Essentials of Turbulence :

Vortex Shedding Past Square Cylinder

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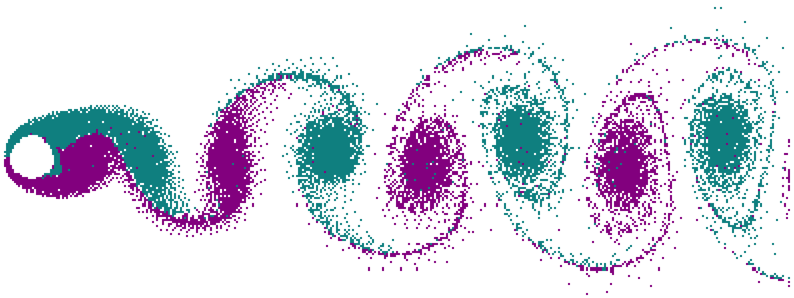
Problem Description

- Vortex Shedding is an oscillating flow that takes place when a fluid flows past a bluff body in certain range Re.

- Vortices are created at the back of the body and detach periodically from either side of the body.

- Strouhal Number $St = \frac{fD}{U}$

- Lyn [1] performed Laser-Doppler Velocimetry for one period of vortex.



Vortex shedding past cylinder

Figure is taken from https://en.wikipedia.org/wiki/Vortex_shedding

Objective

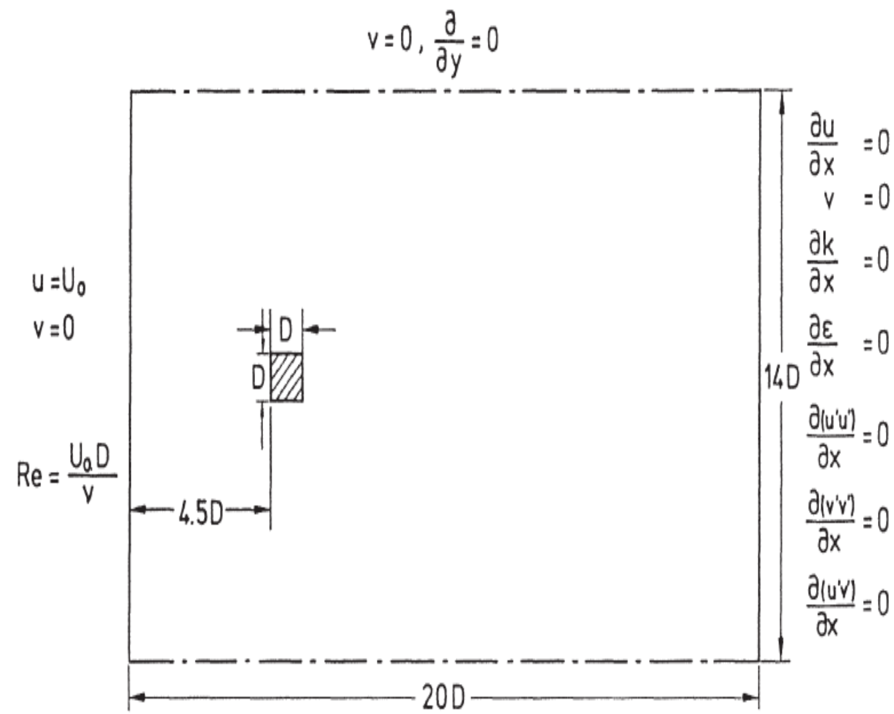
1. Analyse the flow around square cylinder in ANSYS-Fluent and calculate:

- Coefficient of discharge C_d
- Velocity profile at different longitudinal and lateral
- Strouhal number calculation from coefficient of lift C_l
- Streamlines for different phases of vortex shedding

2. Compare Fluent data with Lyin [1] experimental data.

Calculation Domain and BC

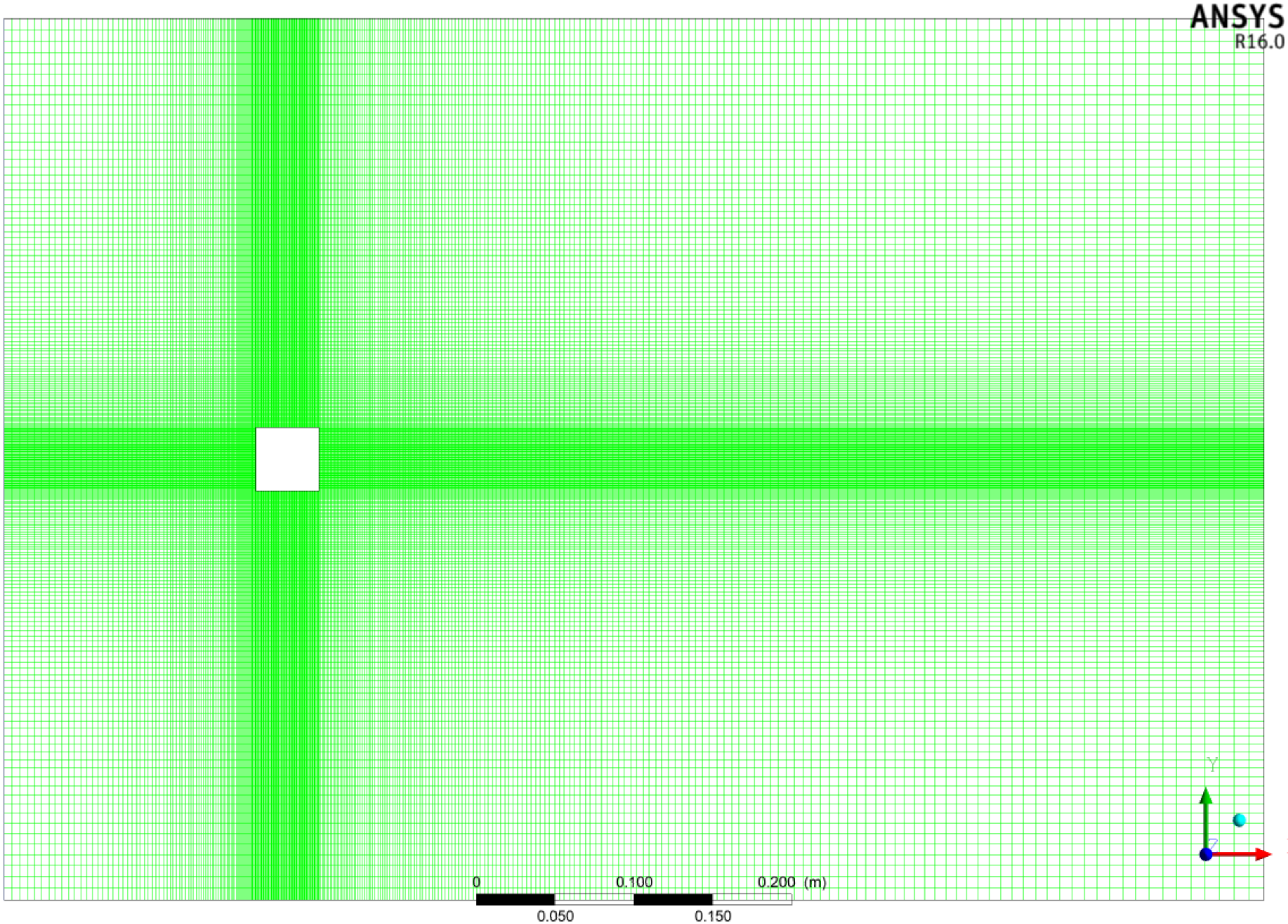
Flow Parameters	**Value**
Reynolds Number	21400
Free stream turbulence level	2%
Strouhal number	0.132
Cylinder diameter	0.04 m
Working Fluid	Water



