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Large Eddy Simulation of a confined planar jet opening in a rectangular channel

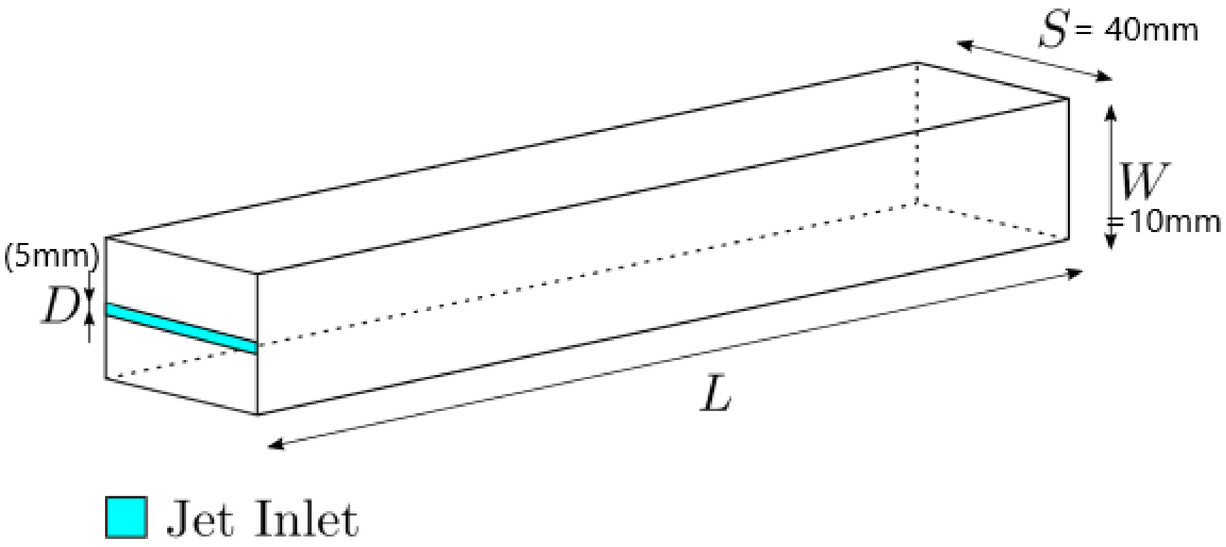


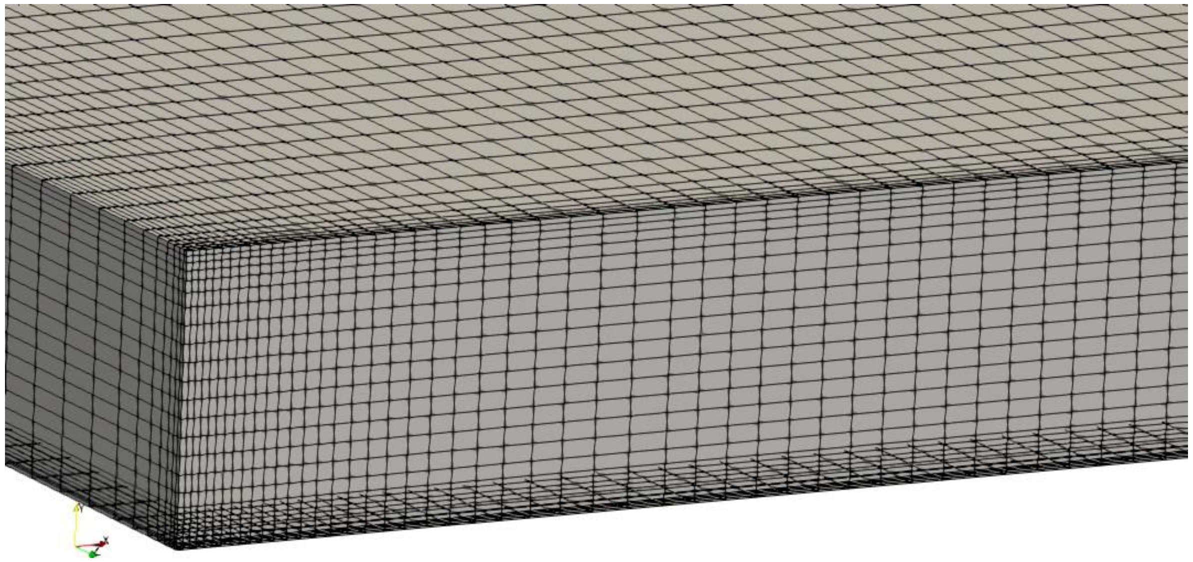
Figure. Schematic of the problem

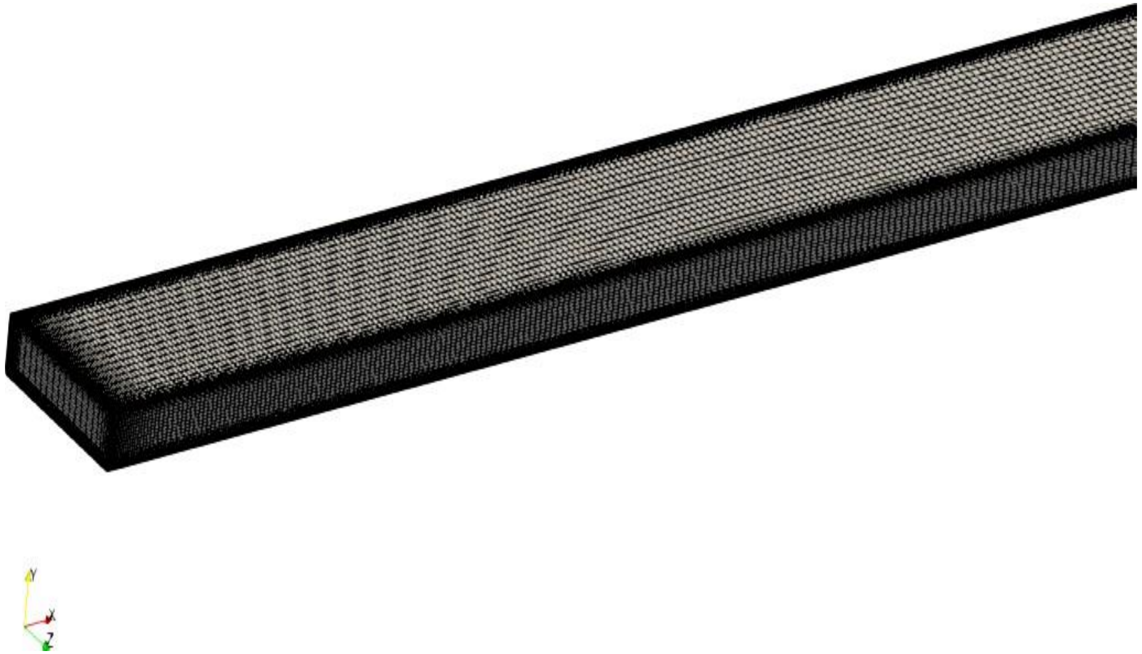
- L is variable → aim to find out L where fully developed turbulent flow is achieved in the channel
- Simulation method: LES (Smagorinsky-Lily, Van Driest damping) using OpenFOAM
- Simulation is to be done for the range of Reynold’s number of 1000-7000

- Simulated Re=1200,1500,1800 & 2400, 5300(ongoing).
- L=1.5m [Lien et al.(2004)→L=150W for fully developed turbulent flow]

Mesh Generation

- Using blockMesh [openfoam inbuilt mesher].
- Δx+=2.5, Δy+=1.1 and Δz+=1.1 [hexahedral cells]





Physical domain [Aspect ratio=4:1]

- x: Longitudinal direction (Mean-flow direction)
- y: Vertical direction (Cross-flow direction)
- z: Spanwise direction

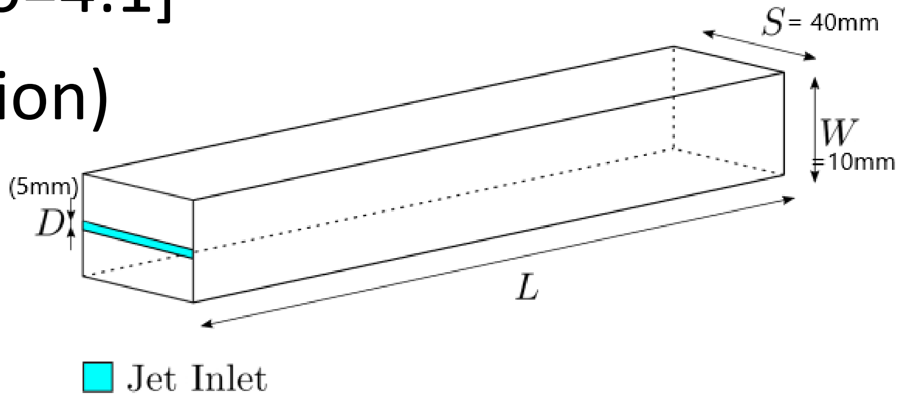


Figure. Schematic of the problem

Initial & Boundary Conditions

- turbulentInlet

→produces spatiotemporal variant pseudo-random no.

[For Re=1200→ $u_{jet} = 3.6m/s$]]

Table 4: Boundary condition for U

Patch	Condition	Value (ms^{-1})
Inlet	turbulentInlet	RMS=0.04
Outlet	inletOutlet	(0, 0, 0)
Top & Bottom	fixedValue	(0, 0, 0)
Front & Back	fixedValue	(0, 0, 0)

