Measurement of Pressure Distribution in the Wind Tunnel Test Section and Flow visualization over a Delta Wing

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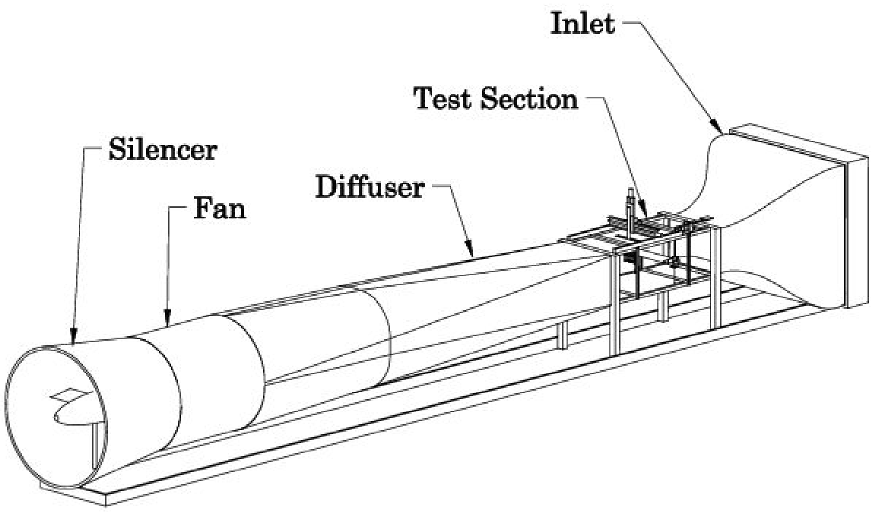
OBJECTIVE

1. Study and sketch the low turbulence tunnel.
2. Measure the C_P distribution in the test section.
3. Observe the vortex pair on the lee side of a delta wing at incidence and study their breakdown.

INTRODUCTION AND THEORY

LOW SPEED WIND TUNNEL



Wind tunnels are large tubes with air blowing through them. In the tunnel, the engineer can carefully control the flow conditions which affect the forces on the aircraft. By making careful measurements of the forces on the model, the engineer can predict the forces on the full scale aircraft. And by using special diagnostic techniques, the engineer can better understand and improve the performance of the aircraft.

Low-speed wind tunnels are used for operations at very low Mach numbers, with speeds in the test section up to 480 km/h (~ 134 m/s, M = 0.4). They may be of open-return type, or closed-return flow with air moved by a propulsion system usually consisting of large axial fans that increase the dynamic pressure to overcome the viscous losses.

The amount of air in the tunnel is constant, and we can use the conservation of mass to relate local speed in the tunnel to the cross-sectional area.

At every point in the tunnel, the velocity **V** times the air density ρ times the area **A** is a constant. For a low speed tunnel the density remains constant through the tunnel and we can further simplify the equation.

At every point in the tunnel:

density x velocity x cross-sectional area = constant

$$\rho \times V \times A = \text{constant}$$

For low speed (constant density):

$$(V \times A)_1 = (V \times A)_2$$

SMOKE GENERATOR

Smoke generator is a machine that heats a fuel (Kerosene in our experiment) for producing a point source of smoke which is then transferred to the the test section in the wind tunnel. Smoke helps in better visualisation of the flow pattern. We are using smoke to visualise vortex formation and vortex breakdown.

