Experiment #1

Flow Past Cylinder

&

Vortex Shedding

Group Members:

Sivashankar S. (AM13M024)

Harshal Kaushik (AM13M025)

Arjun Chandur (CE09B058)

Sivasaichandra (NA10B058)

B.Sandeep Reddy (NA10B052)

V.Vivek (CE10B081)

Flow past cylinder

Introduction:

External flows past objects have been studied extensively because of their many practical applications. Flow past a blunt body, such as a circular cylinder, usually experiences boundary layer separation and very strong flow oscillations in the wake region behind the body. In certain Reynolds number range, a periodic flow motion will develop in the wake as a result of boundary layer vortices being shed alternatively from either side of the cylinder. This regular pattern of vortices in the wake is called a Karman vortex street. It creates an oscillating flow at a discrete frequency that is correlated to the Reynolds number of the flow. The periodic nature of the vortex shedding phenomenon can sometimes lead to unwanted structural vibrations, especially when the shedding frequency matches one of the resonant frequencies of the structure. In this experiment, we are going

- to investigate the flow past a circular cylinder and measure pressure distribution and the velocity of flow field in the wake of the cylinder.
- to observe the vortex shedding phenomena in flow behind a cylinder at moderate Reynolds numbers.

Theory :

The behavior of flow over a cylinder varies with the Reynolds number, Re, given by

$$Re = \rho UD/\mu$$

Where ρis the density of the fluid, U is the velocity of the cross flow, D is the diameter of the cylinder, and μ is the dynamic viscosity of the fluid. For $Re < 5$, flow over a cylinder remains attached to the cylinder surface, while for $Re > 5$ the flow on the downstream end of the cylinder separates from the cylinder surface, forming a wake. For $5 < Re < 40$ this wake is characterized by two stationary eddies that form immediately downstream of the cylinder. For $Re > 40$, this wake becomes unsteady, and its width and nature depend on Re.

The flow over the cylinder is viscous, meaning that the fluid velocity at the cylinder surface must be zero by the 'no-slip' condition. For $Re > 1000$, this no-slip condition leads to the formation of a boundary layer, a thin region adjacent to the surface where viscous effects are important and the velocity increases from zero at the surface to the local free-stream value outside of the boundary layer. Over the forward portion of the cylinder, the surface pressure decreases from the stagnation point toward the shoulder. Thus, the boundary layer in this region develops under a favorable pressure gradient, , where η is a coordinate measured along the surface in the streamwise direction. In this region, the net pressure force on fluid elements in the direction of flow is sufficient to overcome the resisting shear force, and motion of these elements in the flow direction is maintained.

However, farther away from the forward stagnation point, the surface pressure eventually reaches a minimum, beyond which it increases toward the rear of the cylinder. Thus, the boundary layer in this downstream region develops under the influence of an adverse pressure gradient, $\frac{\partial P}{\partial x} > 0$. Since the pressure increases in the flow direction, fluid elements in the boundary layer experience a net pressure force opposite to their direction of motion. At some point, the momentum of these fluid elements will be insufficient to carry them into the region of increasing pressure. Under this scenario, fluid adjacent to the solid surface is brought to rest, causing the flow to separate from the cylinder surface. A region of low pressure forms on the downstream side of the cylinder and is termed the wake region.

Pressure distribution and wake velocity measurement for flow over cylinder

Flow Separation:

The presence of the fluid viscosity slows down the fluid particles very close to the solid surface and forms a thin slow-moving fluid layer called the boundary layer. The flow velocity is zero at the surface to satisfy the no-slip boundary condition. Inside the boundary layer, flow momentum is quite low since it experiences a strong viscous flow resistance. Therefore, the boundary layer flow is sensitive to the external pressure gradient. In this case, the pressure force can assist the fluid movement and there is no flow retardation. If the pressure is increasing in the direction of the flow, an adverse pressure gradient exists. In addition to the presence of a strong viscous force, the fluid particles now have to move against the increasing pressure force. Therefore, the fluid particles could be stopped or reversed, causing the neighboring particles to move away from the surface. This phenomenon is called the boundary layer separation.

Wake:

Consider a fluid particle within the boundary layer around the circular cylinder. From the pressure distribution measured in the experiment, the pressure is a maximum at the stagnation point and gradually decreases along the front half of the cylinder. The flow stays attached in this favorable pressure region as expected. However, the pressure starts to increase in the rear half of the cylinder and the fluid now experiences an adverse pressure gradient. Consequently, the flow separates from the surface creating a highly turbulent region behind the cylinder called the wake. The pressure inside the wake region remains low as the flow separates and a net pressure force (pressure drag) is produced.

Vortex Shedding:

The boundary layer separates from the surface forms a free shear layer and is highly unstable. This shear layer will eventually roll into a discrete vortex and detach from the surface (a phenomenon called vortex shedding). Another type of flow instability emerges as the shear layer vortices shed from both the top and bottom surfaces interact with one another. They shed alternatively from the cylinder and generates a regular vortex pattern (the Karaman vortex street) in the wake. The vortex shedding occurs at a discrete frequency and is a function of the Reynolds number. The dimensionless frequency of the vortex shedding, the shedding Strouhal number, $St = f\,D/V$, is approximately equal to 0.21 when the Reynolds number is greater than 1,000. The flow velocity is also reduced behind the cylinder. In the wake region, the velocity is expected to be minimal near about the central axis of the cylinder.

Experimental setup :

The cylinder and the Pitot tube are arranged in the wind tunnel setup. The Pitot tube is traversed along the slot made on the tunnel wall behind the cylinder to get the velocities in the cross-section at various locations

Procedure:

1. A cylinder of 25mm diameter is placed in the test section of the wind tunnel such that the longitudinal axis of the cylinder is perpendicular to the flow direction.
2. The Pitot tube is fixed to mechanical probe traverse and is connected to pressure measurement device.
3. The cylinder pressure tap is connected to pressure measurement device and wall static pressure tap is connected to Betz manometer.
4. The wind tunnel is started and is kept at a particular speed of the flow in the test section.
5. Readings from Betz manometer and measurement device are recorded to give the wall static and total pressures respectively.
6. The cylinder is rotated by small incremental angle and corresponding reading are taken up to 180 degree.
7. Pitot tube is traversed vertically and the corresponding readings are noted for wake velocity calculations.

