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Experimental Verification of Optimal Design of Rectangular Diffuser

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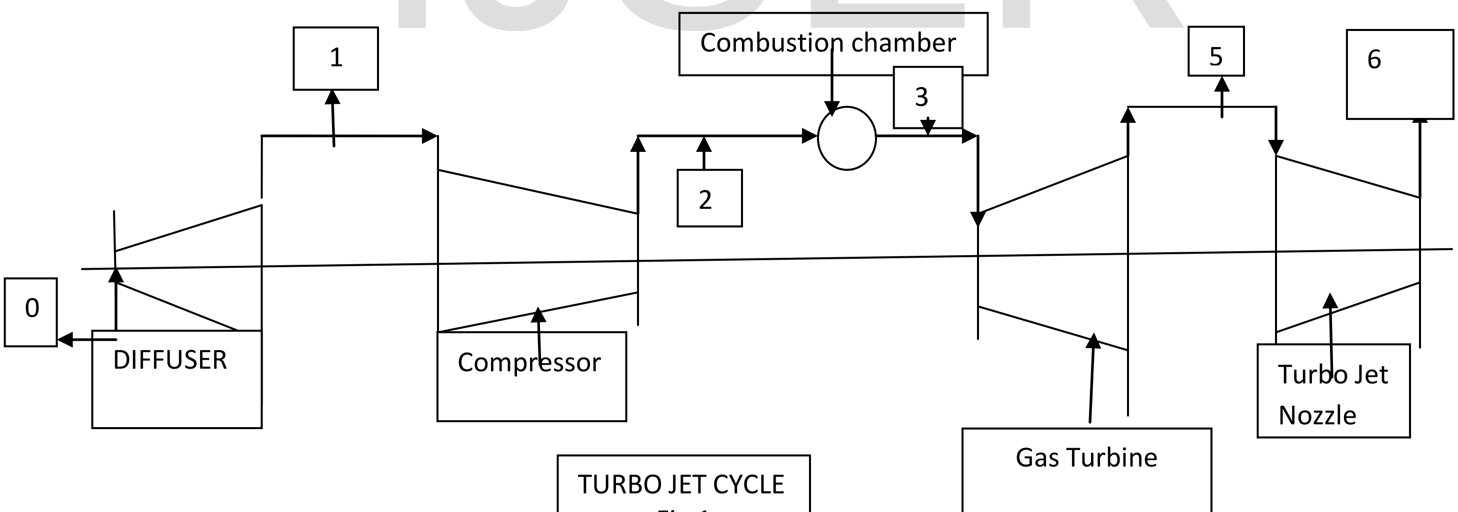
Abstract— In this paper it presents the optimal design of rectangular and its verifications through experiment. The application of diffuser is in turbo jet engine, duct design air conditioning system. The concept of diffuser used in turbo jet engine is explained here. The turbo jet engine Consists of a diffuser, compressor, combustion chamber, turbine and exhaust nozzle. The diffuser in turbo jet engine increases the static pressure before entering the compressor. As pressure increases the compressor work is reduced so jet engine efficiency. Acutely it is based simple gas turbine and the exhaust gas expand in exit through nozzle and converted in to kinetic energy. This kinetic energy gives thrust hence jet moves. So use of is to increase static pressure .Many researcher have designed straight walled conical diffuser like Sovran and Klomp [1].In this paper optimality have tested by conducting an experiment in a rectangular diffuser. David Cerantola designed the conical diffuser discussing the effect of swirl angle, pressure recovery coefficient. The objectives of this paper is to measure optimum length of rectangular diffuser, stability of flow due to occurrence of point of inflection. Obtained data measured by digital manometer is under BIS.The validation has been done as per David Cerantola thesis.

Index Terms— Gas Turbine, Point of Inflection, Pressure Coefficient, Pressure Profile, Recovery Coefficient, Turbo Jet, Velocity Profile.

1 INTRODUCTION

THE cycle for turbo jet engine is the Joule cycle or Brayton cycle. Cycle is now describe clearly to under the purpose of diffuser. The main purpose of diffuser is to convert kinetic energy to static pressure energy. The turbo jet engine the searchers about the application of diffuser. The objectives of this paper is to minimize pressure recovery coefficient and also maximize static pressure. The point where maximum static pressure will occur that is the optimal length of diffuser .Some effects has been discussed to examine the stability of the diffuser like point of inflections. It has been validated the results with David J cerantola.[1].The given diagram will the concept of Turbo Jet Engine.



TURBO JET CYCLE
Fig 1

The processes are as follows:

0-1=Compression of ram air in the diffuser by converting kinetic energy in to pressure energy.

1-2=Compression of air in the compressor.

2-3=Heat addition in the combustion chamber.

3-4=Isentropic expansion in the gas turbine.

4-5=Isentropic expansion in nozzle.

TS diagram

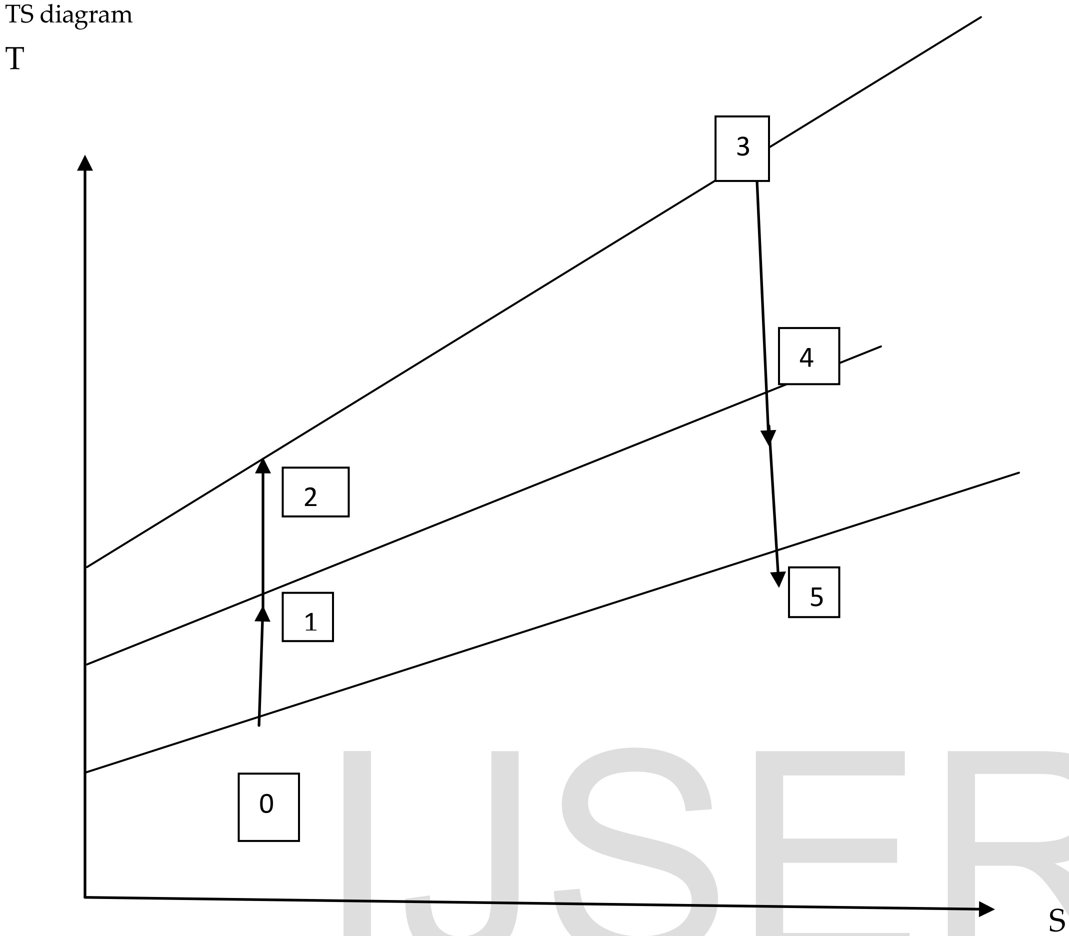


Fig2

T-S diagram

From basic example it is very clear that diffuser slows down air before entering the compressor and converts kinetic energy to pressure energy that is know as ram effect. Now with analyzing thrust, thrust power and propulsive efficiency it can be shown that diffuser affects jet engine performance.

Now if T is thrust of the engine,V0 is the velocity entering the diffuser and Vj is the exit velocity of the nozzle then thrust is given by

T= $\dot{w}_a (V_j - V_0)$

TP= $\dot{w}_a (V_j - V_0)V_0$ Where TP=Thrust power

Propulsive power PP= $\dot{w}_a (V^2{}_j - V_0{}^2)$

Propulsive efficiency= $\frac{TP}{PP} = \frac{2V_0}{V_0 + V_j} = \eta_p$

As the propulsive power depends on velocity at entrance of diffuser entrance ie V0.There fore propulsive efficiency increases as V0 increases. So it can be said that diffuser is the heart of turbojet engine.

The graph is given below presents the ram air pressure at entry in the diffuser increases as velocity decreases hence there is pressure recovery. With increase of pressure air then enters into compressor. After being compressed air then goes into combustion chamber. Heat is added at constant pressure in the combustion chamber. Hot gas now expand in the in the gas turbine and then it enters to the exit nozzle which increase thrust power.

Now in this investigation it is measured mainly the of maximum static pressure, and optimum pressure coefficient recovery. Measuring pressure and velocity profile the point of inflection is determined. Let us go through literature review of many researchers. David J. Cerantola [1] stated in his thesis that the diffuser is important part of gas turbine after burner. Back pressure reduces the work generation. He investigated that the back pressure can be reduced providing more preferable design and in let condition. He and others did not investigated a rectangular diffuser. So Rectangular diffuser with optimal length is new for us. Sovran and Klom[2] published the detailed charts of conical diffuser in his experiment.

For aero space application it was found exhaust must have minimum weight and should fit with space. Some design difficulties exist for short annular diffuser it is found that an 80 divergence angle was an upper limit that yield maximum pressure

recovery in unswirled straight-walled diffuser.[2,3].Some Researcher states that divergence angle is main factor for straight it should 100 in a straight walled diffuser. The length to height ratio is 6.[4].Japikse and Baines[5]acknowledged that pressure coefficient can b tolerated o.2-0.5 short diffuser since better performance could not be achieved.Higgin botham[6] suggested that centered body kept in a diffuser were secondary importance to that of length.Thayer[7],Jirasck and Wendt, s [8] designed a curved walled diffuser to eliminate the line sight of the turbine.To eliminate high radiance Birk[9] proposed a curved path for exhaust.

Numerous experiment were carried out with curved walled diffuser with implementing augmented devices to increases pressure recovery.[1].

From above literature review it can predicted that pressure recovery coefficient can improve by many in let condition. In this thesis it designed a rectangular diffuser incorporating different in let condition. It is obtained in rectangular diffuser a negative pressure recovery coefficient which is better for effectiveness of diffuser. All obtained date measured by digital manometer. Digital manometer is calibrated as per BIS.Experimental data is validated with other experimental data.