The specifications of the low speed wind tunnel are

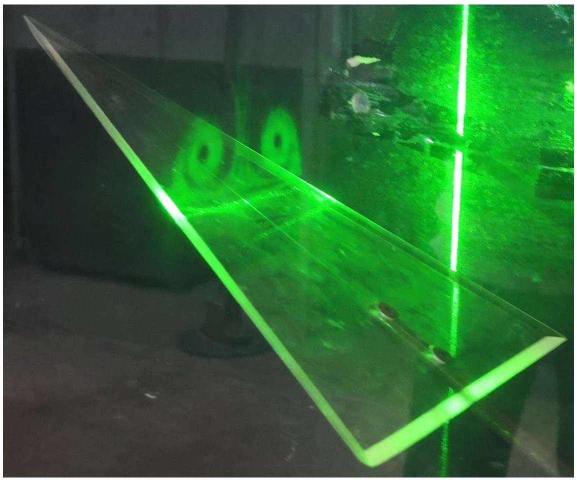
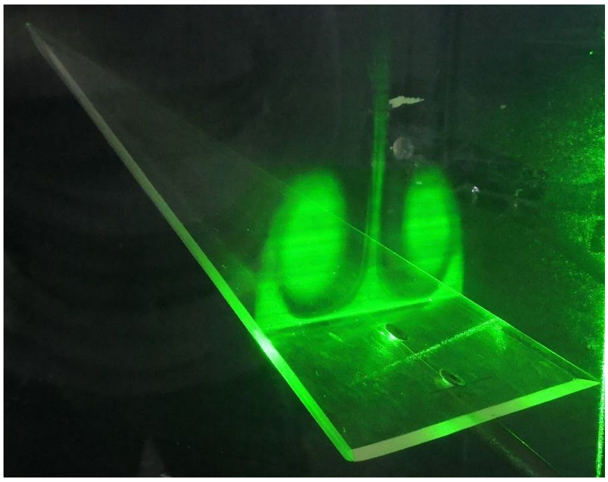
S. No.	Property	Measurement
1	Type	Open – Return Suction Type
2	No. Of Screenings in the settling chamber	6
3	Contraction ratio	16:1
4	Test section dimensions	0.6 m X 0.6 m X 3 m
5	Max. Velocity	~ 25 m/s
6	Motor	20 Hp AC

DELTA WING

The delta wing is a wing shaped in the form of a triangle (delta). The long root chord of the delta wing, and minimal structure outboard, make it structurally efficient. It can be built stronger, stiffer and at the same time lighter than a swept wing of equivalent lifting capability. With sufficient leading edge sweep, a delta wing produces vortex lift, so flow separation can be turned into a means of increasing lift.

Since pressure on the upper surface is lower than the lower surface, at the edges of the delta wings the air from the bottom tries to come up forming a characteristic vortex. As the angle of attack increases, the leading edge of the wing generates a vortex which energises the flow on the upper surface of the wing, delaying flow separation, and giving the delta a very high stall angle.

As we move towards the trailing edge of the delta wing, we find vortex core (black center) starts to disappear which is called **Vortex Breakdown**. There are two types of vortex breakdown: Bubble-type breakdown and Spiral-type breakdown. It is not possible to visually distinguish between the two breakdowns. An important feature of this breakdown is that the axial flow, which is necessary for the breakdown, decelerates along the vortex axis. Within the breakdown structure the vortex is weaker in the sense that the velocity gradients are smaller since the circulation is redistributed over a larger area.

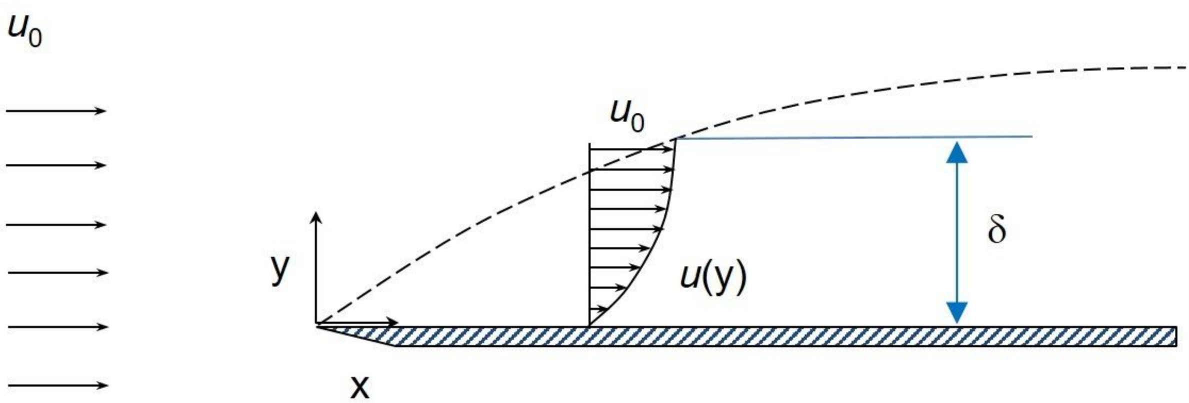
Vortex breakdown is an unsteady process and there is a transition of breakdown form from spiral to bubble and vice versa.

