Numerical Investigation of Turbulent Flow Through Bar racks in Closed Conduits

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Outline

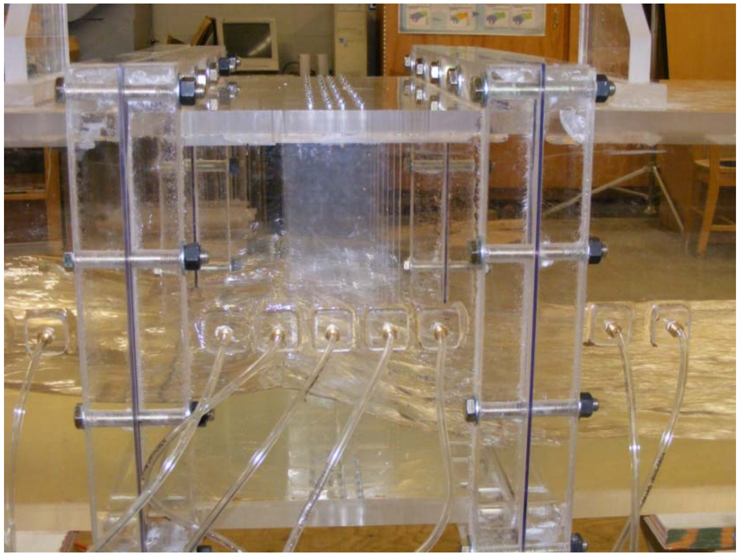
- Background
- Objective
- Previous Work
- Problem Definition
- Methodology
- Results and Discussion
- Concluding Remarks
- Future Work

What are Trash Racks?

- bars and supporting beams
- Protect turbine from debris
- Reduce mortality of larger fish
- energy losses

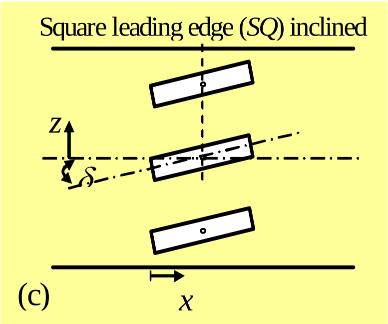
Trash rack in open channel

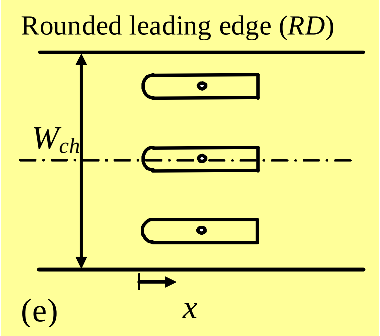
Trash rack in closed conduits

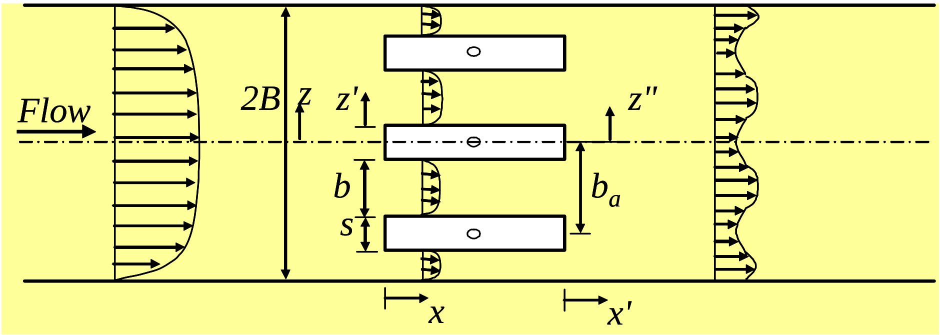


Fish injury or mortality

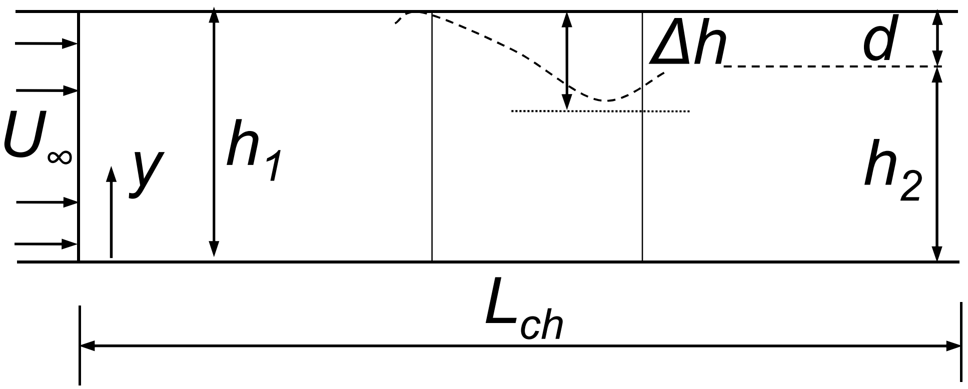
- Reducing fish injury or mortality depends on:
  - Species, sizes, abilities and behaviour
  - Spacing between bars (physical exclusion)
  - Shape of the bars
  - Flow conditions near barracks, particularly magnitude and patterns of flow velocity, acceleration and turbulence fields
  - Turbine design







- **Salient feature of this flow is that it produces head loss.**



- These energy losses can be partly attributed to the turbulent large scale flow structures generated by the bars.