Calculation domain and Boundary Conditions

Figure is taken from Franke and Rodi[2]

Mesh Details



Turbulence Model and Numerical Methods

- URANS SST k-ω model [4,5]
- SST k-ω model has good behaviour in adverse pressure gradients and separating flow [5]
- Numerical C_d matches with experimental value [4]
- 2D simulation model with FVM and SIMPLE algorithm for governing equations. [3]
- Second order implicit scheme for time discretization and third order scheme for spatial discretization.

[3] S. Murakami paper [4] F.Y. Xu paper [5] Ansys Fluent 16 Theory guide

Time step calculation

$$U = 0.5375 m/s$$

$$St = \frac{fD}{U}$$

$$f = \frac{St \cdot U}{D} = 1.77375 Hz$$

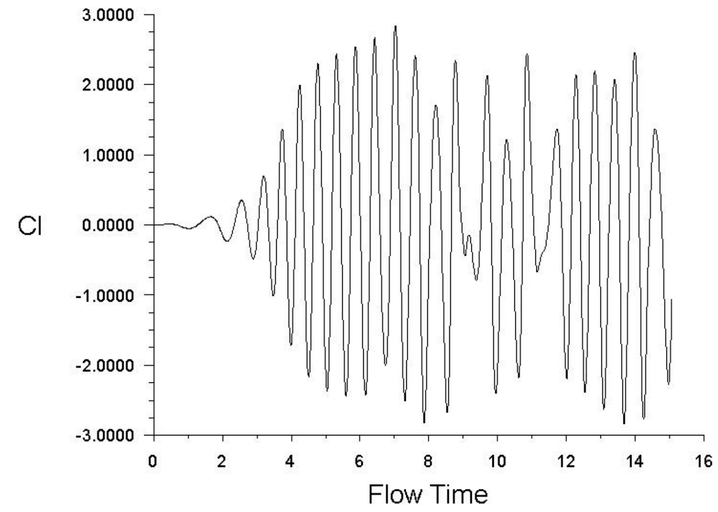
$$T = 0.563777 s$$

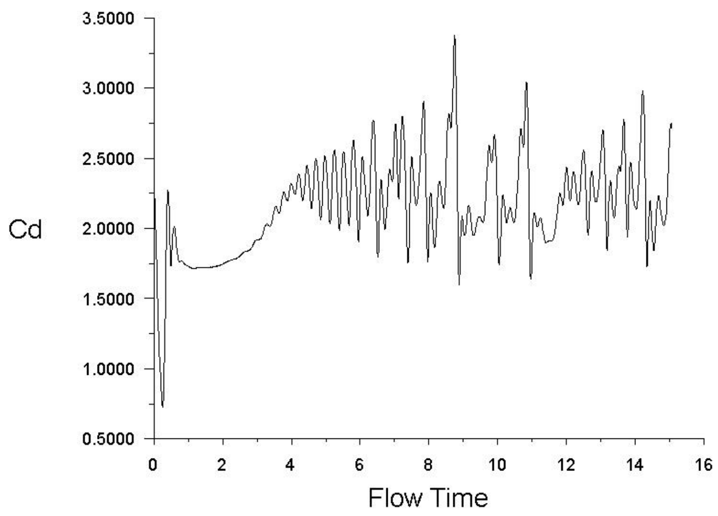
$$Step = 0.01 s$$

$$Iter/Step = 25$$

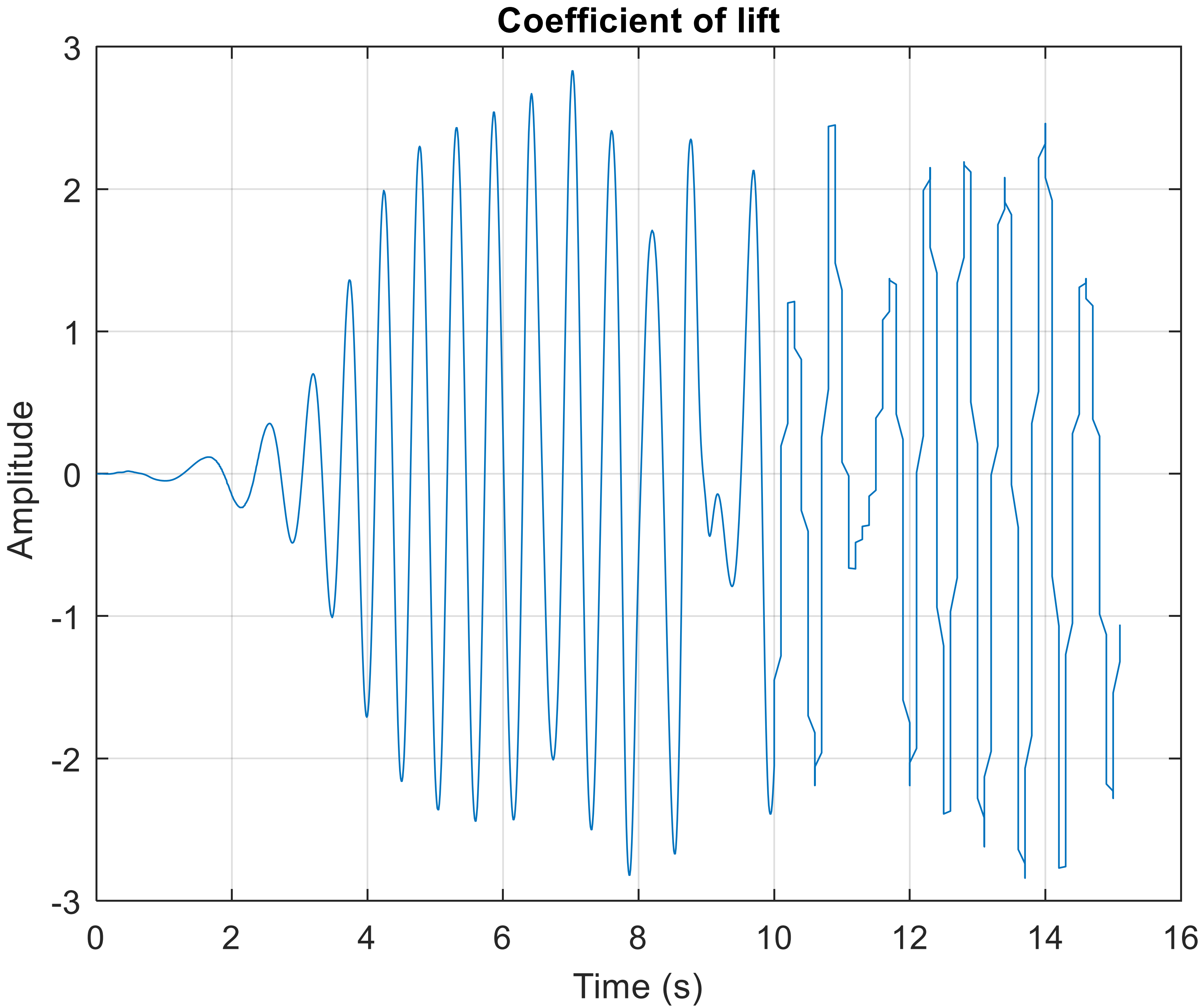
$$Total = 15 s$$

$$Iterations = 1500$$





VALIDATION



Coefficient of lift
Amplitude
Time (s)
3
2
1
0
-1
-2
-3
0
2
4
6
8
10
12
14
16

Strouhal Number Validation

FFT code Output

---FFT of Lift coefficient---

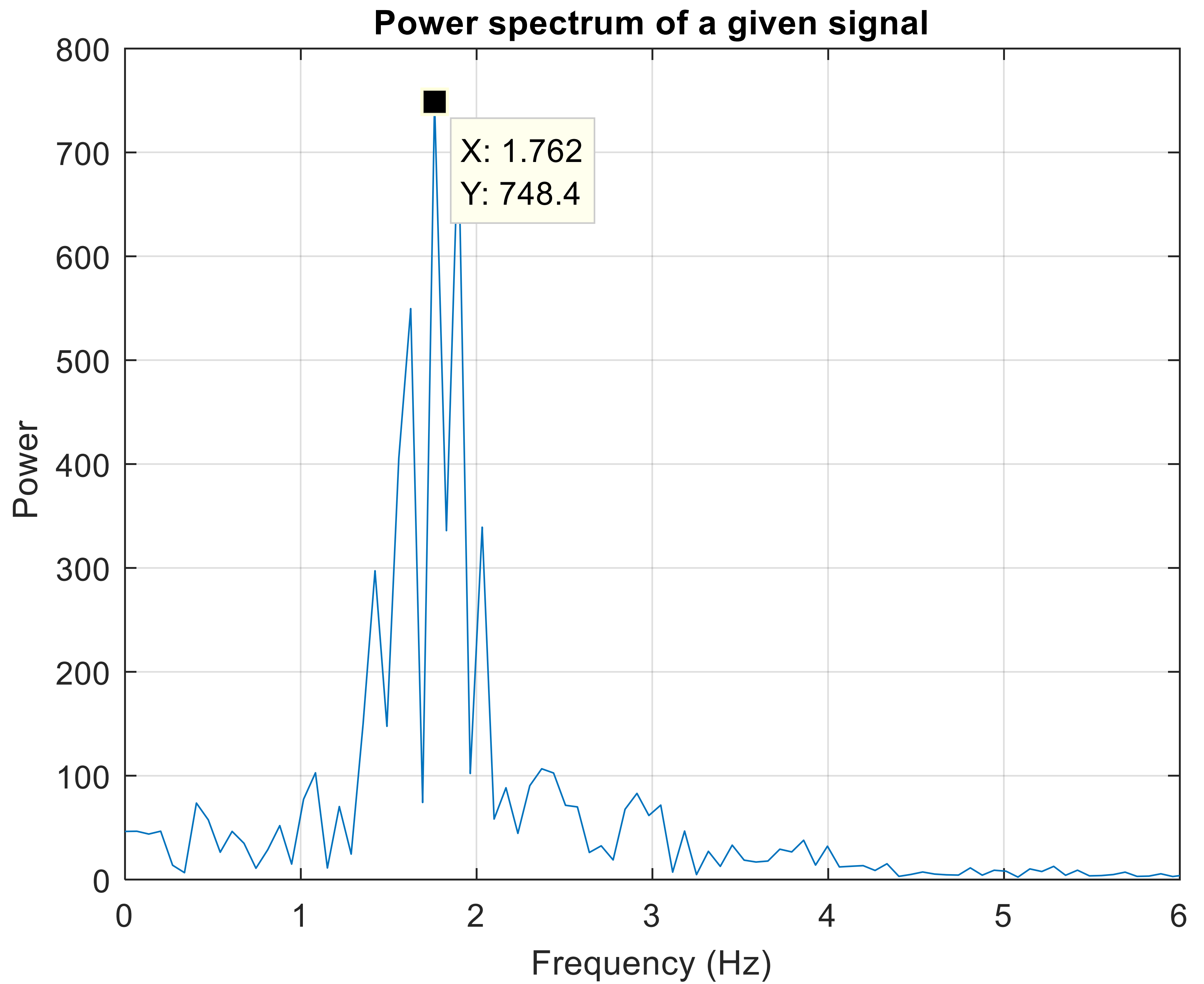
Strouhal Number is 0.131098

Frequency is 1.761633 Hz

Time period is 0.567655 s

Manual Calculation

Start Time	4.23 s
End Time	9.68 s
Total samples	10
Strouhal Number	0.137
Frequency	1.835
Time period	0.545

