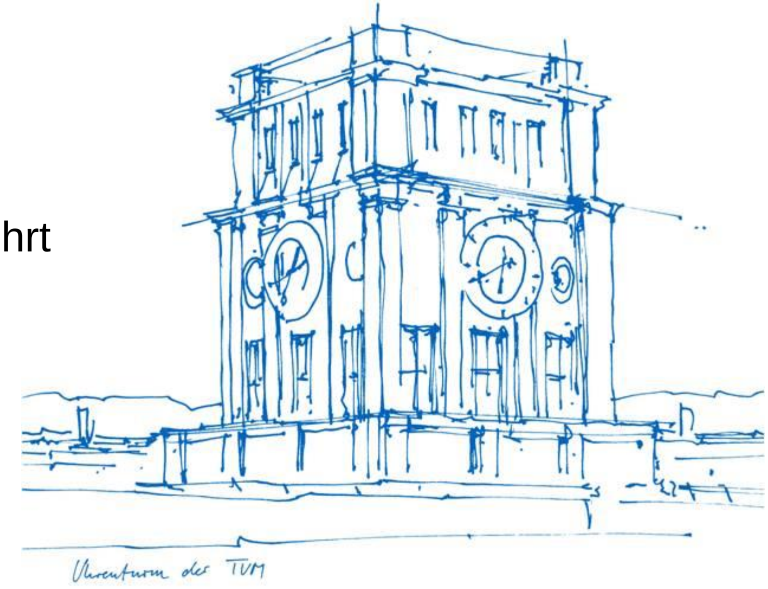
Technische Universität München
Professur für Hydromechanik
Computational Mechanics

Investigation of the Turbulent Horseshoe Vortex Based on LES Data of Flow Around a Scoured Bridge Pier

Alaa Bashir

Supervisor: Lukas Unglehrt

18th August 2021



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- Motivation
- Description of the Dataset
- Assessment of the Simulation
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  - Convergence Study
- Flow Topology
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  - 3D Pressure Contour
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- Turbulent Kinetic Energy (TKE)
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- Summary

Motivation

- Bridges have an important role in goods and people transportation
- Increasing their safety and integrity is a vital issue
- Studying unwanted phenomena such as scouring is an attractive topic
- Scouring caused economic and life losses:
    - Losses of €577 million in Germany (2002)[1]
    - €541 million for scouring risk mitigation[1]
- However, this topic has no clear-cut understanding yet

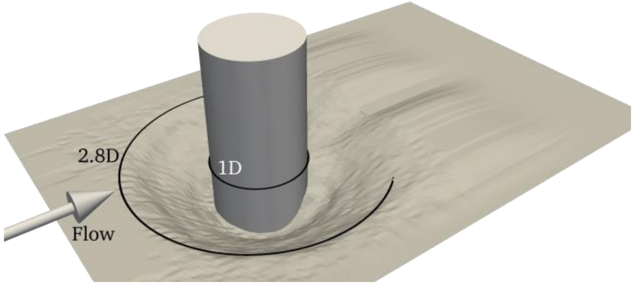
Retrieved from: https://www.ayresassociates.com/battling-bridge-scour-with-research-inspections-and-training/

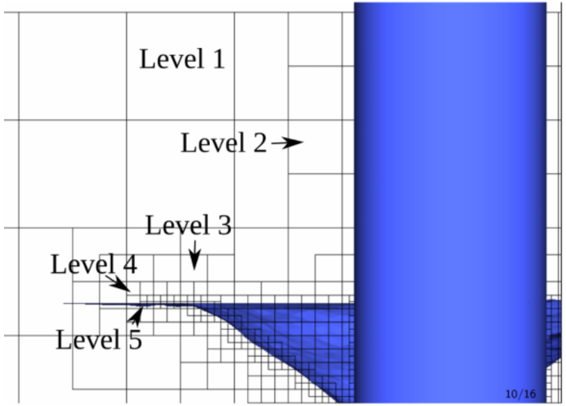
Retrieved from: https://slideplayer.com/slide/12487455/

[1] Alonso Pizarro, Salvatore Manfreda, and Enrico Tubaldi. The science behind scour at bridge foundations: A review. Water, 12(2):374, January 2020. doi: 10.3390/w12020374.

Description of the Dataset

- An open water channel with a 100 mm diameter cylinder mounted in the symmetry plane.
- The chosen dimensions were based on the experiment done by Ulrich Jenssen.
- The LES was conducted by Wolfgang Schanderl.
- Two Reynolds Numbers (Re) are investigated:
  - 20,520 (20k)
  - 41,509 (39k)
- Five levels of locally embedded grids are used.



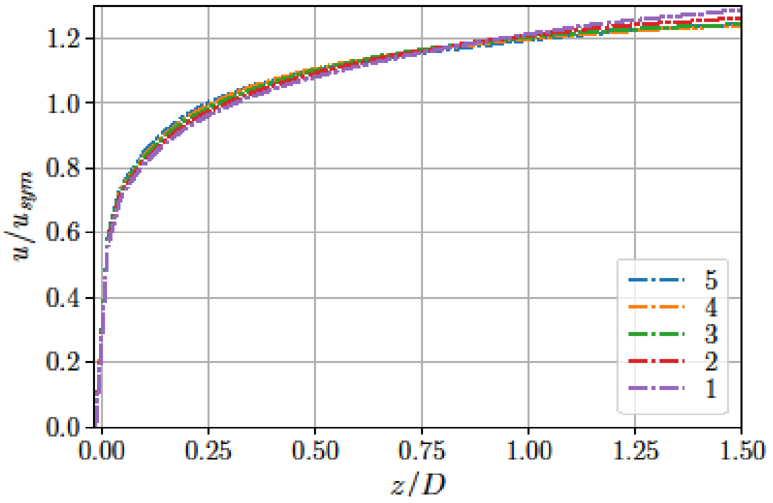


M. Manhart, et al., *The flow inside a scour hole around a circular cylinder: comparison between particle image velocimetry and large–eddy simulation*. 2021.

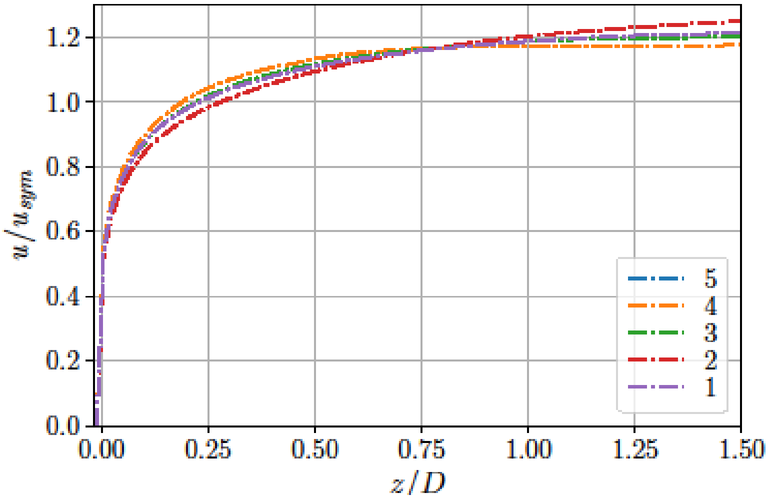
Assessment of the Simulation

1. Inflow Profile

Re = 20k



Re = 39k



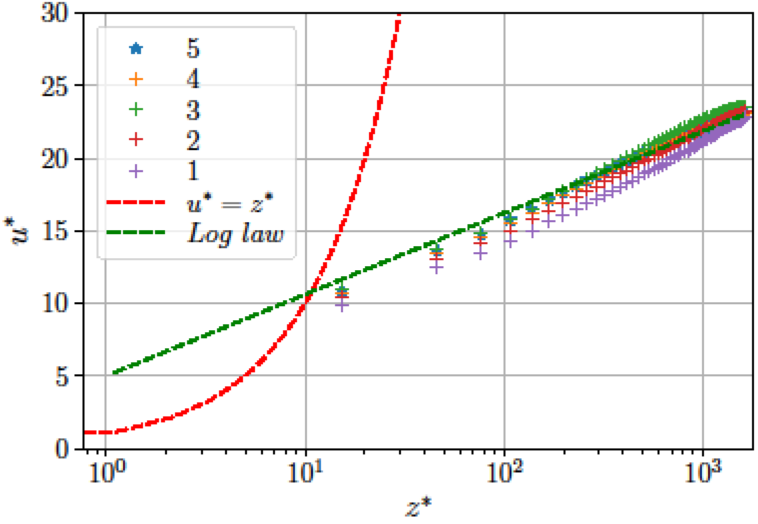
LVL	1	2	3	4	5
u_{sym}	0.74	0.77	0.8	0.78	0.79