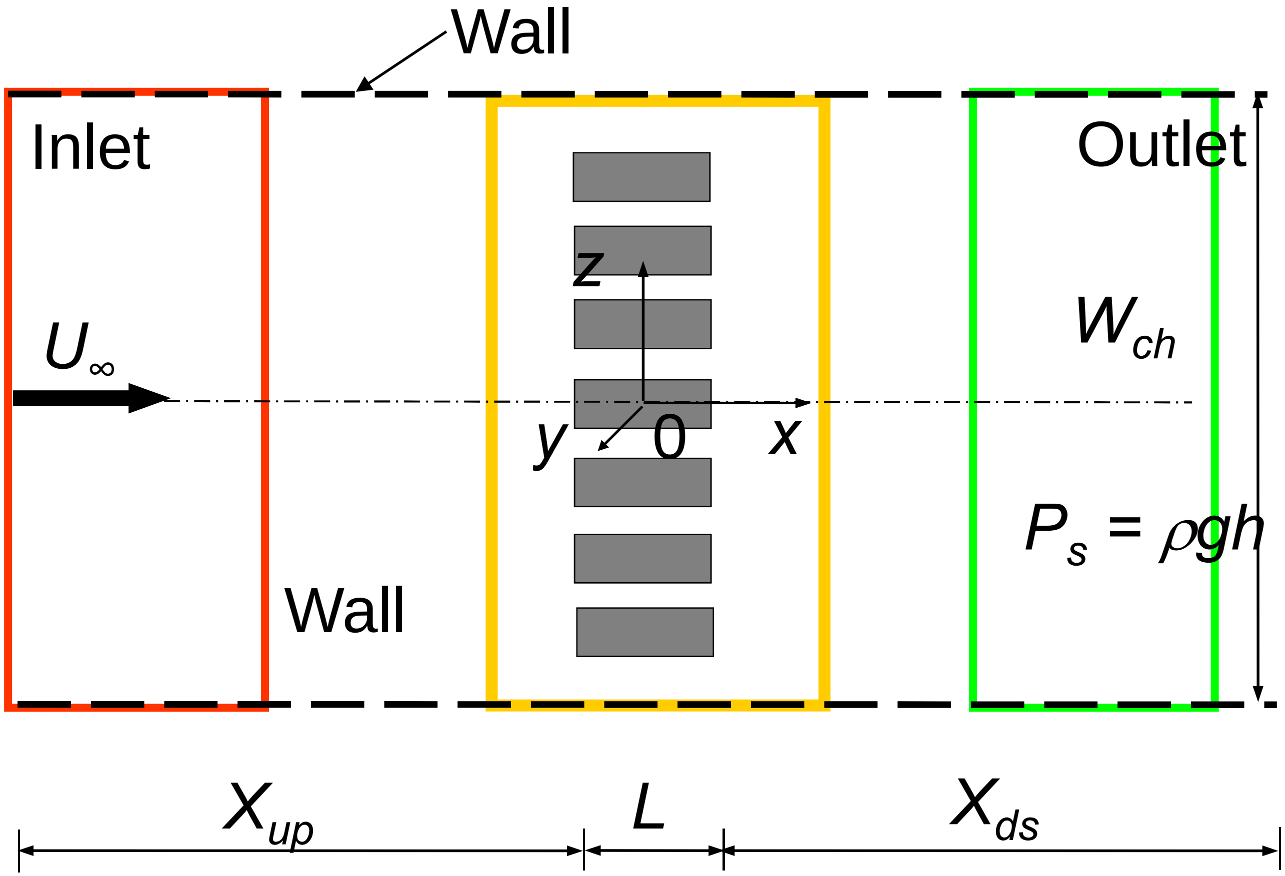
- Both from the fish protection and head loss perspectives, it is important to accurately predict the magnitude and patterns of turbulent flow characteristics, and velocity fields around and between the bars.

- The ability to correctly predict complex turbulent flows is fundamental to the design of trash racks as well as other fluid engineering systems.

Objectives

- To perform numerical investigation of turbulent flow through arrays of rectangular bar models of various configurations in closed conduits using a commercial CFD code, ANSYS CFX 12.1. .
- To evaluate and validate several turbulence models in order to assess the most suitable model for predicting turbulent flow through bar racks closed conduit model
- Assess the streamlines and contours of the mean velocity, turbulence levels, pressure field. As well as the profiles.

Problem Description



Schematic of the flow field around bar racks and solution domain nomenclature

Previous Work

Experimental

Authors	**Remarks**
Mosonyi, 1963; Orsborn, 1968; Wahl, 1992; Meusburger et al (2001)	*Performed bulk flow measurements (i.e., average velocity and pressure) using various bar shape, blockages etc *Developed correlations for calculating head losses, Δh
Tsikata *et al.* 2008 Tsikata *et al.* 2009(a & b)	*Studied the effects of bar shape, depth, thickness, spacing and inclination to the approach flow, on head losses. *Used Proper Orthogonal Decomposition to extract and study the role of the large scale structures in flow around TR.
Clark *et al.* 2010	*Performed velocity and pressure measurement of flow through submerged TR

Previous Work

Numerical

Authors	Model	Code	Remarks
Hermann *et al.* 1998	***DNS, k-ε***	**In-house**	*The DNS produced head losses that compared well with measured values at low blockage ratios but produced higher losses than measured data at higher blockage ratios. *k-ε were in good agreement with the measured data, especially at higher blockage ratios.
Meusburger *et al.* 1999	***DNS, k-ε***		
Nascimento *et al.* (2006)	**Smagorinsy SGS**	**In-house**	*Found that the natural frequencies for a submerged bar-rack are about 30% smaller than the values of the natural frequencies of a non-submerged bar-rack.

Present Work

Summary of geometric parameters and test conditions (University of Manitoba Experimental data for closed conduits by Clark *et al.* 2010, supported by Manitoba Hydro used for validation)

TEST	***n***	***s* [m]**	***L* [m]**	***b* [m]**	***p***	**U_∞ [m/s]**
1	3	0.012	0.100	0.140	0.079	0.32, 0.48, 0.96, 1.12,1.37, 1.64
2	7	0.012	0.100	0.053	0.185	0.49, 0.98, 1.39
3	14	0.012	0.100	0.021	0.369	0.26, 0.78, 1.42

Methodology Cont'd.