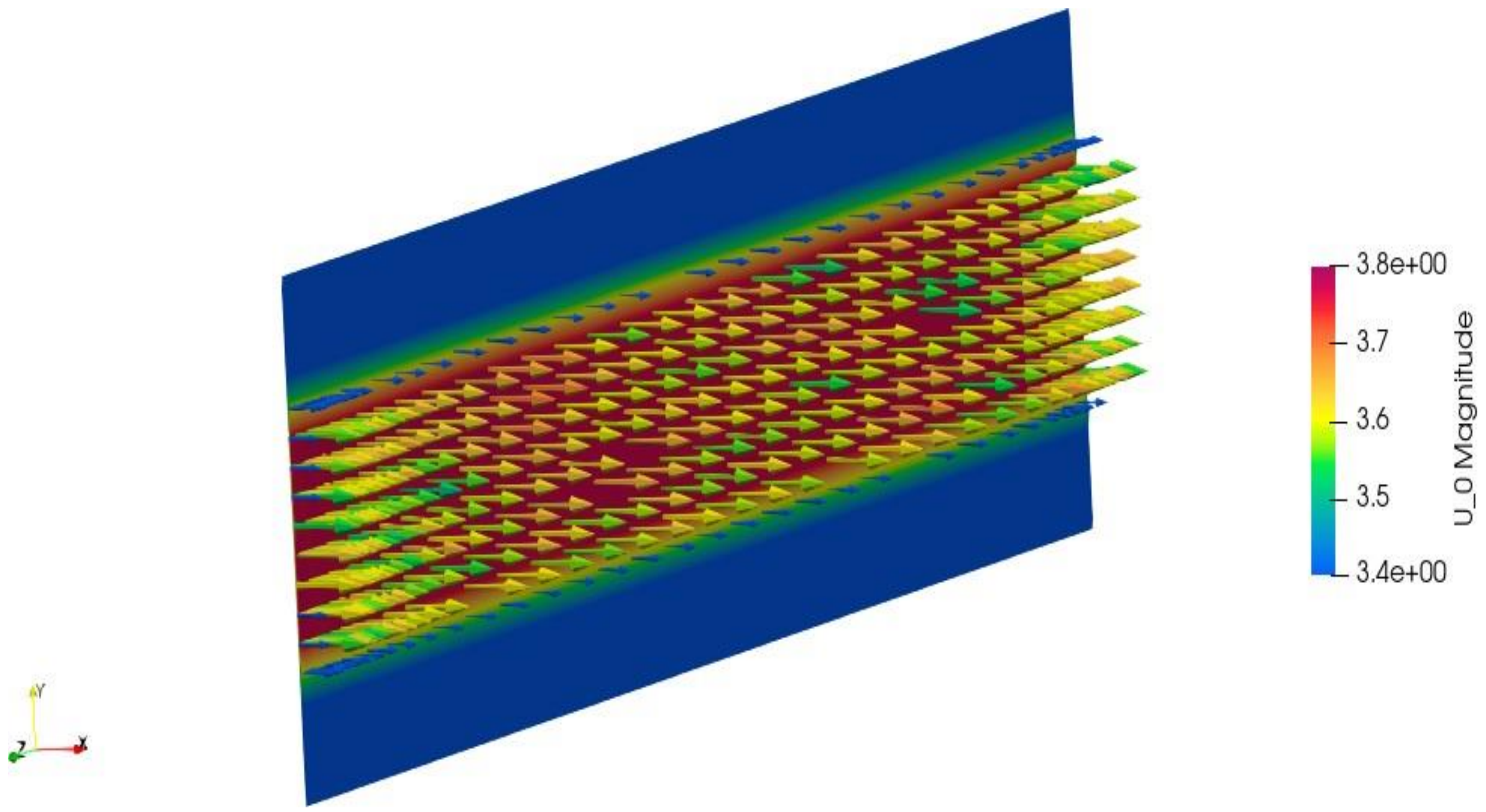

3.8e+00
3.7
3.6
3.5
3.4e+00
U_0 Magnitude
Y
Z
X

Table 5: Boundary condition for p

Patch	Condition	Value (m^2s^{-2})
Inlet	zeroGradient	-
Outlet	fixedValue	0.0
Top &Bottom	zeroGradient	-
Front & Back	zeroGradient	-

Table 6: Boundary condition for nut

Patch	Condition	Value (m^2s^{-1})
Inlet	calculated	-
Outlet	calculated	-
Top &Bottom	zeroGradient	-
Front & Back	zeroGradient	-

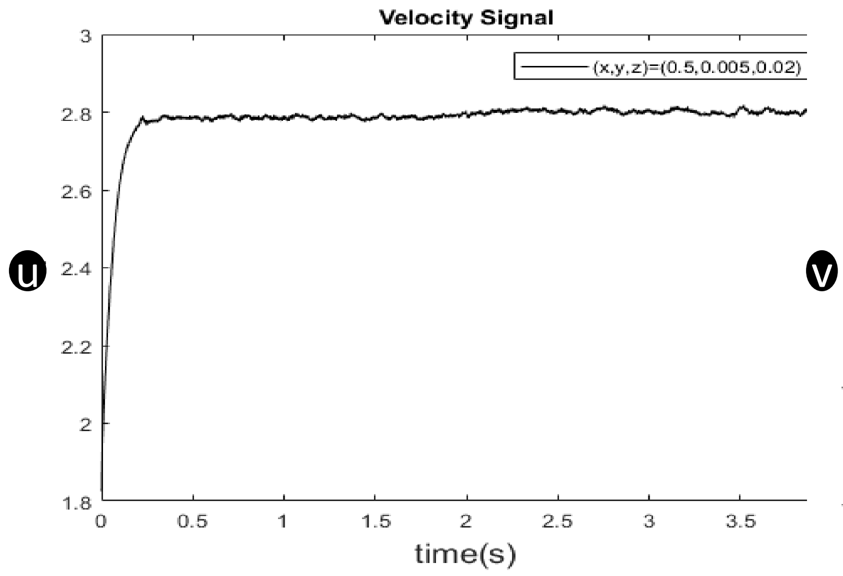
Solver

Table 7: Numerical Solvers

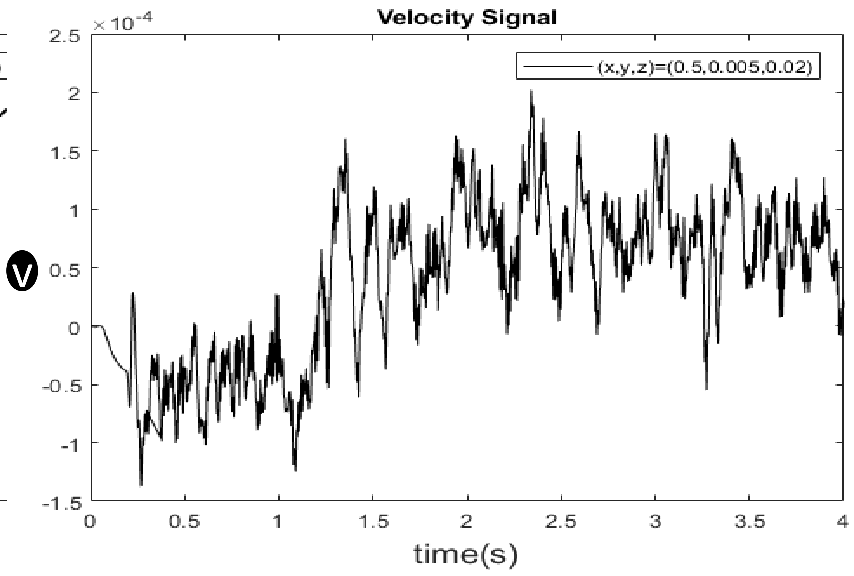
Field	Linear Solver	Smoother	Tolerance
U	Smooth Solvers	Gauss Seidel Smoother	1e-06
p	GAMG Solver	Gauss Seidel Smoother	1e-05
nut	Smooth Solvers	Gauss Seidel Smoother	1e-06

- To solve pressure-velocity coupling in NS eqn→ PimpleFoam

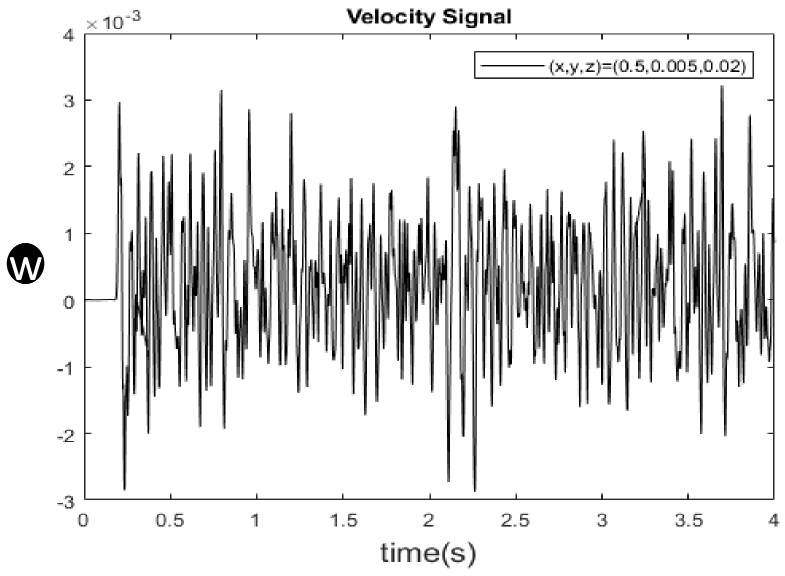
- Re=1200



x-comp of velocity(u)

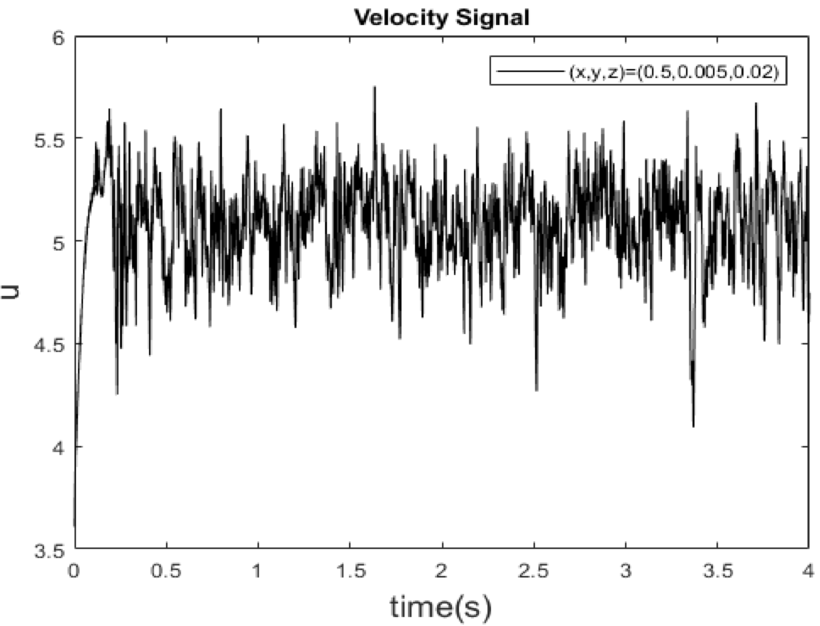


y-comp of velocity(v)