- In Spiral-type breakdown, the vortex centerline deforms into a spiral without any appreciable growth in core size and rotates in the opposite direction to that of the vortex.
- In Bubble-type breakdown, there is rapid expansion of core forming bubble-like structure that is asymmetric.

“A vortex is a region in a fluid in which the flow is rotating around an axis line, which may be straight or curved.” Vorticity is a vector quantity and is mathematically defined as the curl of the velocity field and is hence a measure of local rotation of the fluid.

BOUNDARY LAYER

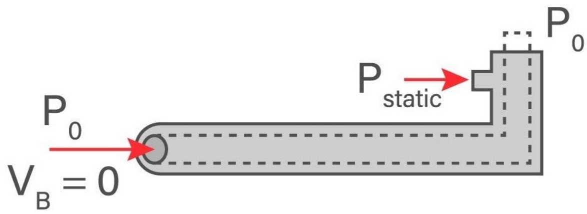
A boundary layer is a thin layer of viscous fluid close to the solid surface of a wall in contact with a moving stream in which the flow velocity varies from zero at the wall (where the flow “sticks” to the wall because of its viscosity) up to U_e at the boundary, which corresponds to the free stream velocity. The fluid in the boundary layer is subjected to shearing forces. Boundary Layer is favoured when there is very high **Reynolds Numbers** (Re) and relatively low viscosity as compared with inertia forces.



DIGITAL MANOMETER

Digital manometers are devices that are capable of measuring pressure and its variations across two points that are a part of the same system-this is known as differential pressure. We use this device to measure velocity head at various points by connecting one port to Pitot Tube (for Stagnation Pressure) and other to holes on the wall (for Static Pressure). The device shows the pressure difference and the corresponding velocity.

PITOT TUBE



A pitot tube is a flow measurement device used to measure fluid flow velocity. Usually it is used in aircrafts to measure air speed. It has two holes one facing the direction of incoming flow and other perpendicular to the direction of incoming flow. Hole perpendicular to the incoming flow measures Static Pressure and the hole facing incoming flow measures Total or Stagnation Pressure. We (differential pressure sensor) measure the difference between the two pressures to find the velocity of the incoming flow.