LVL	1	2	3	4	5
u_{sym}	0.85	0.85	0.87	0.88	0.88

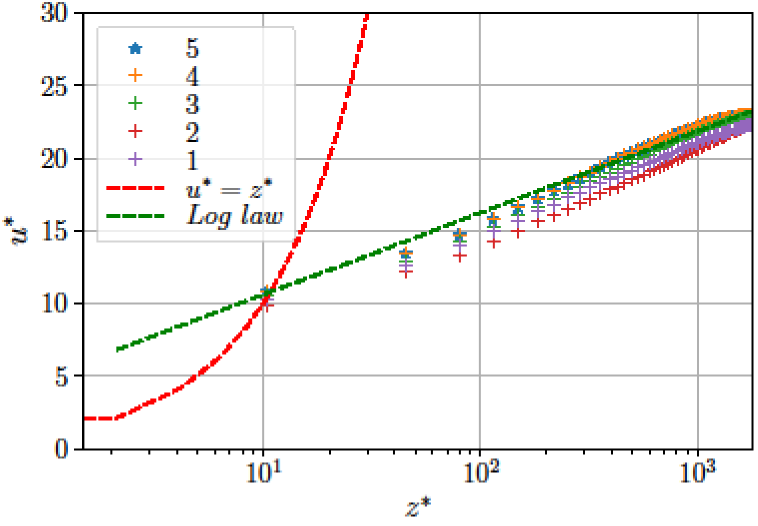
Assessment of the Simulation

1. **Inflow Profile in Log Scale**

Re = 20k



Re = 39k

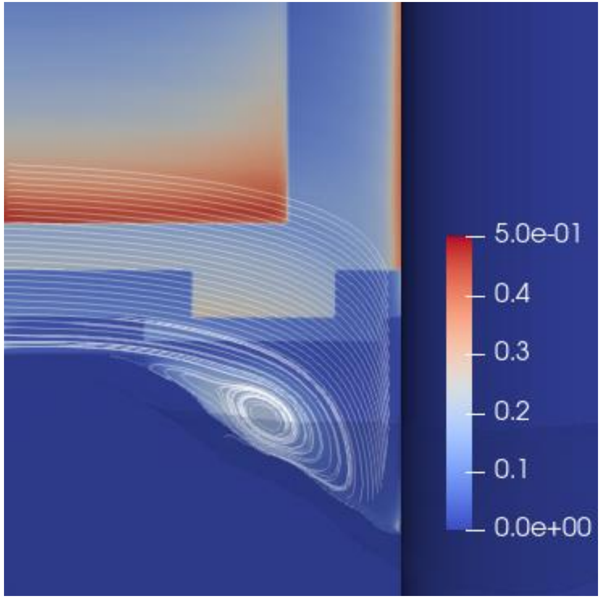


Assessment of the Simulation

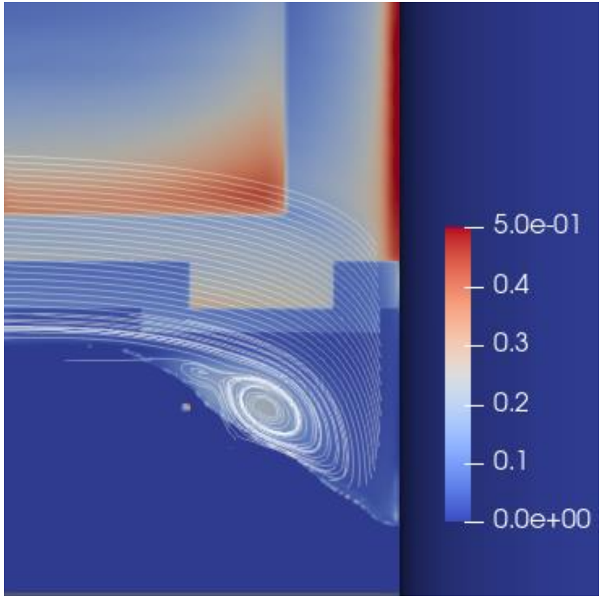
2. Effect of Sub-Grid Sales (SGS)

- Turbulent viscosity to molecular viscosity ratio (v_t / v)

Re = 20k



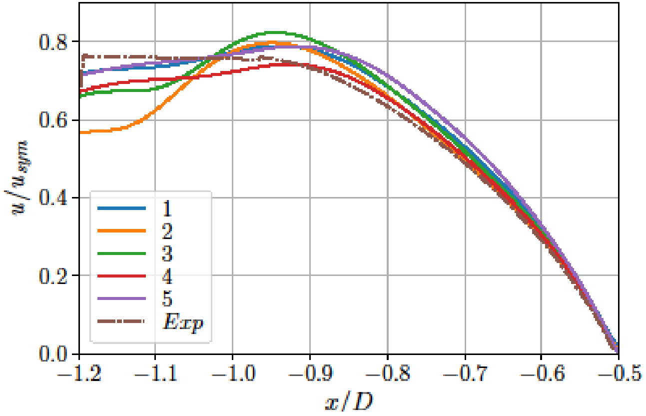
Re = 39k



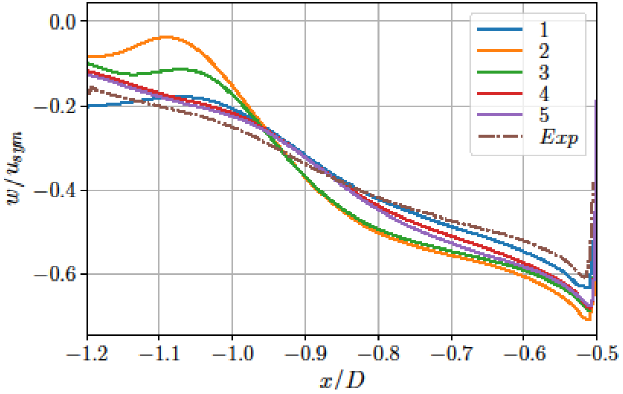
Assessment of the Simulation

3. Convergence study

- Velocity Profile along the Scour Hole

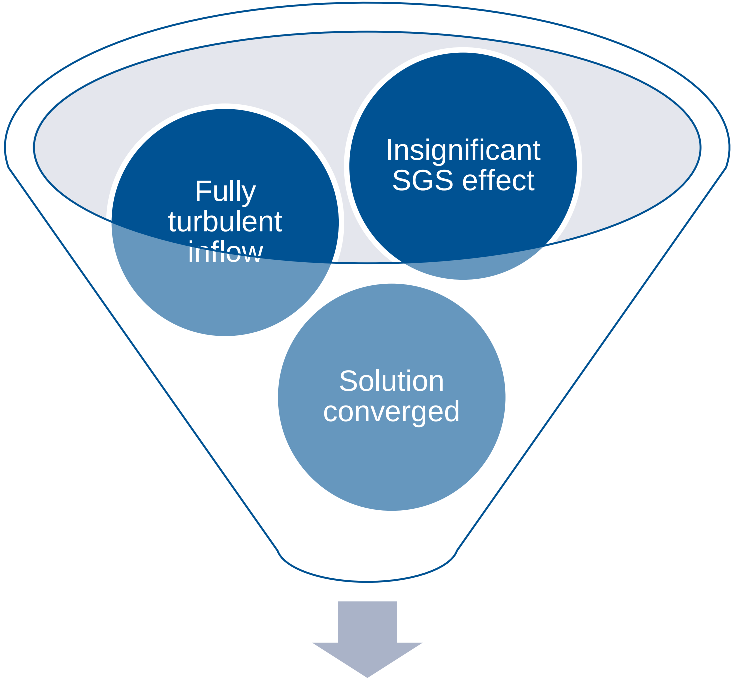


Velocity Component in the Stream-wise Direction (Re = 39k)