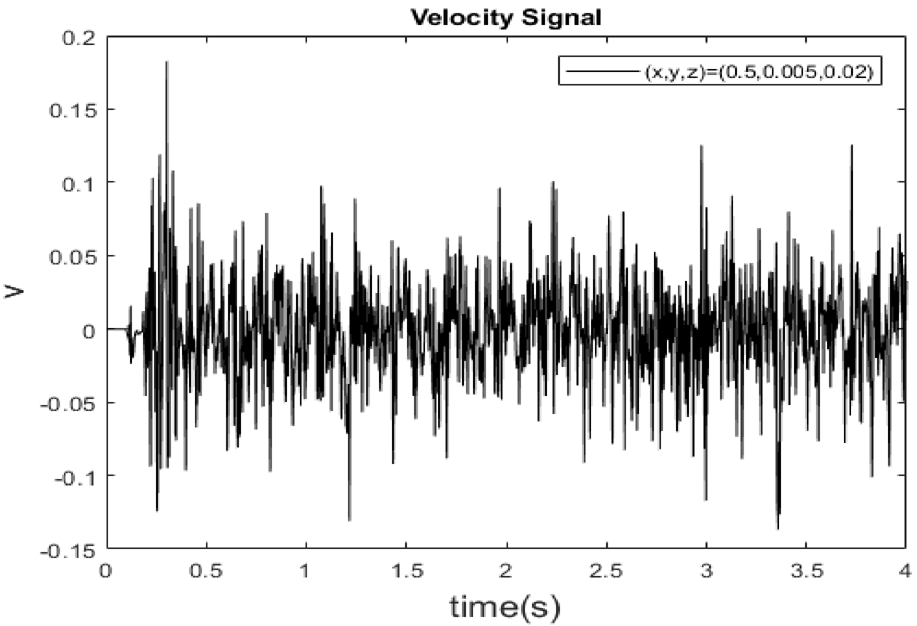


z-comp of velocity(w)

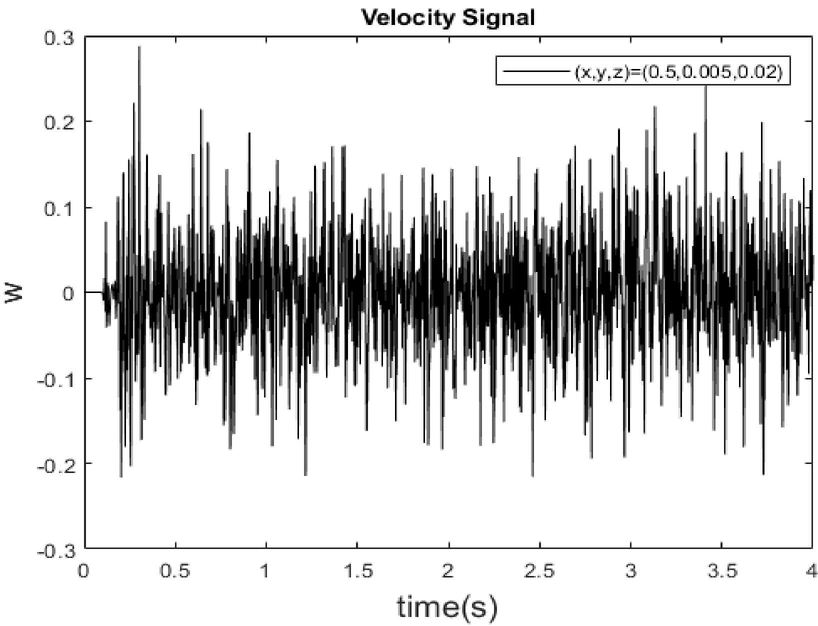
- Re=2400



x-comp of velocity(u)

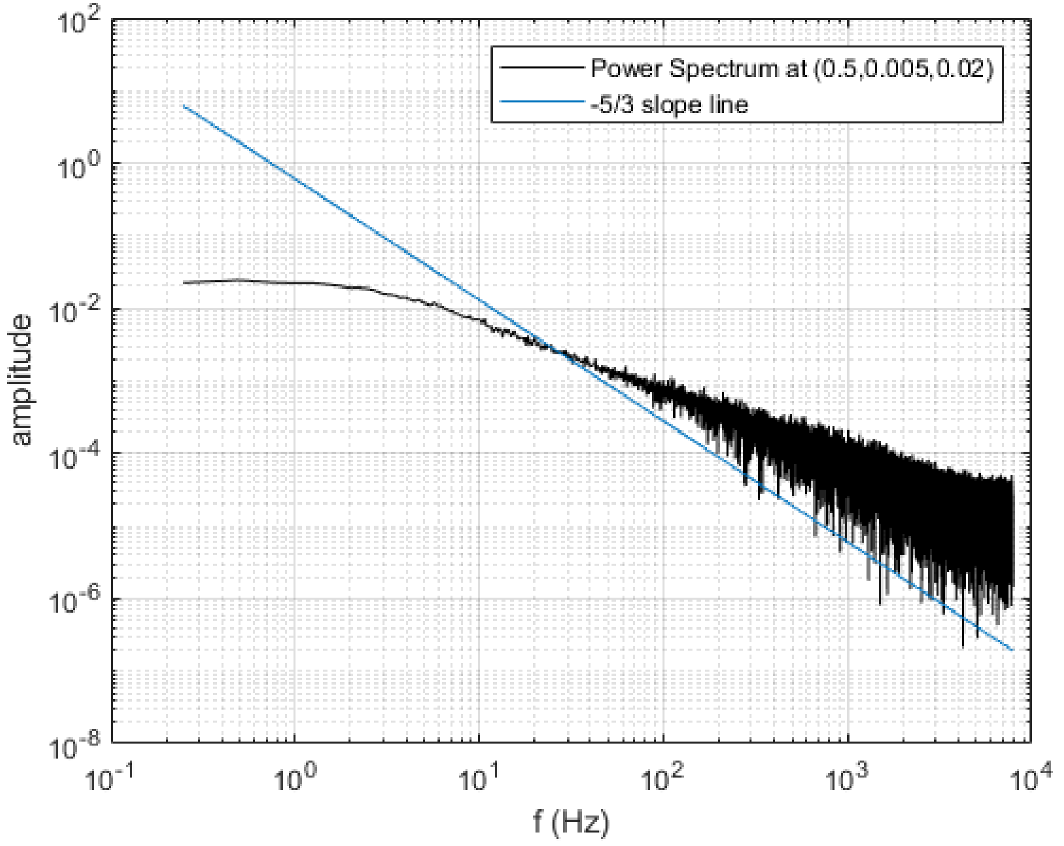


y-comp of velocity(v)

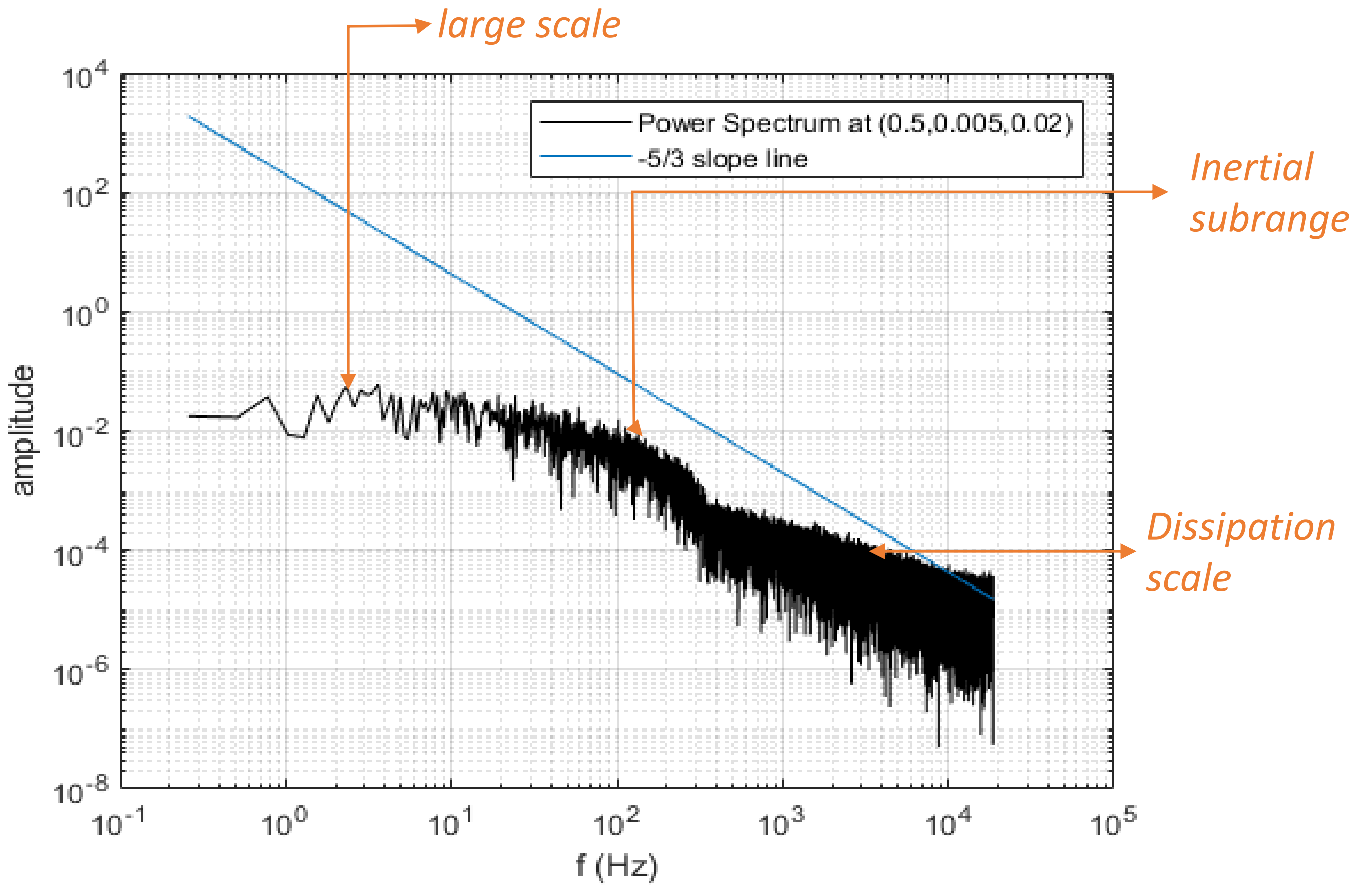


z-comp of velocity(w)

- FFT of those signals at (0.5, 0.005,0.02) → power/energy spectrum.