➢Governing Equations

Assumptions:

- The fluid Newtonian
- Steady, incompressible, and turbulent

Equations:

- Continuity and momentum conservation equations
- Turbulence model equations: RANS 2-eqn, SMC
  (*k*-ε , *k*-ω , *SST*, *LRR-IP*, & *SSG*)

Methodology

Numerical Solution

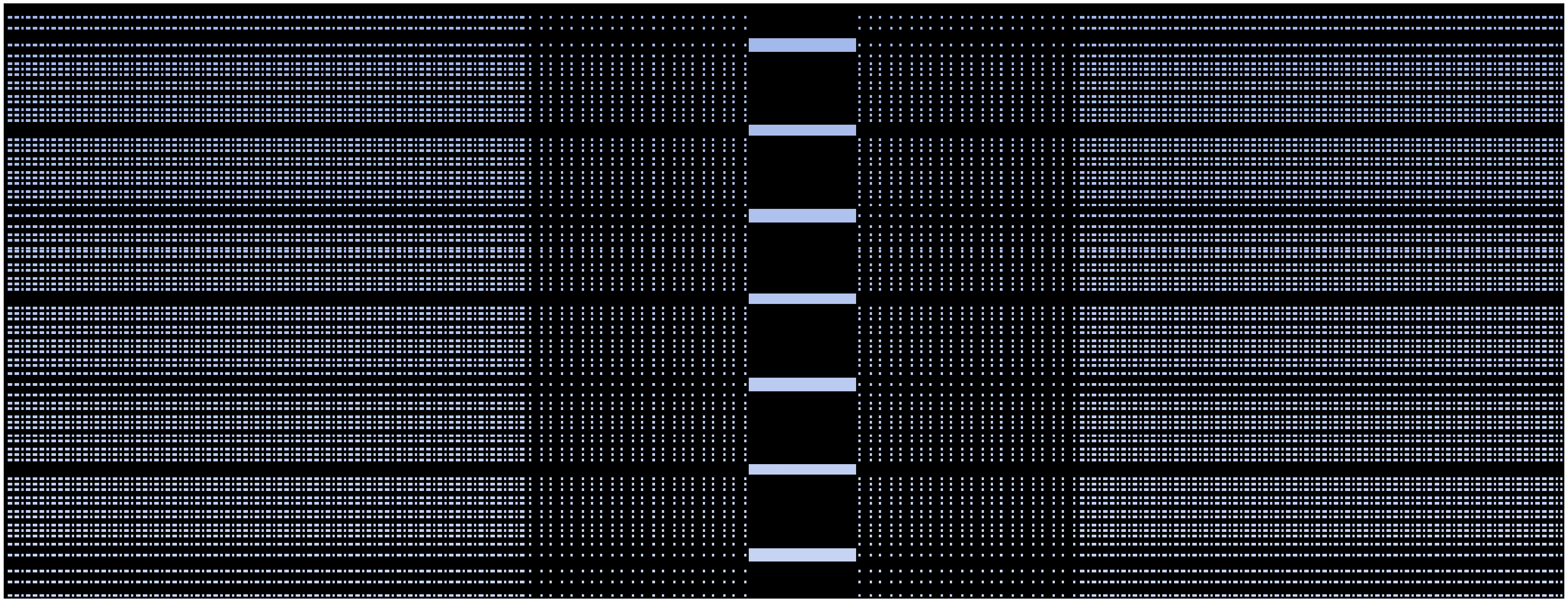
Commercial CFD Code, ANSYS CFX v12.0:

- Element based FVM
- Geometrical representation and integration points are based on FEM

- The coupled discretized mass and momentum equations with the turbulence model equations were solved iteratively using additive correction multi-grid acceleration.
- Solutions were considered converged when the normalized maximum residual of all the discretized equations was less than 1×10^{-4}.

Methodology Cont'd.

- **Numerical Solution: Computational Mesh**



Sample coarse mesh (plan view)

Methodology Cont'd.