2 Governing Equations

Navier Stokes Equation (conservation of momentum)

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\delta p}{\partial x_1} + \frac{\partial}{\partial x_j}\left(v \frac{\partial u_i}{\partial x_j}\right)$$

The continuity equation (conservation of mass)

$$\frac{\partial u_i}{\partial x_j} = 0$$

Pressure coefficient :

$$Cp = \frac{P - P_\infty}{\frac{1}{2}V^2\rho}$$

Where,

P = Pressure at any point
P_∞ = Pressure at free stream velocity
V = Free stream velocity
ρ = Density of air

Pressure recovery coefficient =

$$Crp = \frac{P_{stag} - P_{static}}{\frac{1}{2}V^2\rho}$$

P_{stag} = Stagnation Pressure

P_{static} = Static Pressure

V = Free stream velocity

Bernoulli's equation =

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{V^2{}_2}{\rho g} + z_2$$

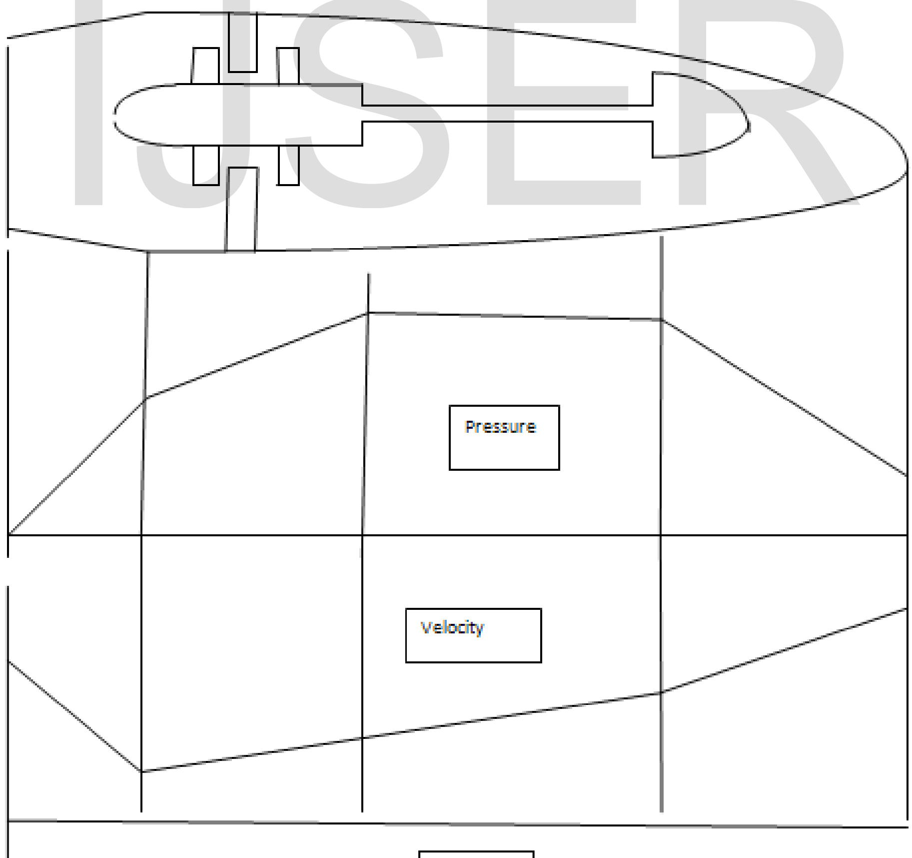


Fig 3

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3 Experimental Set Up

The set up a blower fitted with rectangular diffuser. There 8 stations through pressures are captured by digital manometer.Pressure profiles measure along height perpendicular to axis or length. From pressure profile it is obtained the velocity hence coefficient are obtained. Captured data are calibrated as per BIS standard. The length of the diffuser 760mm.Entrance length 304.8 mm.Traps are 70mm apart.

EXPERIMENTAL SET UP

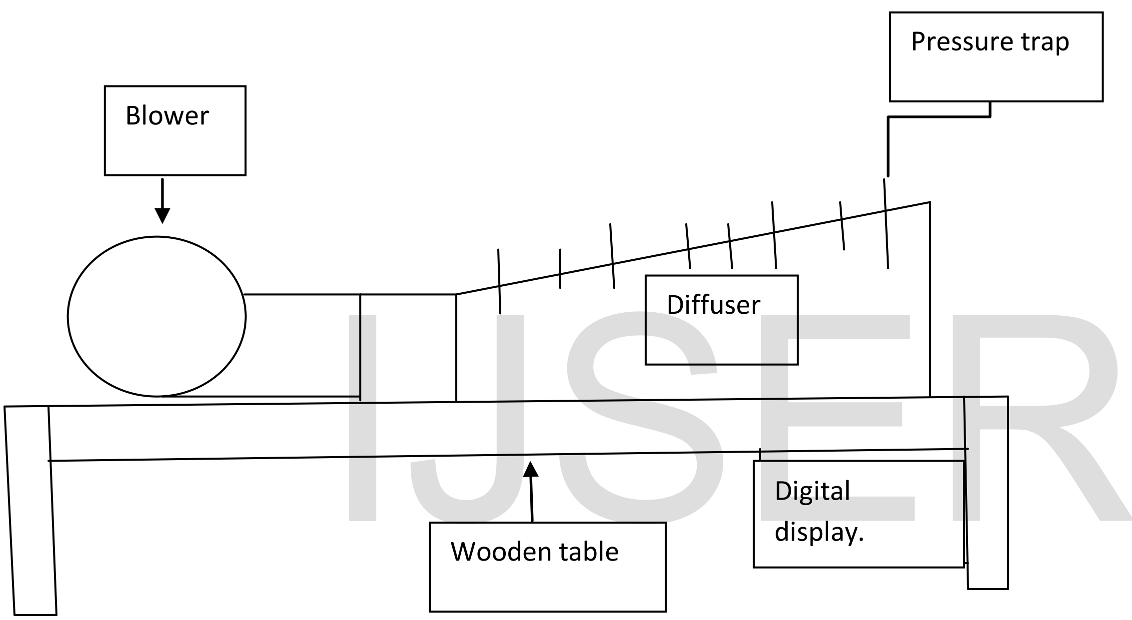
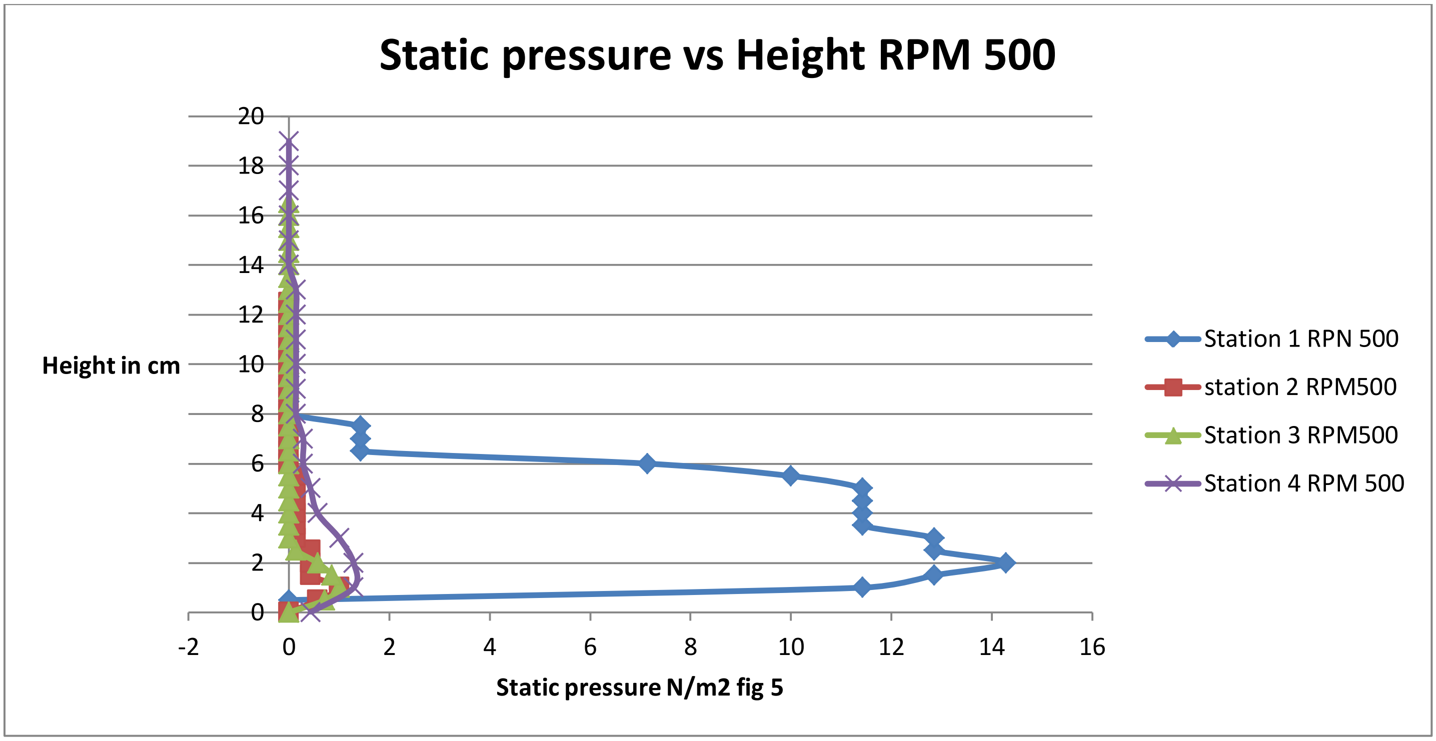