Observation

Table: 1 Pressure distribution over cylinder

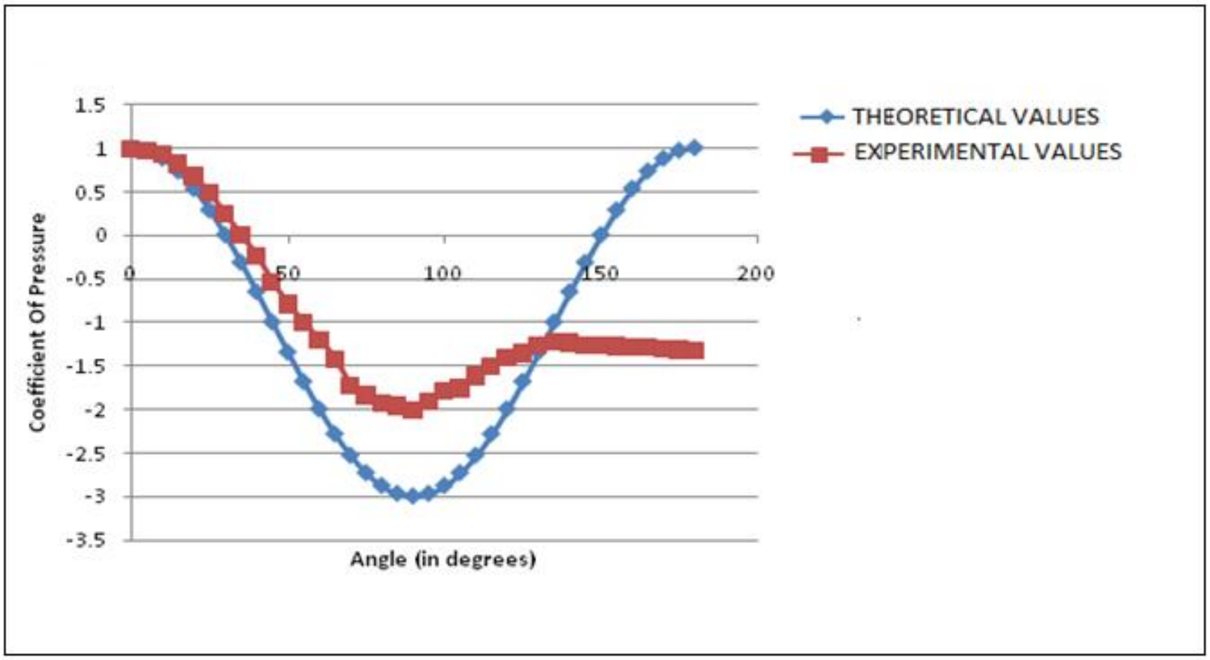
S.No	Theta (deg)	Pressure measured on the cylinder(Pa)	Cp (Theory)	Cp (Experimental)
1.	180	141	1	0.99185
2.	175	145	0.969485	0.97525
3.	170	154	0.879136	0.9379
4.	165	181	0.731698	0.82585
5.	160	216	0.531648	0.6806
6.	155	261	0.285067	0.49385
7.	150	320	-0.00056	0.249
8.	145	377	-0.31654	0.01245
9.	140	435	-0.65329	-0.22825
10.	135	507	-1.00058	-0.52705
11.	130	569	-1.34784	-0.78435
12.	125	621	-1.68454	-1.00015
13.	120	662	-2.00044	-1.2003
14.	115	703	-2.28595	-1.415
15.	110	713	-2.53239	-1.72356
16.	105	683	-2.73228	-1.83211
17.	100	666	-2.87953	-1.91486
18.	95	661	-2.96969	-1.95125
19.	90	656	-3	-1.99789
20.	85	654	-2.96955	-1.89995
21.	80	658	-2.87927	-1.78542
22.	75	660	-2.73189	-1.75146
23.	70	658	-2.5319	-1.61258
24.	65	658	-2.28536	-1.49658
25.	60	660	-1.99978	-1.39546
26.	55	662	-1.68382	-1.34587
27.	50	668	-1.34709	-1.25125
28.	45	673	-0.99981	-1.21595
29.	40	675	-0.65253	-1.22425
30.	35	682	-0.31582	-1.2533
31.	30	683	0.000111	-1.25745
32.	25	686	0.285657	-1.2699
33.	20	687	0.532144	-1.27405
34.	15	687	0.732083	-1.27405
35.	10	694	0.8794	-1.3031
36.	5	695	0.969619	-1.30725
37.	0	698	1	-1.3197

