

# COMPUTATIONAL FLUID DYNAMIC ANALYSIS OF INLET AIR SYSTEM

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**Abstract**—The inlet air system of a compressor appear as a simple component but it is actually very critical component. The inlet air system consist of the ducting and the silencer section which is responsible for filtering the air before it enters into the compressor. The silencer section performs the function of keeping the sound levels within the permissible limits. The major problems encountered in the inlet ducting are major losses in the silencer section and the elbow duct, and also there are swirl formations in the elbow which needs to be eliminated. To eliminate these losses and swirl formations a through a (CFD) Computational Fluid Dynamic Analysis of the duct is to be done and the areas of major pressure losses are to be highlighted. For this optimization the design of the duct is modified. All designs are done with respect to their cost and efficiency of operation.

**Keywords**— CFD analysis, Compressor, Duct, Pressure drop, Silencer, Swirl, Design, Optimization.

## 1. INTRODUCTION

This project title deals with the design and optimization of an inlet air duct of a compressor that is going be the inlet to the gas turbine plant. Here I have analyzed the flow of the air through the duct, the points are highlighted where the pressure losses are taken place. Design of the duct also optimized for acoustic analysis. So accordingly redesign the system to reduce the pressure losses and sound levels. Air from the duct passes to the compressor, here the air is compressed in the combustion chamber. When the compressed air is supplied from the compressor, the burnt high temperature gases are passed through the turbine where its high pressure and temperature energy is used to develop work. The power developed by the turbine is used to run the compressor and remaining energy can be used to generate electrical energy.

### 1.1 Problem Statement

The problem of pressure drop in duct which is taken from one of the industry, analysis which was done in that industry, and some of the common problems were arises, 1) Pressure losses in Duct. 2) Another major problem in the duct is the sound levels as a result of air flow through the ducts. 3) Elbow section of the duct is the part in which pressure loss is occurring. 4) Due to sharp bend of 90° turn the swirl of air is formed. 5) Material selection for duct.

Following Figure shows the 2 dimensional drawing of existing duct. This drawing prepared in AutoCad software.

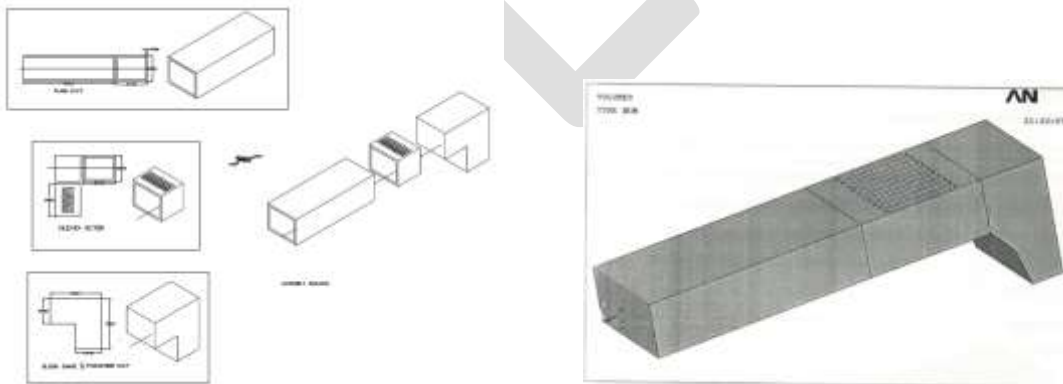


Fig 1.1 shows 2D drawing of the duct

Fig 1.2 shows 3D Model of the duct

### 1.2 Detail Description of the Design:

The components of the duct are:

1. Plain duct: The plain duct is of rectangular hollow cross section. Its dimensions are 8.33ft height and 10.75ft width. The purpose of the plain duct is to act passage for the air coming from the filter section. The plain duct length is 29 ft. long
2. The silencer section: Connecting to the plain duct is the silencer section of 8.33 ft long, this is also a rectangular shell of walls with mineral wool padding inside, in addition to this total 10 panels are arranged side by side each with mineral wool padding. The purpose of this is to provide a absorbent surface to absorb the sound produced due to the flow of air through the ducting. The panels are 150mm thick and span the entire length of the silencer section. The construction of the panels is such that the mineral wool padding comes in between two sheets of stainless steel.
3. The elbow duct: The ducting takes 90 degree turn after the silencer section. To facilitate this an elbow section is provided.
4. The transition duct: The transition duct is the one that connects the elbow to the inlet plenum of the compressor. This is a converging part as it goes down to the plenum covers.