Velocity Component in the Normal Direction (Re = 39k)

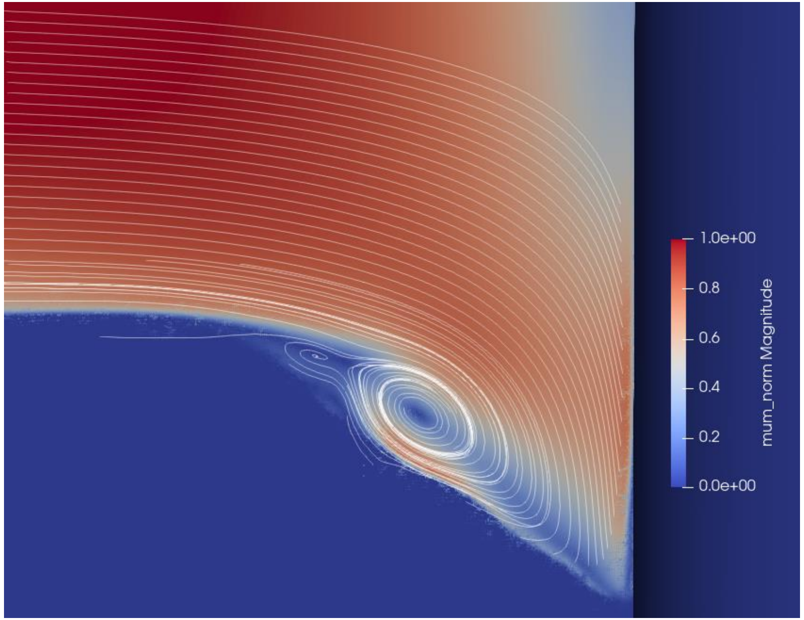
Assessment of the Simulation



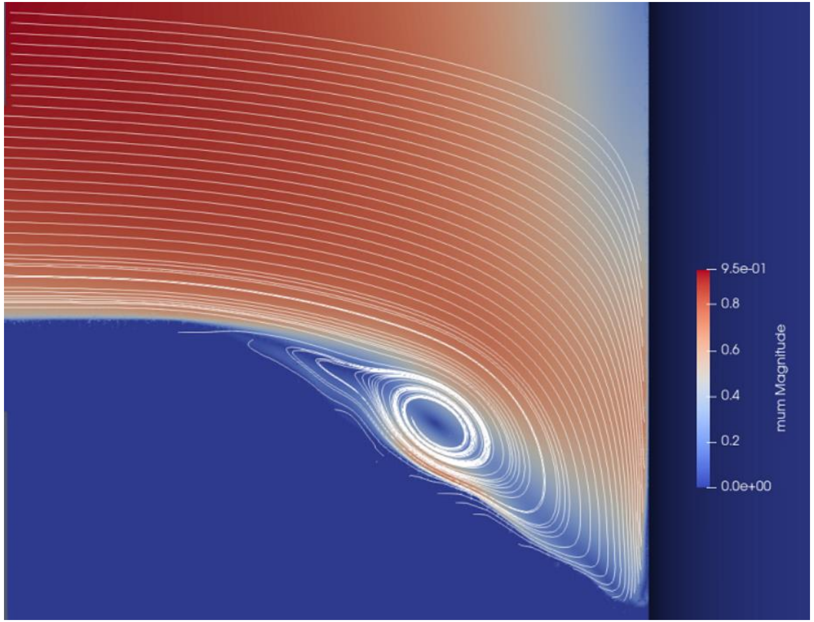
Reliable simulation

Flow Topology

Re = 20k



Re = 39k



Time-averaged Horseshoe Vortex

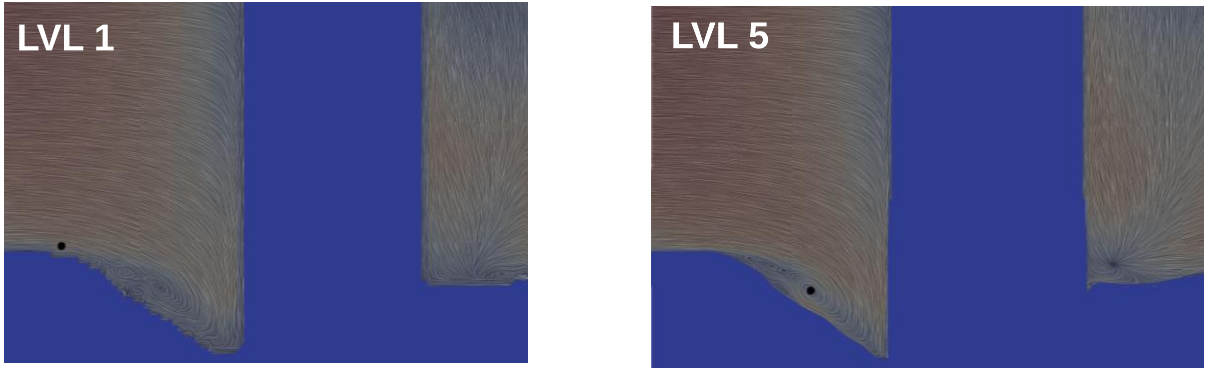
1. **Horseshoe Vortex Center**

Re	20,000			39,000		
LVL	$\frac{\Delta p}{\frac{1}{2}\rho u_{sym}^2}$	x/D	z/D	$\frac{\Delta p}{\frac{1}{2}\rho u_{sym}^2}$	x/D	z/D
1	-0.92	-1.37	0	-0.9	-0.91	-0.20
2	-1.23	-0.98	-0.14	-1.27	-0.97	-0.135
3	-1.24	-0.98	-0.133	-1.30	-0.96	-0.143
4	-1.33	-0.90	-0.186	-1.25	-0.91	-0.182
5	-1.20	-0.88	-0.20	-1.24	-0.89	-0.193
Exp	-	-0.89	-0.182	-	-0.92	-0.167