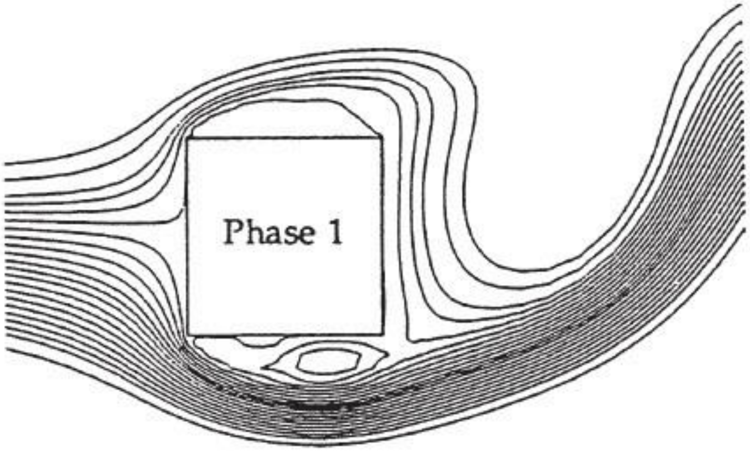


Power spectrum of a given signal
X: 1.762
Y: 748.4
Power
Frequency (Hz)
0
100
200
300
400
500
600
700
800
0
1
2
3
4
5
6

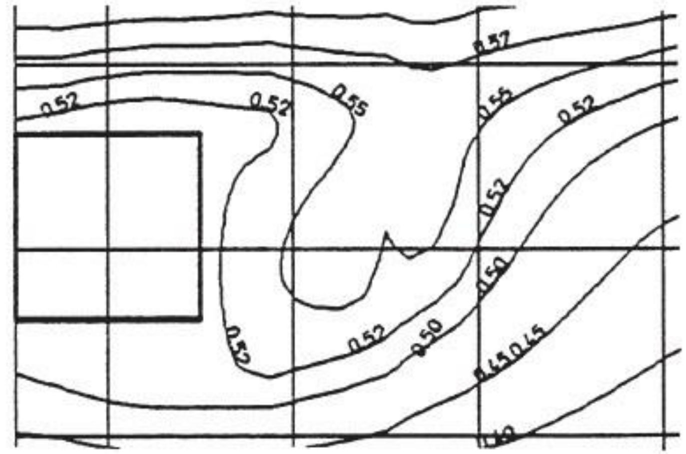
Comparison

Flow Parameters	Experiment Value	Numerical Model
Reynolds Number	21400	21400
Free stream turbulence level	2%	2%
Strouhal number	0.132	0.131
Drag Coefficient	2.05-2.23	2.14
Working Fluid	Water	Water

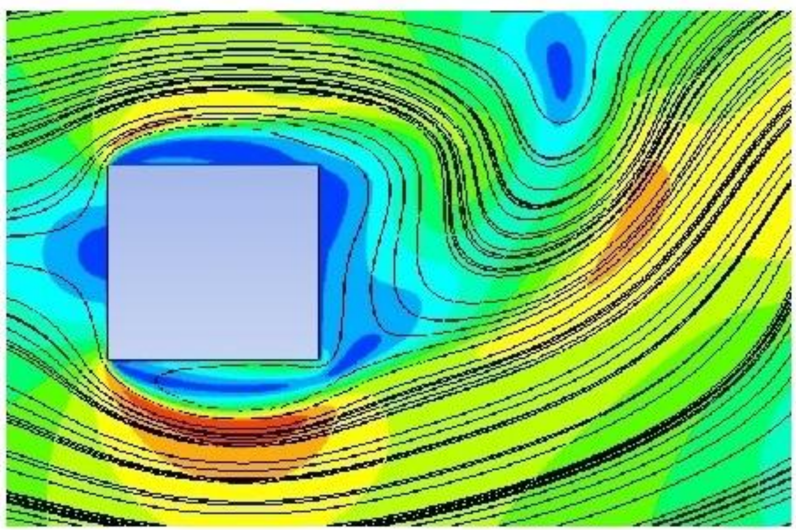
RESULTS



[A]

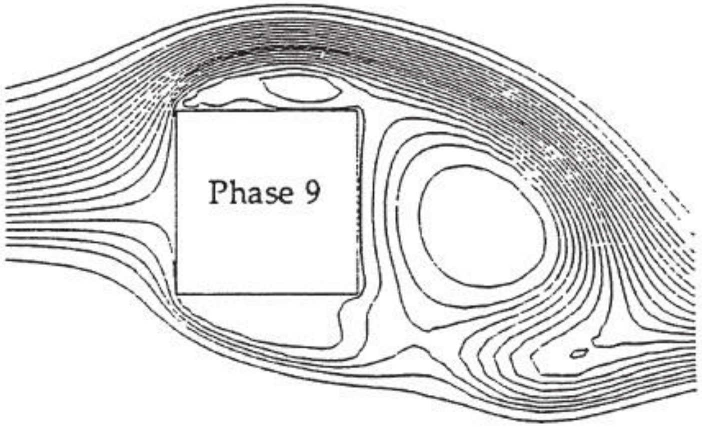


[B]

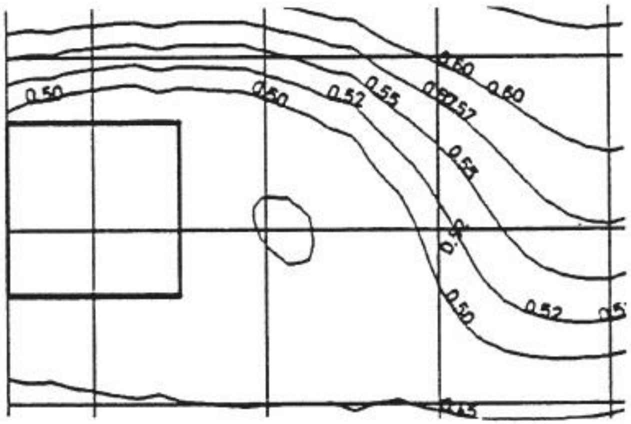


[C]

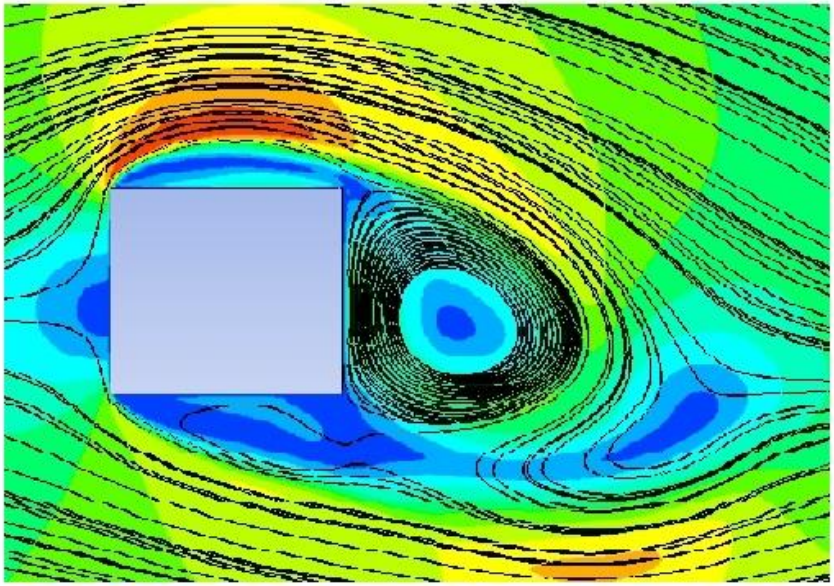
Streamline Plot for phase 1
[A] Franke and Rodi[2]
[B] Lyin [1]
[C] Present numerical calculation