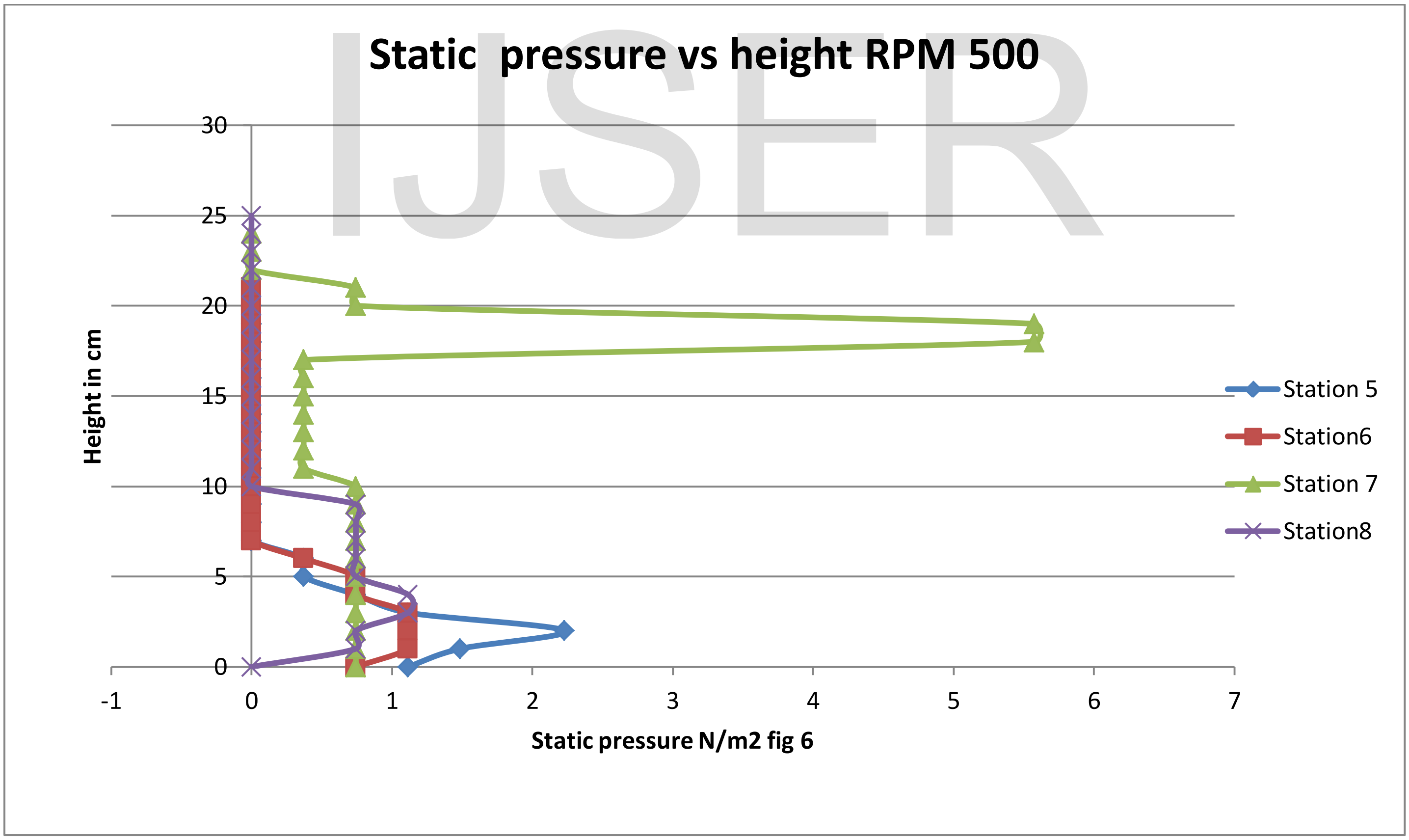
Fig 4

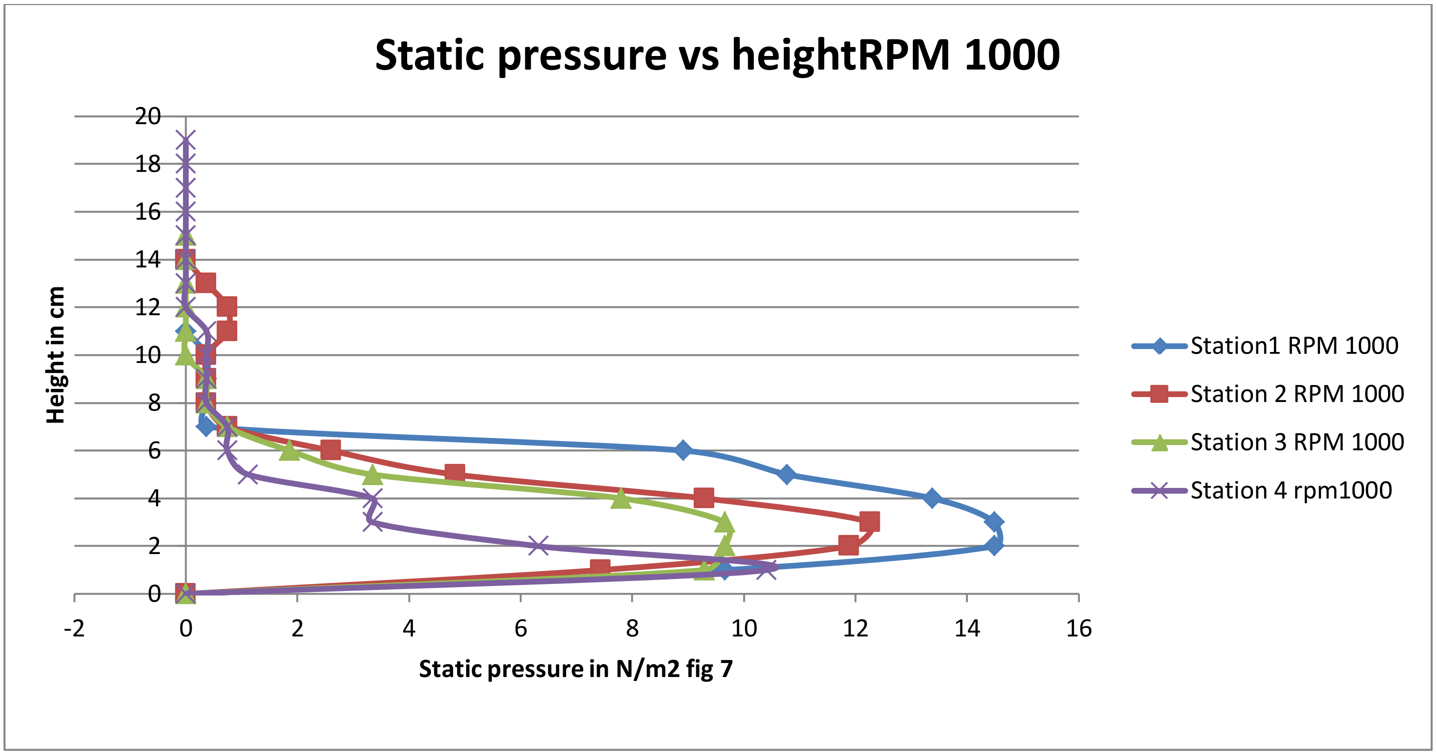
4 Results and Discussions

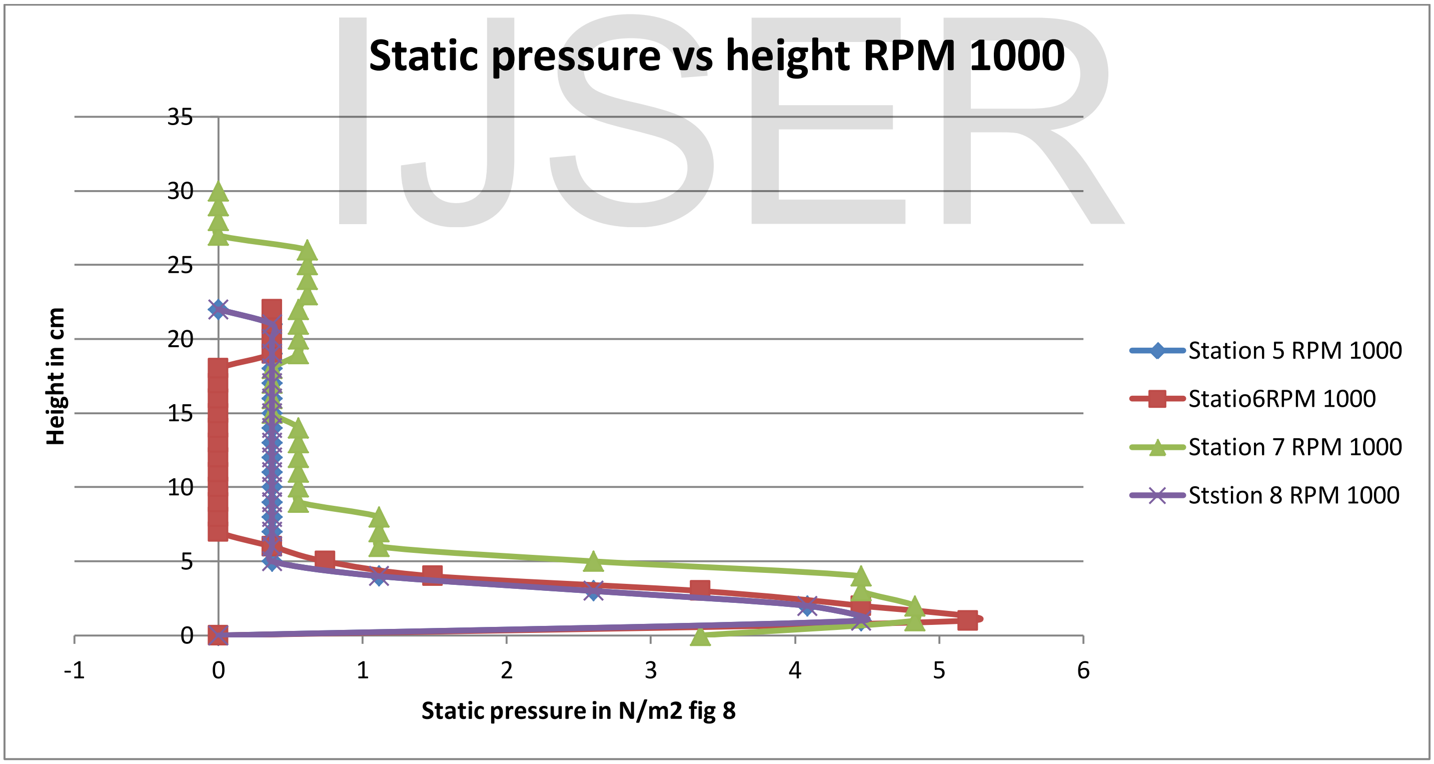
From the graph it is that static pressure attains a maximum value at station 7 which is at a distance 490 mm.

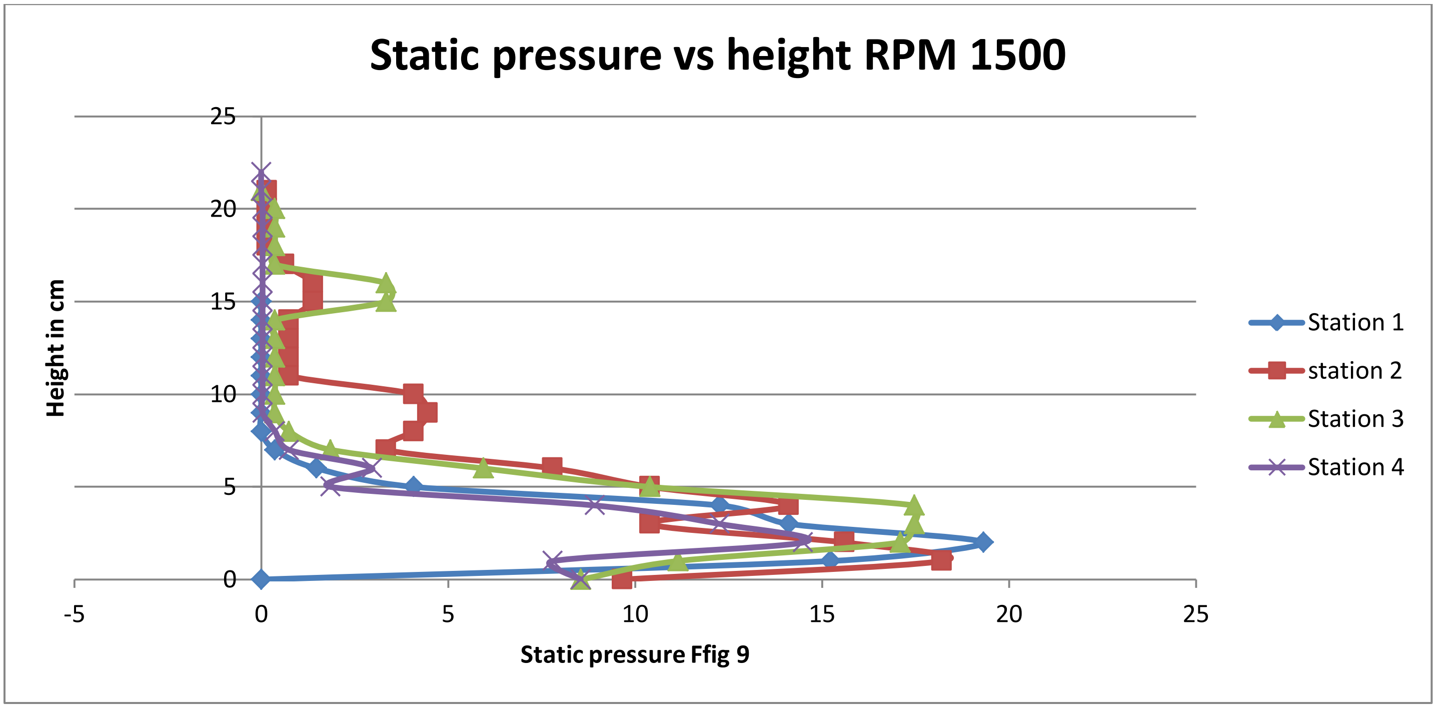
From the inlet.Occurance maximum value at different station are different. Range of Reynolds number is 8227 to 2.5×104.But as maximum of the maximum is at 490mm from entrance. So optimal size of the diffuser is 490 mm.From the fig 7 it is observed occurrence of Maximum static for speed 1000, 110 mm.So optimality can vary as per Reynolds number. Fig 5,6,7,8 shows the variation of static pressure along length. Now it is observed coefficient static pressure recovery.