- **Numerical Solution: Boundary conditions**

Inlet

- $U = U_\infty, I = 0.05$

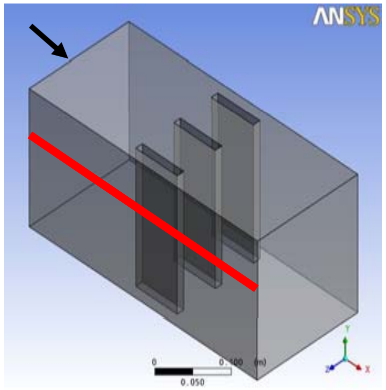
Outlet

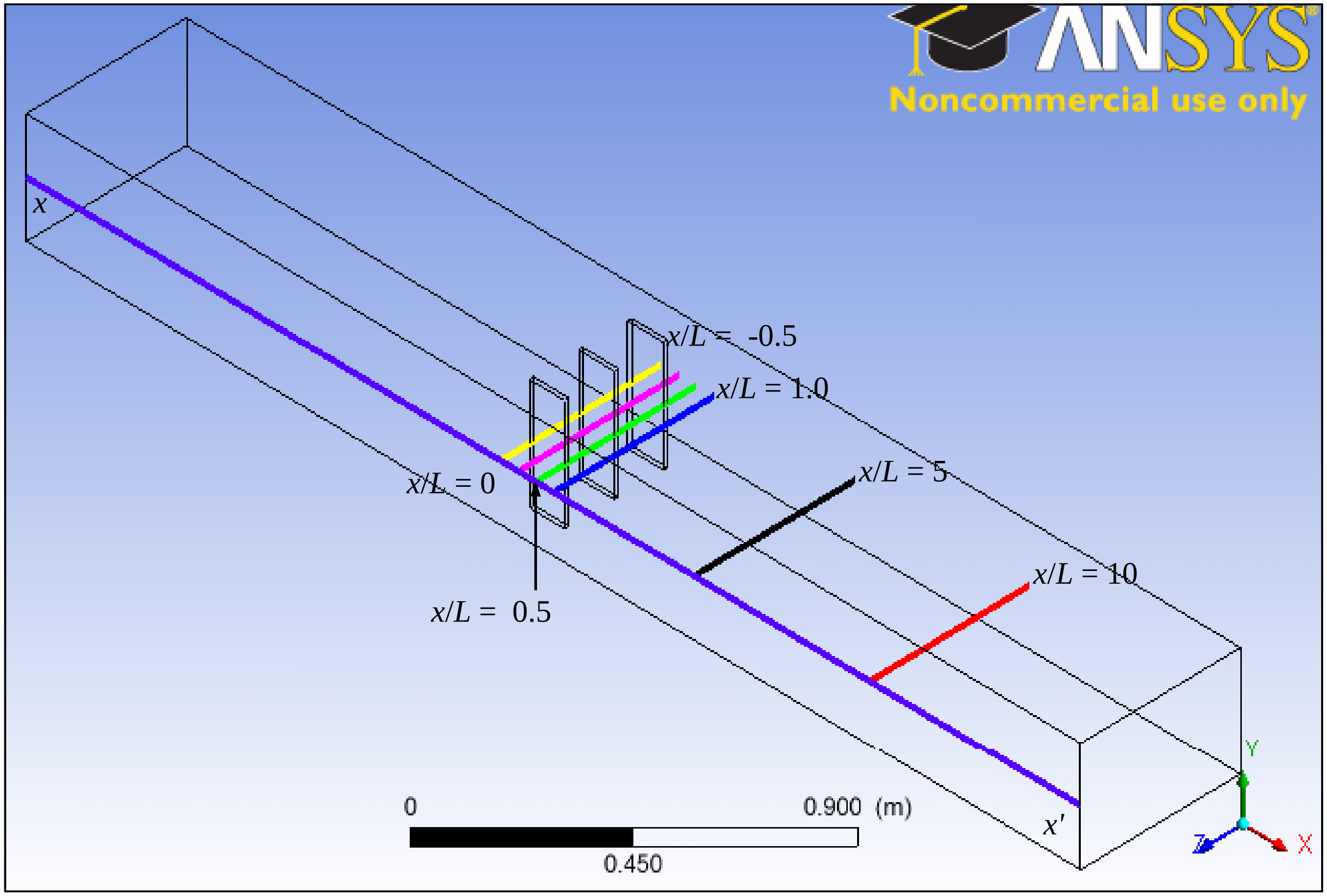
$P_s = \rho g h$

Walls

- No-slip
- Low Reynolds number near-wall treatment for all models

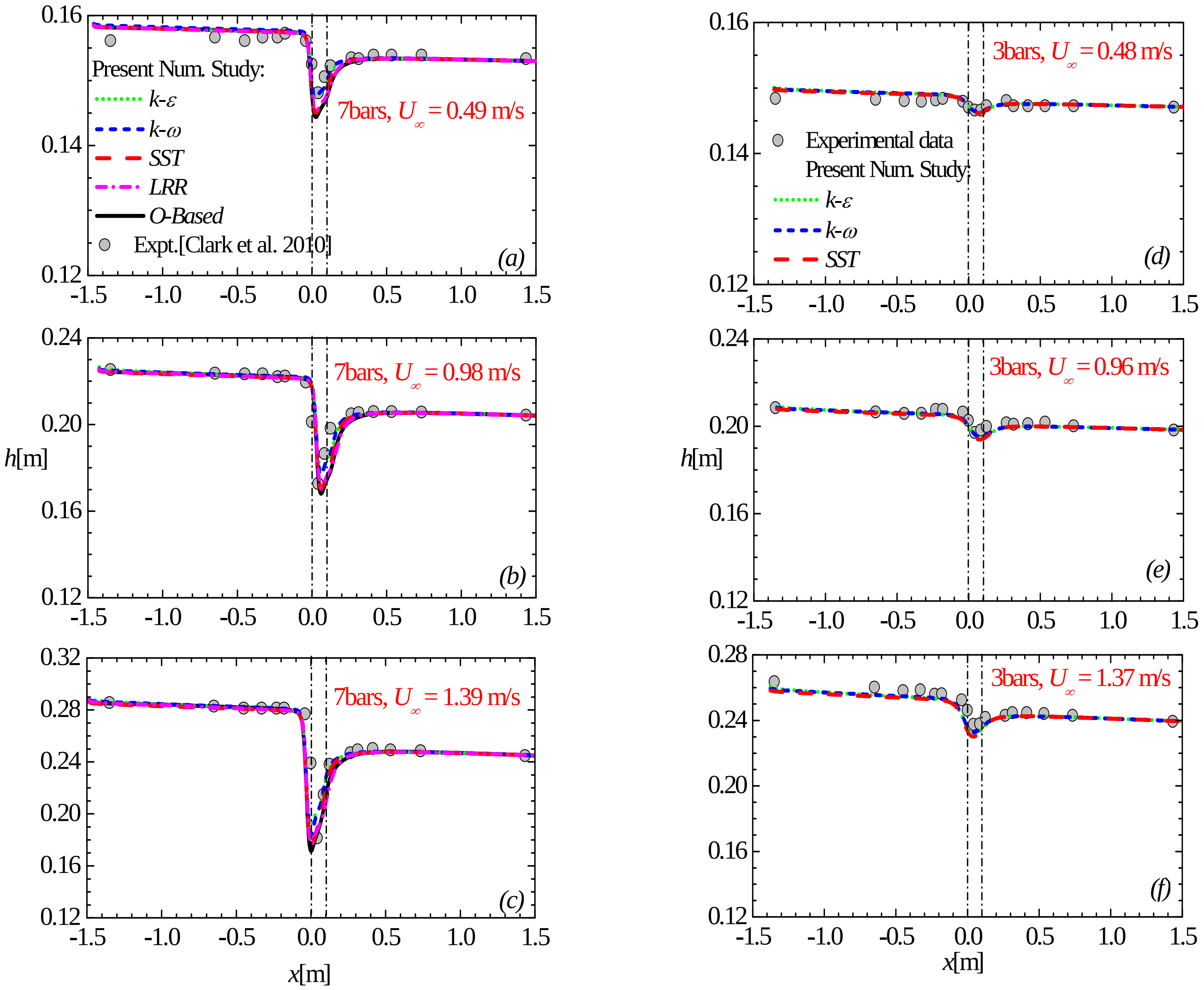
Results & Discussion





Geometrical layout showing a typical location at which sample results are presented

Results & Discussion Cont'd.



Comparison between profiles of predicted pressure head with measured values for selected approach velocity: (a, b, c) 7 bars and (e, f, g) 3 bars.

Results & Discussion Cont'd.

Table 1: Summary of head loss coefficient for Test 2

Model	L(m)	n	p	U_∞(m/s)	Numerical Study		Expt.
					Δh	Δh^*	Δh^*
k-ε	0.10	7	0.185	**0.49**	0.0042	**0.343**	**0.334**
	0.10	7	0.185	**0.98**	0.0170	**0.343**	**0.334**
	0.10	7	0.185	**1.39**	0.0340	**0.343**	**0.334**
k-ω	0.10	7	0.185	0.49	**0.0044**	0.360	0.334
	0.10	7	0.185	0.98	**0.0180**	0.360	0.334
	0.10	7	0.185	1.39	**0.0350**	0.360	0.334
SST	0.10	7	0.185	0.49	0.0043	0.351	0.334
	0.10	7	0.185	0.98	0.0170	0.351	0.334
	0.10	7	0.185	1.39	0.0350	0.351	0.334
LRR-IP	0.10	7	0.185	0.49	0.0040	0.347	0.334
	0.10	7	0.185	0.98	0.0170	0.347	0.334
	0.10	7	0.185	1.39	0.034	0.347	0.334
SSG	0.10	7	0.185	0.49	0.0040	0.351	0.334
	0.10	7	0.185	0.98	0.0172	0.351	0.334
	0.10	7	0.185	1.39	0.0346	0.351	0.334

Results & Discussion Cont'd.