[A]

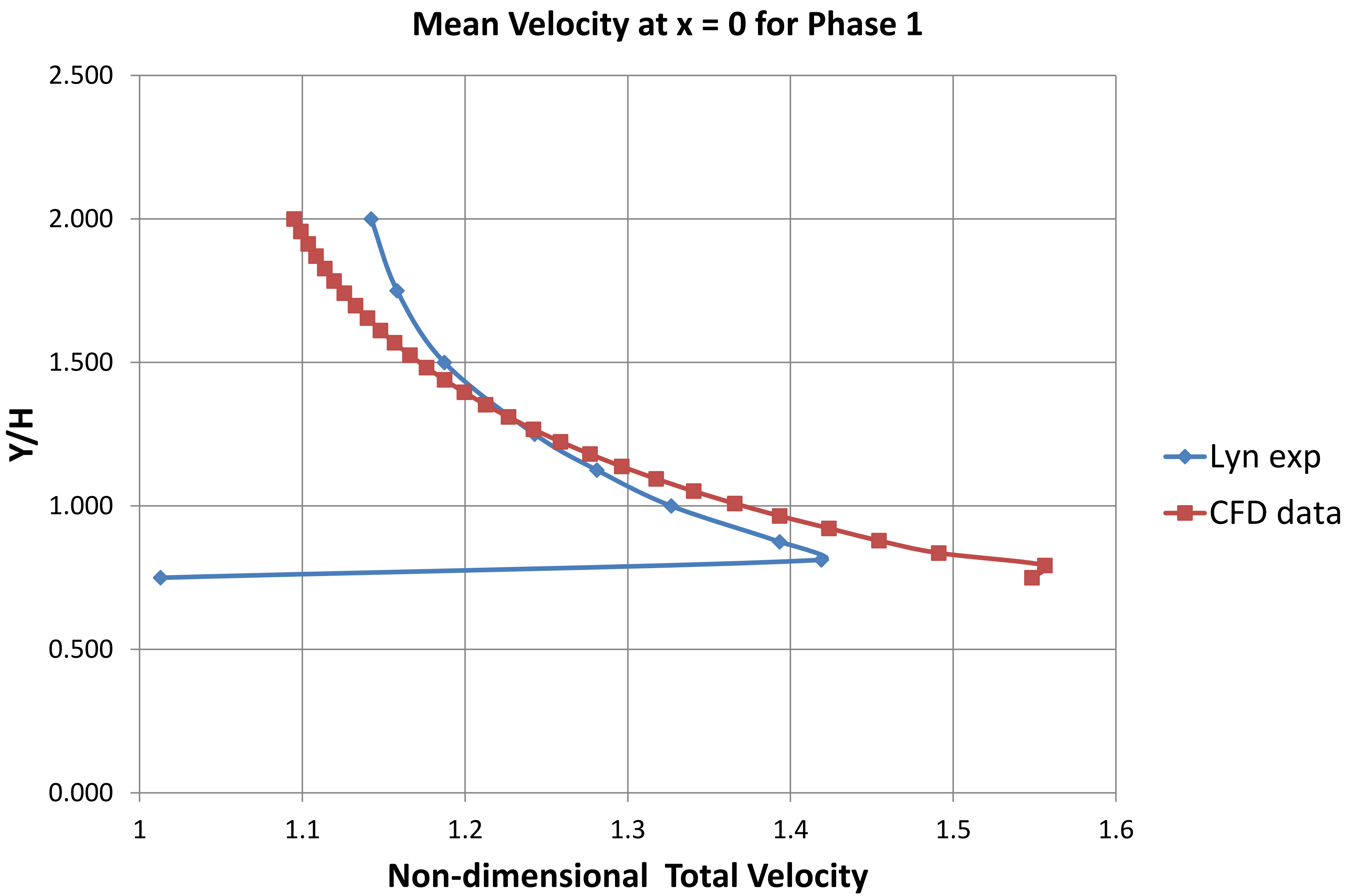


[B]