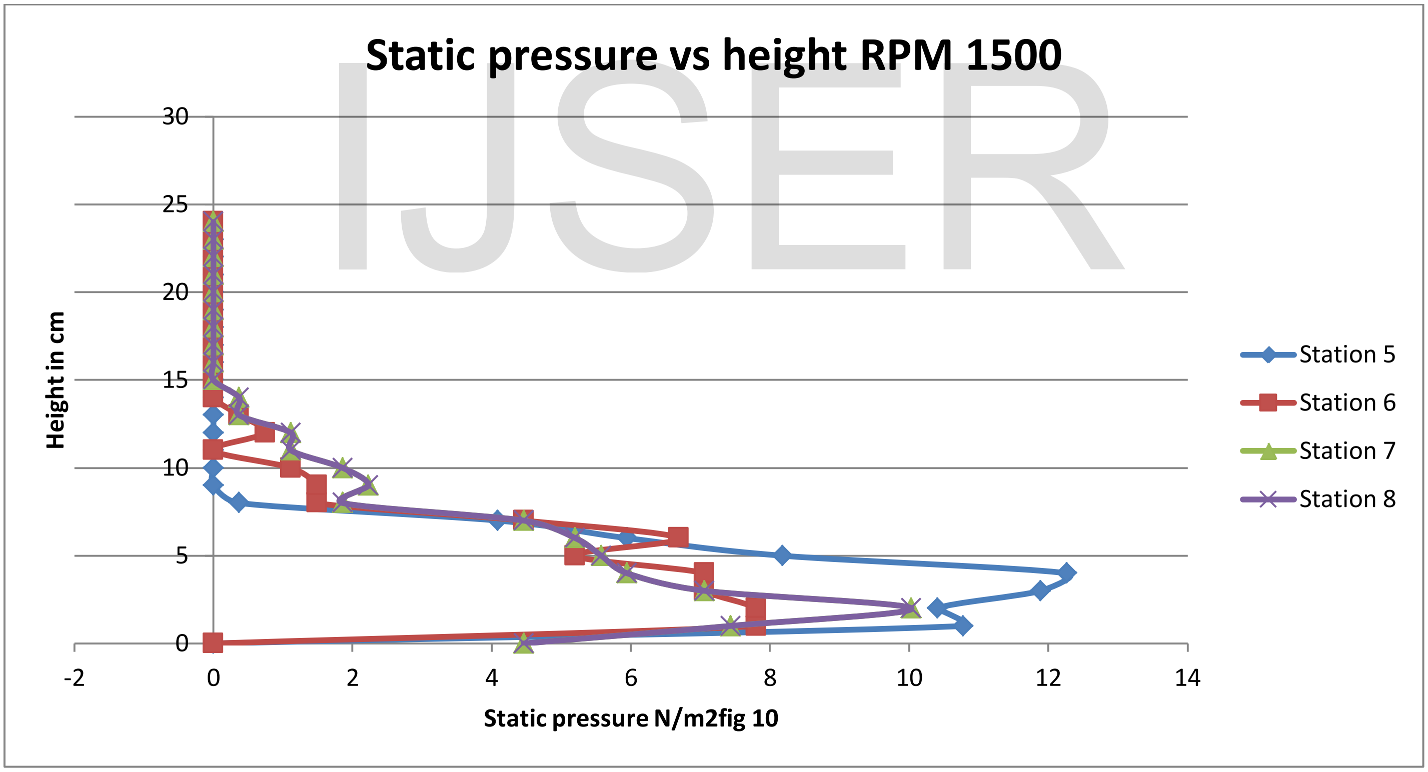

Static pressure vs Height RPM 500
Height in cm
20
18
16
14
12
10
8
6
4
2
0
-2
0
2
4
6
8
10
12
14
16
Static pressure N/m2 fig 5
Station 1 RPN 500
station 2 RPM500
Station 3 RPM500
Station 4 RPM 500


Static pressure vs height RPM 500
Height in cm
30
25
20
15
10
5
0
-1
0
1
2
3
4
5
6
7
Static pressure N/m2 fig 6
Station 5
Station6
Station 7
Station8


Static pressure vs heightRPM 1000
Height in cm
Static pressure in N/m2 fig 7
Station1 RPM 1000
Station 2 RPM 1000
Station 3 RPM 1000
Station 4 rpm1000
20
18
16
14
12
10
8
6
4
2
0
-2
0
2
4
6
8
10
12
14
16


Static pressure vs height RPM 1000
Height in cm
Static pressure in N/m2 fig 8
Station 5 RPM 1000
Statio6RPM 1000
Station 7 RPM 1000
Ststion 8 RPM 1000
35
30
25
20
15
10
5
0
-1
0
1
2
3
4
5
6





From fig 9,10 pressure recovery co efficient decreasing axially along the diffuser so it is good .So from the graph it is obtained that optimal length of the diffuser is 360 mm.The length of diffuser taken here is 760 mm.Required optimal length of the diffuser is 360 mm.The value of the pressure co efficient is 0.165.Tolatated value 0.2 to 0.5.[1].The graphs 11,12.13.14 gives the nature of pressure recovery for rpm 1500.Minimum of the maximum pressure recovery co efficient the optimal length of diffuser.For higher speed pressure recovery coefficient decreases hence there is better pressure recovery.Now it is discussed velocity profile for the flow of air in diffuser.

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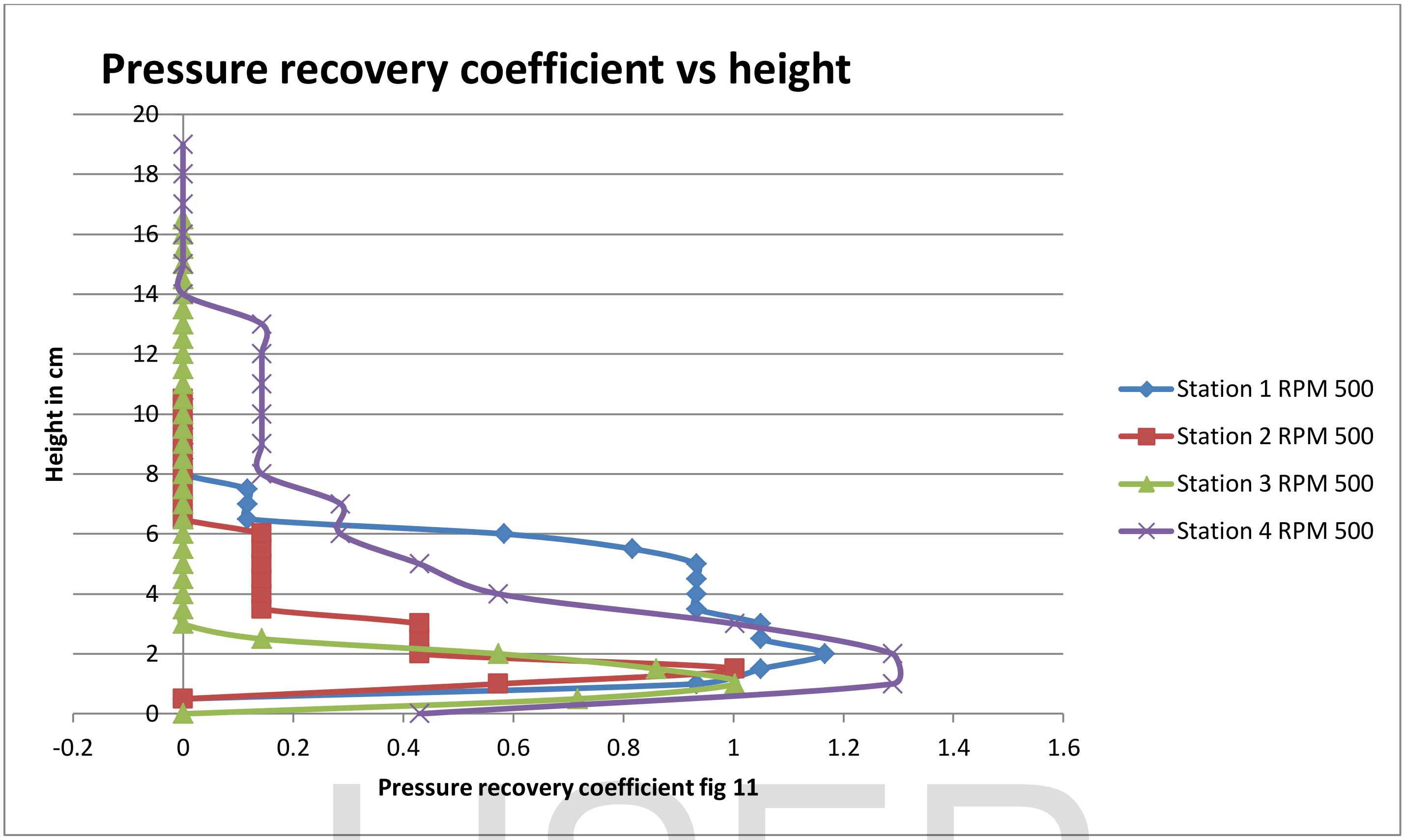

