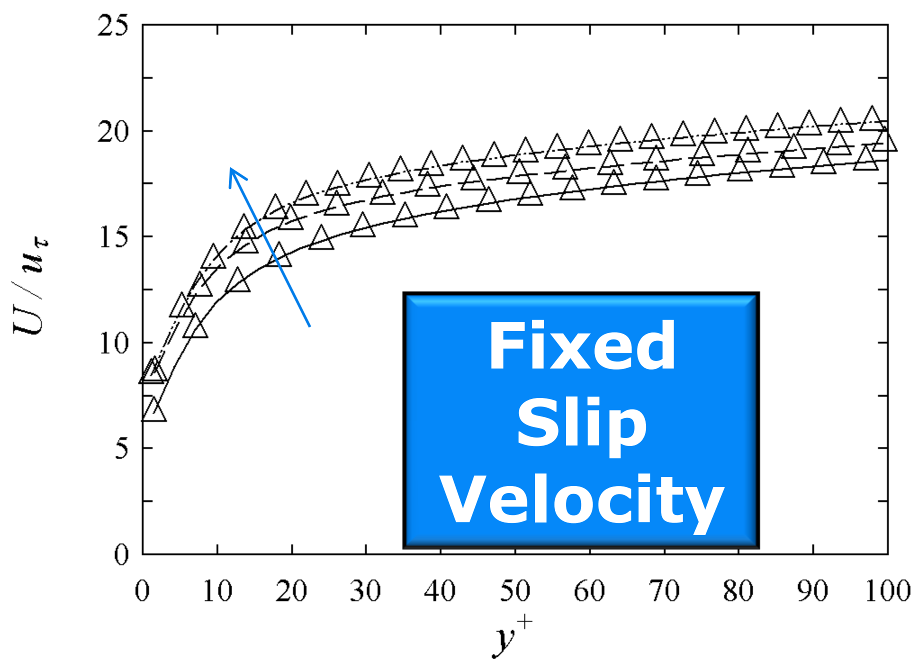


Reynolds Number

Velocity
8-8 Ridges

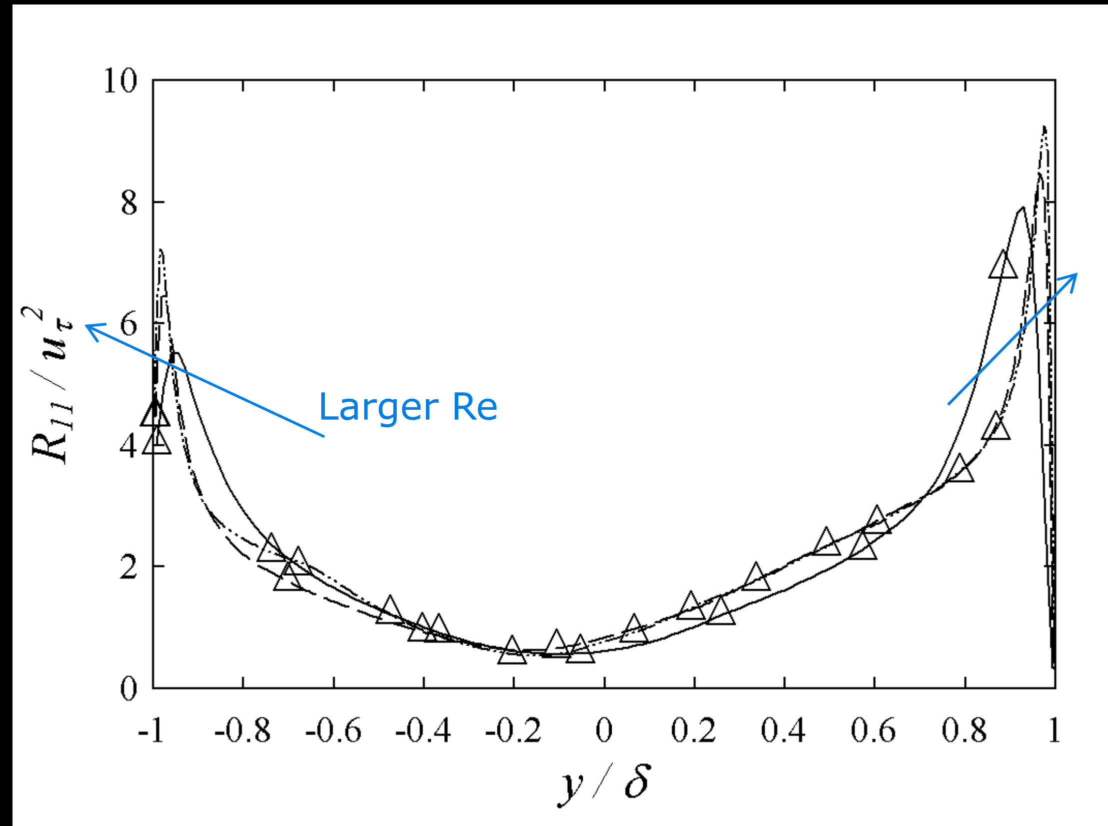


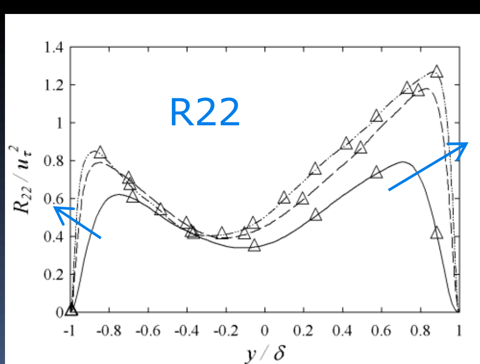