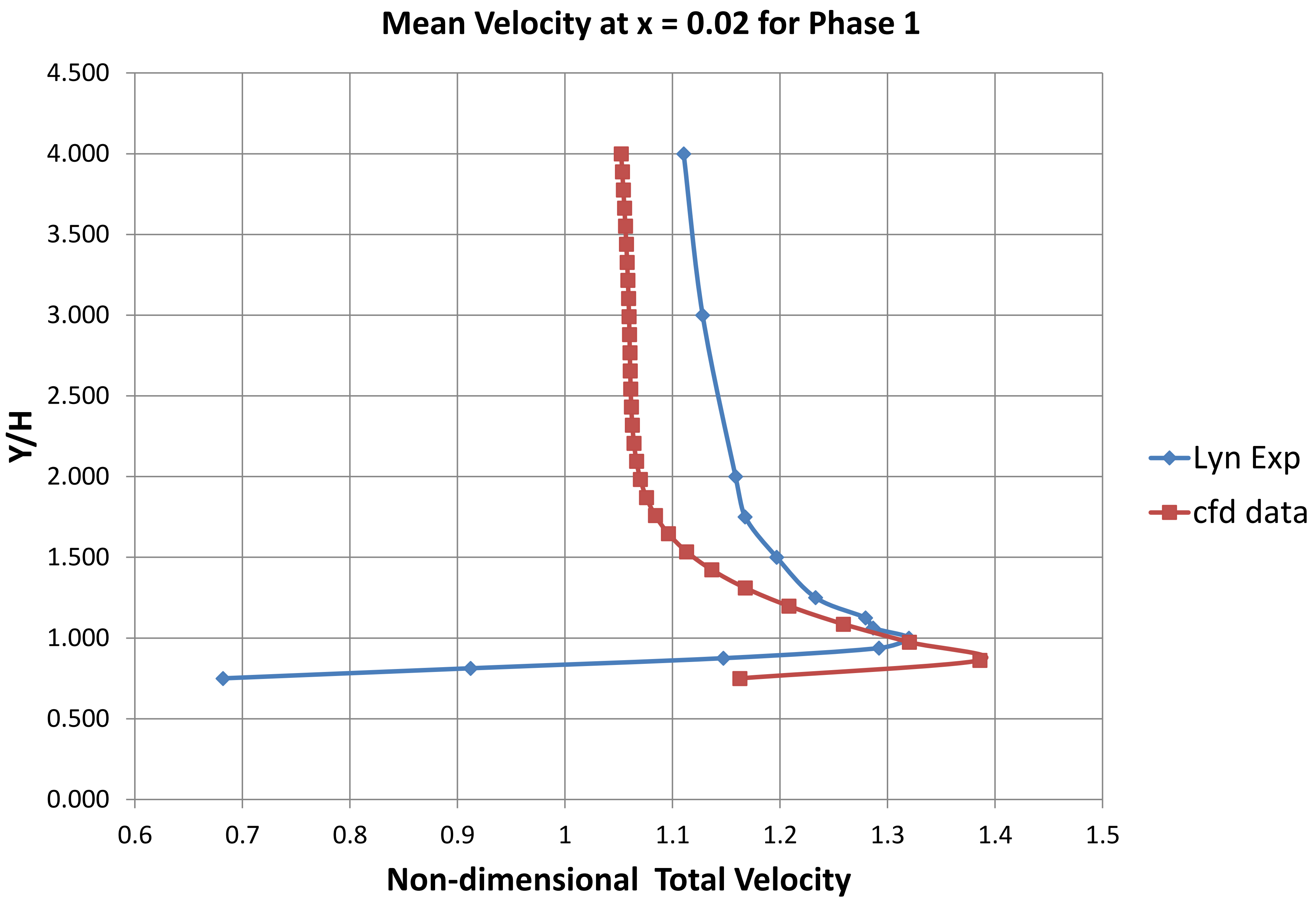


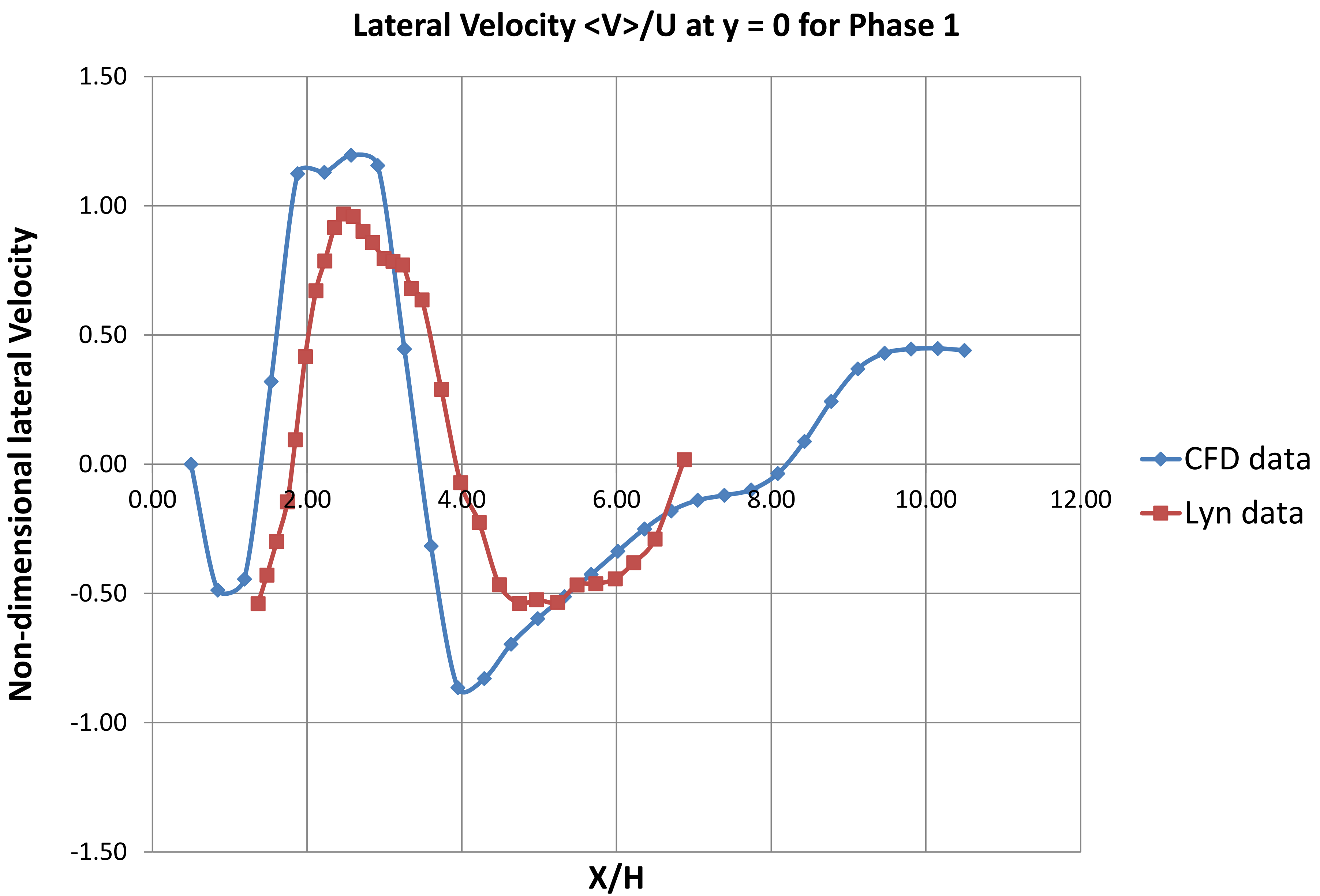
[C]

Streamline Plot for phase 9
[A] Franke and Rodi[2]
[B] Lyin [1]
[C] Present numerical calculation