PROCEDURE

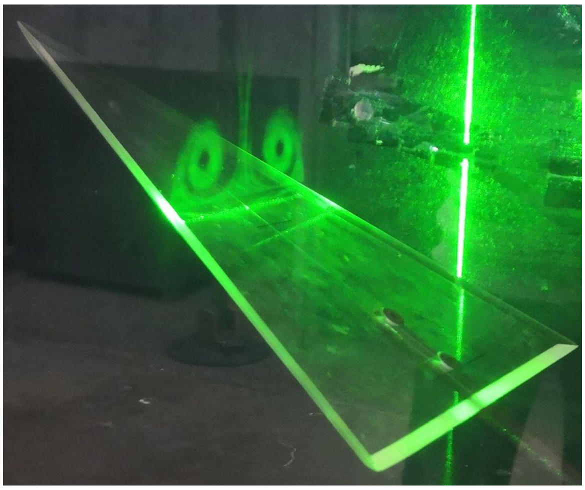
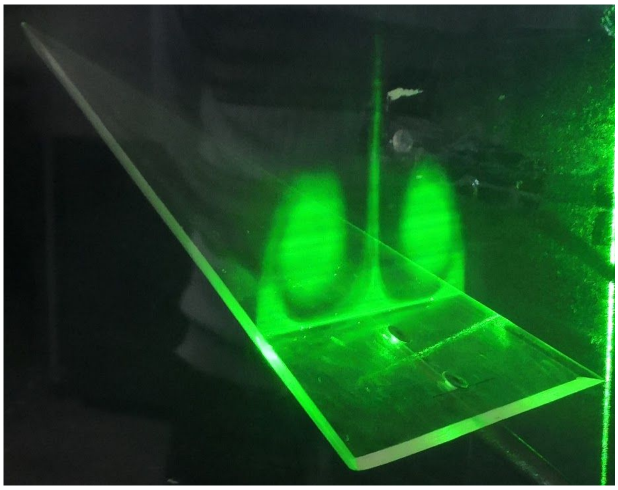
1. Firstly, we fixed a delta wing in the test section of the wind tunnel and turned on the flow (the flow is nearly symmetric). We then turn the smoke machine and laser on to better visualise the flow. We will be able to see vortex. Now we move the laser towards the trailing edge to see vortex core disappear (vortex breakdown). We also change the velocity to observe the variation of vortex and its breakdown.
2. Then we will replace this delta wing with another delta wing which can freely rotate about its root chord. Then we turn on the flow, smoke machine and the laser. Then we will slowly increase the flow speed till it starts wobbling.
3. For the last part, we connect the pitot tube to one port on the digital manometer and the other port is connected to holes on the walls to measure velocity at different points.

EQUIPEMENTS

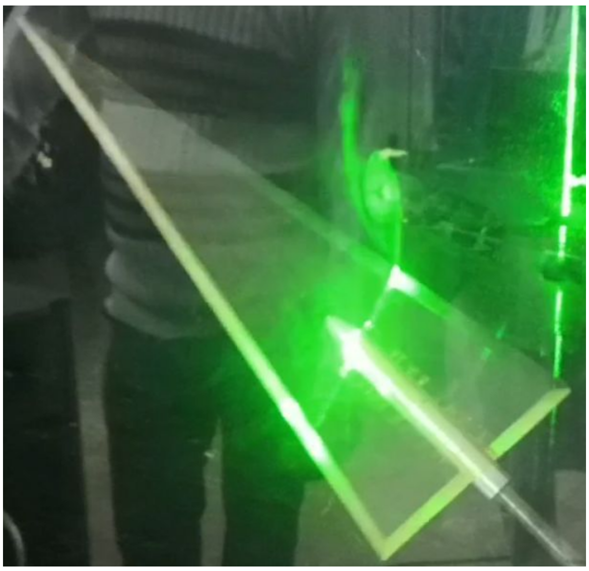
1st Experiment: Low speed wind tunnel, laser, smoke generating machine, a fixed and a rotatable delta wing of .
2nd Experiment: Low speed wind tunnel, Pitot Tube, Digital Manometer.

OBSERVATION & RESULTS

For fixed delta wing, we can observe from the images below that there is vortex formation and it vortex breakdown occurs down towards the trailing edge.

For delta wing with freely rotating axis, we observe that at low speed delta wings remain still but as speed increases wing starts wobbling due to pressure difference in upper and lower surface.