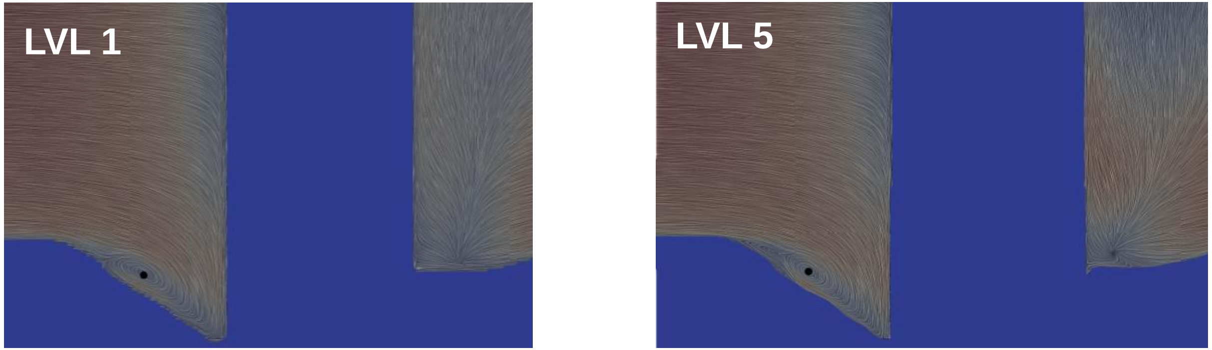
Time-averaged Horseshoe Vortex

1. **Horseshoe Vortex Center**

Re = 20k



Re = 39k

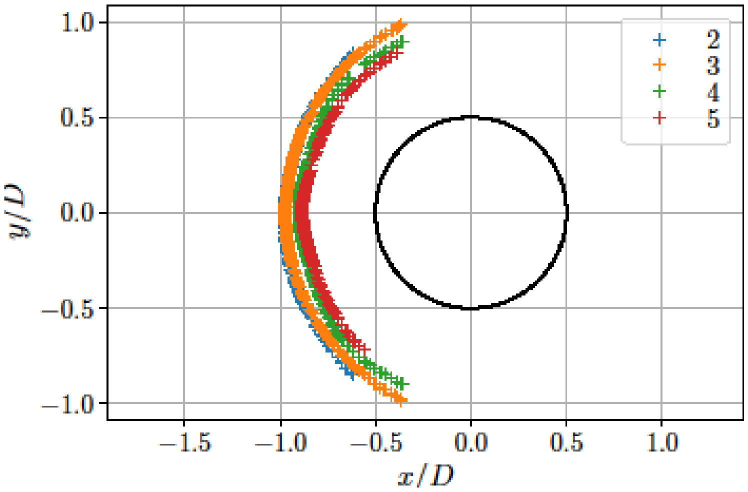


Time-averaged Horseshoe Vortex

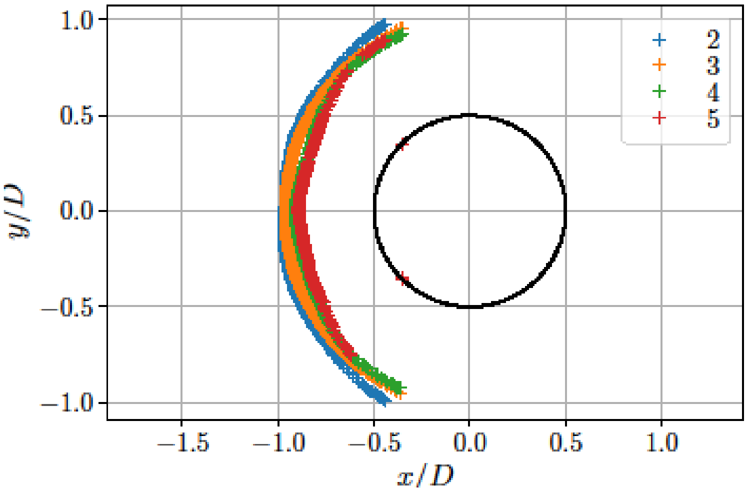
2. Horseshoe Vortex Core-line

- Using the Sujudi and Haimes method

Re = 20k



Re = 39k

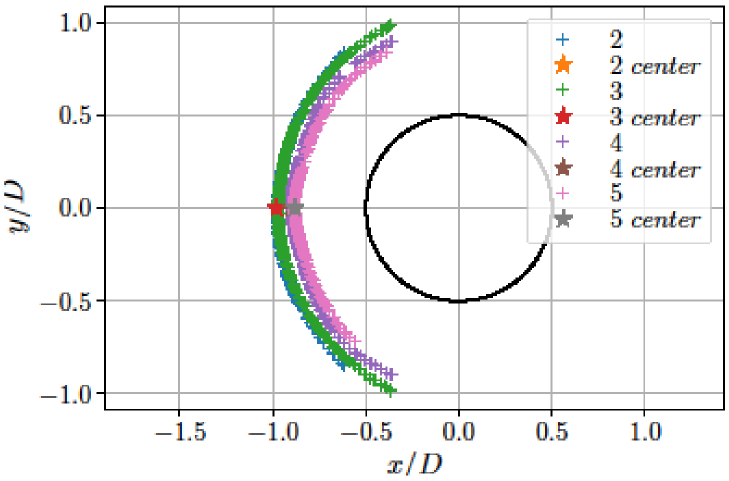


Time-averaged Horseshoe Vortex

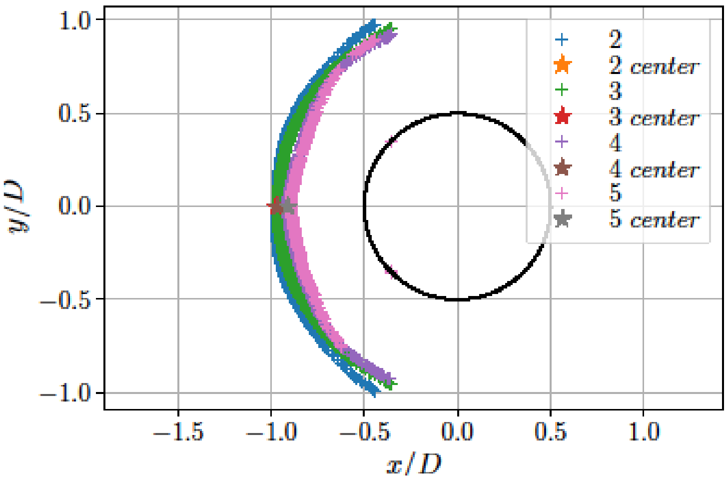
2. Horseshoe Vortex Core-line

- Verification of the detected vortex

Re = 20k



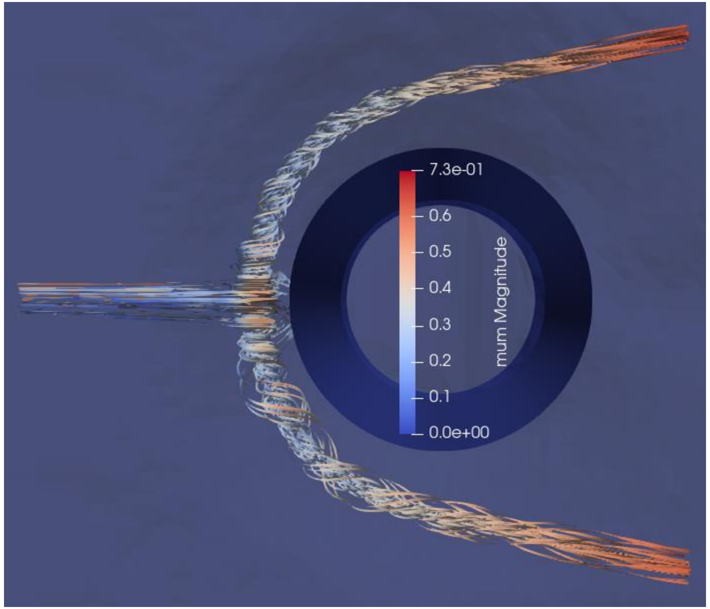