Posts Look the Same

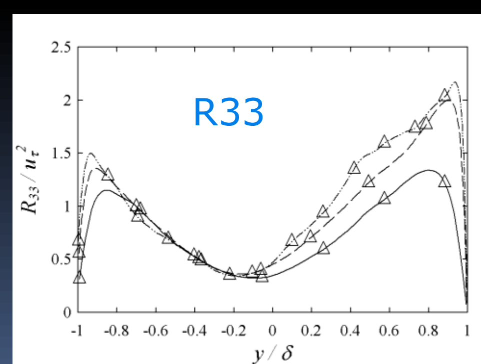


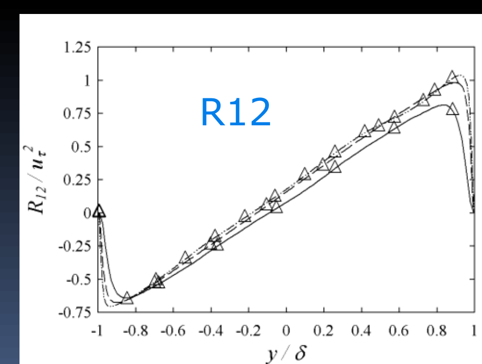
Reynolds Number

Turbulence
8-8 Ridges



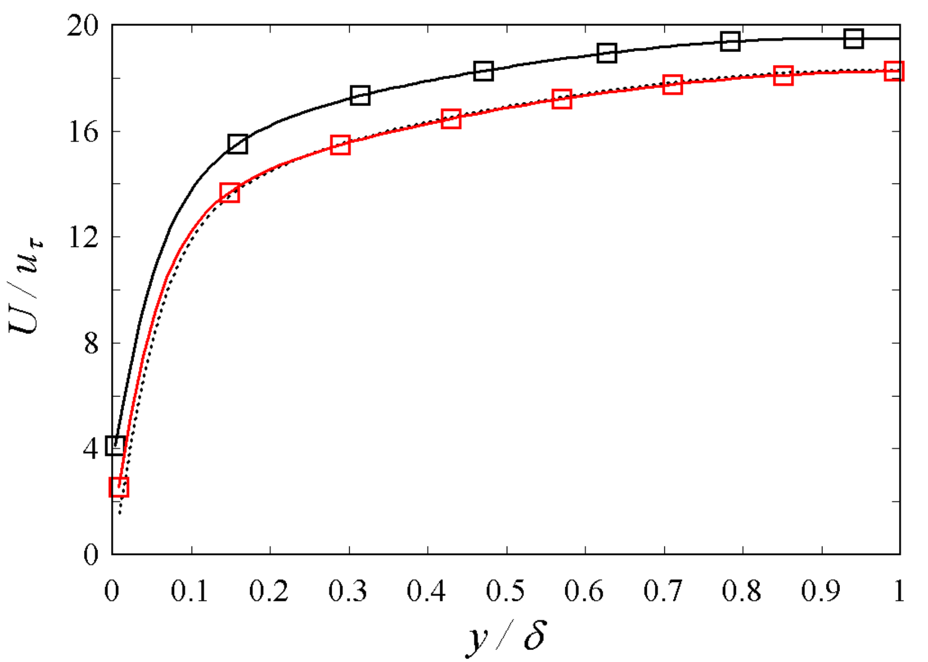




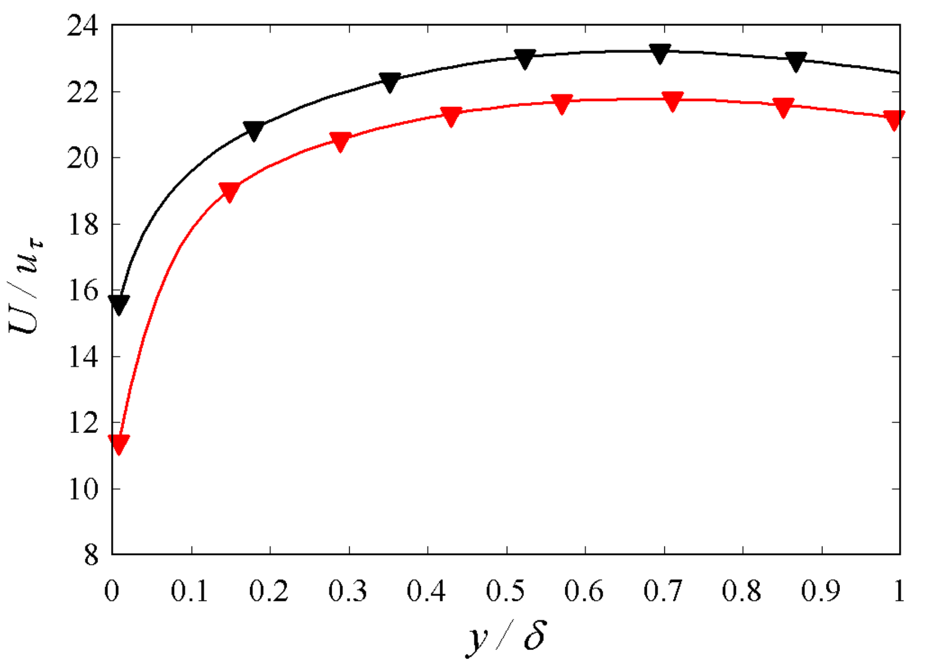


Angle

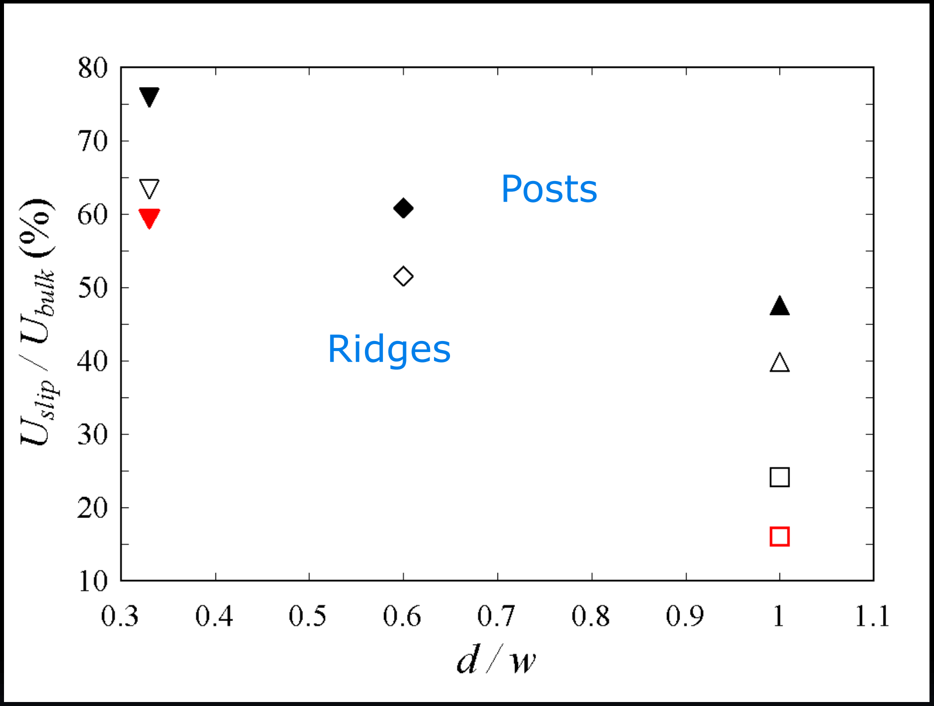
Velocity
4-4 Ridges
Transverse Dierection