Pressure difference measured at different points in wind tunnel:

Port	x/L	Velocity (m/s)	Pressure (mm Water)	C_P (Coeff. of Pressure)
1	0.10463	4.0	1.0	1.00067857
2	0.15493	4.0	1.0	1.00067857
3	0.20523	4.0	1.0	1.00067857
5	0.40141	4.1	1.1	1.0477063
6	0.45171	4.1	1.1	1.0477063
7	0.50201	4.2	1.1	0.99840946
10	0.65292	4.2	1.2	1.08917396
11	0.70322	4.4	1.3	1.07510921
12	0.75352	4.3	1.2	1.03910376
13	0.80382	4.3	1.2	1.03910376
14	0.85412	4.3	1.1	0.95251178
15	0.90443	4.3	1.2	1.03910376

C_P is always less than or equal to 1. In our experiment, it should ideally be 1 but due to inaccuracies of measuring devices and the setup some C_P are a bit higher than 1.

DISCUSSION

For fixed delta wing, we maintained a flow of 5 m/s and as the speed was increased vortex breakdown was moving towards the leading edge.

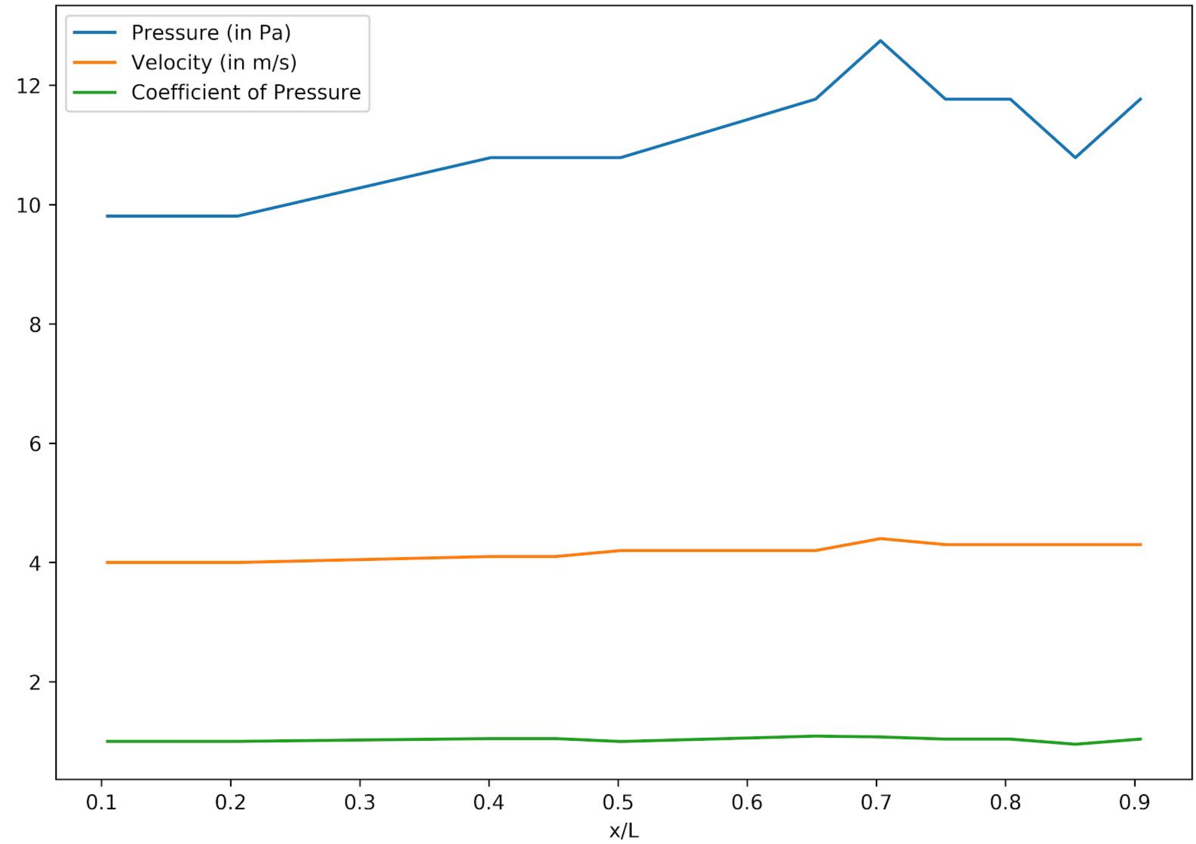
For rotatable delta wing, we started with 5 m/s velocity, but the delta wing started wobbling at around 7 m/s. As velocity increases, irregularities increases. Vortex breakdown occurs on one side and the wing loses its lift. Then the other side moves up and then the breakdown voltage occurs on that side. As a result delta wing oscillates about its axis. The frequency of oscillation increases if flow velocity or angle of attack is increased.