Re = 39k

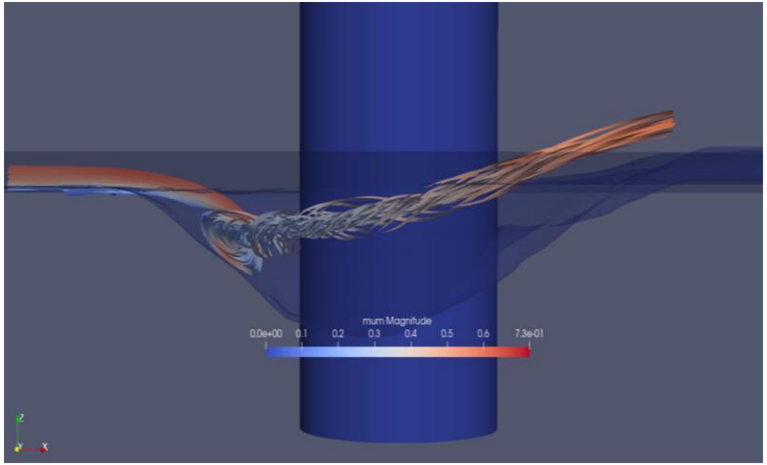


Time-averaged Horseshoe Vortex

3. Streamlines Visualization

Re = 20k

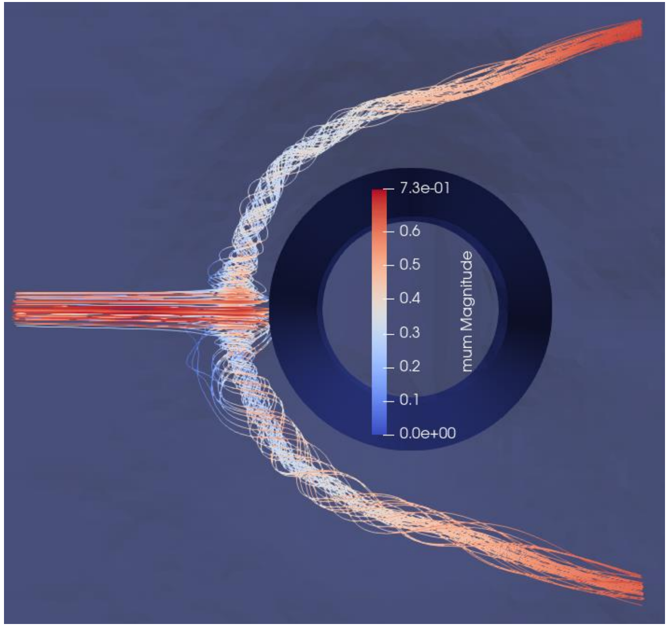


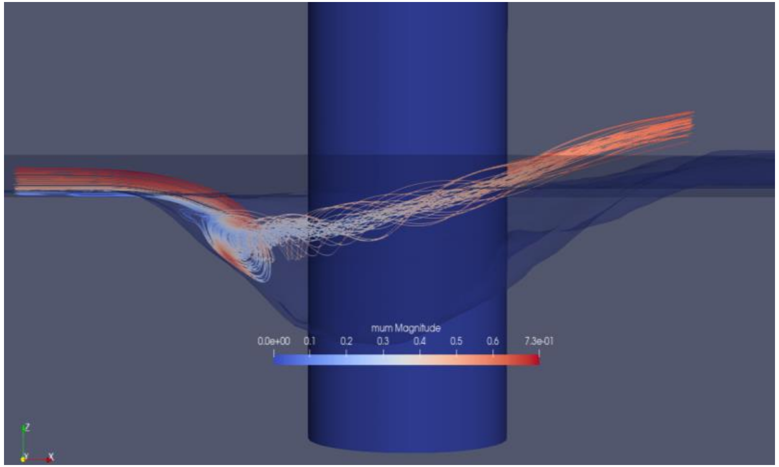


Time-averaged Horseshoe Vortex

3. Streamlines Visualization

Re = 39k

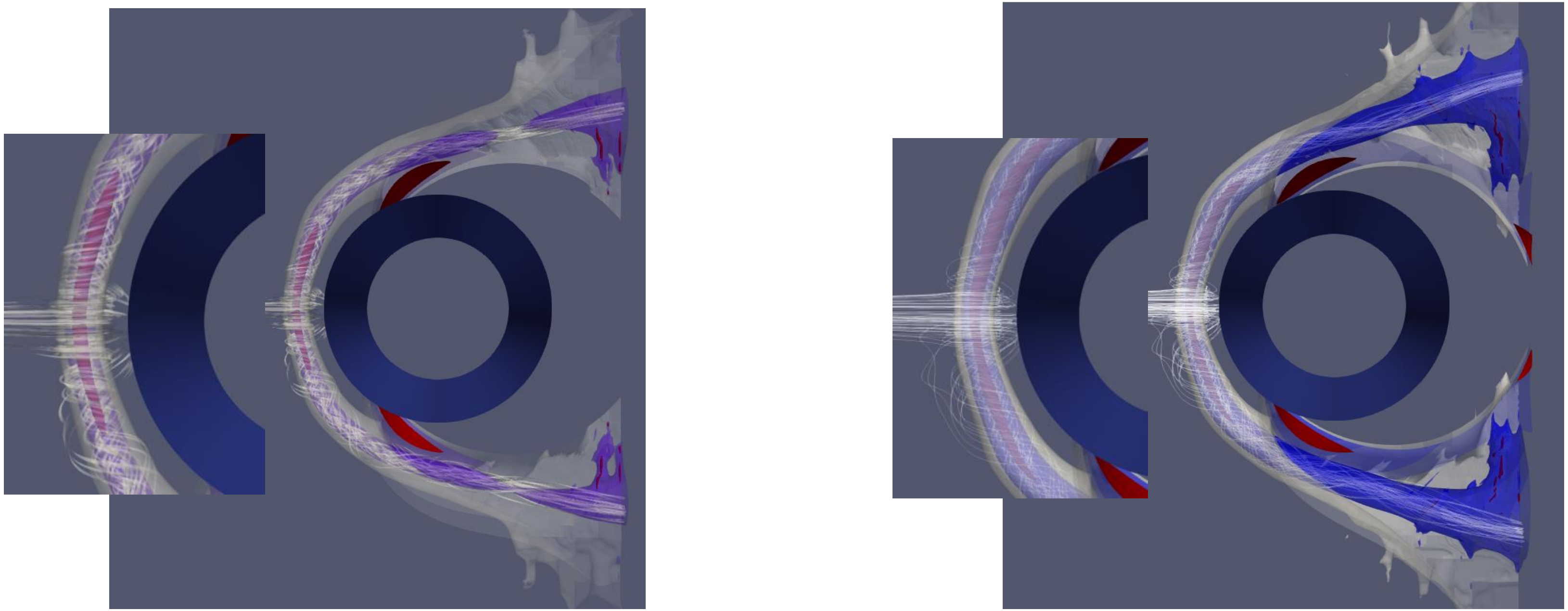




Time-averaged Horseshoe Vortex

4. **3D Pressure Contour**

Re = 20k　　　　　　　　　　　　　　Re = 39k

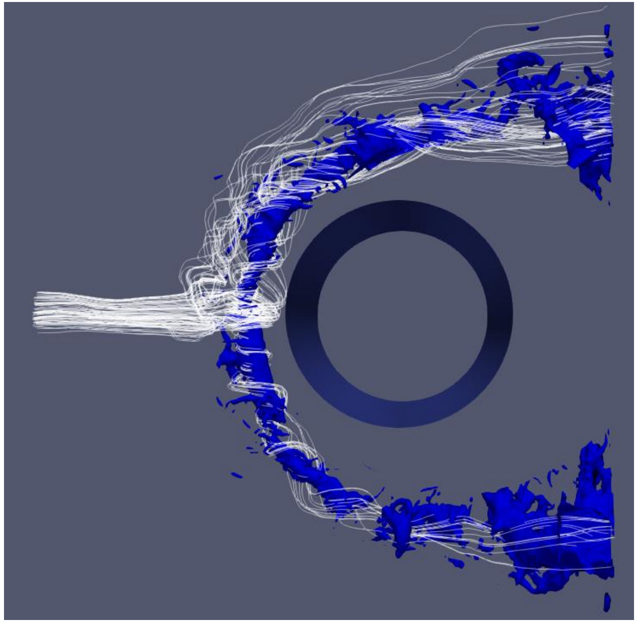


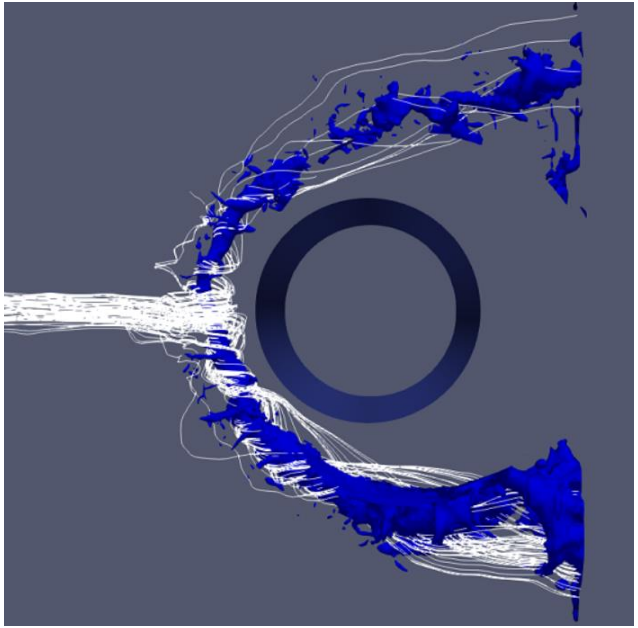
P_{norm} of -1.2 (red), -1.0 (blue), and -0.88 (white)