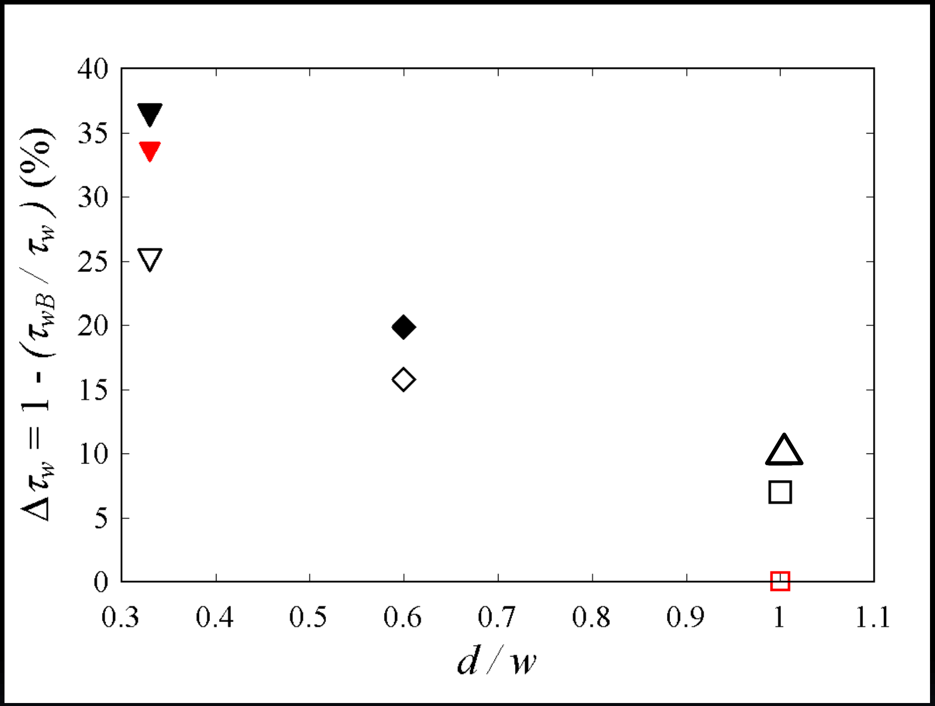
Velocity
8-24 Posts
17.5 degrees



Overview



Slip



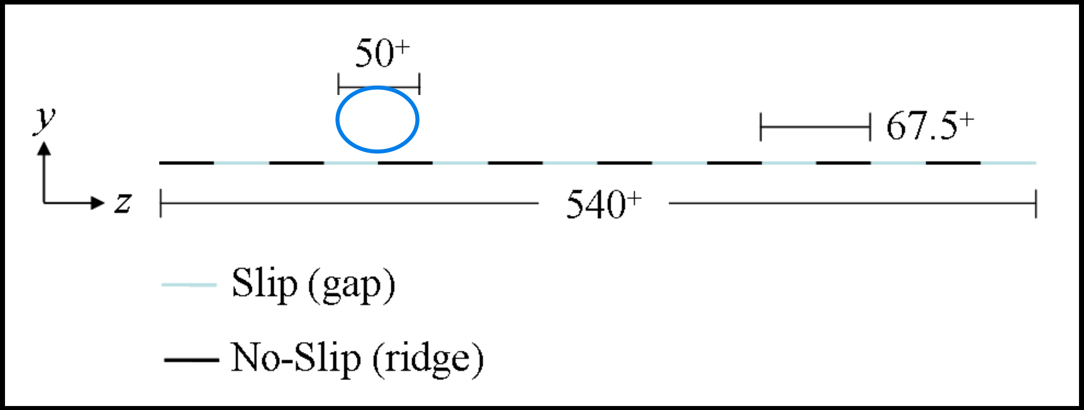
Drag

Best = Aligned posts with large spacing
Chemistry is not very important

Structures

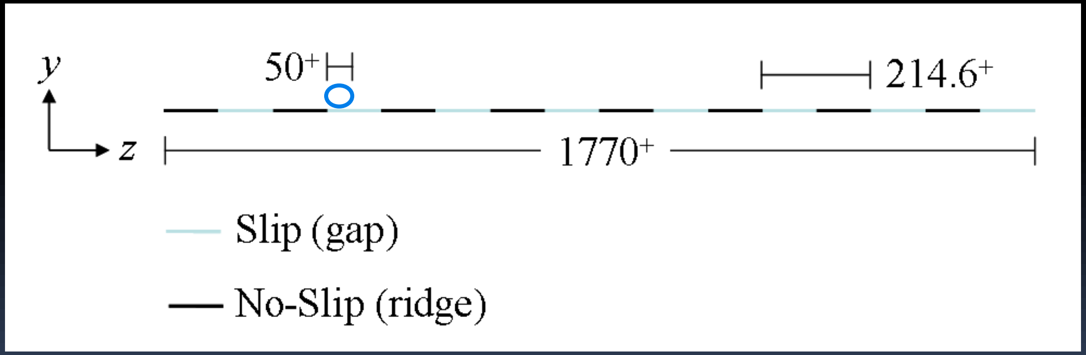
$$Re_\tau = 180$$

8-8 Ridges
(8 of them)