Table 2: Summary of non-dimensional head loss coefficient for all test cases

Model	**Test**	***s*(m)**	**n**	**p**	**U_∞(m/s)**	***Δh^****			
						Expt	**Eq. (4.1)**	**Eq. (4.2)**	**Eq. (4.3)**
k-ε	1	0.012	3	0.079	0.48	0.085	0.091	0.044	0.072
				0.079	0.96	0.085	0.091	0.044	0.072
				0.079	1.37	0.085	0.091	0.044	0.072
k-ε	2	0.012	7	0.185	0.49	0.334	0.334	0.243	0.337
				0.185	0.98	0.334	0.334	0.243	0.337
				0.185	1.39	0.334	0.334	0.243	0.337
k-ε	3	0.012	14	0.369	0.26	1.089	1.148	0.967	1.257
				0.369	0.78	1.089	1.148	0.967	1.257
				0.369	1.42	1.089	1.148	0.967	1.257

$$\Delta h = \phi (s/b)^{4/3} (U^2/2g) \sin\alpha$$

Eq. (4.1): Kirschmer (1926)

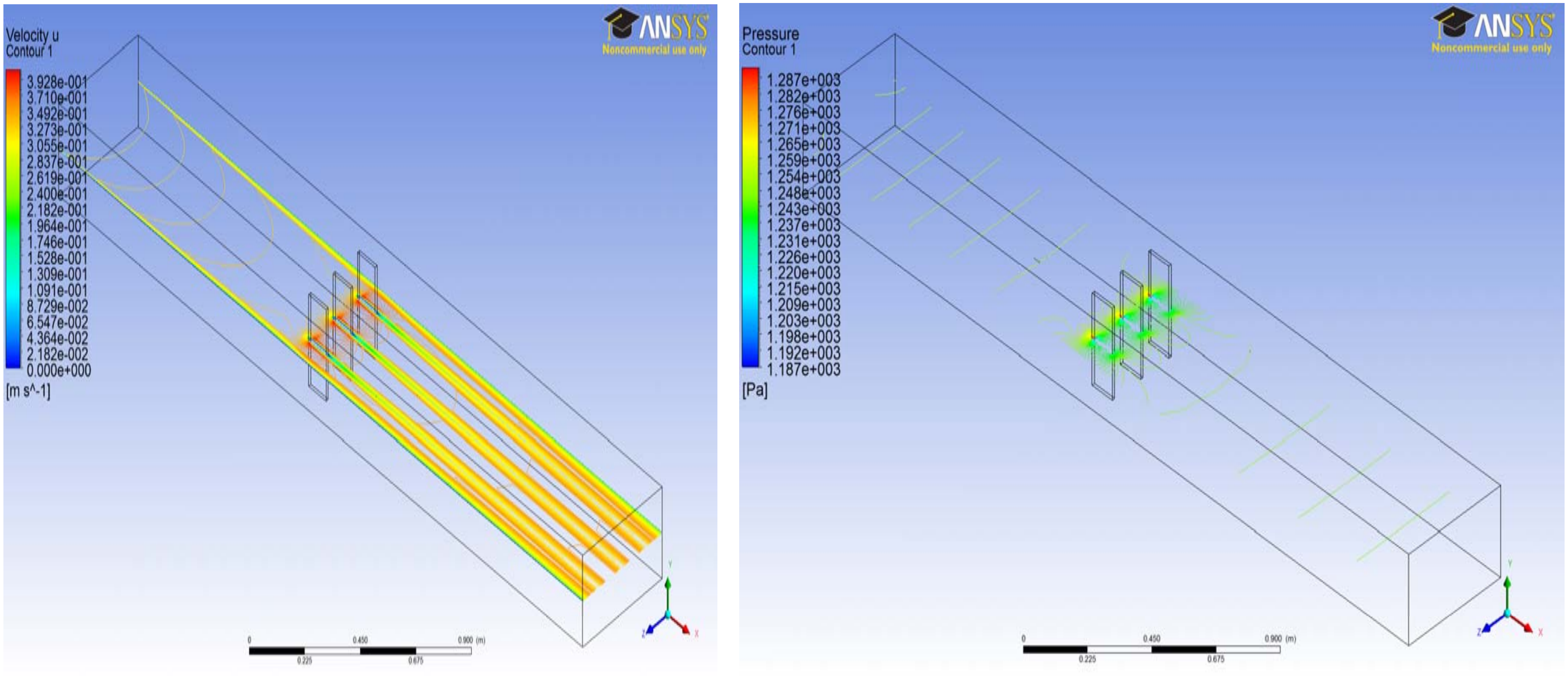
$$\Delta h = k p^2 (U^2/2g) \sin\alpha$$

Eq. (4.2): Fellenius and Lindquist (1929)

$$\Delta h = \phi (1 + B\tan\theta) p^C (b/L)^D (U^2/2g) \sin\alpha$$

Eq. (4.3): Meusburger *et al.* (2001)

Results & Discussion Cont'd.