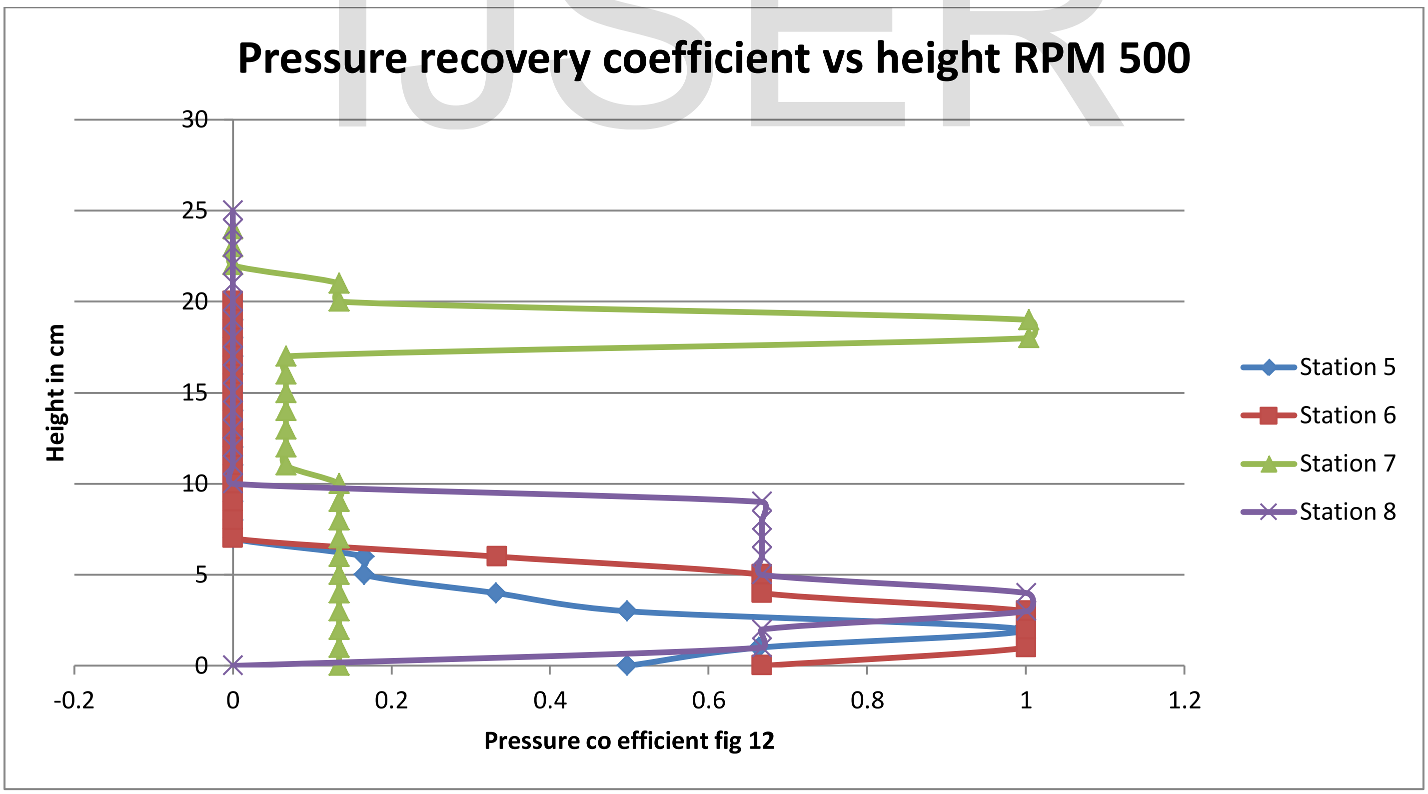

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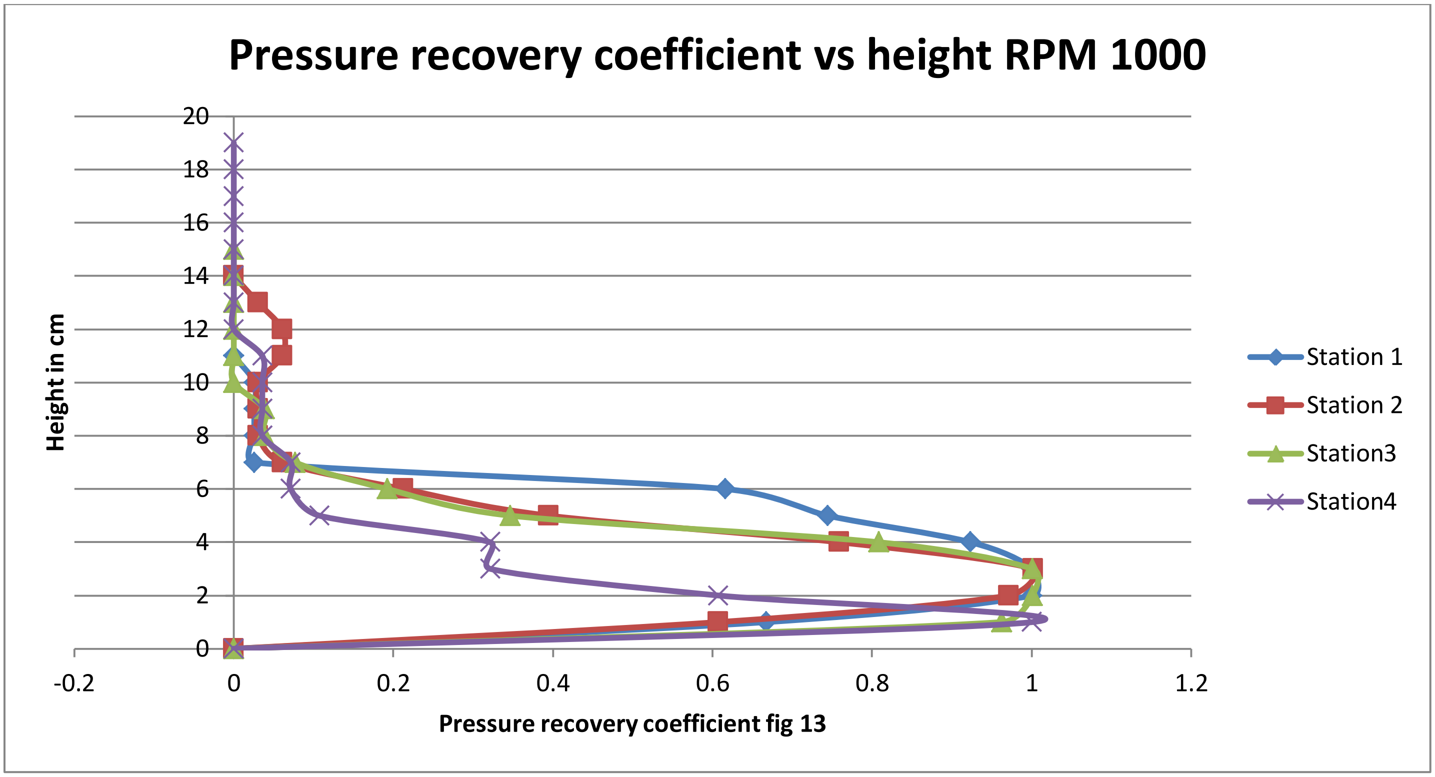