Table:2Wake velocity measurement

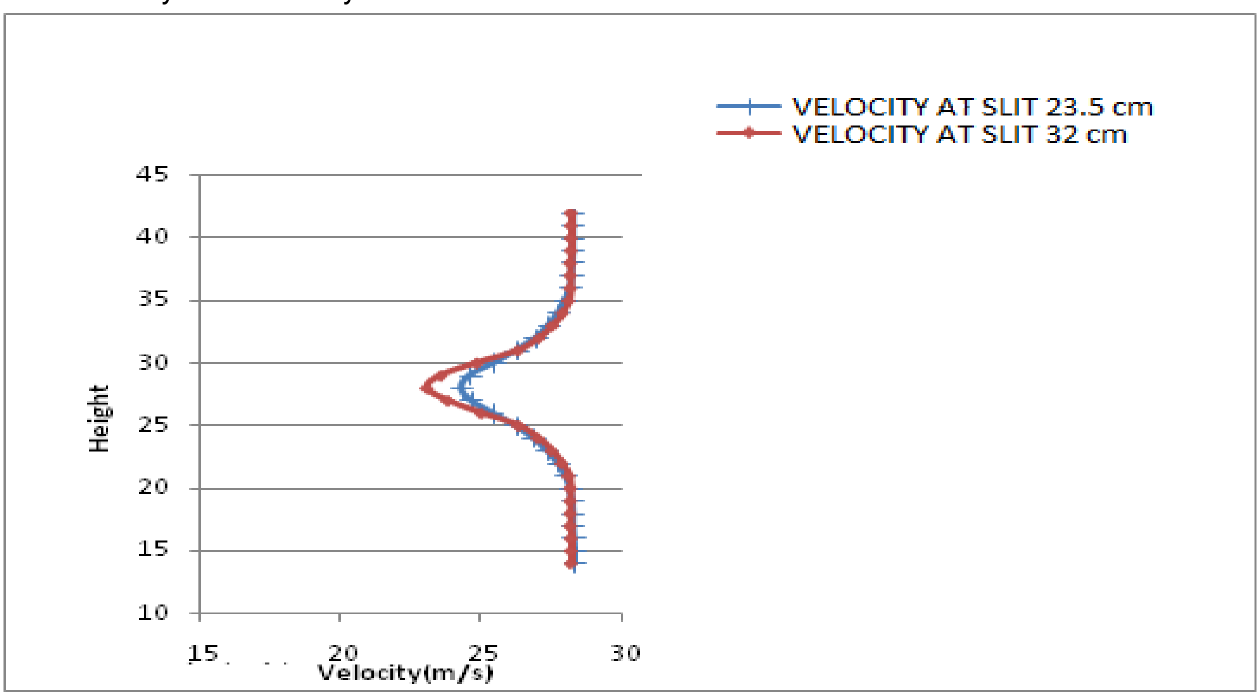
S.No	Distance (y) mm	Total pressure (Pa)	Velocity (u) m/s
1.	14	137	28.37252
2.	15	137	28.37252
3.	16	138	28.34314
4.	17	139	28.31372
5.	18	139	28.31372
6.	19	140	28.28427
7.	20	143	28.19574
8.	21	148	28.04758
9.	22	157	27.77889
10	23	170	27.38613
11	24	186	26.89486
12	25	206	26.26785
13	26	232	25.42964
14	27	255	24.66441
15	28	265	24.3242
16	29	256	24.6306
17	30	230	25.4951
18	31	205	26.29956
19	32	183	26.98765
20	33	168	27.44692
21	34	157	27.77889
22	35	149	28.01785
23	36	142	28.22528
24	37	141	28.25479
25	38	140	28.28427
26	39	139	28.31372
27	40	139	28.31372
28	41	139	28.31372
29	42	139	28.31372

Plots for the experimental data:

1. Cp (Theory) vs Cp (Experimental)



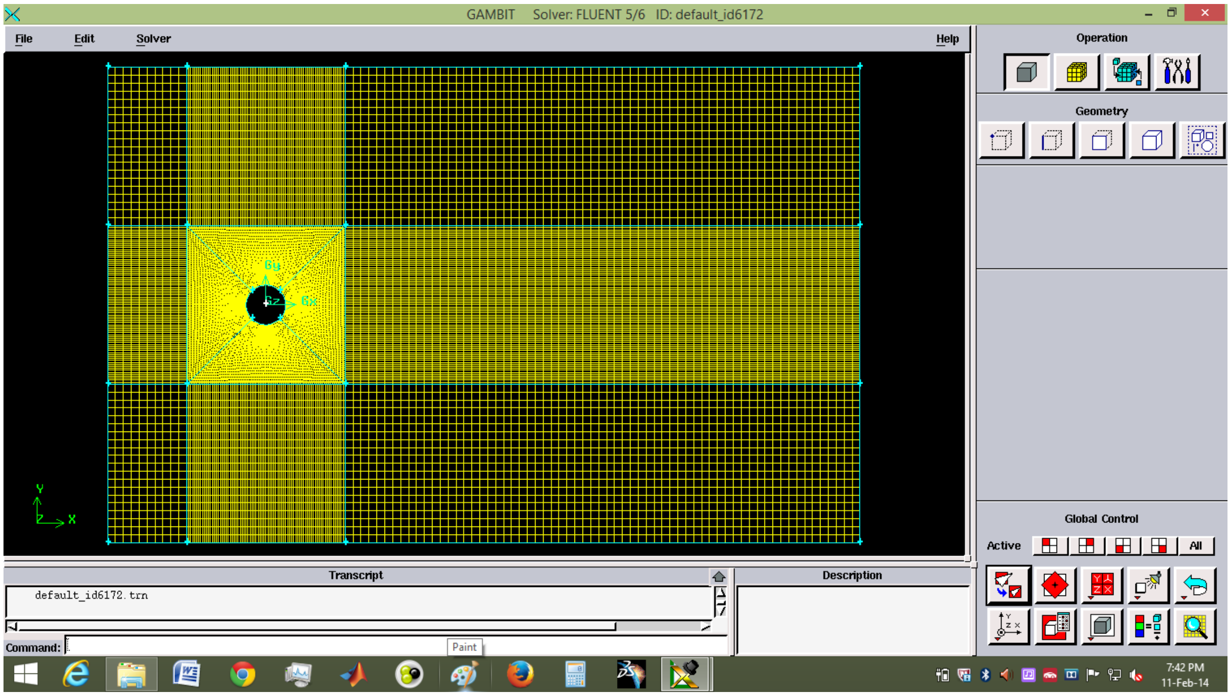
Wake velocity behind the cylinder



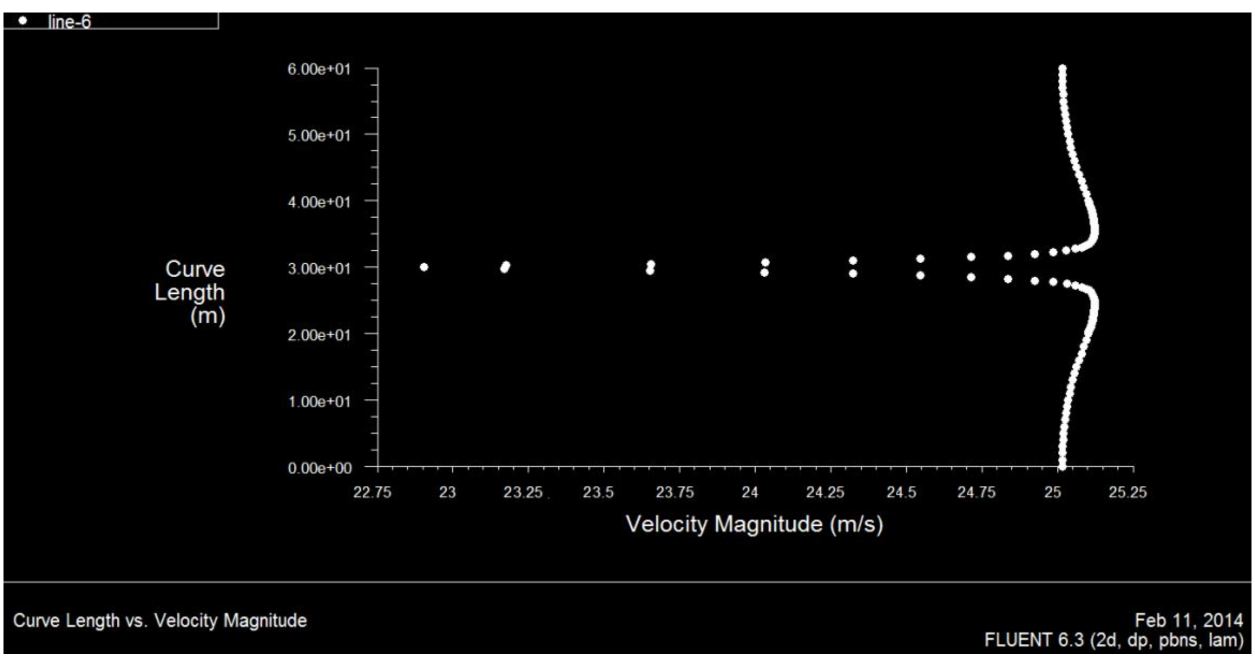
CFD simulations

Flow past circular cylinder to get pressure distribution and wake velocity is simulated using fluent software with the help of boundaries and mesh generated from Gambit software.

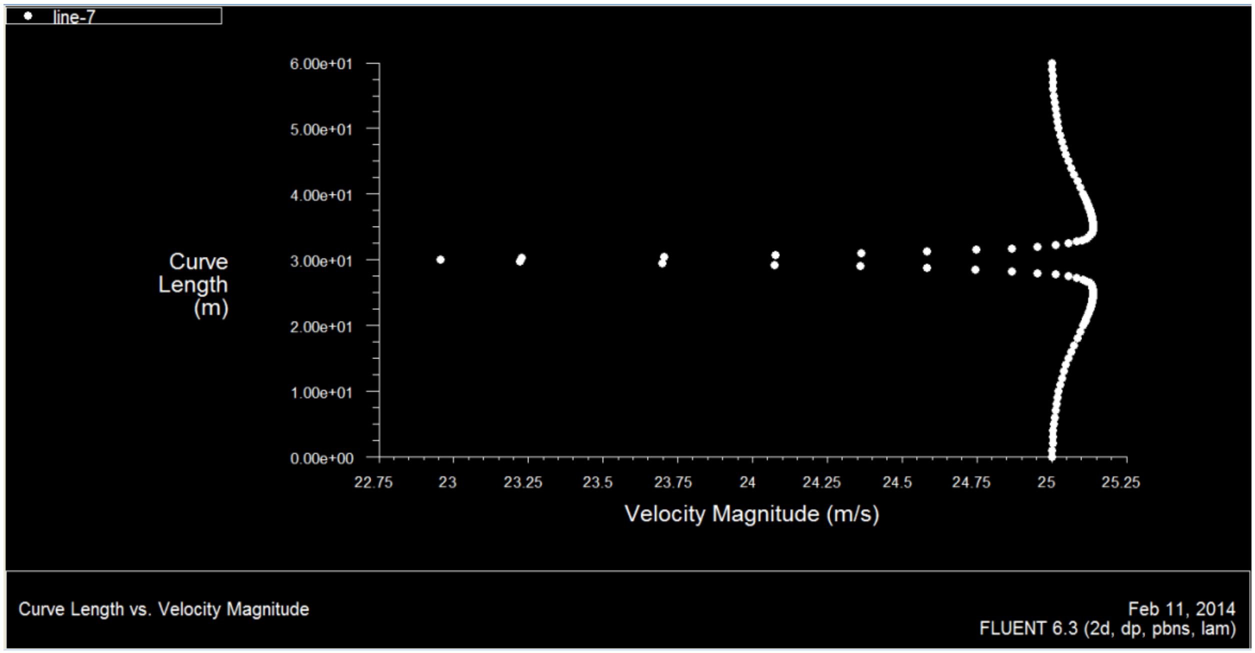
Grid used:-



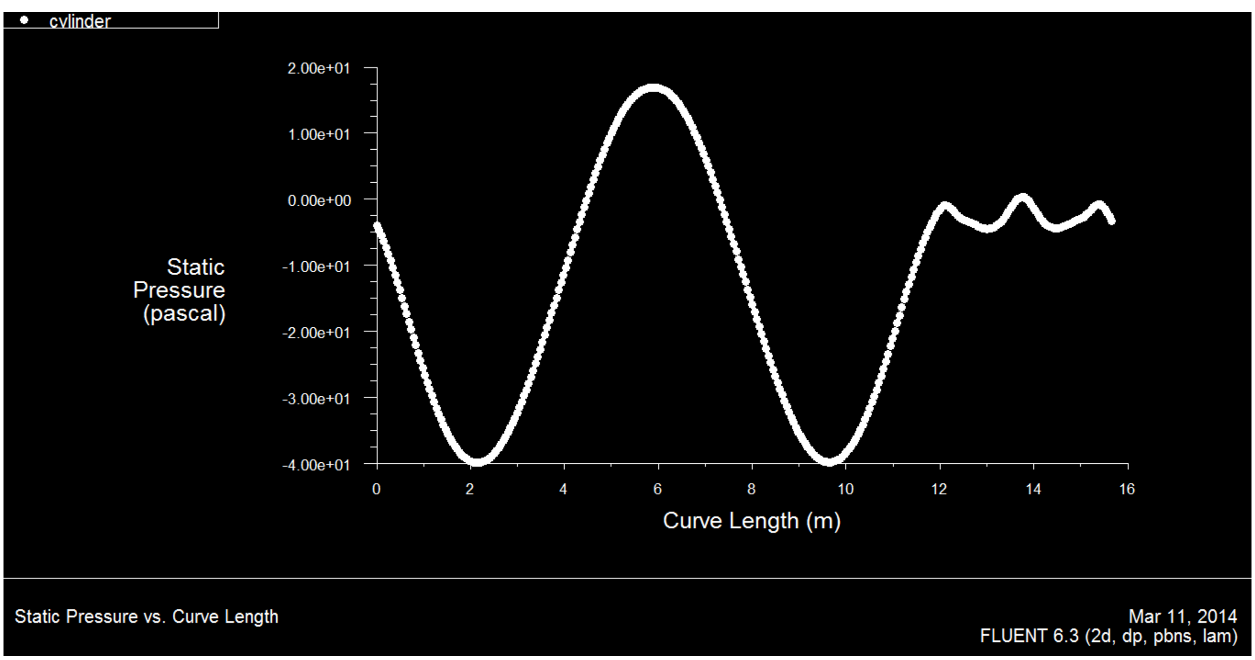
Velocity distribution at slit 23.5 cm from centre of the cylinder:



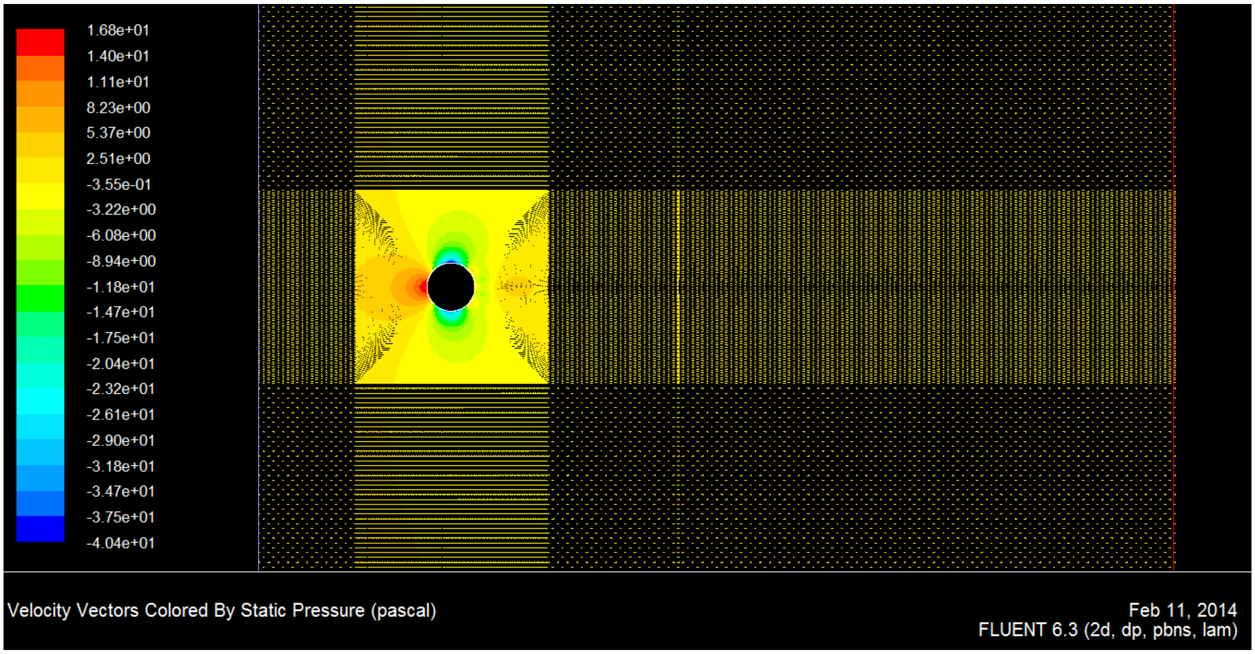
Velocity distribution at slit 32 cm from centre of the cylinder:



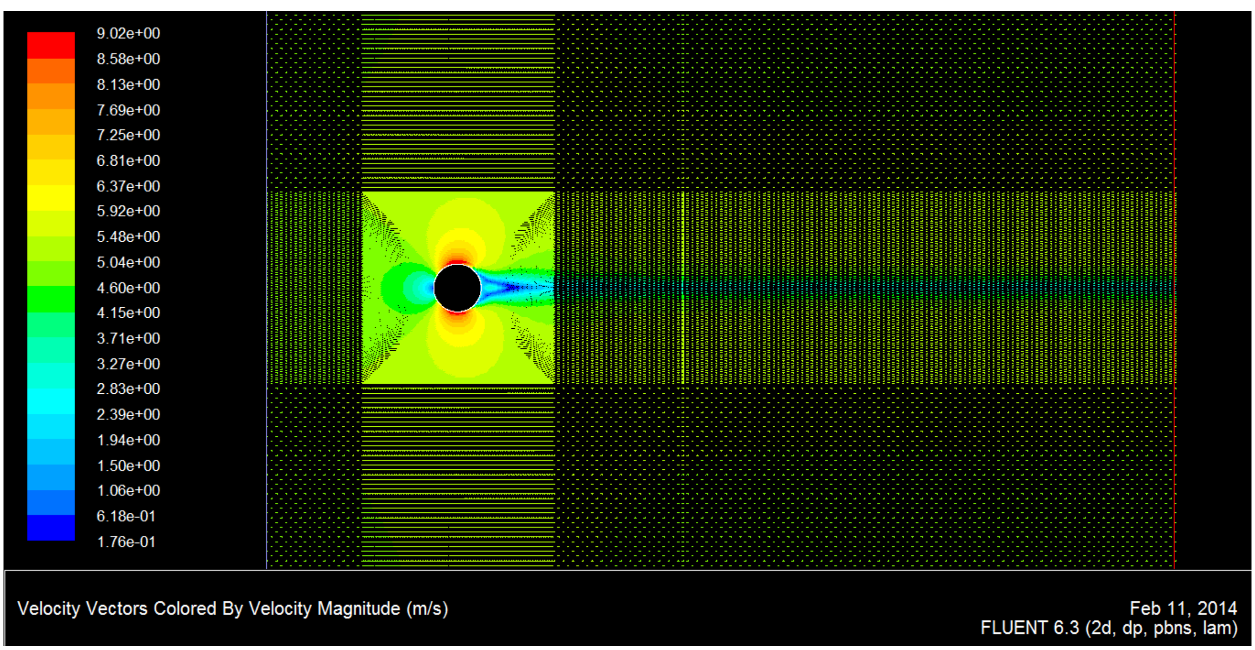
Pressure distribution around the cylinder:



Pressure contour:



Velocity contour



Experimental report on Vortex Shedding from a cylinder

1.0 Aim

To observe the vortex shedding phenomena in flow around a cylinder at medium Re.The dependence of the non-dimensional frequency of vortex shedding on Re is to be studied.

2.0 Theory

Flows with steady boundary conditions can have unsteady solutions; flows around bluff bodies at intermediate Re are the common examples. For flow around a cylinder, at low Re (< 1, based on cylinder diameter and free stream velocity) the vorticity generated at the surface of the body is diffused (not advected) and there is fore and symmetry of flow. When Re is increased above 40 the wake begins to become unstable. With increasing Re, the oscillating wake rolls up into two counter rotating vortices in two staggered rows. These staggered rows of vortices are known as the Karman vortex street. For 40 < Re < 80 the vortex street does not affect the attached vortices on the cylinder. When Re > 80 the vortex street forms closer to the body and the eddies periodically break off alternately from the two sides of the cylinder creating an unsteady flow in the wake. The successive vortices have opposite sense of circulation; the circulation around the cylinder changes sign periodically resulting in an oscillating lateral force on the cylinder. If the frequency of this vortex shedding is close to the natural frequency of the cylinder, resonance could occur, resulting in structural damage. Wires sing because the frequency of this vortex shedding lies in the acoustic range.

Below Re = 200 the wake is laminar while the wake is turbulent (but the boundary layer laminar) for $200 < Re < 3 \times 10^5$. For Re < 2500 the shed vortices are known to form a regular vortex street beyond four to five diameters from the cylinder. In all the cases where Re > 80, a definite periodic oscillation of the flow (same as the vortex shedding frequency) near the cylinder is observed till Re = 4 × 105, when the boundary layer on the cylinder surface becomes turbulent. The non-dimensional frequency of vortex shedding is known as the Strouhal number denoted by S = f/(U1/d) where f = frequency of vortex shedding, d = diameter of the cylinder and U1 = the free stream fluid velocity. The objective of the experiment is to explore the dependence of this non dimensional vortex shedding frequency on the Reynolds number for 900 < Re < 1.3 × 104.

3.0 Experimental setup

Figure 1 shows a schematic of the setup. The setup consists of a tank 2.5m×1.5m with a depth of 150mm, at one end of which are located 2 sets of aluminium disks which rotate and create a flow. The flow is guided to the test section where cylinders of different diameters can be placed. The flow rate is adjusted by controlling the rate of rotation of the disks; velocities ranging from 0.01 m/s to 0.2 m/s can be achieved. Water, made black in colour by dissolving a dye, is used as the fluid and aluminium powder is used as the tracer. The free stream velocity is measured by noting the time taken for a floating particle to traverse a fixed distance in the test section. Photographs of the flow phenomena can be taken by capturing the reflected light from the aluminium powder by an over head camera.

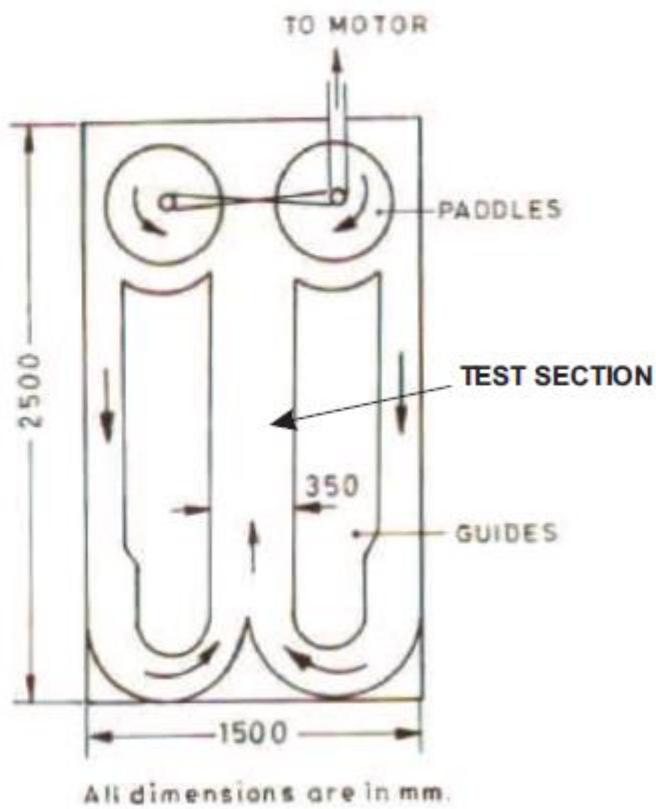


Figure 1: Schematic (top view) of the experimental setup

4.0 Procedure

1. Fill the tank with water which has a black dye dissolved in it. Add sufficient quantity of Aluminium powder. Switch on the power to the motor with the variac at its lowest position.
2. Turn the variac clockwise very slowly to start the rotation of the vanes. Adjust the variac to obtain steady rotation of the disks.
3. Find the velocity of flow by noting the time (t) taken for a floating particle to traverse a fixed distance (L) in the test region. The floating particle should be away from the walls. Repeat this measurement a few times and calculate the mean time (t_m) to estimate the average free stream velocity ($U_1 = L/t_m$).
4. Place the cylinder with diameter d =3 cm in the test section and observe the flow pattern. Measure the time taken (t_v) to shed a specific number (n) of vortices from the cylinder. Calculate the shedding frequency $f = n/t_v$. Repeat a few times and calculate the mean vortex shedding frequency. Take a photograph (slow shutter speed so that streaks are seen) of the flow phenomena around the cylinder.
5. Repeat the experiment for higher velocities (3 more velocities, say 0.1, 0.15 and 0.2m/s). Take a photograph of the phenomena for each cylinder diameter & velocity.
6. Calculate the Strouhal number(S) for each frequency of vortex shedding. Plot S Vs Re. Comment on the results.