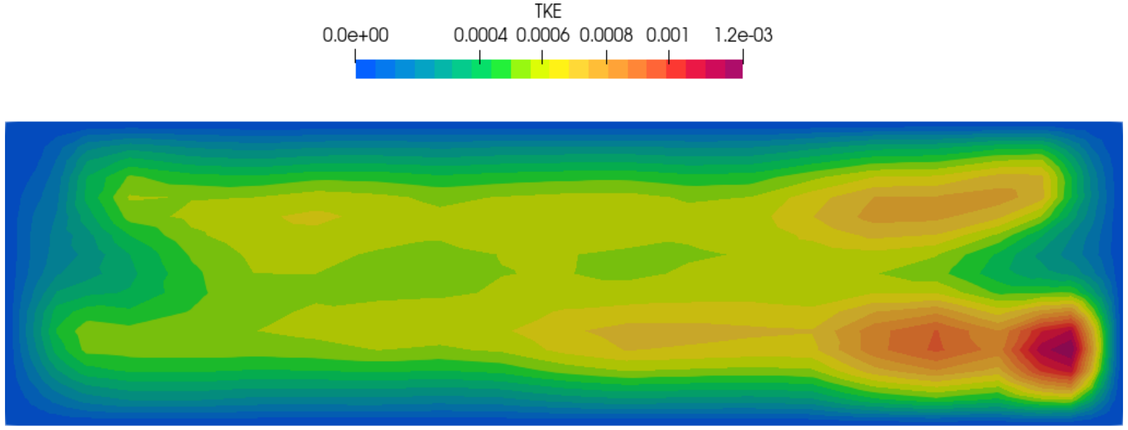
Re=1200
(turbulent eddies are damped out)



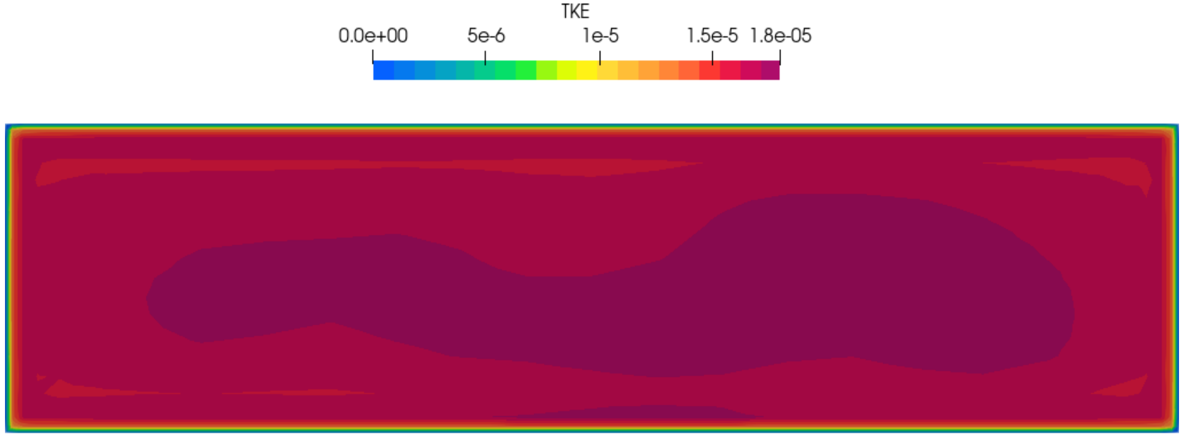
Re=2400
(presence of turbulence)

Turbulent Kinetic Energy contours at yz-plane(cross-section)

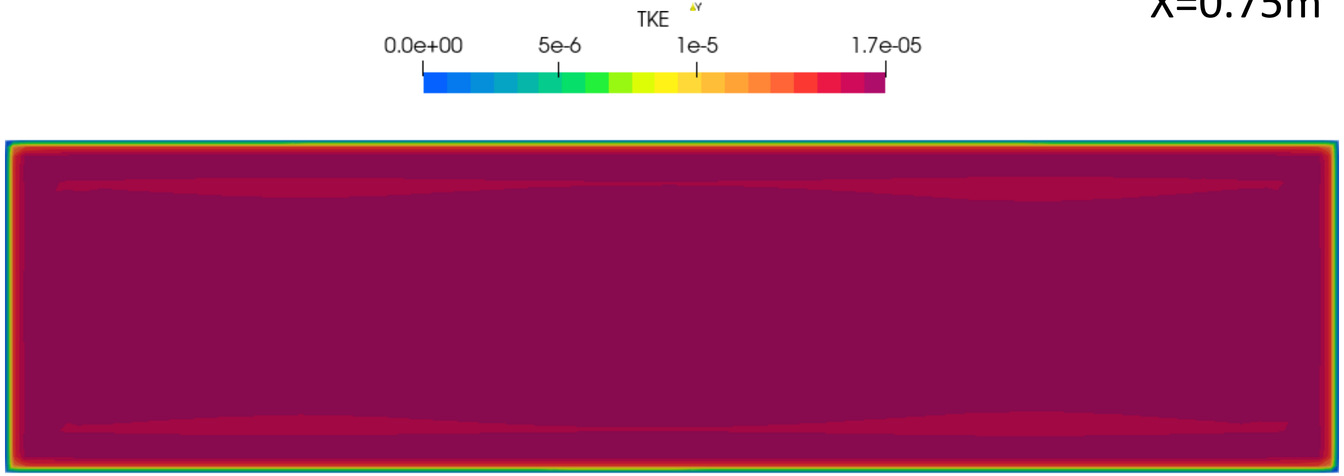
- Helps to understand eddy sizes at different locations
- Re=1200