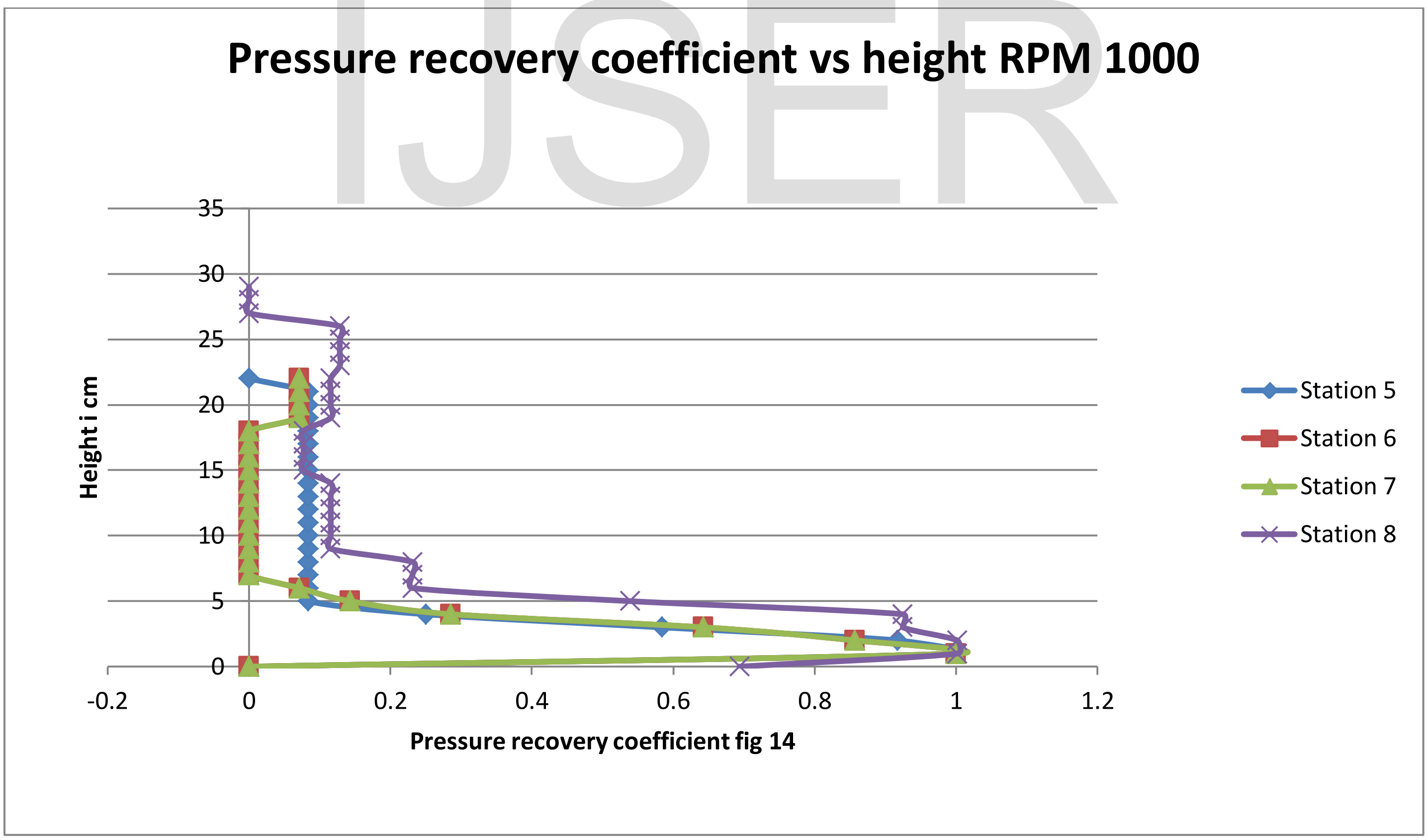
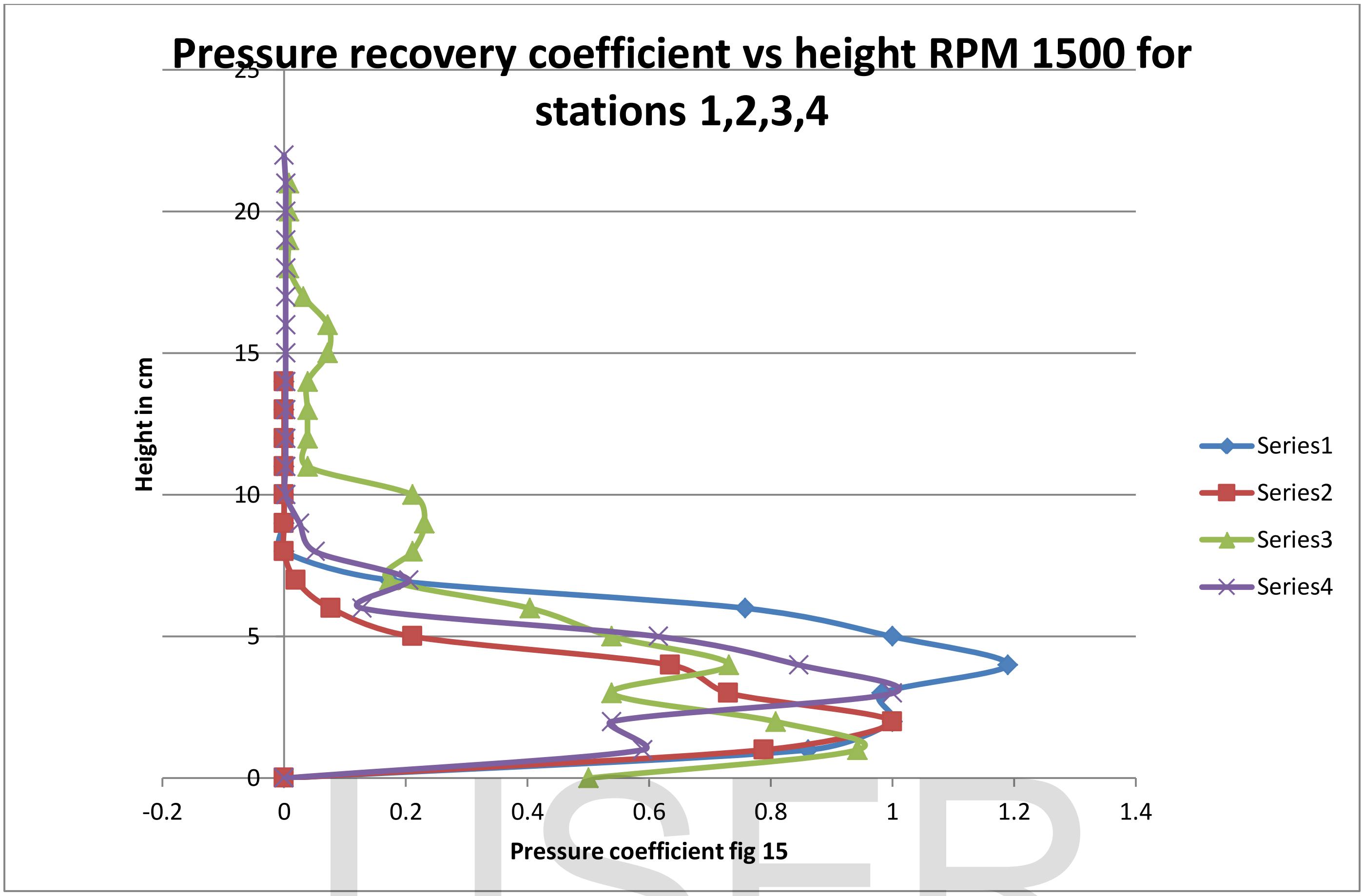
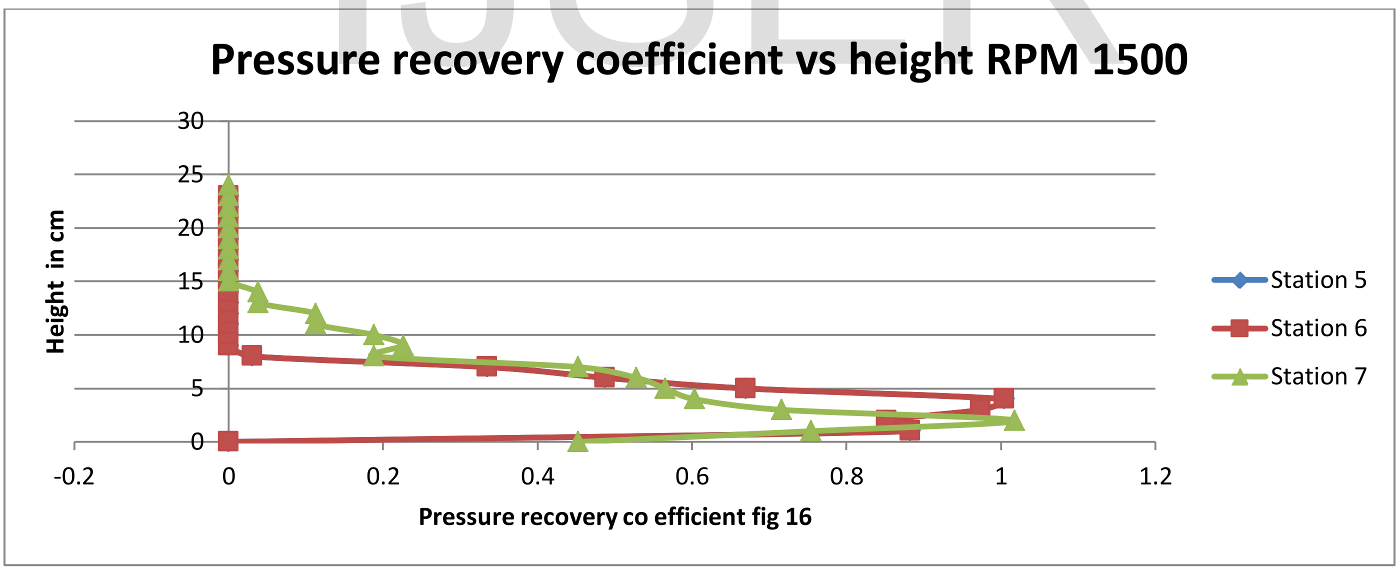
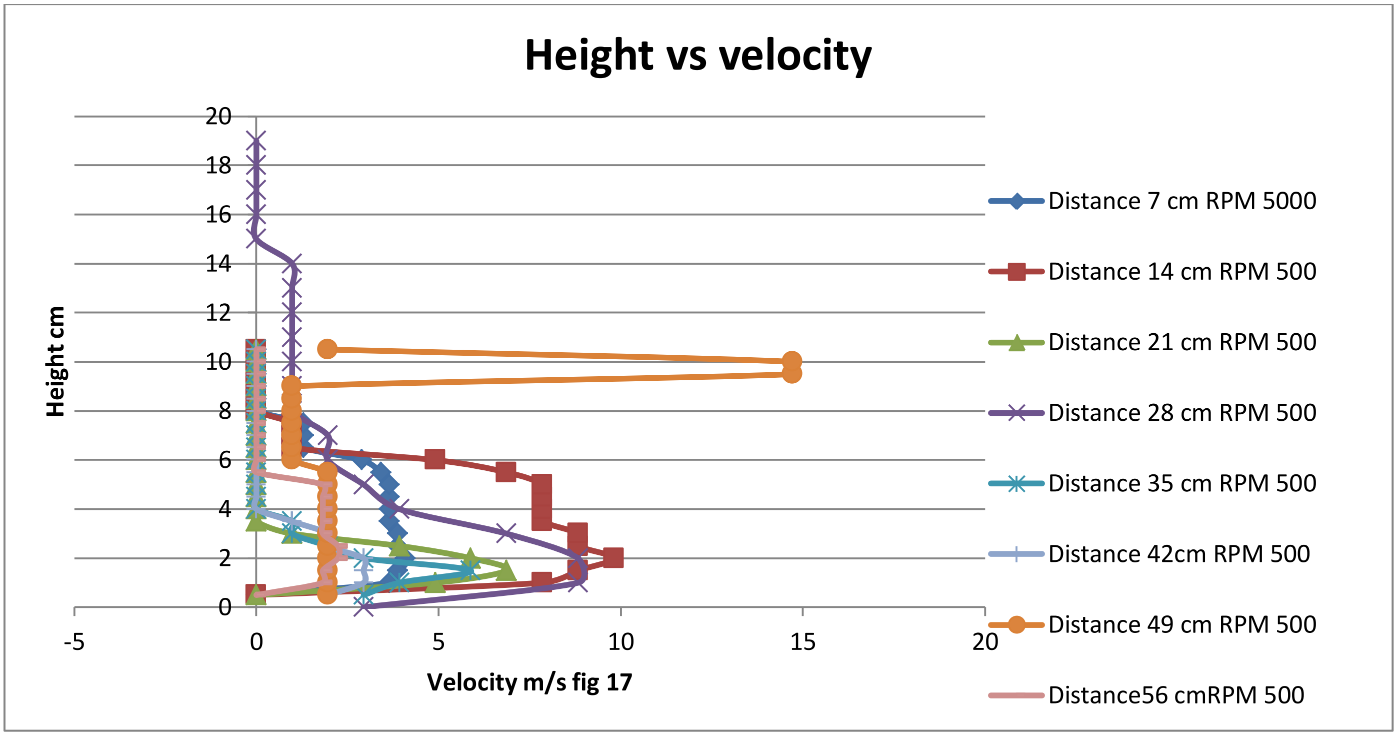