Instantaneous Horseshoe Vortex

1. **3D Pressure Contour**

   Re = 20k



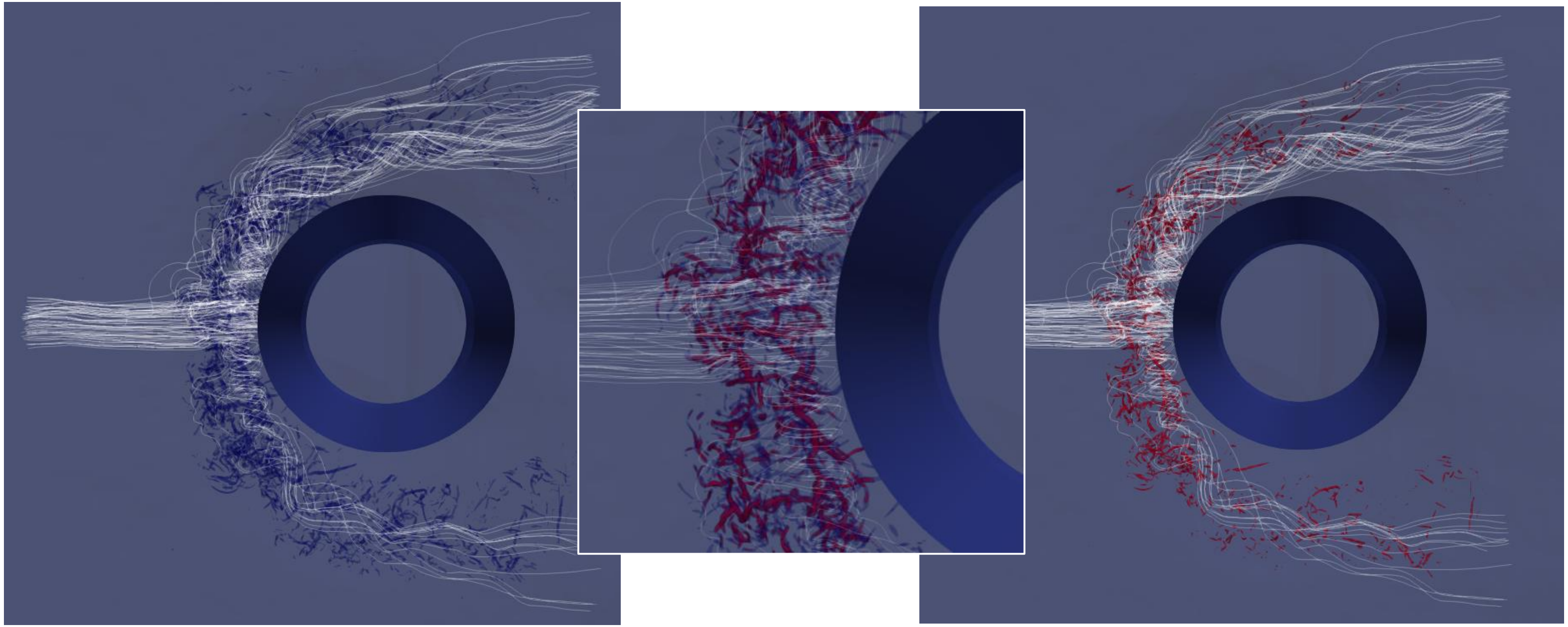


$P_{norm} = -1.0$

Instantaneous Horseshoe Vortex

2. **Q-criterion**

Re = 20k

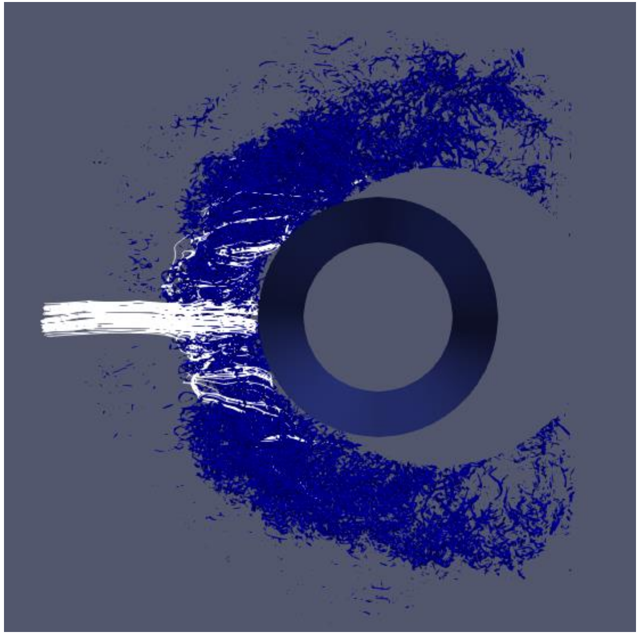


$Q_{norm} = 500$ $Q_{norm} = 1000$

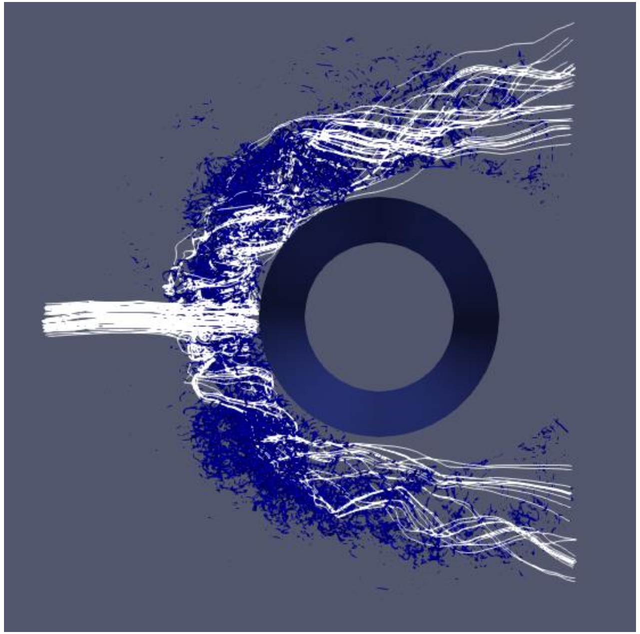
Instantaneous Horseshoe Vortex

2. Q-criterion

Re = 39k



$Q_{norm} = 500$

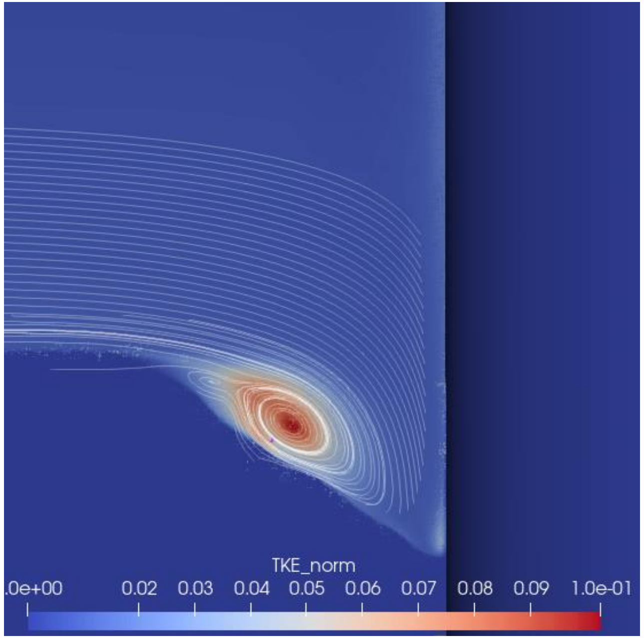


$Q_{norm} = 1000$

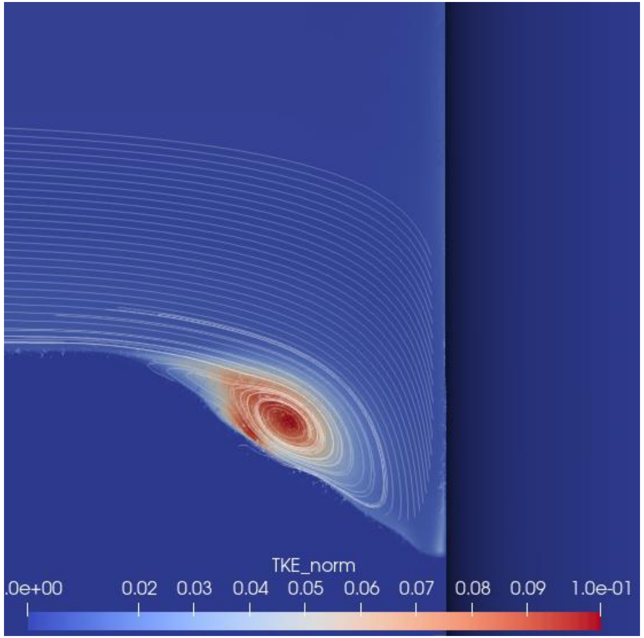
Turbulent Kinetic Energy

1. 2D Turbulent Kinetic Energy

Re = 20k



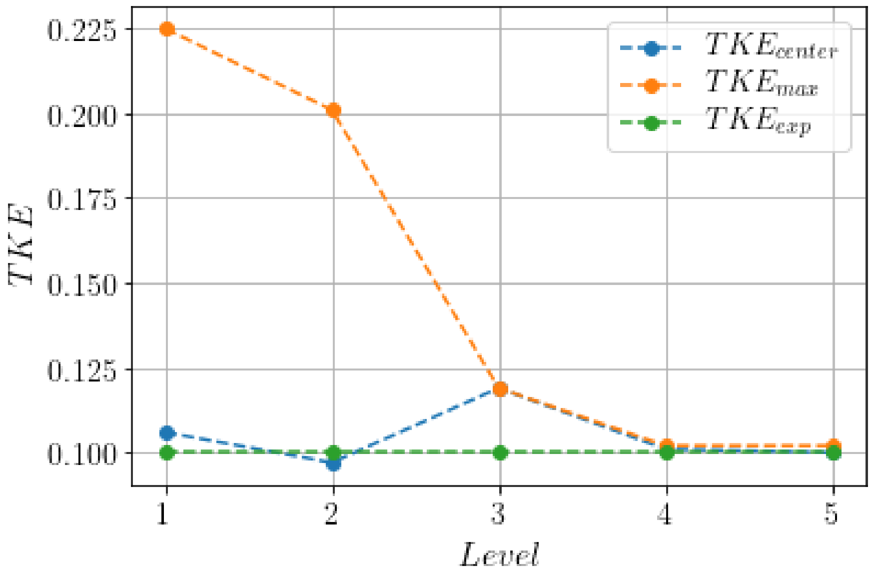
Re = 39k



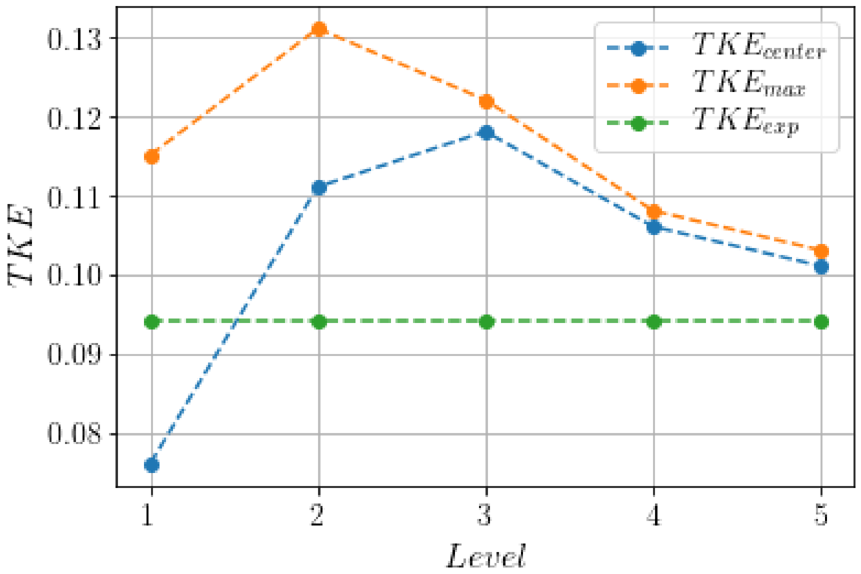
Turbulent Kinetic Energy

2. Turbulent Kinetic Energy at the HSV center

Re = 20k



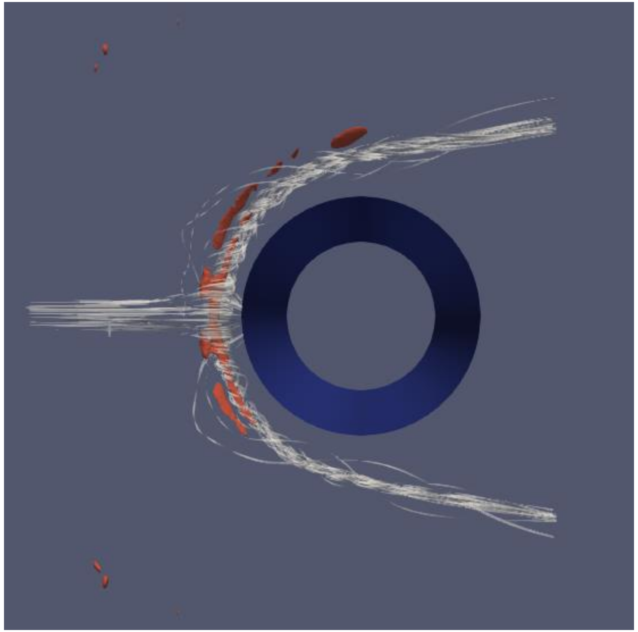
Re = 39k



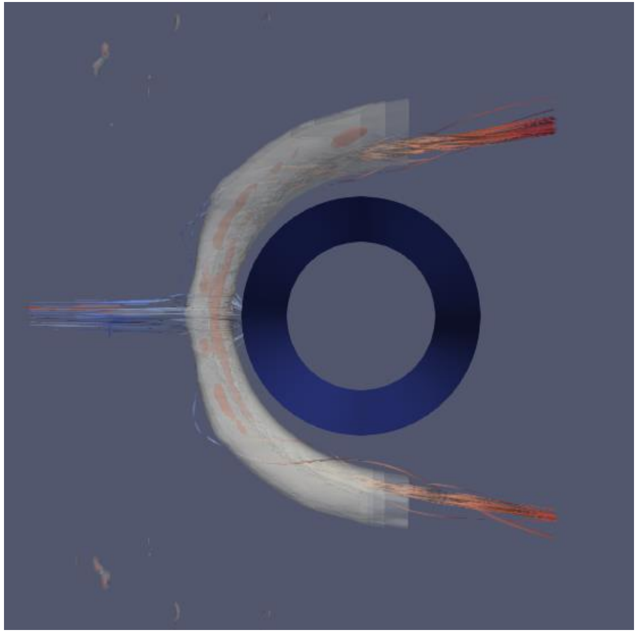
Turbulent Kinetic Energy

3. 3D Turbulent Kinetic Energy contour

Re = 20k



$TKE_{norm} = 0.09$