X=0.1m

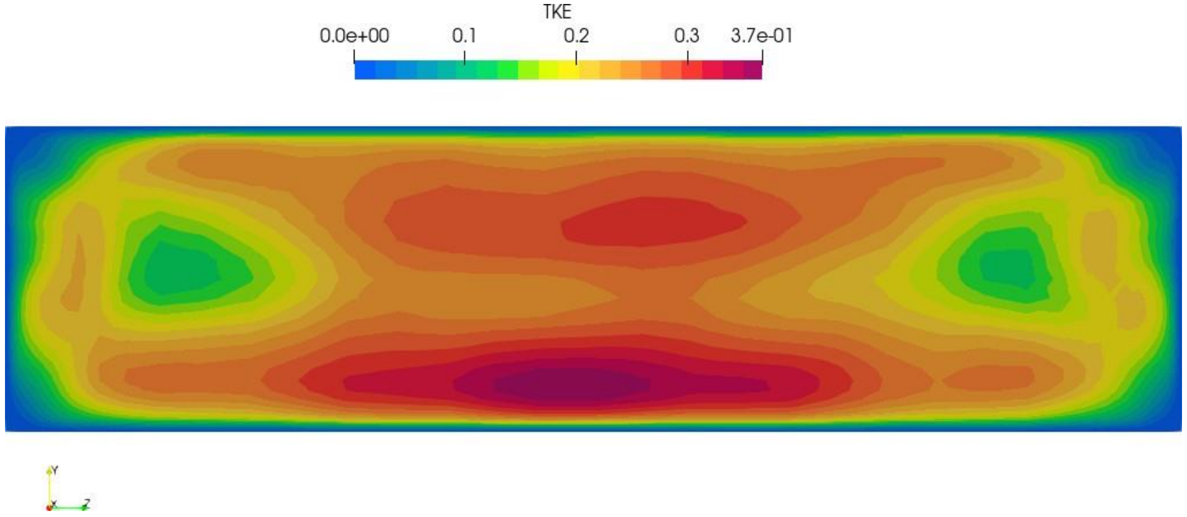


X=0.75m

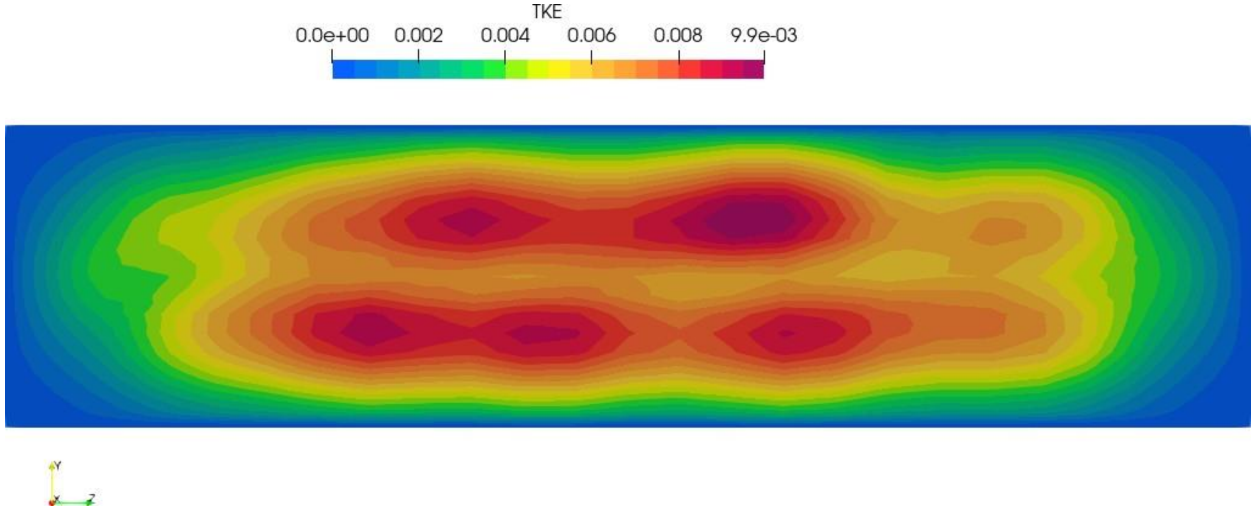


X=1.4m

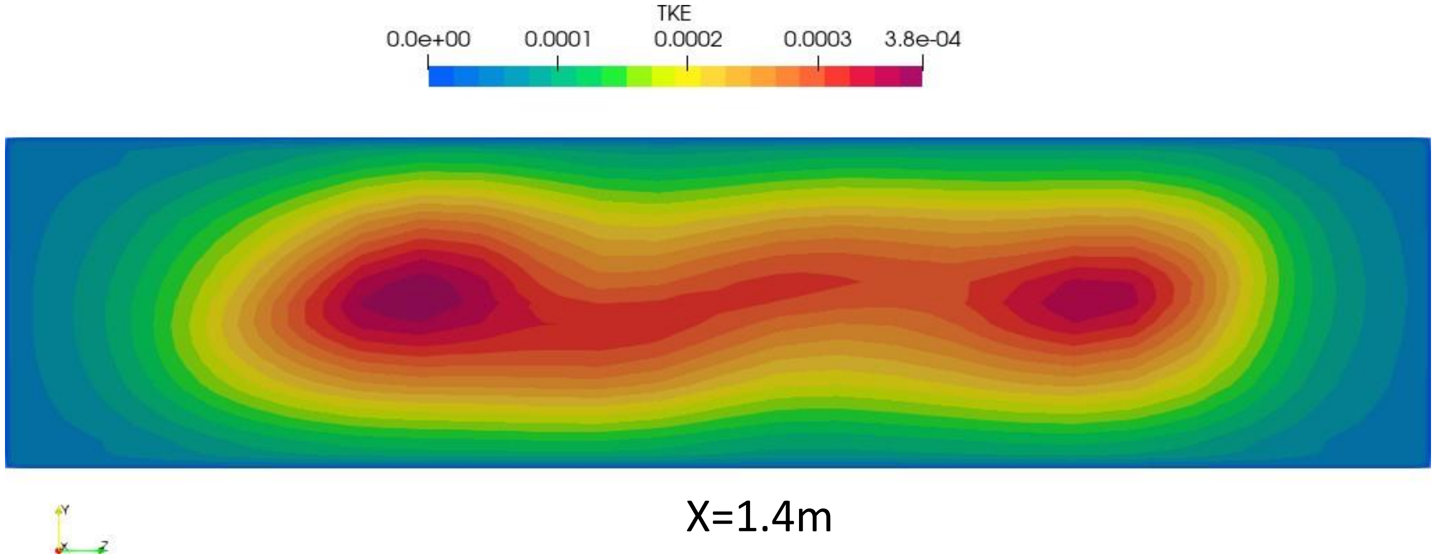
- Re=2400



X=0.01m



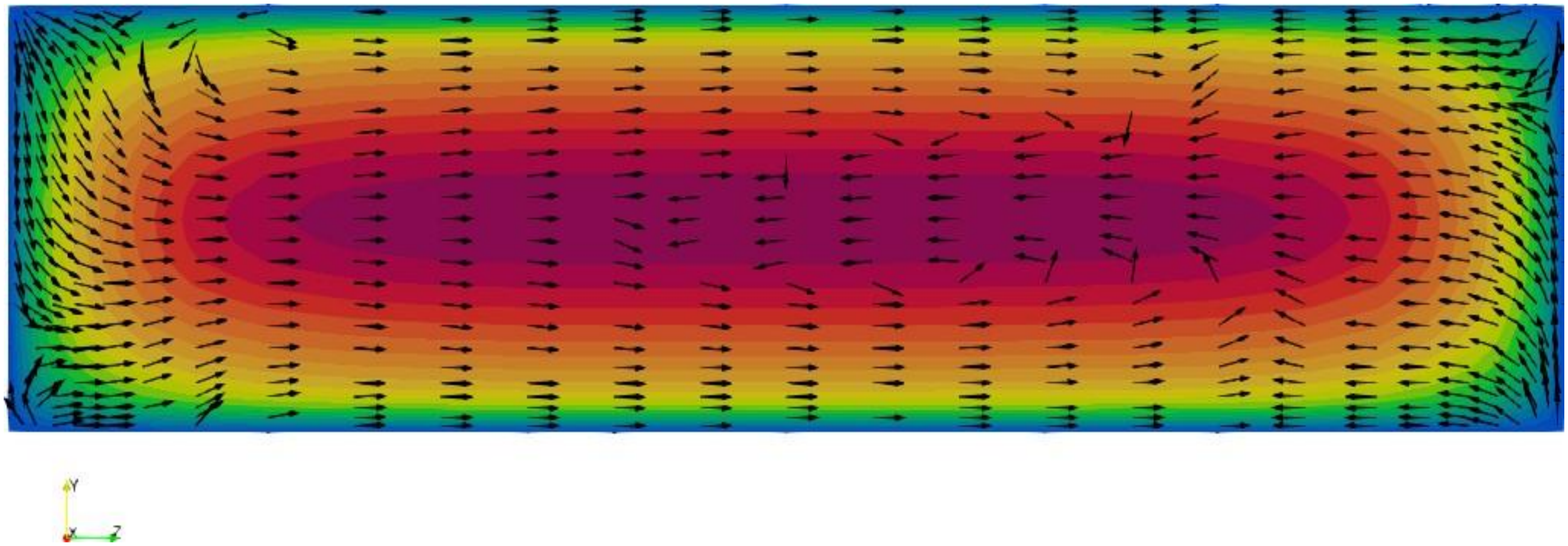
X=0.75m



X=1.4m

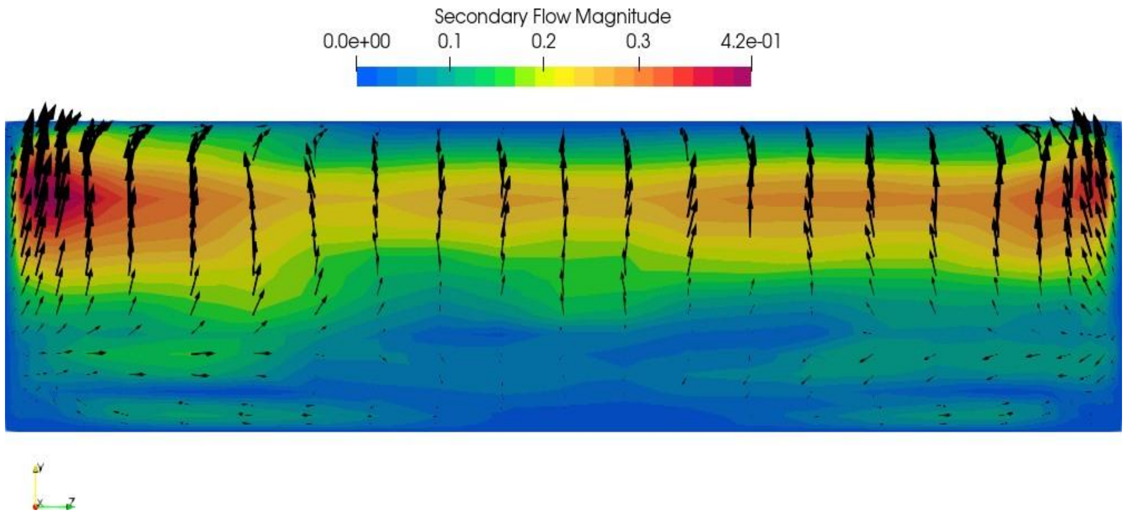
Secondary flow analysis [flow in y and z directions]

- Helps to decide whether flow is laminar/turbulent at different location.