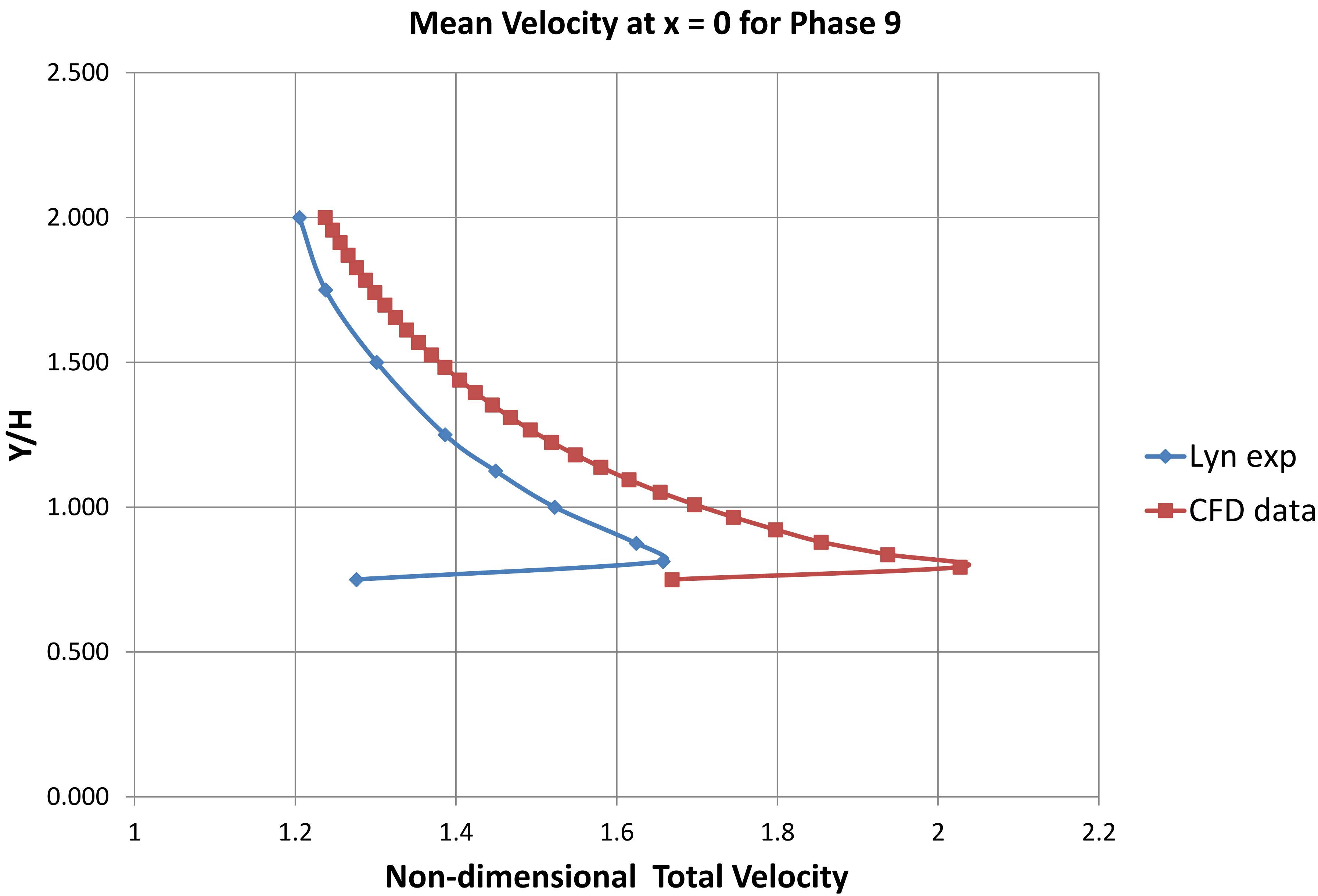


Mean Velocity at x = 0 for Phase 1
2.500
2.000
1.500
1.000
0.500
0.000
Y/H
1
1.1
1.2
1.3
1.4
1.5
1.6
Non-dimensional Total Velocity
Lyn exp
CFD data

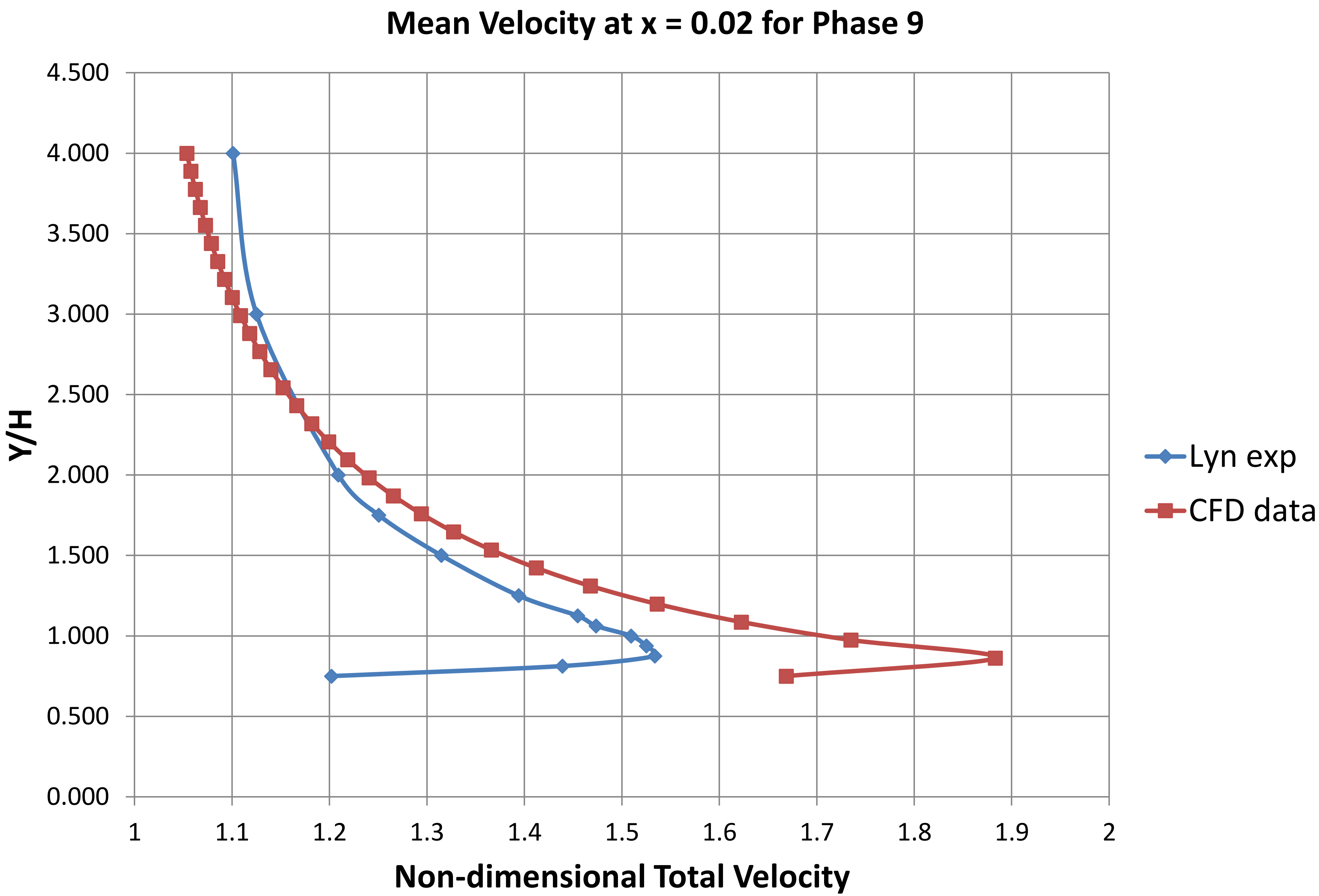

Mean Velocity at x = 0.02 for Phase 1
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
Y/H
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Non-dimensional Total Velocity
Lyn Exp
cfd data