### 1.3 Aims and Objectives:

**Aims:** The Inlet duct which is connected to the compressor and compressor is the inlet component to the gas turbine. As we already know that the compressor consumes almost two thirds of the power developed by the turbine any loss in compressor section could effect on overall efficiency of the gas turbine power plant. Another major problem in the duct is the elevated sound level as a result of air flow through the duct. This causes inconvenience to the operator so it should be reduced to permissible levels without causing any increase in the pressure loss.

**Objectives:** To achieve the aim a complete Fluid Dynamic Analysis of the duct is required, the flow pattern need to be mapped and pressure drop calculated from above mapping, the following things should have to be achieved,

To develop 3D model of an intake system.

To observe the pressure drop inside the air intake system.

To develop new design for optimization of an air intake system.

## 2.LITERATURE REVIEW

### 2.1 Literature No.1

The second part Numerical Investigation on The effect of Angle of Attack on the Square Ducting Design 2007 by Mohd Hafiz Mohd Noh<sup>1, a</sup>, Ahmad Hussein Abdul Hamid<sup>2,b</sup>, Helmi Rashid<sup>3,c</sup>, Muhammad Izzuddin Ahmad Sfhafi<sup>4</sup>, This research is focus on the effect of increasing the angle of attack and increasing the bend radius for the square area duct. To further minimize the pressure drop CFD Analysis And Simulation is done.

### 2.2 Literature No.2

Design And Optimization of industrial duct using CFD Analysis. By Dr.Neihad AL-khalidy 2011.The main objective of this work is to improve flow condition along the duct. 3D CFD model is studied. The following modifications were investigated-1. changing the length of the duct2. changing the pressure drop3. proposing a new design.

### 2.3 Literature No.3

Swirling Airflow Influence on Turbocharger Compressor Performance by Department of Applied Mechanics Division of Combustion CHALMERS UNIVERSITY OF TECHNOLOGY, Göteborg, Sweden 2014, Literature review showed many possible ways to improve air intake system performance for compressor. Three paths were suggested for Air Induction System that could be further investigated. Swirl investigation 90 bend improvement Investigation of different duct shapes.

## 3. METHODOLOGY:

Problem Solving Steps:

1. Create the Model geometry
2. Drawing appropriate 2D and 3D modeling.
3. Discretization
4. Apply Boundary Condition and Generation of grid
5. Select the basic equation to be solved: Laminar or Turbulent
6. Specify Laminar/Turbulent flow
7. Mach No. less than 0.3.

8. Specify the algorithm and perform simulation
9. Run command in Fluent
10. Result analysis and post process the simulation to get the result.

Following fig. shows improved design of duct.

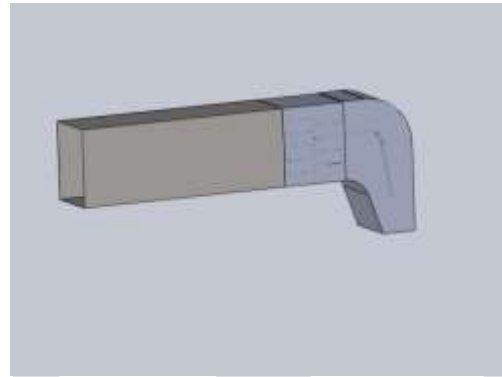
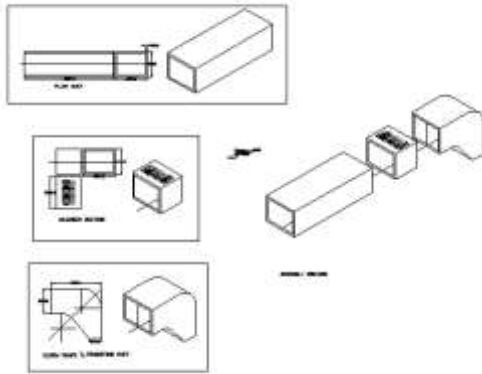


Fig No. 3.1 Shows the improved 2D drawing of the duct system      Fig No. 3.2 Shows the improved 3D model of duct system.

### 3.1 Discretization :

A mathematical model is discretized by dividing it into a mesh of finite elements. Thus a fully continuous field is represented by a piecewise continuous field defined by a finite number of nodal quantities and simple interpolation within each element.