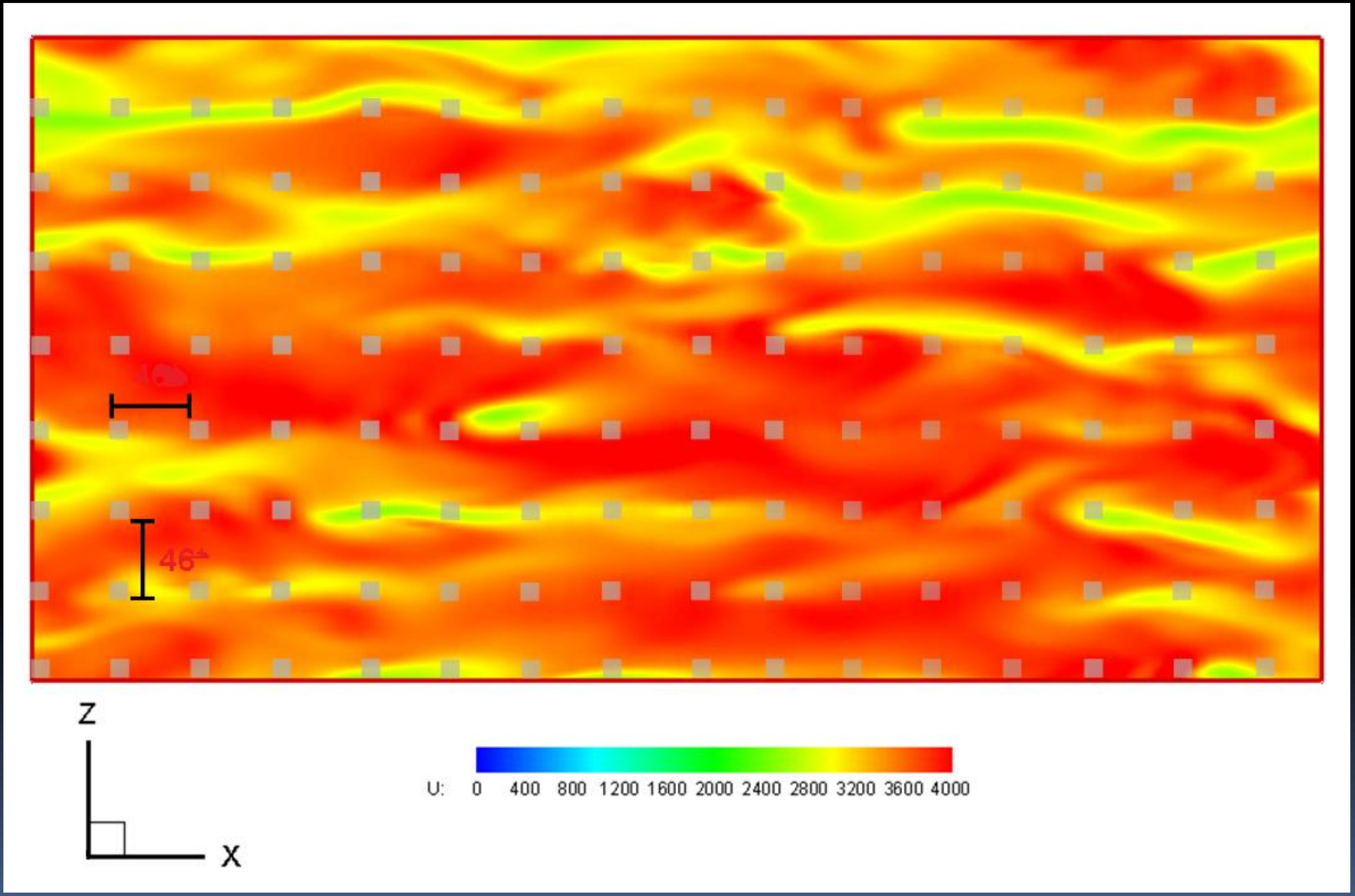
$$Re_\tau = 590$$

8-8 Ridges
(resolution of 32-32)