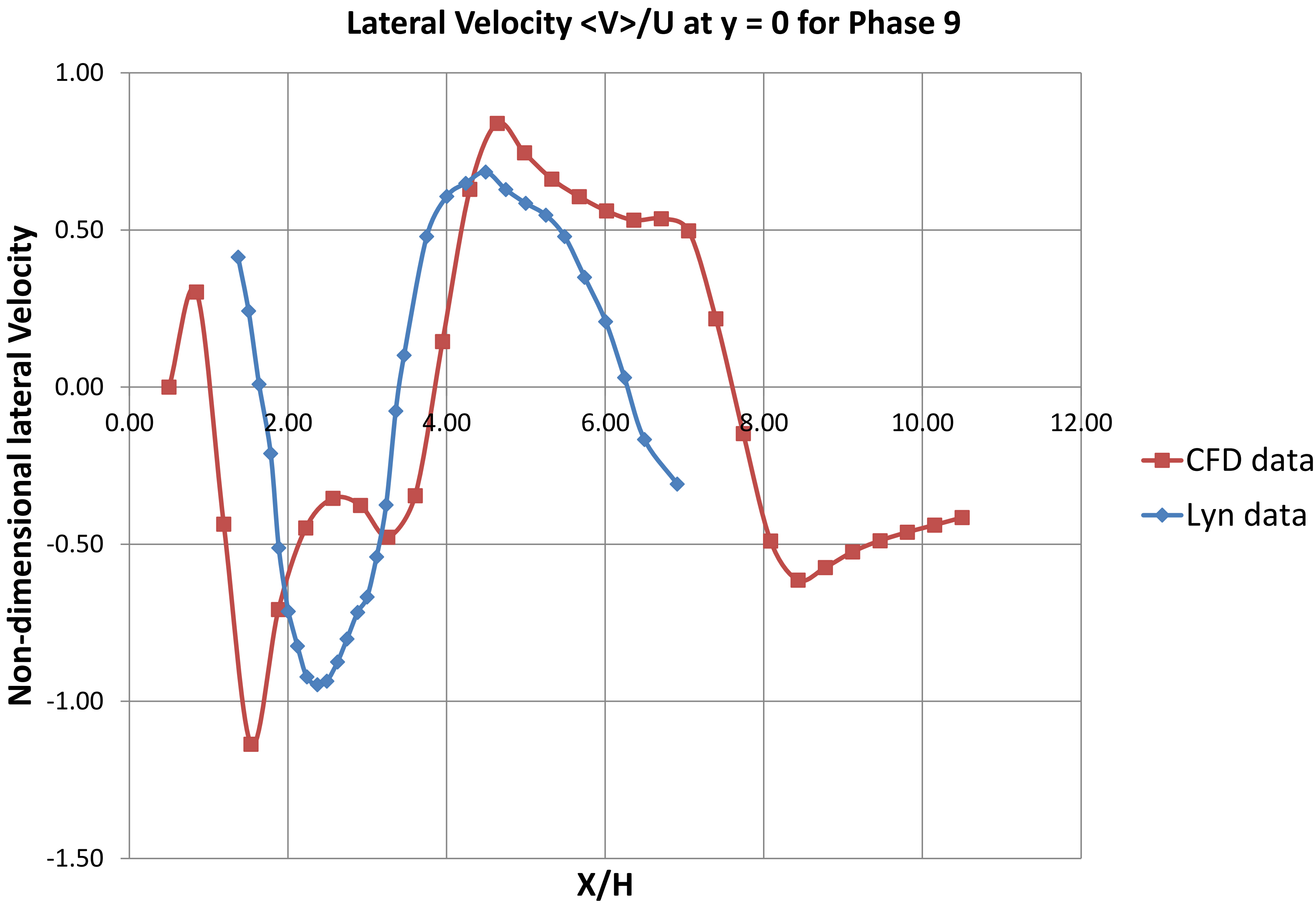
Lateral Velocity <V>/U at y = 0 for Phase 1
Non-dimensional lateral Velocity
X/H
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
0.00
2.00
4.00
6.00
8.00
10.00
12.00
CFD data
Lyn data



Mean Velocity at x = 0 for Phase 9
Y/H
2.500
2.000
1.500
1.000
0.500
0.000
1
1.2
1.4
1.6
1.8
2
2.2
Non-dimensional Total Velocity
Lyn exp
CFD data



Mean Velocity at x = 0.02 for Phase 9
Y/H
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
Non-dimensional Total Velocity
Lyn exp
CFD data



Lateral Velocity <V>/U at y = 0 for Phase 9
Non-dimensional lateral Velocity
X/H
1.00
0.50
0.00
-0.50
-1.00
-1.50
0.00
2.00
4.00
6.00
8.00
10.00
12.00
CFD data
Lyn data

Sources of Error and Conclusion

- Time step was approximated as 0.56s and divided into 20 phases for simplicity
- Time step size can have effect on the results as St = 0.131 for present case while St = 0.121 for Xu et al [4].
- By and large the SST k-ω model predicts the vortex shedding behaviour. Velocity is overestimated by the model.
- One can create 3D square cylinder to check the accuracy of the model.

References

[1] J.H.P. D.A. Lyin., S.Einav., W.Rodi., "A laser-Doppler velocimetry study of ensemble-averaged characteristics of the turbulent near wake of a square cylinder," J. Fluid Mech. 304 (1995) 285–319. doi:10.1017/S0022112095004435

[2] R. Franke, W. Rodi, "Calculation of Vortex Shedding Past a Square Cylinder with Various Turbulence Models," Turbul. Shear Flows 8. (2011) 189–204. doi:10.1007/978-3-642-77674-8_14

[3] S. Murakami, A. Mochida, "On turbulent vortex shedding flow past 2D square cylinder predicted by CFD," J. Wind Eng. Ind. Aerodyn. 54–55 (1995) 191–211. doi:10.1016/0167-6105(94)00043-D

[4] F.Y. Xu, X.Y. Ying, Z. Zhang, "Prediction of Unsteady Flow around a Square Cylinder Using RANS," Appl. Mech. Mater. 52–54 (2011) 1165–1170. doi:10.4028/www.scientific.net/amm.52-54.1165

[5] FLUENT, Inc., ANSYS FLUENT 16.0 Theory Guide, 2015.