Since the flow is viscous, boundary layer forms on the surfaces of the test section, decreasing the effective area of the test section and thus increasing velocity (by continuity equation). This shows that we cannot use the full cross section of the test section for testing but we have to keep the object within the effective area.

If the pressure changes along a streamline, then the flow is accelerating or decelerating. If the pressure changes across the flow, the the flow is curving. The flow in a wind tunnel is designed to be parallel and of constant velocity everywhere (in the absence of a model), so the static pressure is the same everywhere.

In the boundary layer, the velocity is lower than in the freestream, but that is due to viscous shear stresses and they do not change the static pressure. The static pressure is the same all through the boundary layer, especially since this is on a flat plate.

That is the reason why we can measure velocity at the wall and can comment on the velocities at the center of the test section. So, as the static pressure is constant everywhere, velocity is increasing near the wall, velocity also increases at the center.



CONCLUSION

We learnt about the low speed wind tunnel, delta wing, vortices and how vortices help in increasing efficiency of the delta wing, vortex breakdown and its effects. We also learn about the boundary layer formation in the wind tunnel and how it can affect our results.

PRECAUTIONS

1. Do not stand in the laser light path.
2. Make sure that the laser light reflected back from the wing surface does not hit any person visualizing the flow.
3. Before opening the test section for model removal or mounting, always turn off the tunnel.
4. Keep the room well ventilated while running the smoke generator machine.

APPENDIX

Coefficient of pressure: The pressure coefficient CP is a dimensionless number which describes the relative pressures throughout a flow field in fluid dynamics.
Here,

$$C_p = \frac{p - p_\infty}{\frac{1}{2}\rho_\infty V_\infty^2}$$

p = pressure at point where CP is to be measured.
p_∞ = pressure at free stream or reference pressure.
ρ_∞ = reference density.
V_∞ = refrence velocity.

If we consider the flow to be incompressible, then by Bernoulli's equation

$$\frac{1}{2}\rho v^2 + \rho g z + p = \text{constant}$$

We arrive at the relation for Cp to be,

$$C_p = 1 - \left(\frac{V}{V_\infty}\right)^2$$

Continuity Equation:

$$\rho_2 A_2 v_2 = \rho_2 A_1 v_1$$

Same, incompressable, fluid so roe drops out!

$$A_1 v_1 = A_2 v_2$$

Q. What is the effect of sharp leading edges of the delta wing?
A. Sharp edges on the wing favours vortex formation.
Q. Does the vortex pair always remain symmetric with an increasing angle of attack?
A. No, they become unsymmetric due to vortex breakdown.
Q. What are advantages due to lee side vortices of a delta wing?
A. Induces reduced upper surface pressure resulting in increased lift.

Lab 1

February 7, 2020

[2]:

```
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
import math
from scipy import interpolate
```