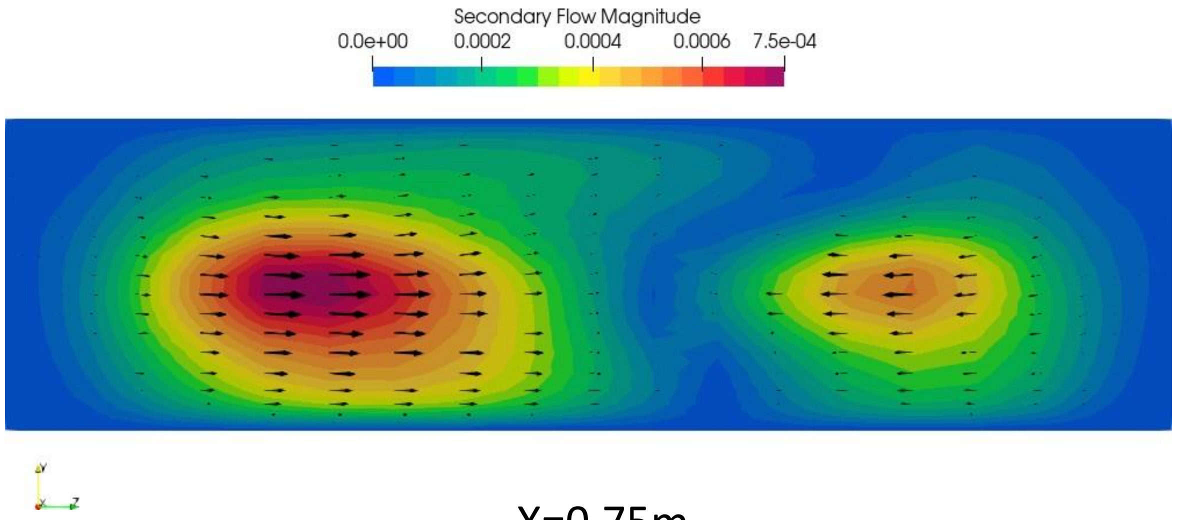


Secondary Flow vector plot without scaling at yz plane

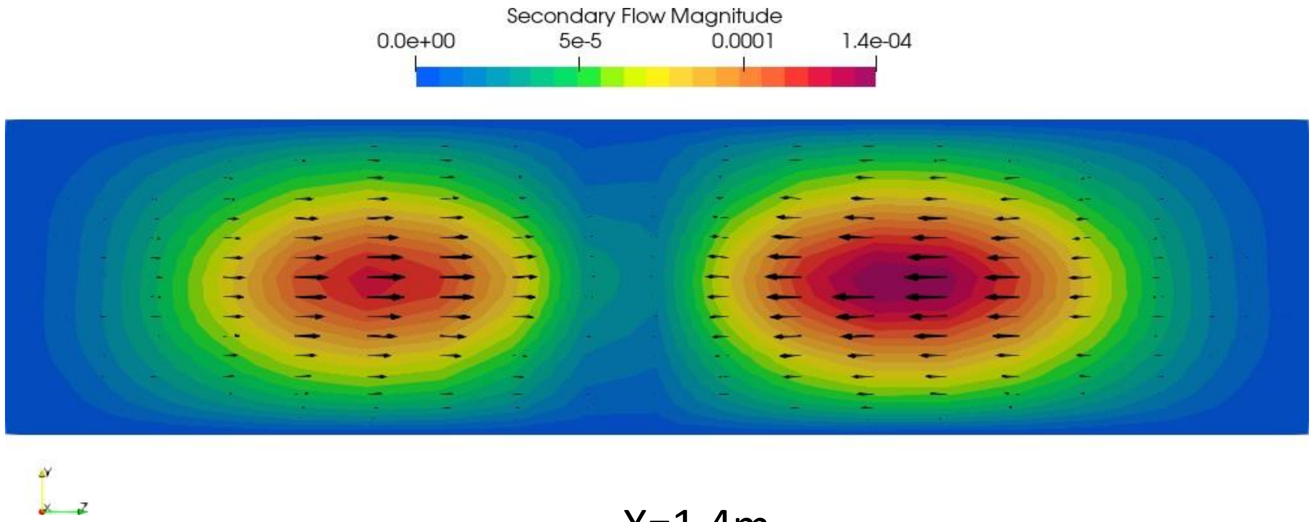
- Re=1200



X=0.01m

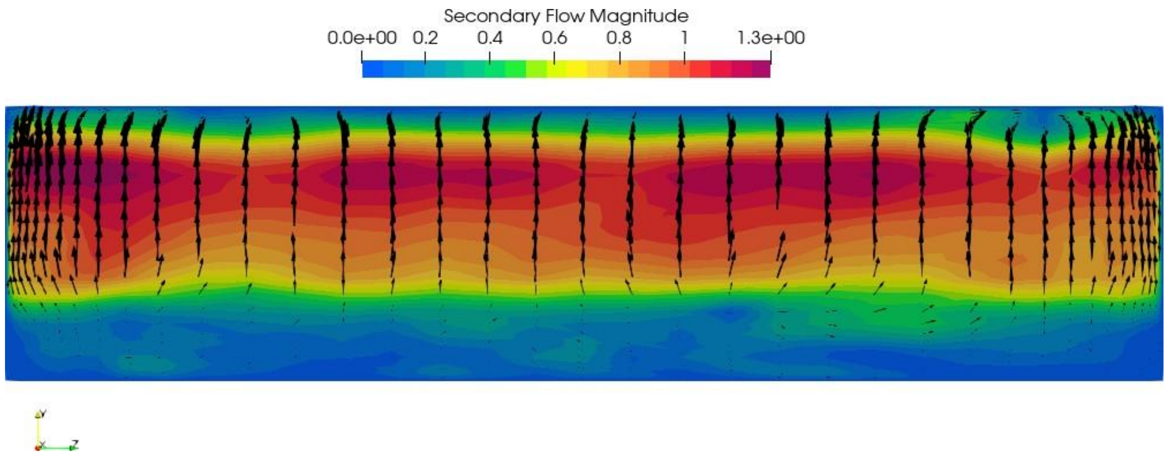


X=0.75m

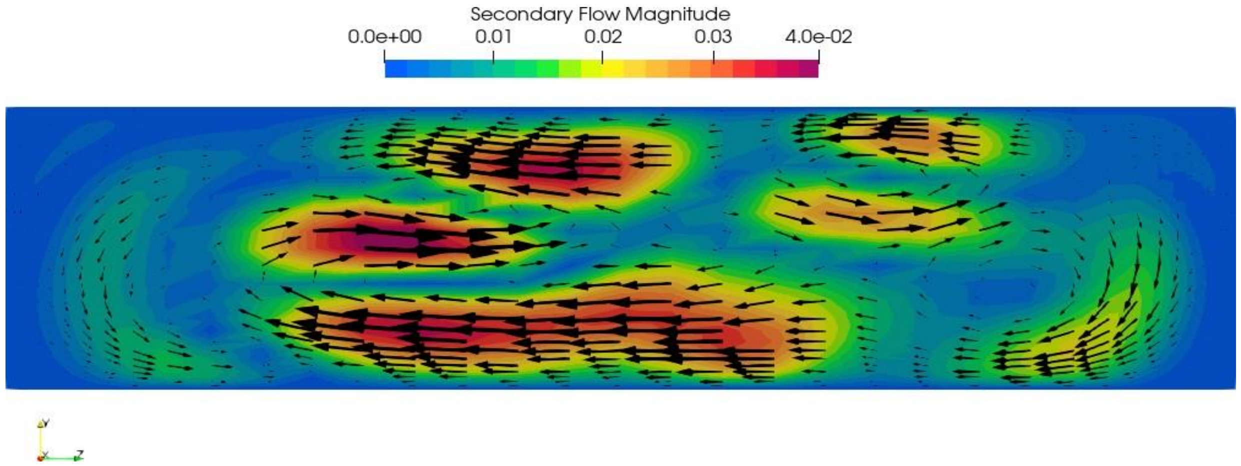


X=1.4m

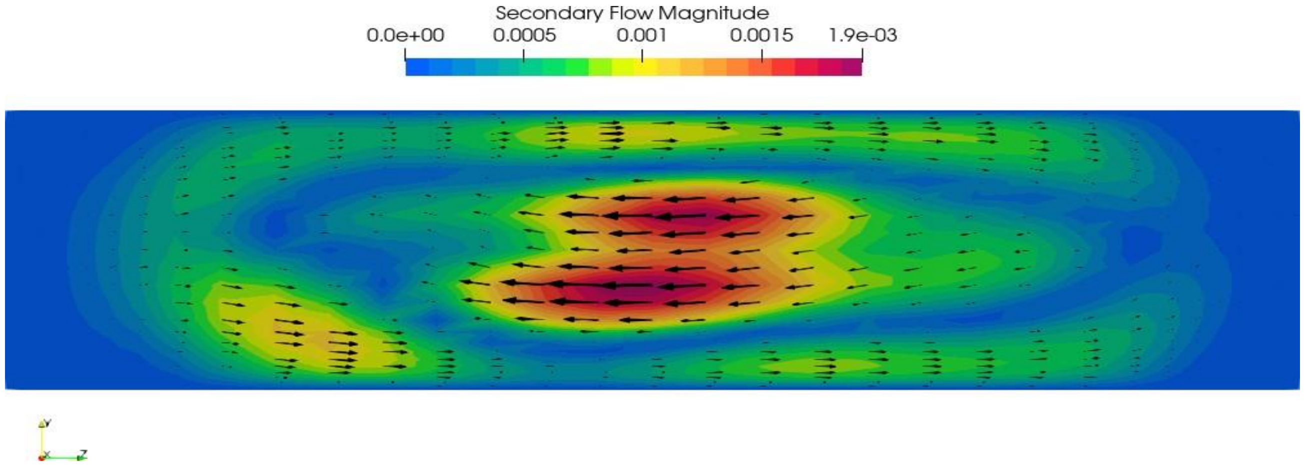
- Re=2400



X=0.01m



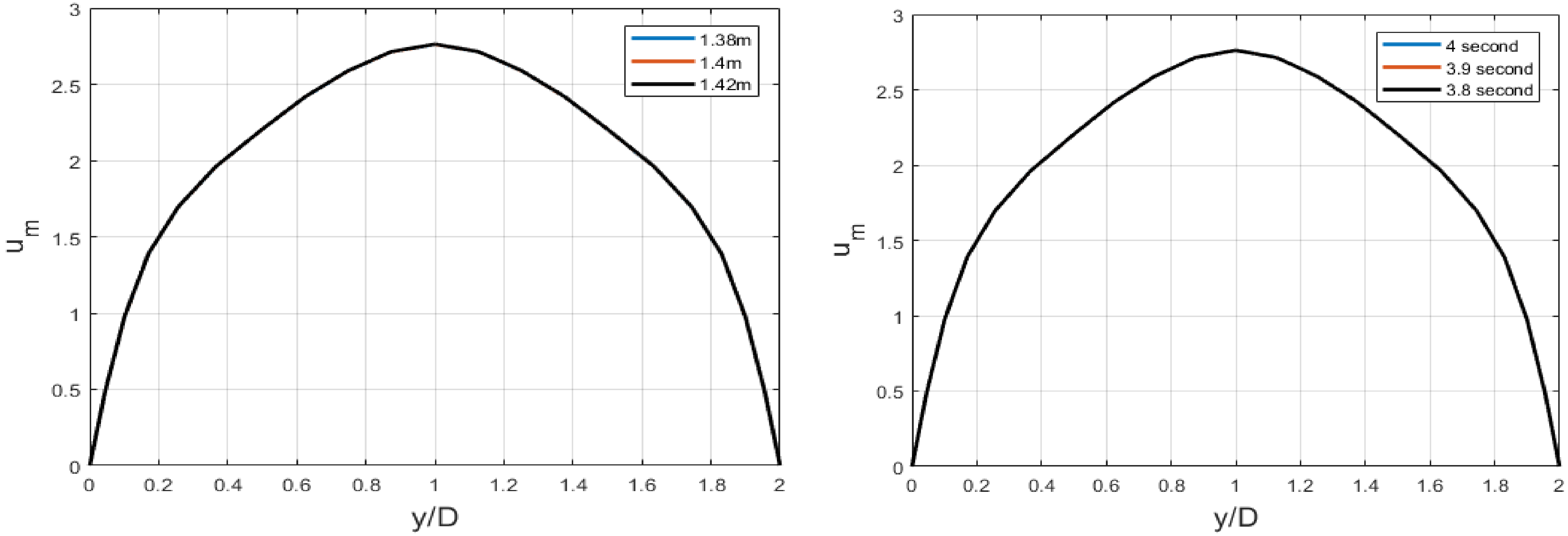
X=0.75m



X=1.4m

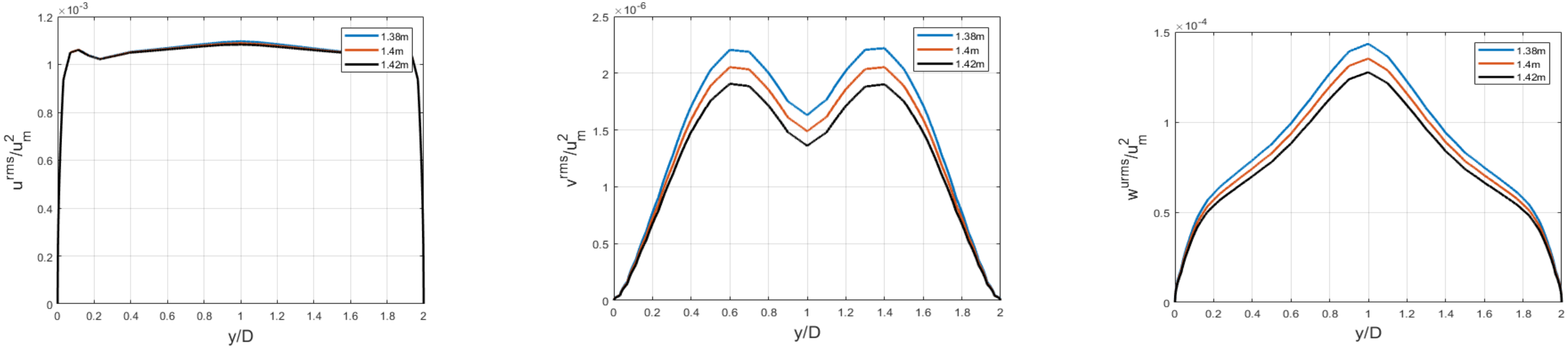
Mean velocity and Reynold’s stresses plot

- Showing temporal and spatial convergence
- Re=1200

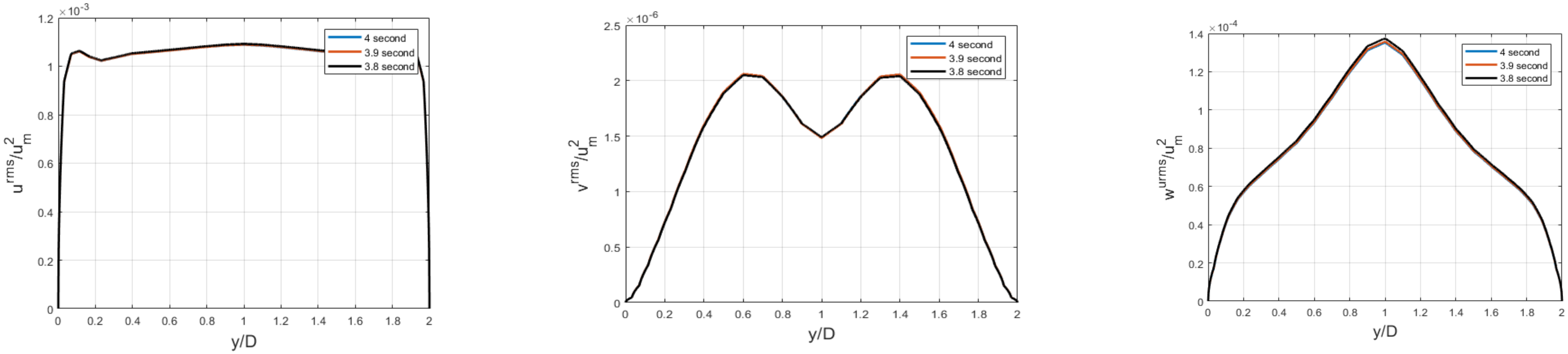


Mean Velocity Profiles of Re=1200 (confined). From left to right: spatial and time convergence