5. Results and discussion

Experiments are conducted on cylinders having various diameters. The general data of the experiments are given below

1) Cylinder A diameters is 0.03 meter.
2) Length of flow of fluid considered for measuring free stream velocity (L)= 0.7mtrs
3) Coefficient of viscosity of water at 30°C= 0.000798Pa.Sec
4) Density of water (ρ)= 1000kg/mtr^3

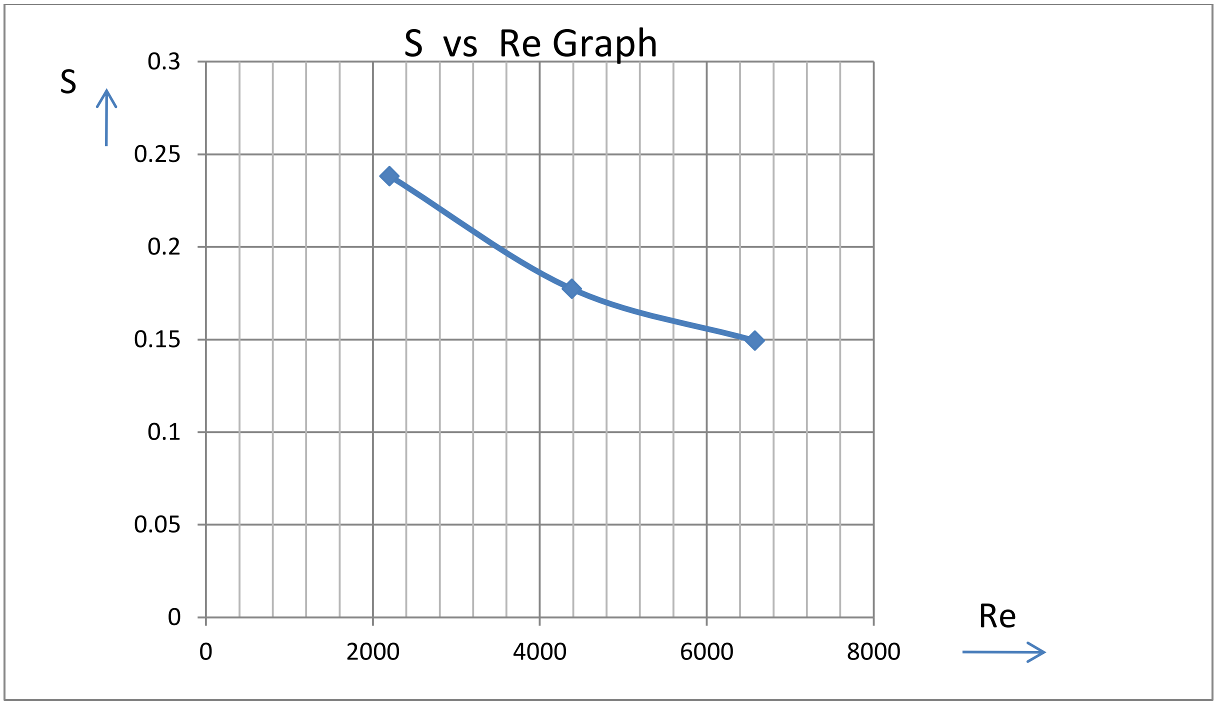
Experimental observations

Measurement of Reynolds Number of flow around cylinder

Sl No	Time taken for a fluid particle in the free stream flow to travel over the length (L), measured T(in sec)	Free Stream Velocity(V)= L/T(in mtrs/sec)	Average Free stream Velocity (V_{avg})	Re=$\rho V_{avg} D/\mu$
1	13	0.054		
2	12	0.058	0.059	2203.206
3	11	0.064		
4	6	0.117		
5	6	0.117	0.117	4385.965
6	6	0.117		
7	4	0.175		
8	4	0.175	0.175	6578.947
9	4	0.175		

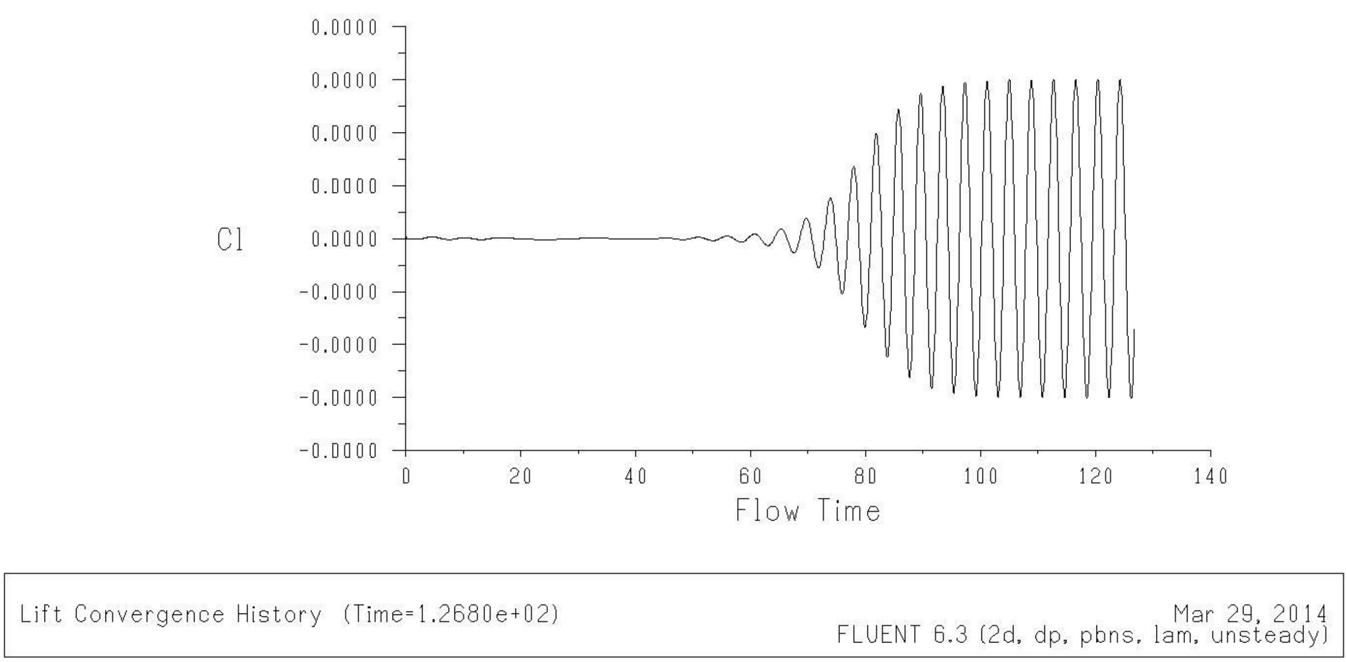
Measurement of Strouhal Number of flow around cylinder