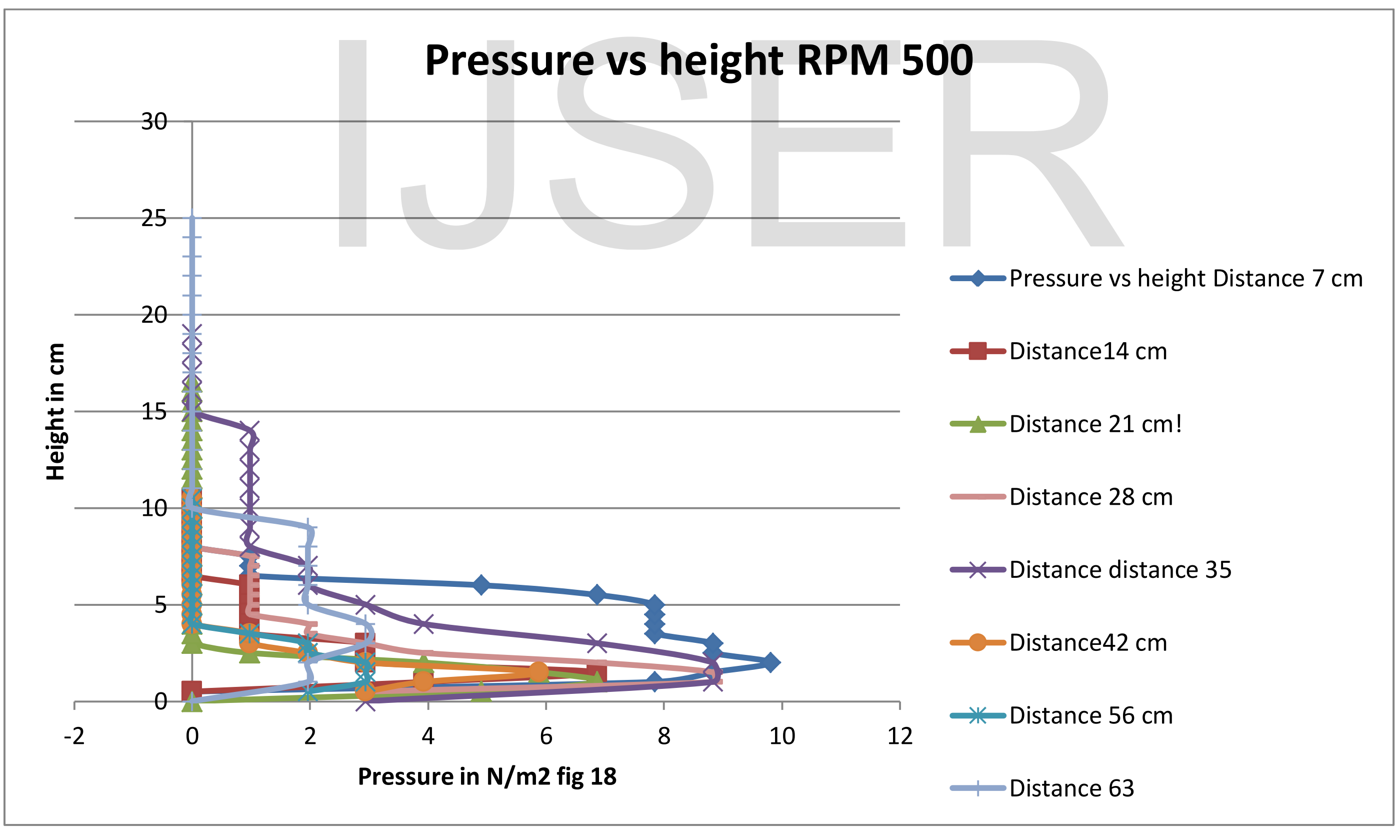


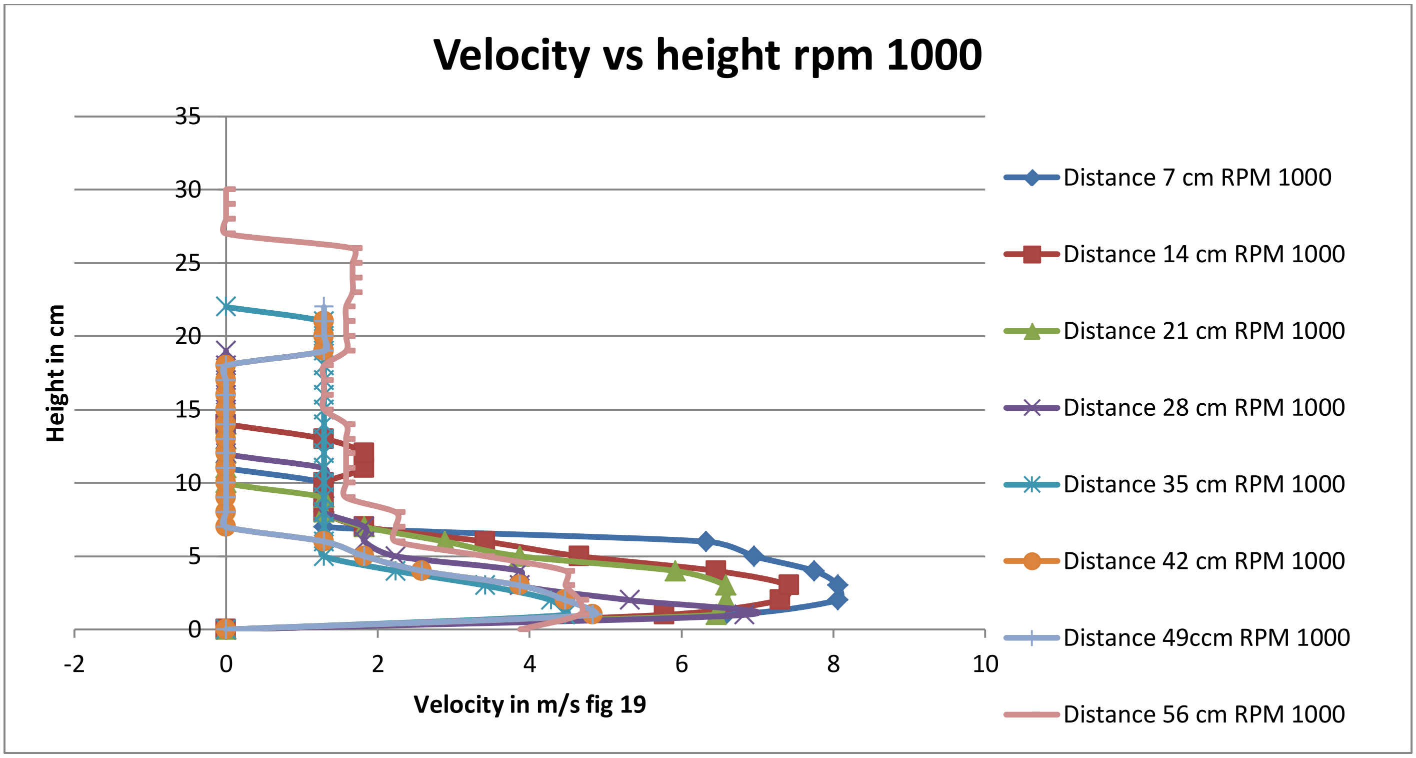


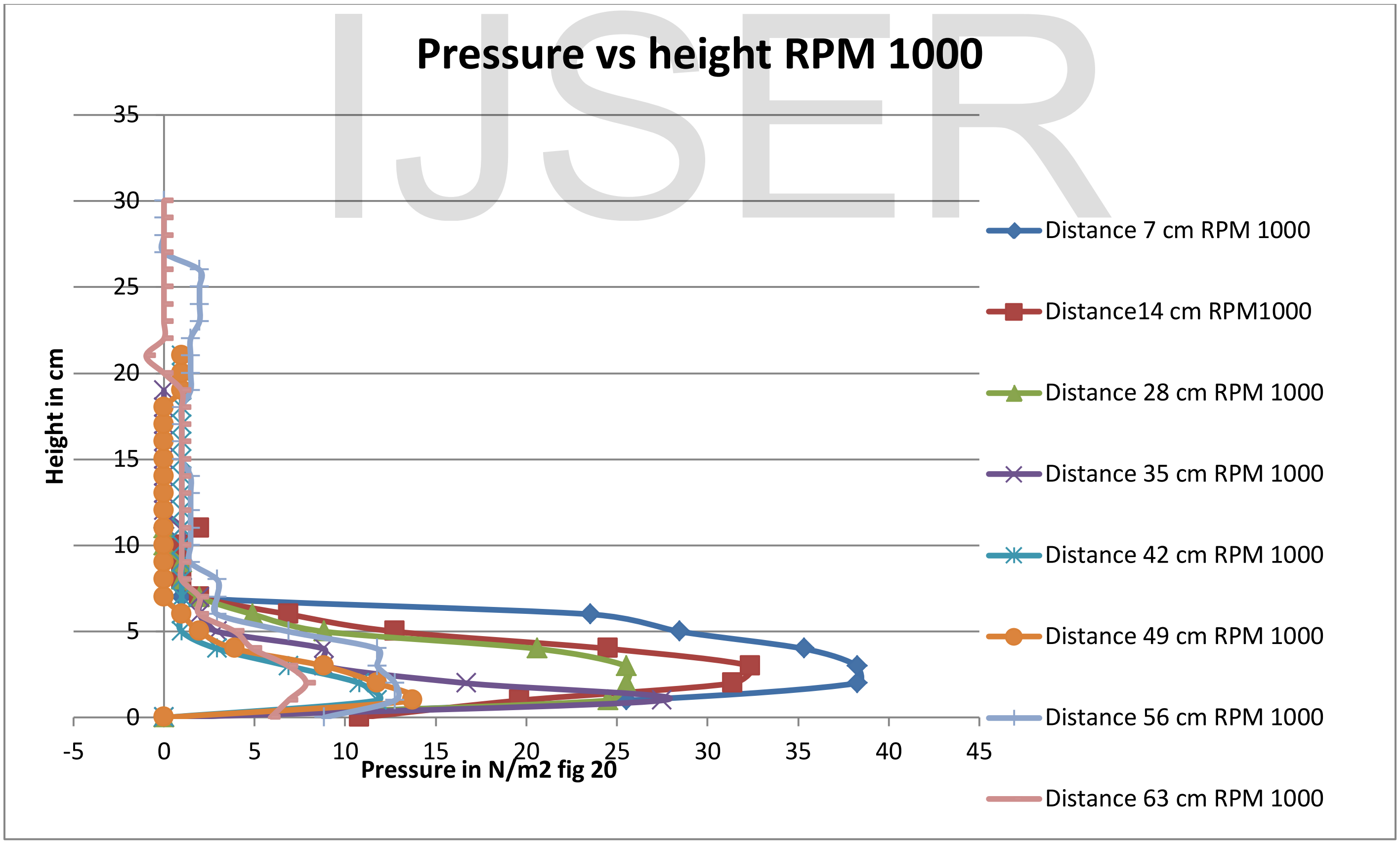


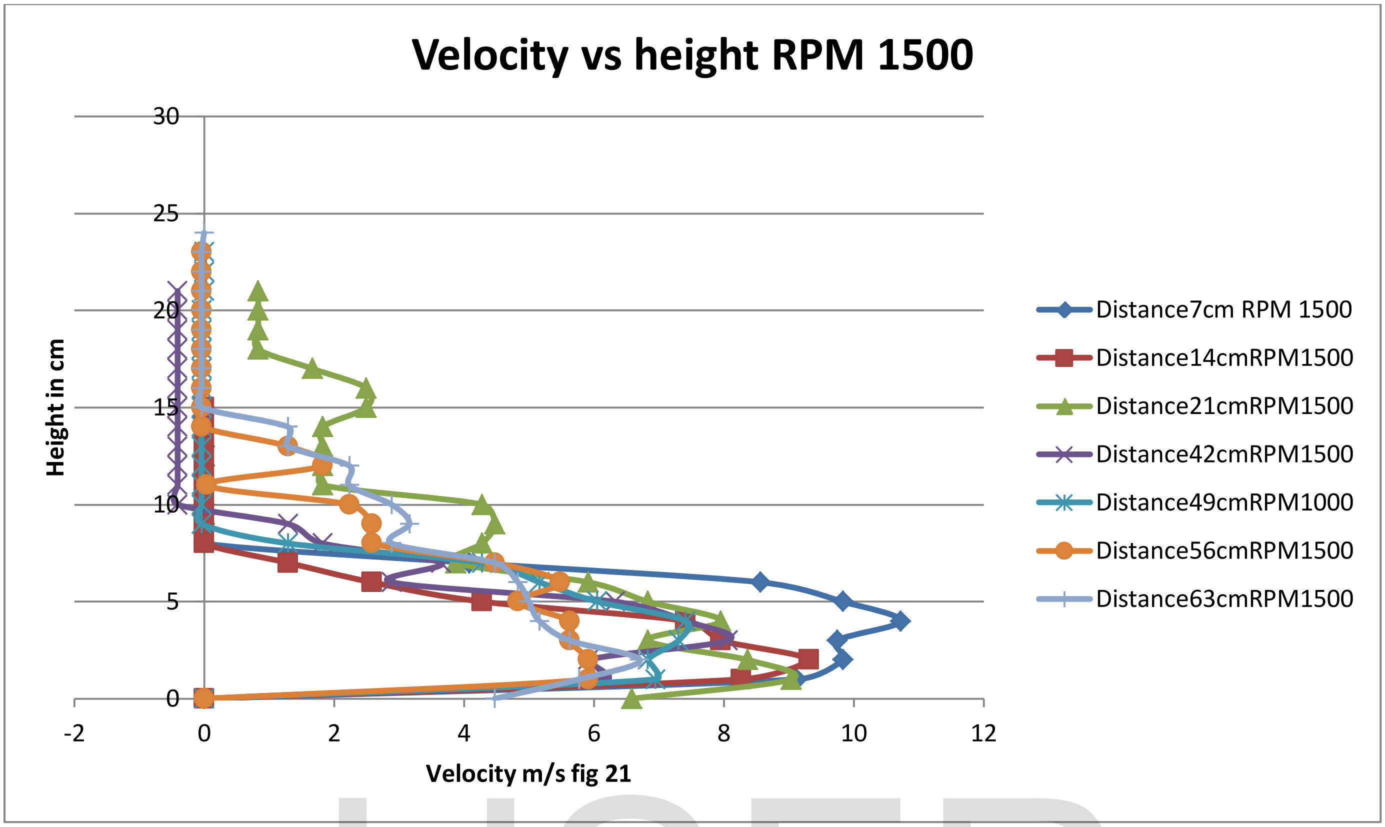
The velocity profiles are shown below. It is observed from the graph maximum values of the velocities gradually hence there is a pressure recovery. The nature of pressure profile also show below. Form graph 20 it is observed that there is negative pressure and velocity at a distance 490 mm.It indicates that there is a point of inflection exist. Due this point of inflection there is instability of flow also there is flow separation due recirculation.

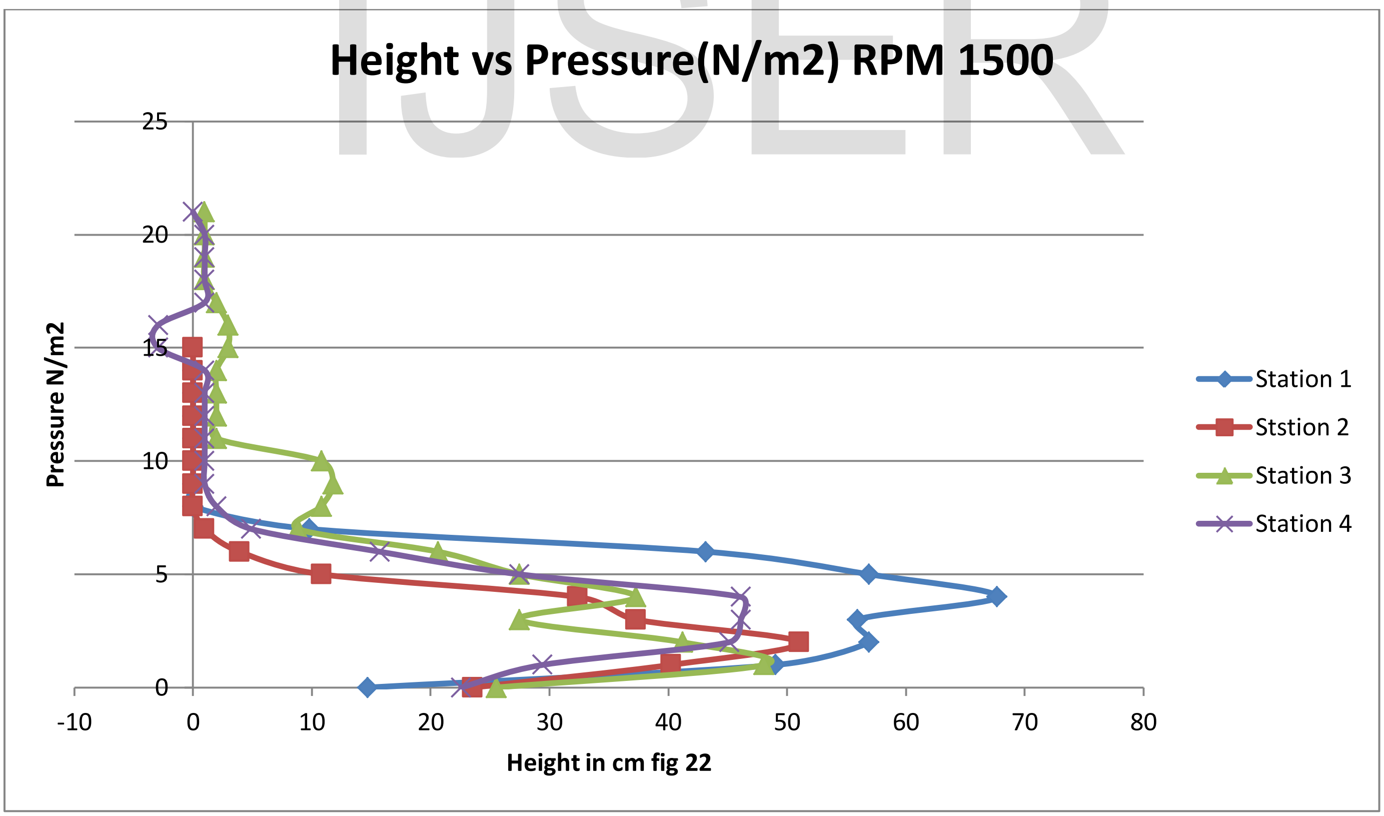

Height vs velocity
Height cm
20
18
16
14
12
10
8
6
4
2
0
-5
0
5
10
15
20
Velocity m/s fig 17
Distance 7 cm RPM 5000
Distance 14 cm RPM 500
Distance 21 cm RPM 500
Distance 28 cm RPM 500
Distance 35 cm RPM 500
Distance 42cm RPM 500
Distance 49 cm RPM 500
Distance56 cmRPM 500