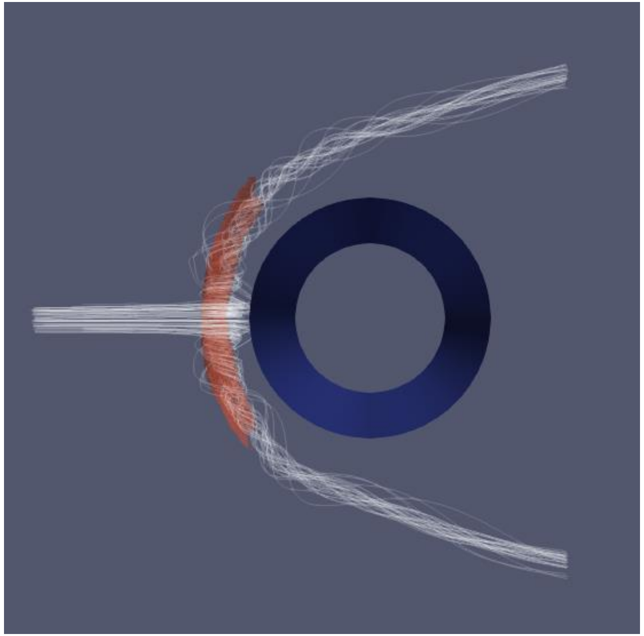


$TKE_{norm} = 0.05$

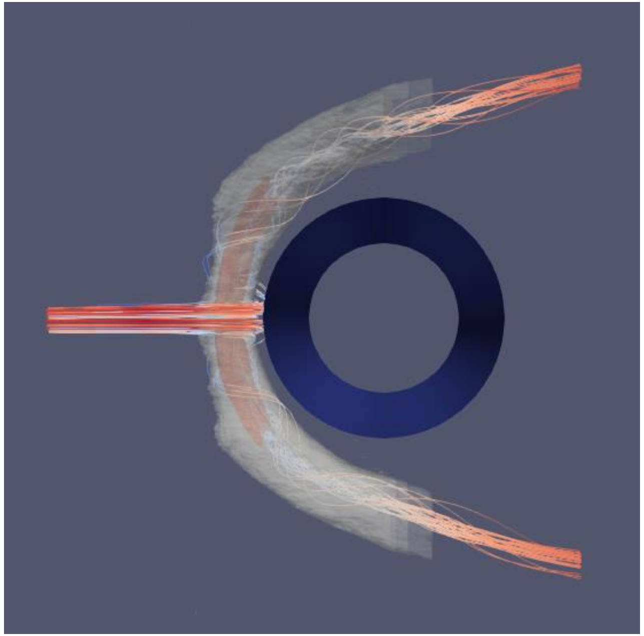
Turbulent Kinetic Energy

3. 3D Turbulent Kinetic Energy contour

Re = 39k



$TKE_{norm} = 0.09$

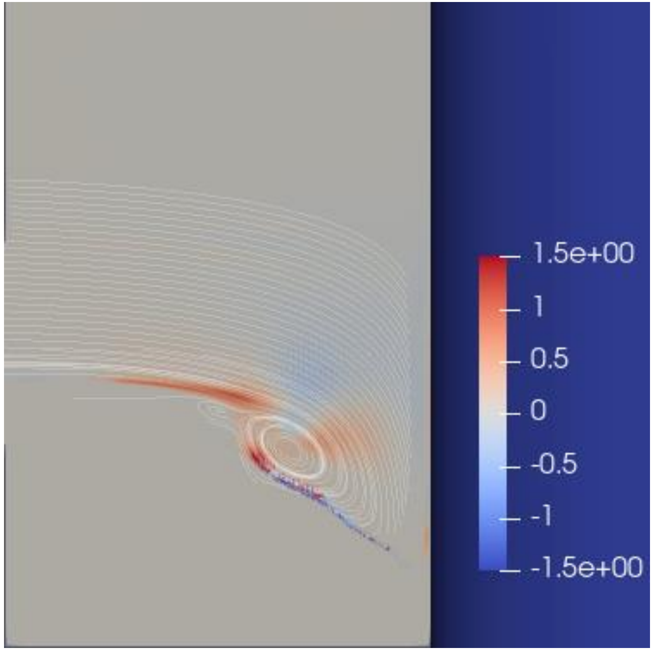


$TKE_{norm} = 0.05$

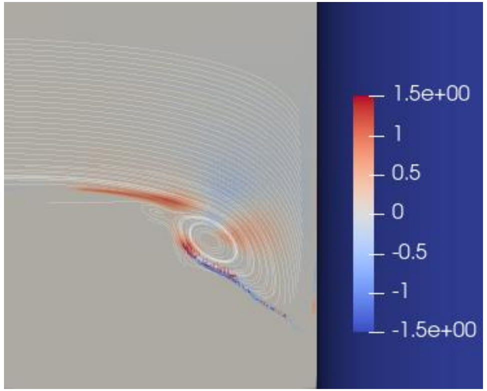
Budget of Turbulent Kinetic Energy

1. Turbulent Kinetic Energy Production

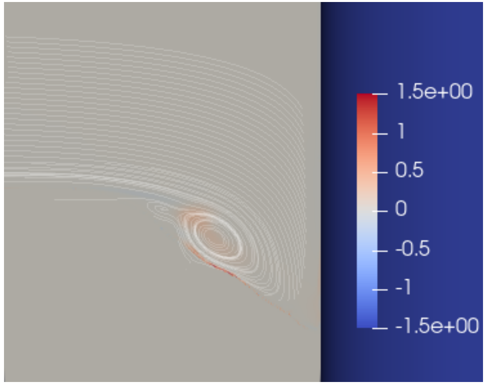
Re = 20k



Shear Production



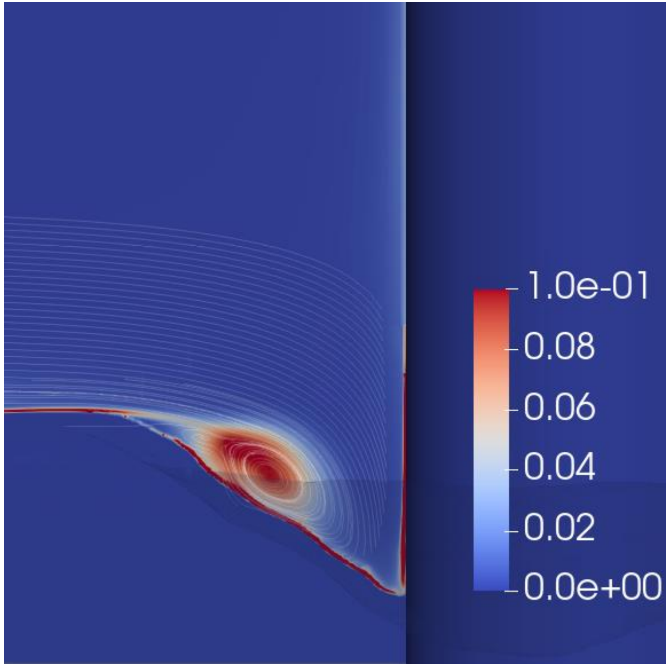
Normal Production



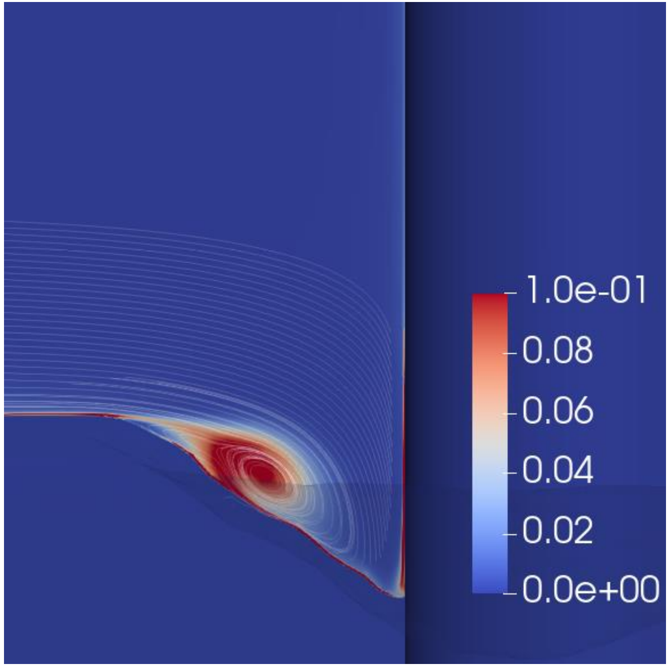
Budget of Turbulent Kinetic Energy

2. Turbulent Kinetic Energy Dissipation

Re = 20k



Re = 39k



Summary

- An LES dataset is investigated at two Reynolds Numbers
- Quality of the simulation is assessed → Simulation is reliable
- Flow topology is weakly dependent on Reynolds Number
- Secondary vortex is suspected, and no corner vortex detected
- The time-averaged HSV is investigated:
    - HSV center and core-line are specified
    - 3D streamlines and pressure contour
- Instantaneous behavior of the HSV is investigated:
    - 3D pressure contour
    - Q-criterion method

Summary

- Turbulent kinetic energy is studied:
  - TKE has c-shape structure with a maximum at the HSV center
- Turbulent kinetic energy budget is investigated

References

[1] Alonso Pizarro, Salvatore Manfreda, and Enrico Tubaldi. The science behind scour at bridge foundations: A review. Water, 12(2):374, January 2020. doi: 10.3390/w12020374.

[2] M. Manhart, et al., *The flow inside a scour hole around a circular cylinder: comparison between particle image velocimetry and large–eddy simulation*. 2021.

[3] N. Majaj, Using HECRAS to Evaluate Scour at Bridges. 2001

[4] *Battling Bridge Scour With Research, Inspections, And Training.* 2019. Retrieved from: https://www.ayresassociates.com/battling-bridge-scour-with-research-inspections-and-training/


THANK YOU :)