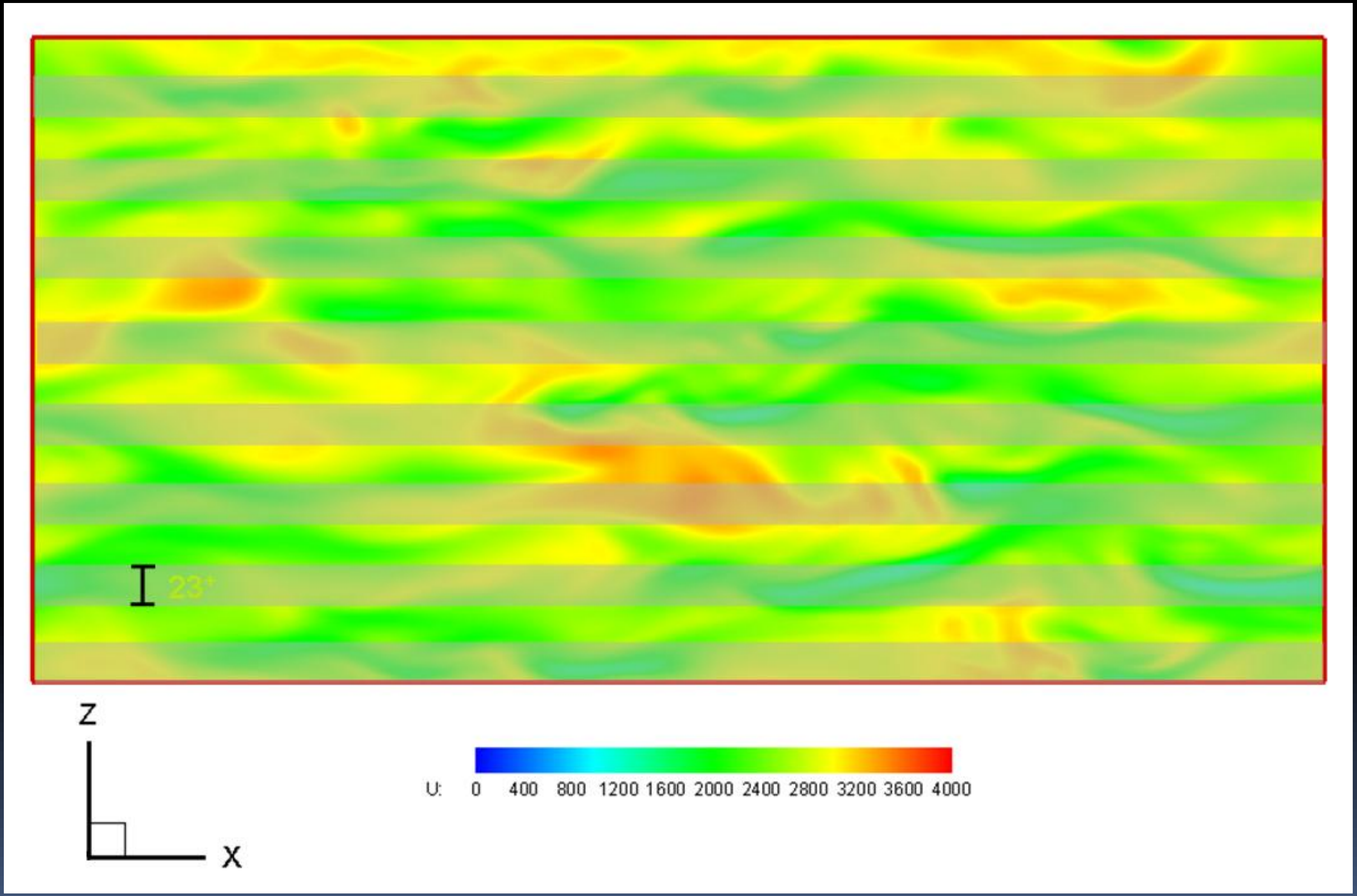
Flow Field

8-24 posts $\mathrm{Re}_\tau = 180$



Flow Field

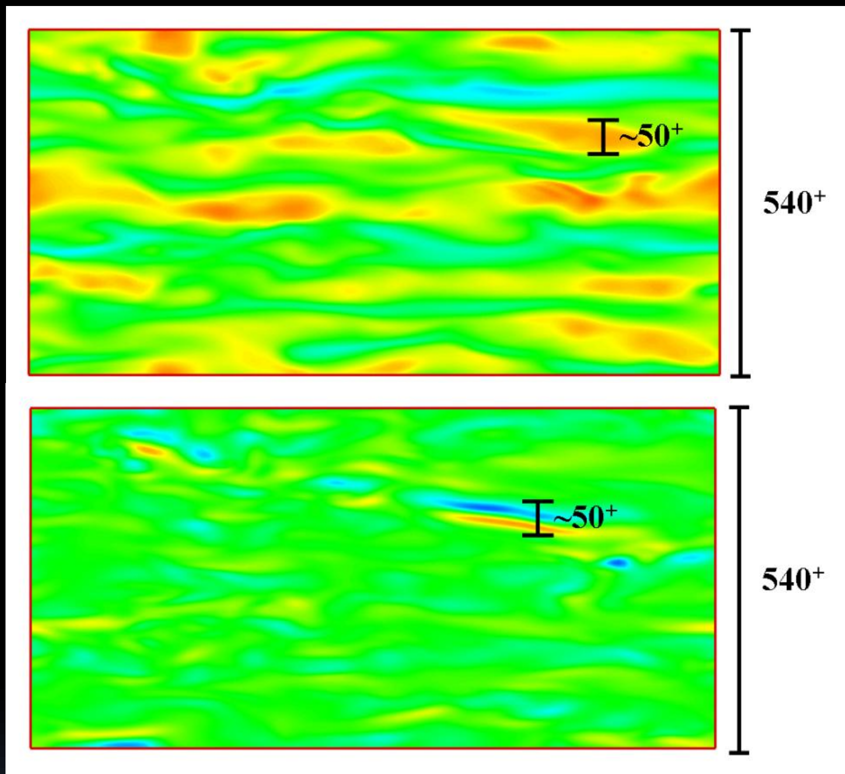
8-8 ridges $\mathrm{Re}_{\tau} = 180$

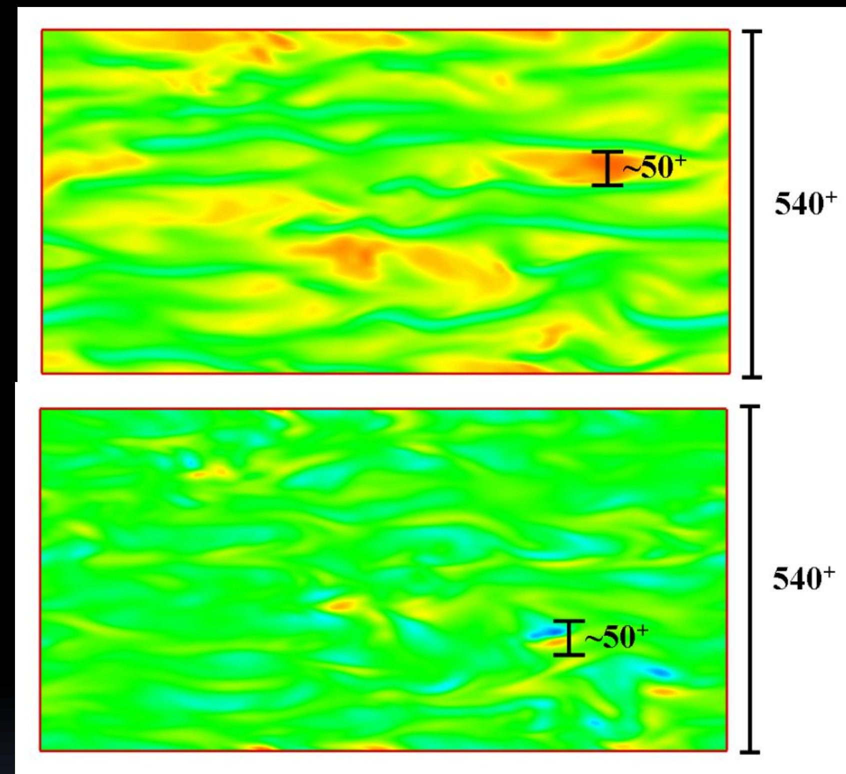


Flow Field

U

V



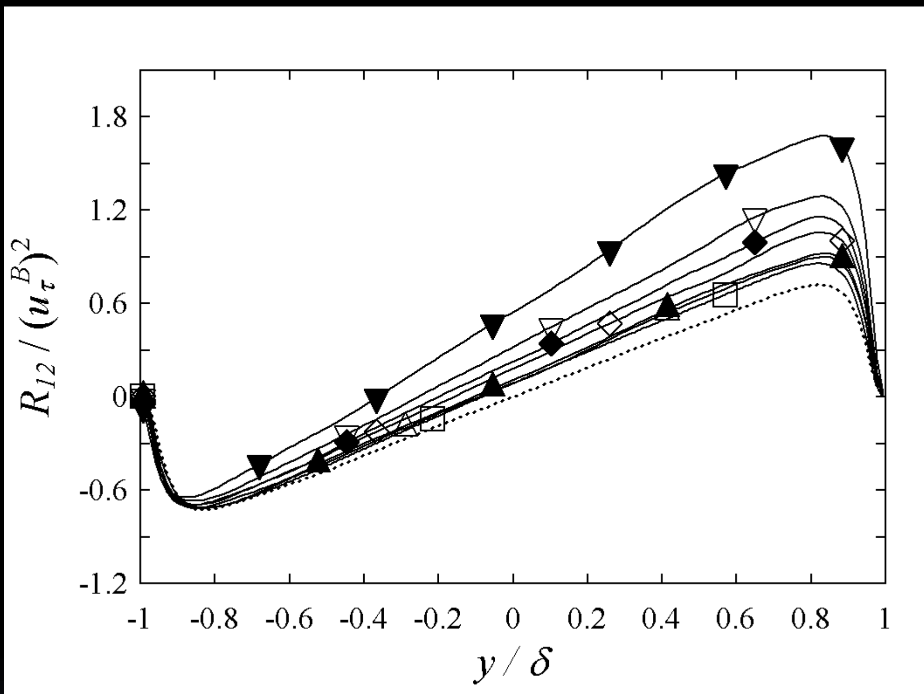