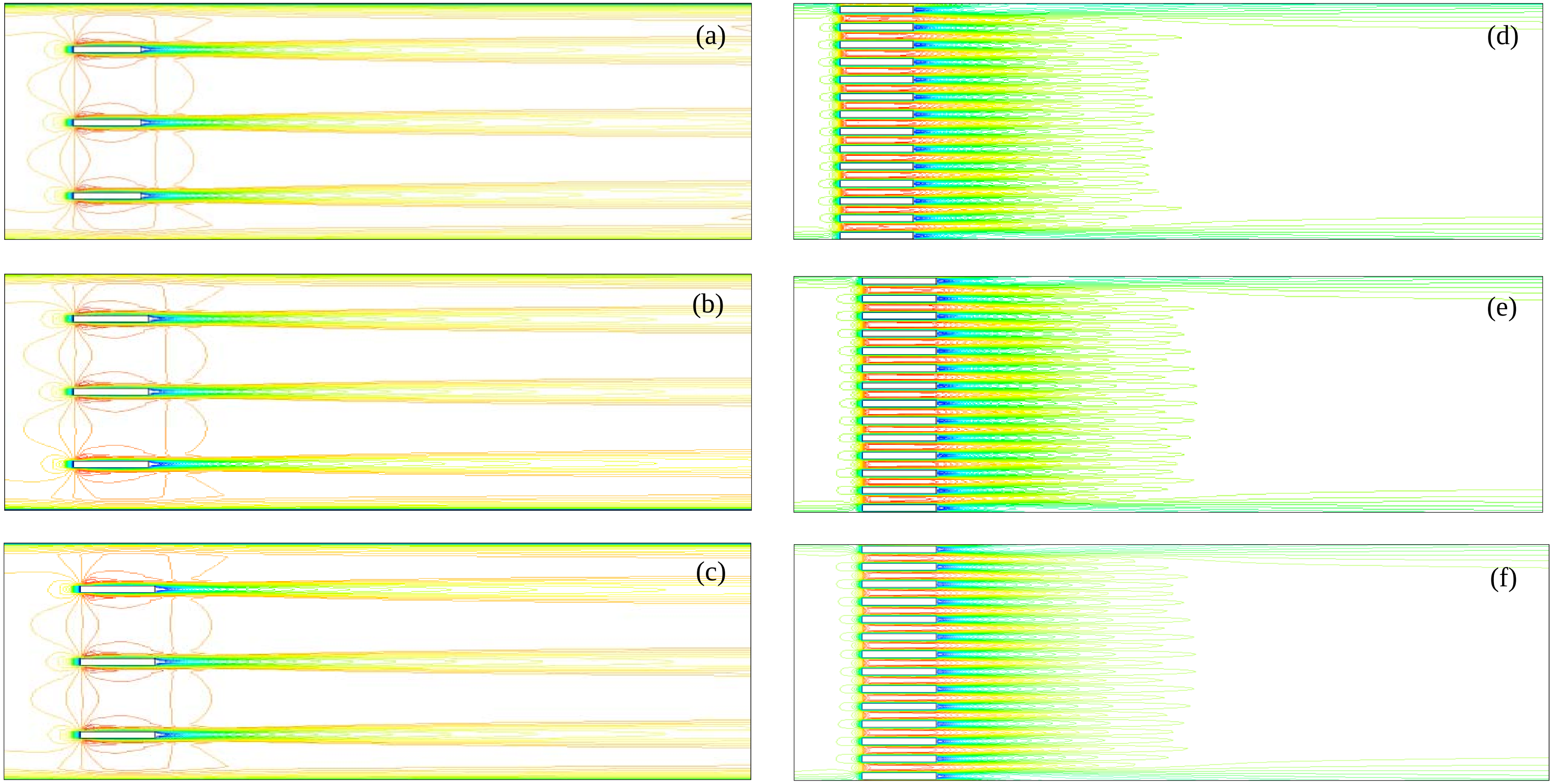


(a)

(b)

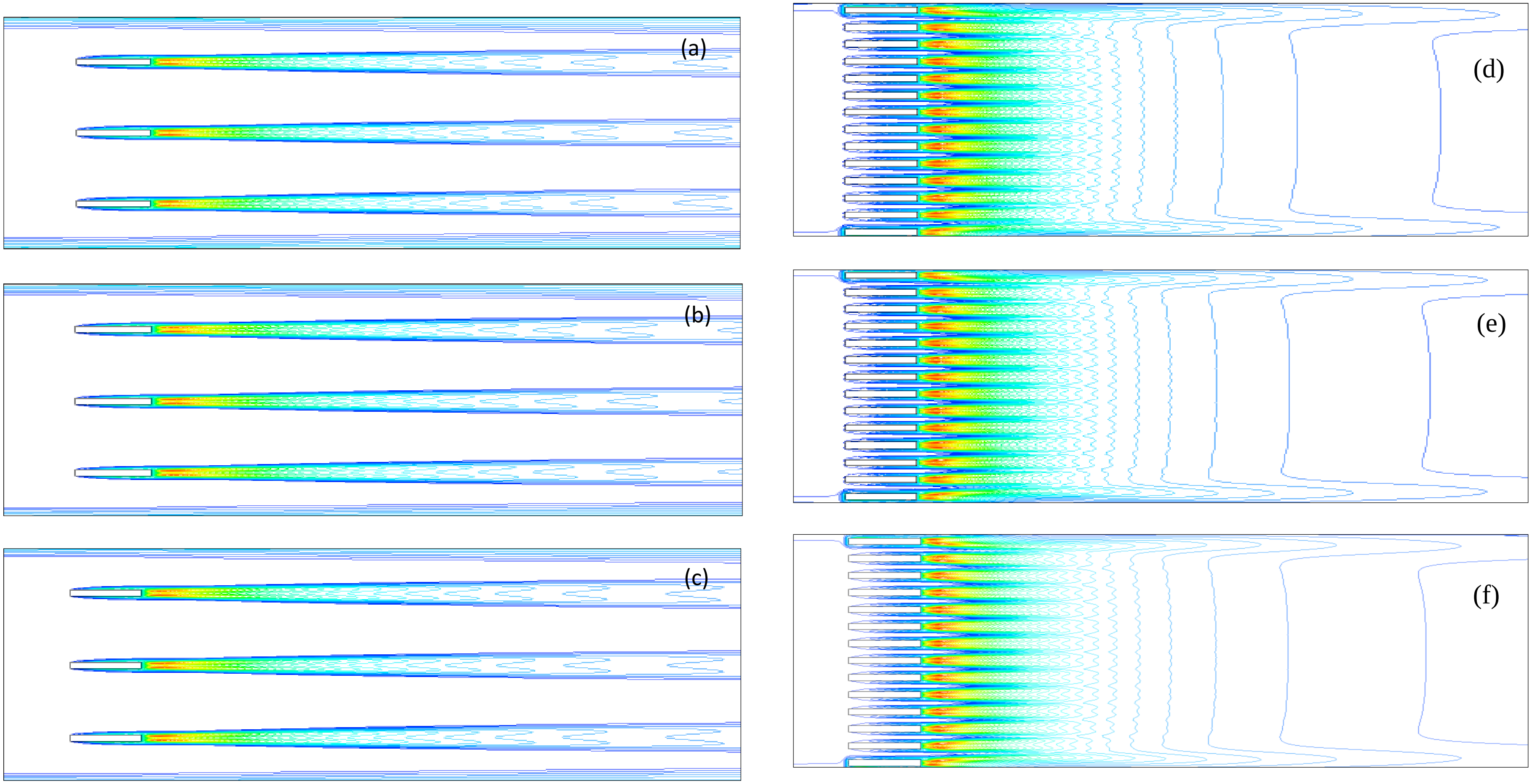
Contours of: (a) mean streamwise velocity and (b) static pressure field

Results & Discussion Cont'd.