### 3.2 Apply Boundary Condition and Generation of grid

Once the meshing is complete the next step is to apply the loads and specifying the boundary conditions. according to the design data provided the mass flow rate at the inlet of duct is 112.1 kg/sec. According to formula:

$$\text{Discharge} = \text{Density} \cdot A \cdot V$$

$$\text{Discharge} = \text{Density} \cdot A \cdot V$$

$$112.1 \text{ kg/s} = 1.1272 \text{ kg/m}^3 \cdot (2.540 \text{ m} \cdot 3.278 \text{ m}) \cdot V$$

$$112.1 = 9.38520 \cdot V$$

$$V = 11.94 \text{ m/s}$$

From the above equation the velocity was found to be 11.94 m/sec

### 3.3 The Role Of Reynolds Number

Pipe flow may be either laminar flow or turbulent flow. Laminar flow is characterized by low flow velocity and high viscosity. Turbulent flow is characterized by high flow velocity and low viscosity.

For Reynolds number < 2100, flow is laminar. For Reynolds number > 4000, flow is turbulent.

$$\text{Reynolds Number} = \frac{\text{Inertial force}}{\text{Viscous force}} \quad Re = \frac{\rho VL}{\mu}$$

Where,

V is the velocity of the fluid,  $\rho$  is the density of fluid,  $\mu$  is the viscosity of fluid, L is the length or diameter of the fluid.

$$Re = \frac{\rho VL}{\mu}$$

$$= \frac{1.1272 \text{ kg/m}^3 \cdot 11.94 \text{ m/s} \cdot 8.993 \text{ m}}{1.983 \cdot 10^{-5} \text{ kg/m.s}}$$

$$= 5853132 \text{ this value is that standard value so the flow is turbulent.}$$

### 3.6 Calculation For Mach No.

If the velocity of gas flow is larger than  $Ma 0,3$  it must be regarded as compressible. In air, this corresponds to approximately 100m/s at 1bar and  $0^{\circ}C$ . The dynamic pressures occurring in the flow here are equal to a maximum of 60bar. Below this limit, a gas flow can be considered as incompressible fluid with good approximation. In most flows of liquids, and of gases at low Mach number, the density of a fluid can be considered to be constant, regardless of pressure variations in the flow. Therefore, the fluid can be considered to be incompressible and these flows are called incompressible flow.

### 3.8 Turbulence Models

We need to be aware that when an analysis begins the effective viscosity initializes as a multiple of the laminar value. This initialization occurs whether a model is active or not. The default value of this multiple (also called the turbulence ratio is 1000).

FLUENT(CFD) offers six turbulence models, Normally the standard k-epsilon model is the first model to apply. It usually provides a realistic picture of the flow in a converging nozzle.

### 3.9 Specify The Algorithm

Once the problem is defined the next step is to specify the algorithm. There are two types of algorithm SIMPLEF, SIMPLER

SIMPLER algorithm generally used for the turbulent analysis. Thus the problem is turbulent, incompressible flow with no heat flow.

### 3.10 Result Analysis

Once all these have been completed the analysis started by giving the RUN command in Fluent. After the analysis is complete the result can be viewed in the post processor. In the post processor first the vector plot of the flow is made to see the nature of the flow and to check the velocities at various points in the flow regime. After this a contour plot of the pressure is made to plot the pressure variation through the duct.

## 4 PRELIMINARY ANALYSIS AND OBSERVATION

Before going to start out to make changes in the design we need to make a fluid dynamic analysis of the original design and find out the pressure distribution. From this we need to calculate the total loss in the duct. The original model has been prepared and control volume is to be generated. After this the meshing is done the next step is to apply the boundary condition. Here in this the inlet velocity is 11.94 m/sec. and suction pressure at the exit of the duct as 19,305.83 N/m<sup>2</sup>.