Velocity Fluctuations

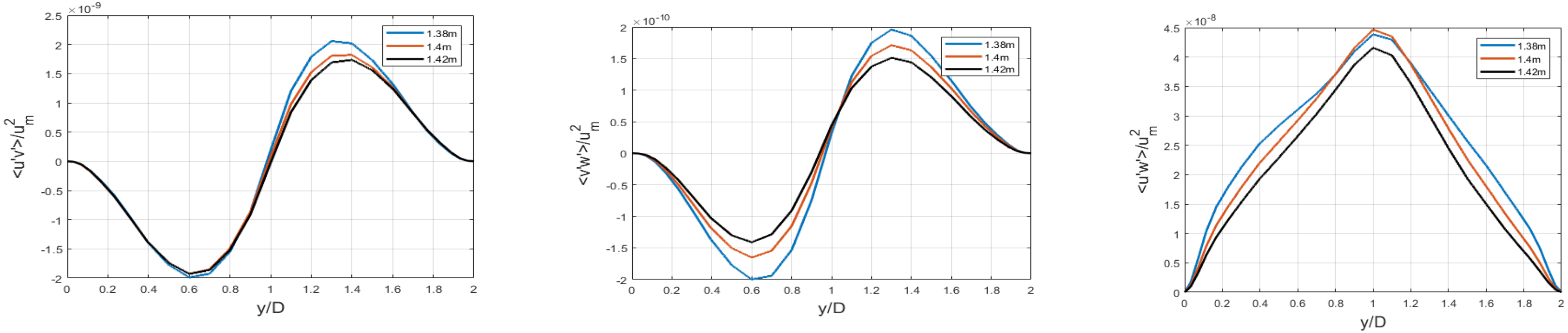


Profiles of fluctuating velocity of Re=1200 for spatial convergence

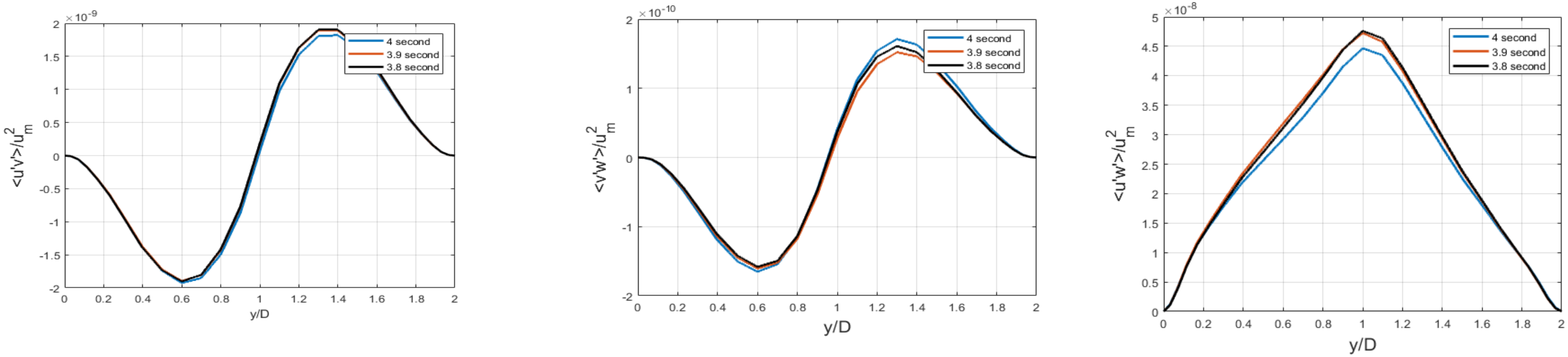


Profiles of fluctuating velocity of Re=1200 for time convergence

Turbulent shear stresses

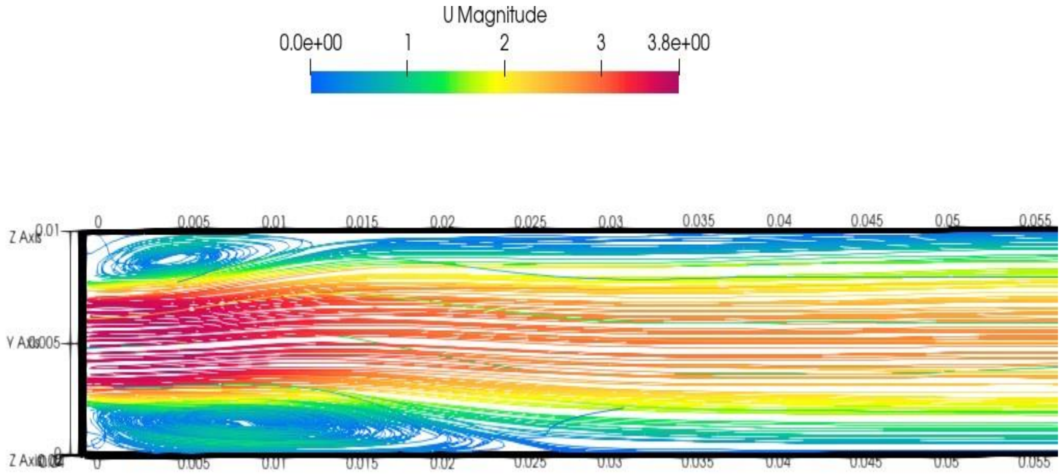


Turbulent shear stress components of Re=1200 for spatial convergence

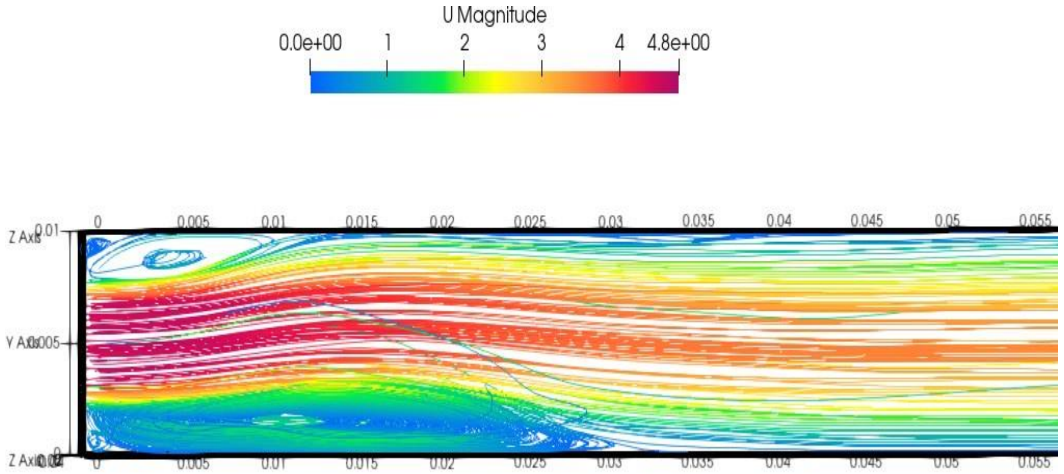


Turbulent shear stress components of Re=1200 for time convergence

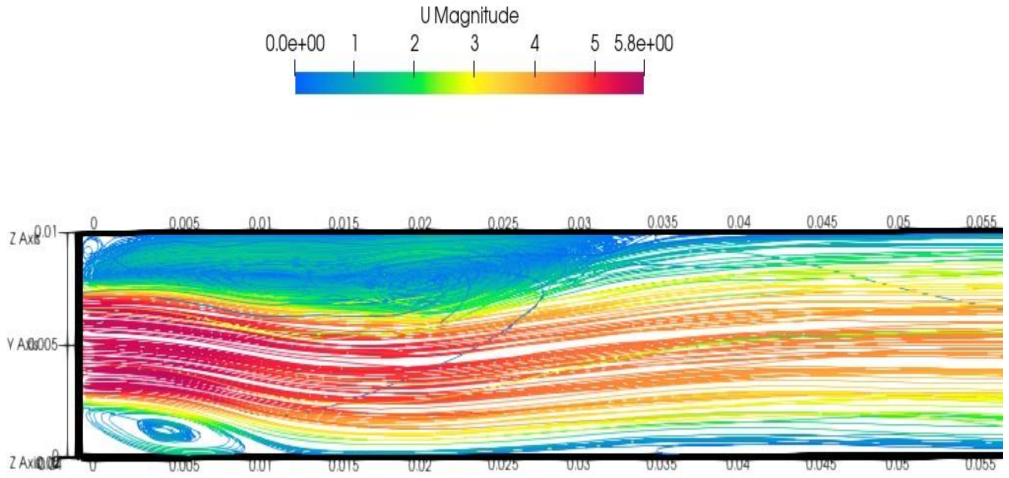
Streamlines near the inlet of channel



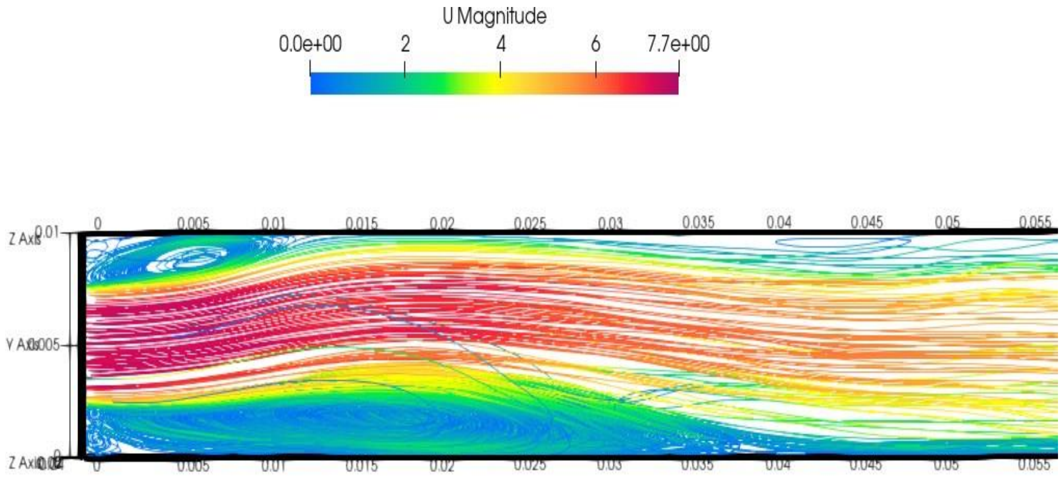
Re=1200



Re=1500

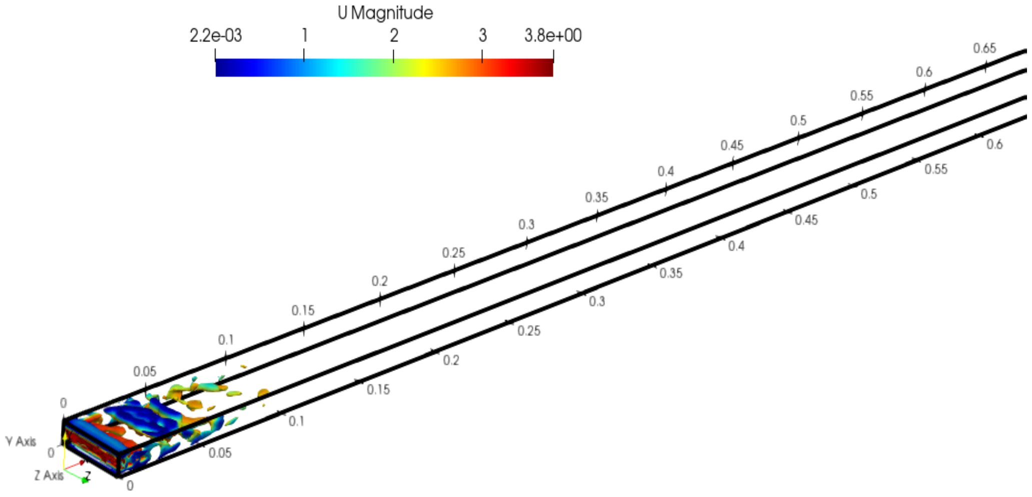


Re=1800

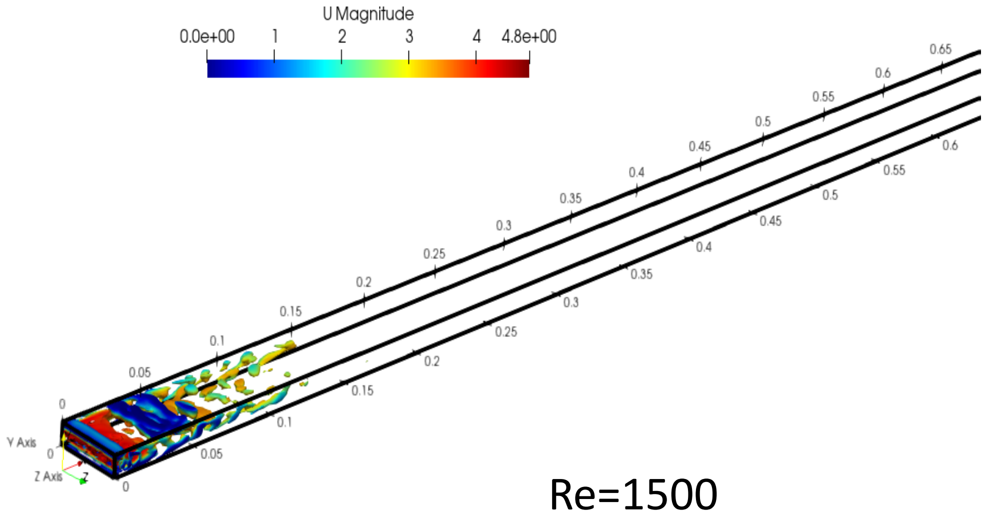