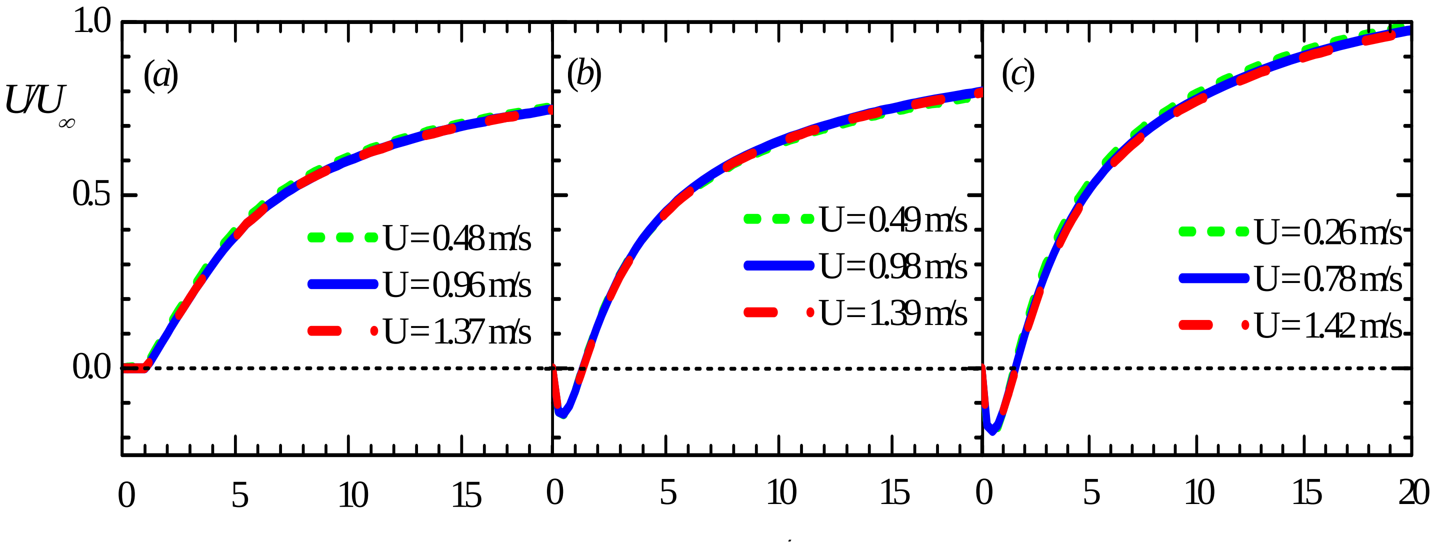
Contours of mean velocity ($U^* = U/U_\infty$) for 3bars: (a) U = 0.48 m/s, (b), 0.96 m/s, and (c) 1.37 m/s, and for 14bars: (a) U = 0.26 m/s, (b), 0.78 m/s, and (c) 1.42 m/s

Results & Discussion Cont’d



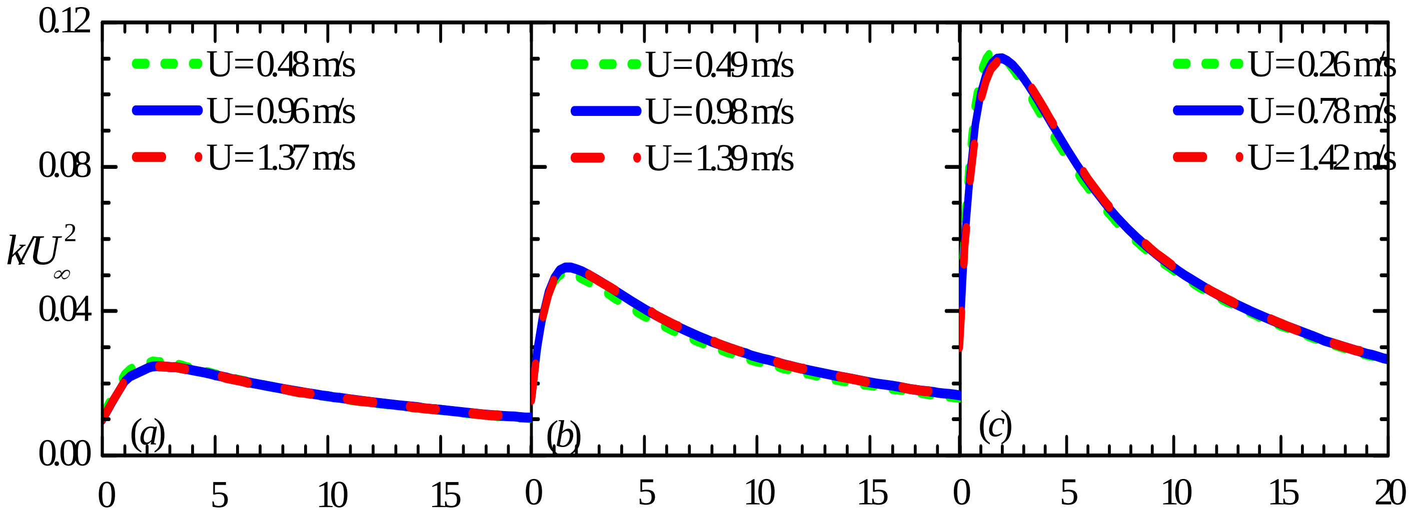
Contours of Tke ($k^* = k/U_\infty^2$) for 3bars: (a) U = 0.48 m/s, (b), 0.96 m/s, and (c) 1.37 m/s, and for 14bars: (a) U = 0.26 m/s, (b), 0.78 m/s, and (c) 1.42 m/s