Sl No	Time period in seconds for consecutive 10 vortices (t)	Frequency (f= t/10) in sec^{-1}	Avg. Frequency (f_{avg}) in sec^{-1}	Avg. free stream velocity(V_{avg})(in mtr/sec)	Strouhal number(S) = [$f_{avg}/(V_{avg}/D)$]
1	22	0.455			
2	21	0.476	0.465	0.059	0.238
3	21.5	0.465			
4	14.5	0.690			
5	14.5	0.690	0.690	0.117	0.177
6	14.5	0.690			
7	12	0.833			
8	11.5	0.870	0.871	0.175	0.149
9	11	0.909			

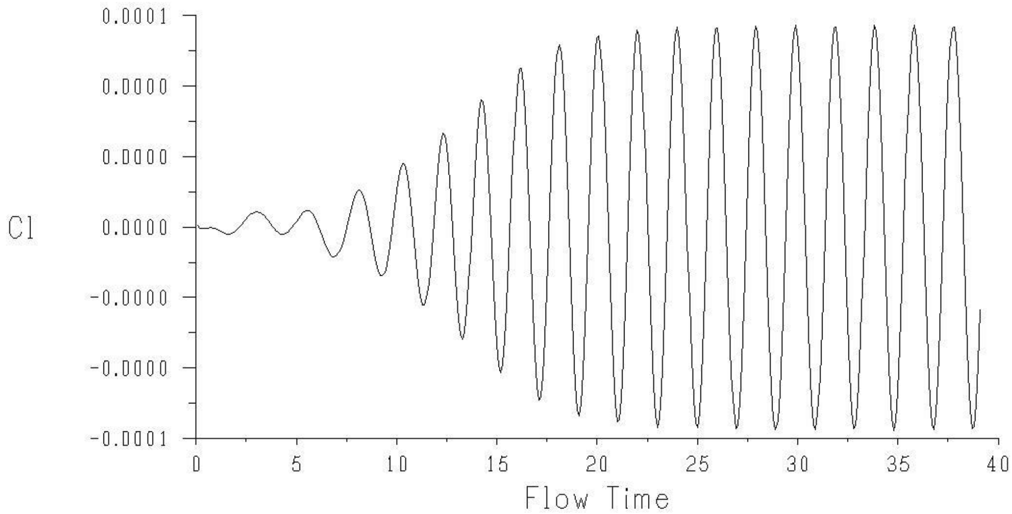


Results for vortex shedding from Fluent:

1. For velocity 5.9 cm/s:

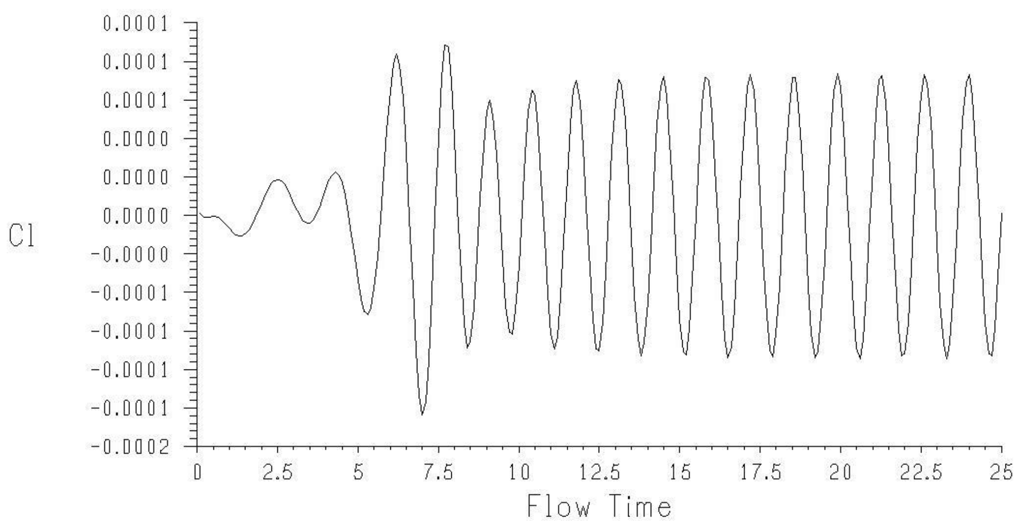


2. For velocity 11.7 cm/s:



Lift Convergence History (Time=3.9100e+01) Mar 29, 2014
FLUENT 6.3 (2d, dp, pbns, lam, unsteady)

3. For velocity 17.5 cm/s:



Lift Convergence History (Time=2.5000e+01) Mar 29, 2014
FLUENT 6.3 (2d, dp, pbns, lam, unsteady)

Conclusions:

Experimental Values of vortex Shedding and Values obtained from Fluent:

Velocity (cm/s)	Experimental Frequency	Frequency by Fluent
5.9	0.465	0.5
11.7	0.690	0.7
17.5	0.871	1.08

- By increasing Re value Strouhal number is decreasing when 2000<Re>12000.
- The vortices are disappearing in the downstream due to viscous effects.