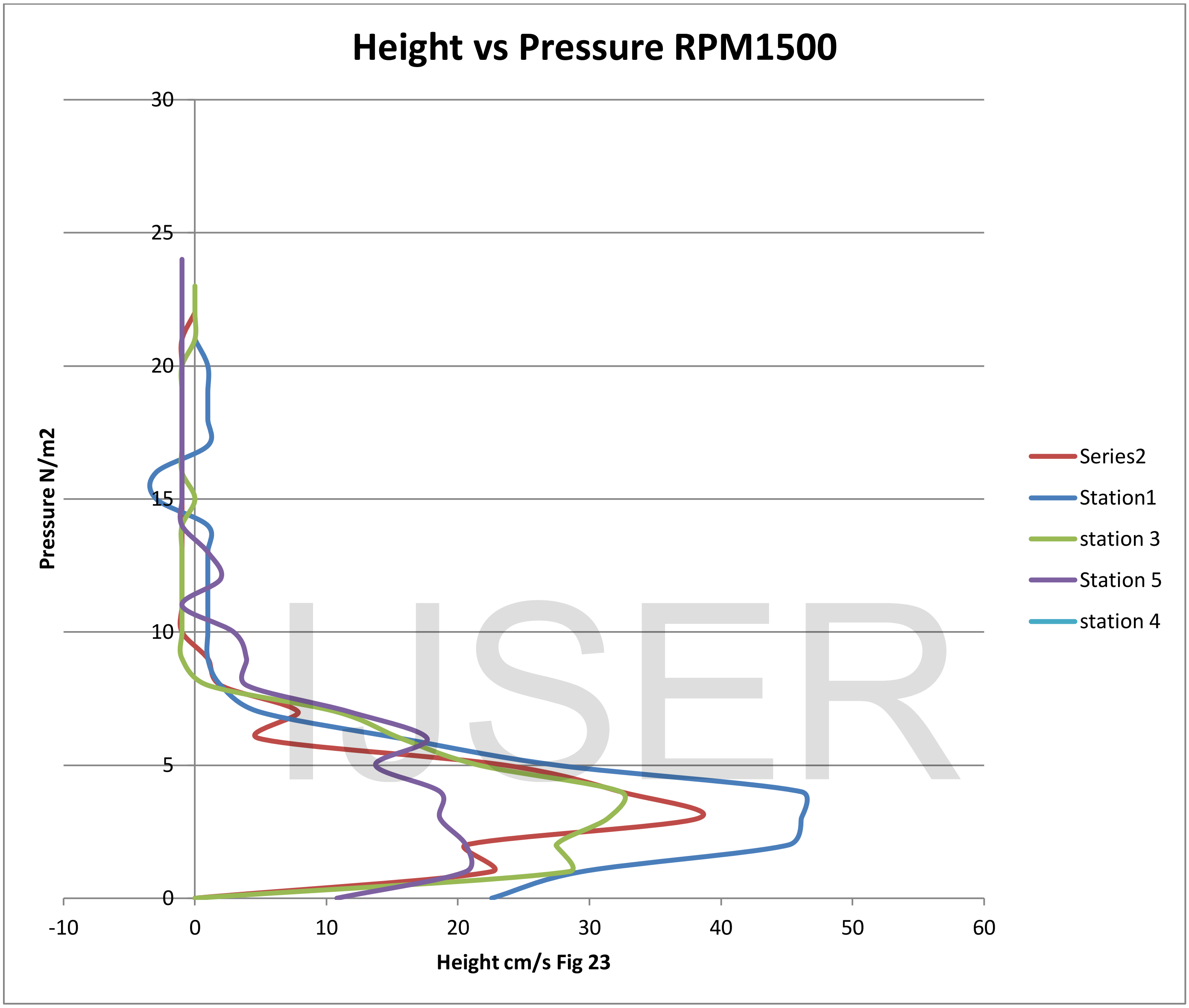

Pressure vs height RPM 500
Height in cm
30
25
20
15
10
5
0
-2
0
2
4
6
8
10
12
Pressure in N/m2 fig 18
Pressure vs height Distance 7 cm
Distance14 cm
Distance 21 cm!
Distance 28 cm
Distance distance 35
Distance42 cm
Distance 56 cm
Distance 63


Velocity vs height rpm 1000
Height in cm
35
30
25
20
15
10
5
0
-2
0
2
4
6
8
10
Velocity in m/s fig 19
Distance 7 cm RPM 1000
Distance 14 cm RPM 1000
Distance 21 cm RPM 1000
Distance 28 cm RPM 1000
Distance 35 cm RPM 1000
Distance 42 cm RPM 1000
Distance 49ccm RPM 1000
Distance 56 cm RPM 1000


Pressure vs height RPM 1000
Height in cm
35
30
25
20
15
10
5
0
-5
0
5
10
15
20
25
30
35
40
45
Pressure in N/m2 fig 20
Distance 7 cm RPM 1000
Distance14 cm RPM1000
Distance 28 cm RPM 1000
Distance 35 cm RPM 1000
Distance 42 cm RPM 1000
Distance 49 cm RPM 1000
Distance 56 cm RPM 1000
Distance 63 cm RPM 1000


Velocity vs height RPM 1500
Height in cm
30
25
20
15
10
5
0
-2
0
2
4
6
8
10
12
Velocity m/s fig 21
Distance7cm RPM 1500
Distance14cmRPM1500
Distance21cmRPM1500
Distance42cmRPM1500
Distance49cmRPM1000
Distance56cmRPM1500
Distance63cmRPM1500


Height vs Pressure(N/m2) RPM 1500
Pressure N/m2
25
20
15
10
5
0
-10
0
10
20
30
40
50
60
70
80
Height in cm fig 22
Station 1
Ststion 2
Station 3
Station 4

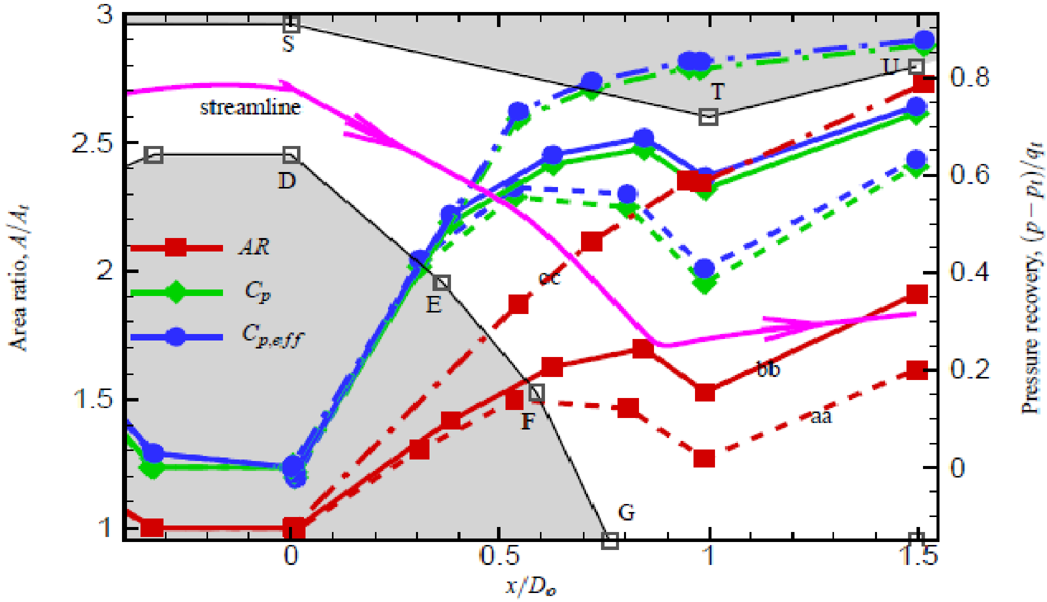


From fig 21, 22 it is observed that there negative pressure hence there negative velocity.So it can concluded there are point of inflections.Due this inflections points there will recirculation zone.

5 Validation

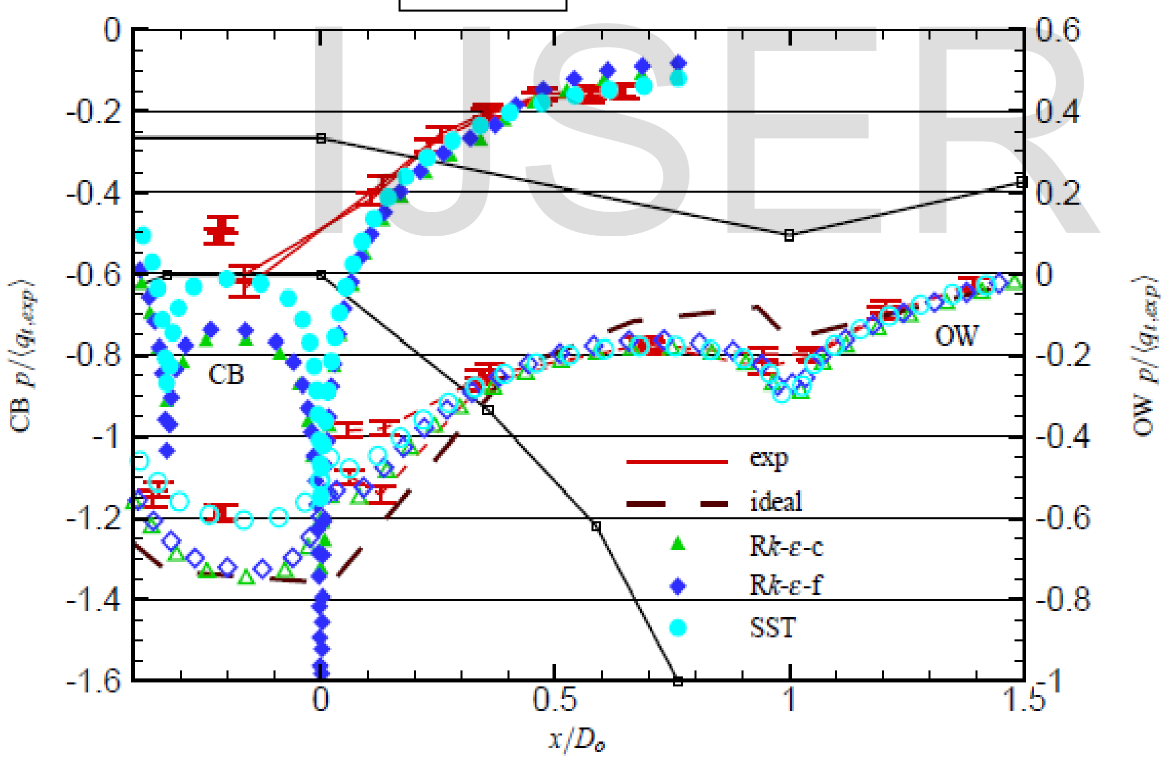
From David Cerantola thesis[1] it is observed pressure recovery coefficient attains maximum at the out let but in the existing paper pressure co efficient attains maximum at particular point along the axis which is the optimal length of diffuser.By calculating from the graph optimal of the diffuser is 360 mm from starting end.This length gives gives maximum pressure recovery.

From this fig 24 it is observed that pressure recovery coefficient attains negative minimum due centered body.But rectangular diffuser pressure coefficient is very very small quantity.Which indicates static pressure recovery is almost equal to stagnation pressure.



igure 5.3: Area distributions and pressure coefficients for Configs. aa (dashed), bb (solid), and cc (dash-dot) based on the flow path of an assumed streamline.

Fig 24



(b) Config. bb

Fig 25

6 Conclusions

1. For for rectangular diffuser pressure recovery co efficient decreases to a small quantity which improves static pressure recovery hence increases gas turbine.
2. For higher speed there is instability due to occurance of point of inflections.
3. Optimal length is the point where the pressure co efficient attains minimum.
4. Optimal length of the rectangukar diffuser is 360 mm.

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