[6]:

```
p=np.array([1,1,1,1.1,1.1,1.1,1.2,1.3,1.2,1.2,1.1,1.2]) # pressure in mm Water
v=np.array([4,4,4,4.1,4.1,4.2,4.2,4.4,4.3,4.3,4.3,4.3]) # velocity in m/s
x=np.array([0.10463,0.15493,0.20523,0.40141,0.45171,0.50201,0.65292,0.70322,0.
 ↪75352,0.80382,0.85412,0.90443]) #position of holes

# Calculating Cp
p=p*9.80665
cp=np.divide(p,v)
cp=np.divide(cp,v)
cp=2/1.225*cp

print('Coefficient of Pressures are: ',cp)

fig=plt.figure(figsize=(10,7))
l1,=plt.plot(x,p)
l2,=plt.plot(x,v)
l3,=plt.plot(x,cp)
plt.xlabel('x/L')
# plt.ylabel('Pressure/Velocity')
plt.legend((l1,l2,l3),('Pressure (in Pa)','Velocity (in m/s)','Coefficient of␣
 ↪Pressure'))
fig.savefig("prelocity.png", bbox_inches='tight', dpi=600)
```

```
Coefficient of Pressures are:  [1.00067857 1.00067857 1.00067857 1.0477063
1.0477063  0.99840946
 1.08917396 1.07510921 1.03910376 1.03910376 0.95251178 1.03910376]
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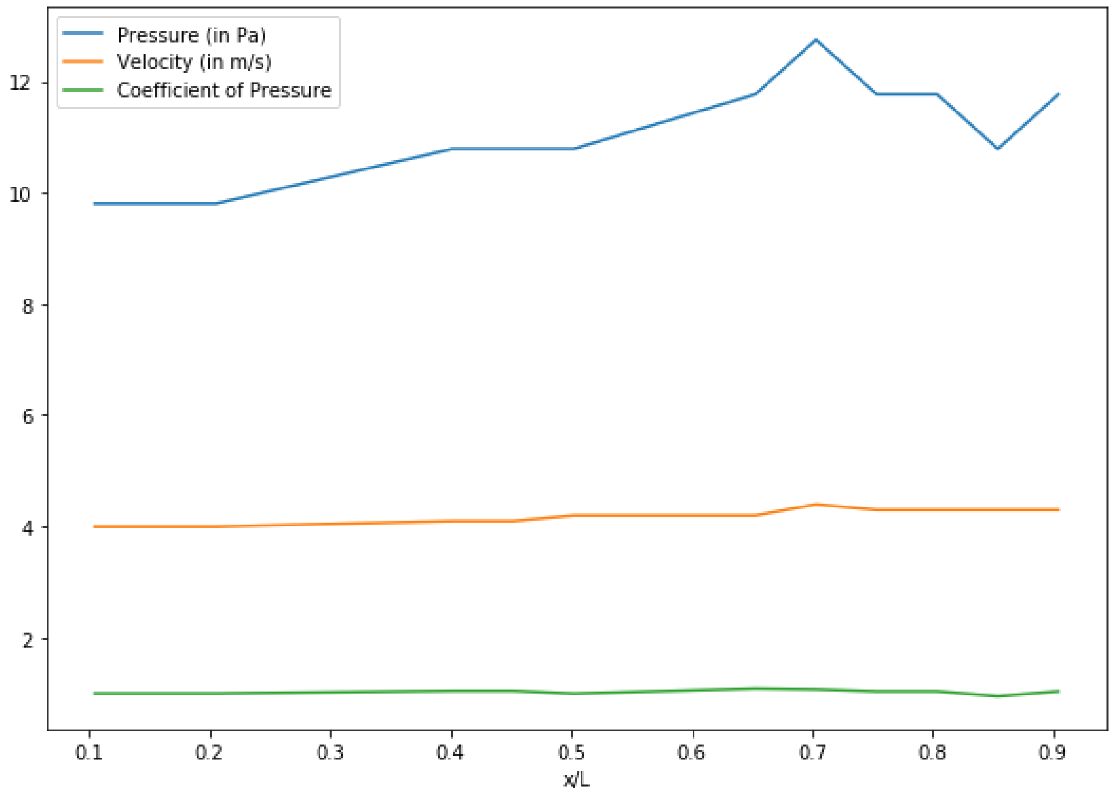
Pressure (in Pa)
Velocity (in m/s)
Coefficient of Pressure
12
10
8
6
4
2
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x/L