Regular Channel
y+ = 21

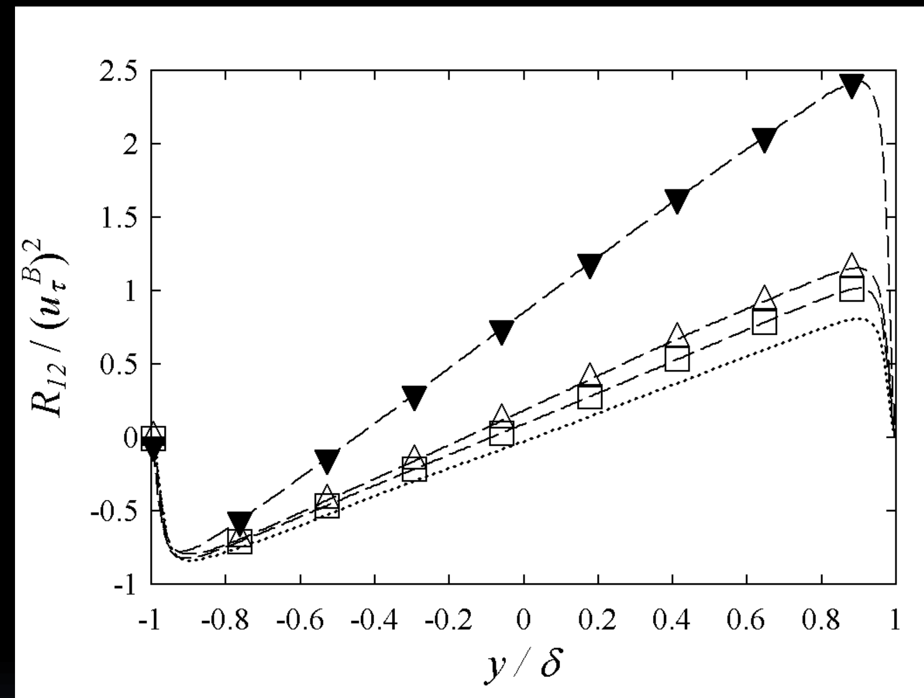
8-8 Ridges
y+ = 12

Same Shear

Shear Stress Scaling



$\mathrm{Re}_\tau = 180$



$\mathrm{Re}_\tau = 395$

Scale with the local shear velocity.
Turbulent B.L. still scales the same with odd BCs.

Summary

- Superhydrophobic surfaces reduce drag.
- Spacing matters the most (larger = better).
- Up to 37% drag reduction
- Still behaves very like a turbulent B.L.

Future

- Delayed Transition
- Delayed Separation
- Reduced Fouling
- Effects on Particles
- Macroscopic BCs

www.ecs.umass.edu/mie/tcfd/Publications.html