Re=2400

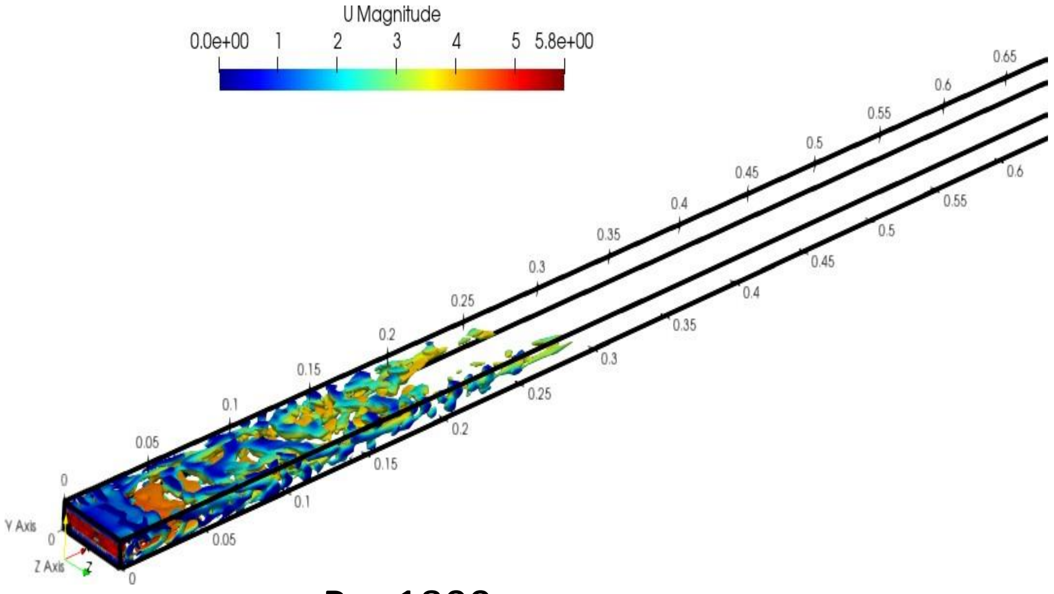
Q-criterion plot using iso-surface value of 500



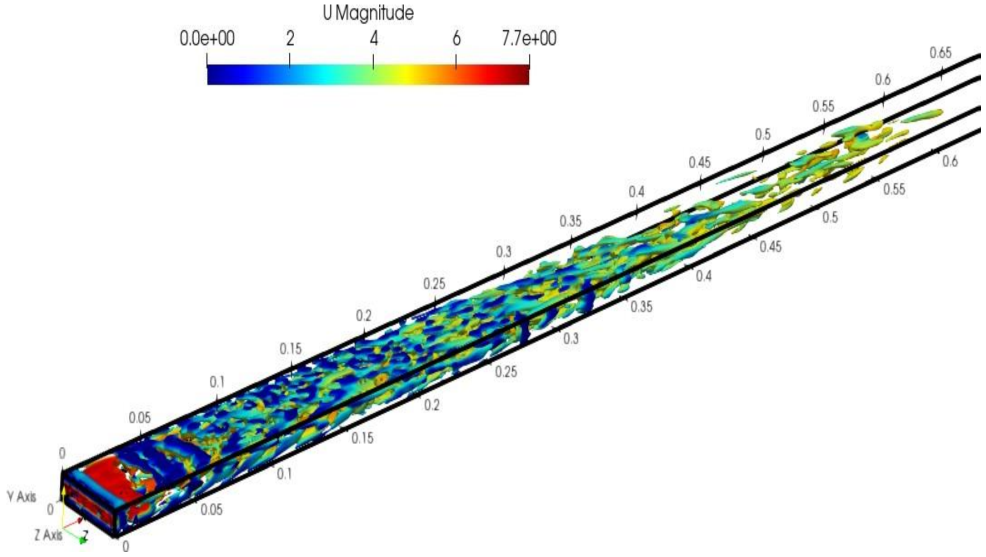
Re=1200



Re=1500

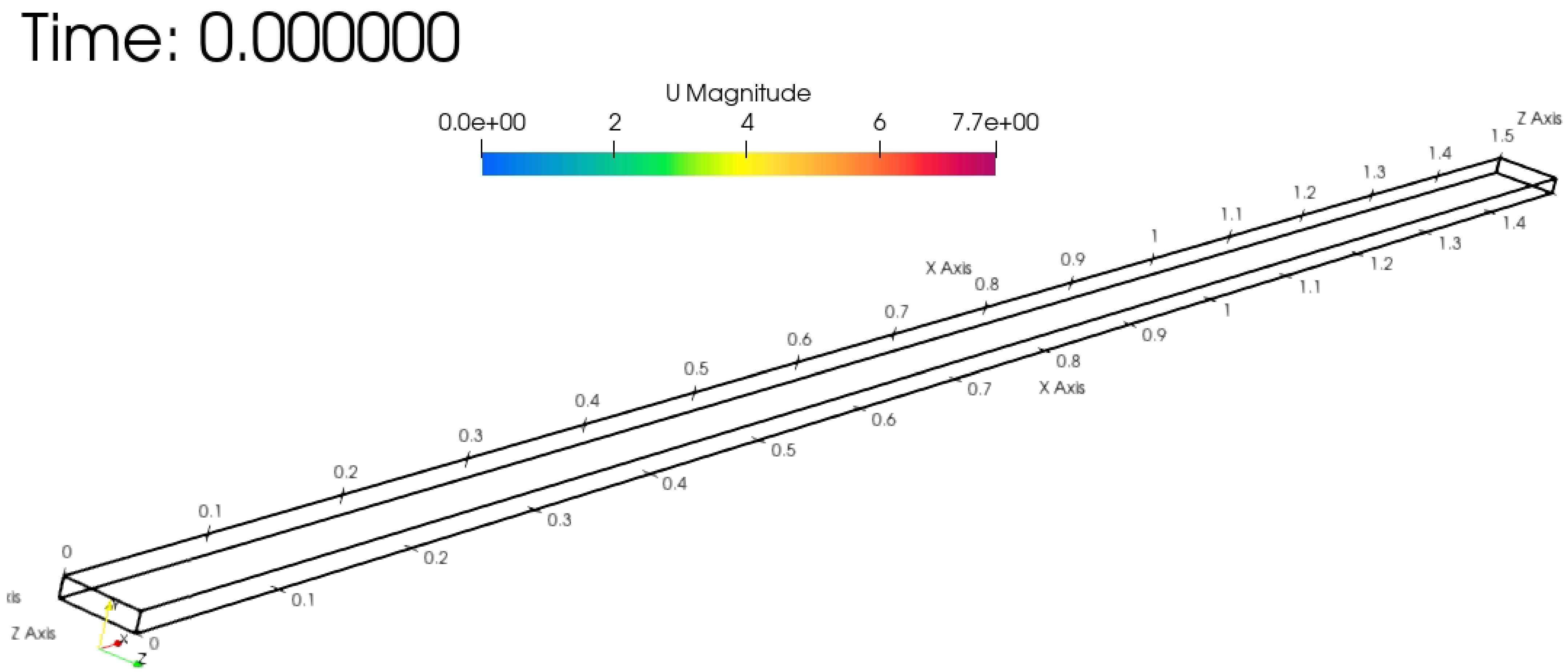


Re=1800



Re=2400

- Re=2400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6
7.7e+00
X Axis
Z Axis
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5

Conclusions

- Laminar-fully turbulent transition happens around Re=2400 or more.

[Hanks and Ruo (1966) theoretically analyzed $Re_{critical}$ =2315 for A=3.92]

- Procedures to conduct LES calculation is analyzed in a detailed manner.

- The mean and statistics are to be collected after a steady solution to obtain mature results quickly.

THANK YOU!