Results & Discussion Cont'd



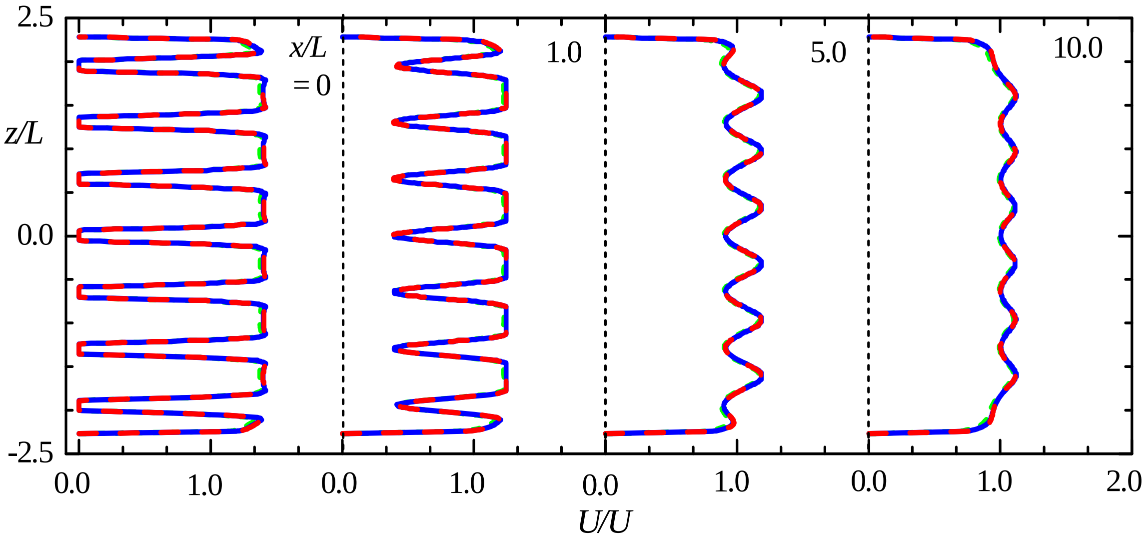
Mean velocity profile along the wake axes; (a) 3 bars , (b) 7 bars , and (c) 14 bars ; correspondingly, the blockage ratios are, respectively, 0.079, 0.185, and 0.369

Results & Discussion Cont’d

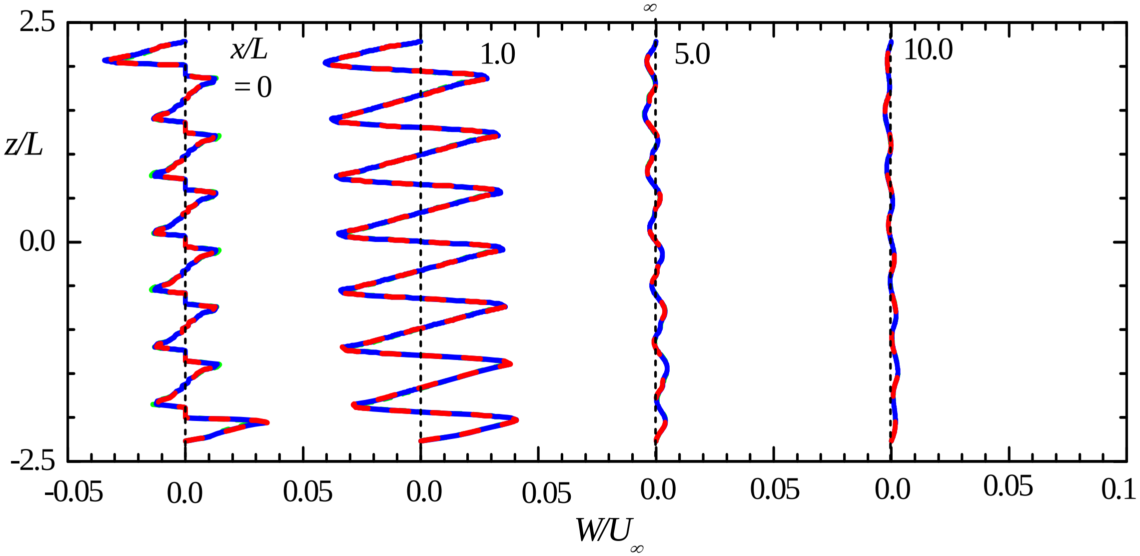


Turbulence kinetic energy profile along the wake axes: (a) 3 bars , (b) 7 bars , and (c) 14 bars ; correspondingly, the blockage ratios are, respectively, 0.079, 0.185, and 0.369

Results & Discussion Cont’d



Profiles of U/U_∞ across the wake axis of the bar racks at selected x/L locations



Profiles of W/U_∞ across the wake axis of the bar racks at selected x/L locations

Concluding Remarks

- The ANSYS-CFX reproduces the flow characteristics reasonably well
  - ✓ k-ε models give better results than the other models
  - ✓ Present results were in good agreement with prior results
  - ✓ k- ε model predicted the mean velocity, turbulence kinetic energy, and pressure coefficient reasonably well. It was found that the head loss increases with blockage ratio as well as the independence of dimensionless pressure head (Δh^*) on the Reynolds number.
  - ✓ The recovery of mean velocity to its upstream value ($U/U_\infty = 1$) is most rapid at higher blockage ratio.
  - ✓ the level of turbulence increases with increasing blockage ratio

Future works

Future Works

- Will provide further insight into the effects of bar **leading** and **trailing** edges, bar shape, bar depth, bar thickness, bar spacing and bar **inclination** to the approach flow, on head losses in model bar racks using Flow 3-D software for **improved bar rack design** and **fish survival at hydroelectric turbines**.

- Influence of the following flow parameters on fish survival:
  - Turbulence and turbulence intensity (area upstream of bar racks)
  - Shear in flow (area upstream of bar racks)
  - Acceleration (area upstream of bar racks)
  - Areas of maximum flow speed (area upstream of bar racks)

  will be fully examined.

Acknowledgement

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Question

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