According to the given data

1. Mass flow rate at the inlet of the duct= 112.1 kg/sec.
2. the suction pressure at the exit of the duct= 19,305.83 N/m<sup>2</sup>
3. Pressure loss in the silencer section= 2596 N/m<sup>2</sup>
4. pressure loss in elbow section= 498N/m<sup>2</sup>
5. power consumed by compressor = 34.714 MW

Following Fig shows the pressure plot, it is clear that the majority of the **pressure loss is taking place in the silencer section the total loss is 2966 N/M<sup>2</sup>**

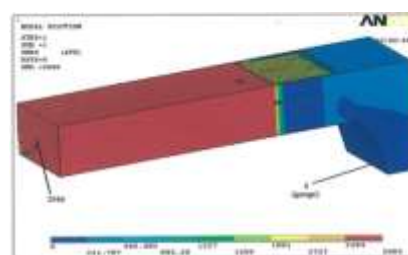
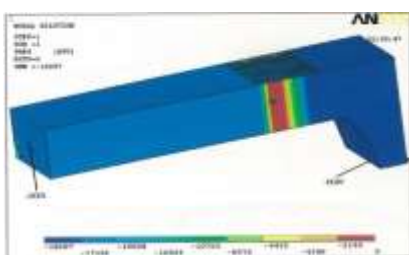


Fig No.4.1 Pressure distribution in duct

Fig no. 4.2 Total back pressure in the duct

The inlet velocity in the previous section case as 11.94 m/sec. But The exit pressure instead of defining it as suction pressure keep it as **open to atmosphere**, that is specify the exit pressure as 0 N/m<sup>2</sup>. by this method the this fig shows the total back pressure 2986 N/M<sup>2</sup>

## 5 RECOMMENDATIONS FOR THE DESIGN CHANGE

### 5.1 Deign No 1

Since the main pressure loss was taking place in the silencer section so that should be the main area for design change. one of the main reason for the loss was found that the panels was closely tight and so there causing a sudden contraction of the flowing fluid resulting in pressure loss. one way to reduce this effect was to provide more gap between two panels. The shape of the panel has to be changed in aerodynamic shape.



Fig No 5.1 New Shape (Design No 1)

### 5.2 Design No. 1

Following diagram shows the arrangement of panels and the thickness of the panel is 150mm.

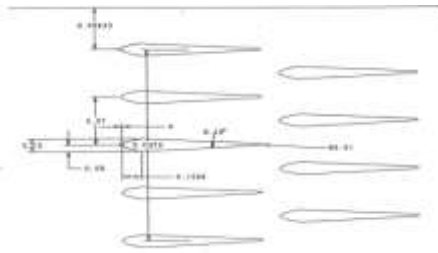


Fig no 5.2 Shows the arrangement of panels

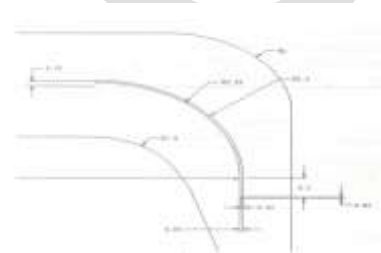


Fig No. 5.3 The Modified Elbow Duct

### 5.3 The modified elbow duct

Following fig. shows the Elbow section which also modified with panels so as to guide the air through the bend with as less turbulence as possible. The thickness of the turning panel is kept at 50mm.



Fig No 5.4 Shows 3D Model of the design No.1

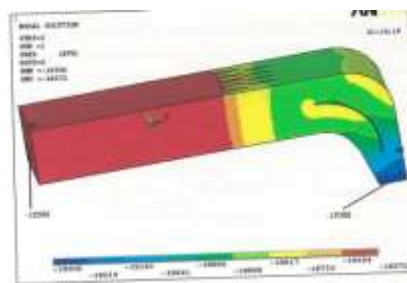


Fig No.5.5 shows the Pressure plot Result

#### 5.4 Result of design No 1

Now after the model is ready the meshing is done and the loads are applied as before. Then the solution options and the execution controls are given and the analysis started. After the analysis is complete the pressure distribution plot are shown. Fig No.5.4.2 shows the total pressure loss in the duct that has been reduced from the original **value of 2986 N/m<sup>2</sup> to a value of 710 N/m<sup>2</sup>.**

Calculated power from Fig No.5.5

The following are the design values of the compressor.

Atmospheric pressure=101.32KN/m<sup>2</sup>, Discharge pressure=936.27KN/m<sup>2</sup>, Pressure ratio=9.4279, Ambient Temperature=40°C=313K

Loss in the conventional design=2900N/m<sup>2</sup>, Loss in the new design=710N/m<sup>2</sup>, Power Consumed by the compressor=  $m \cdot C_v \cdot (T_2 - T_1)$

Ideal power required by the compressor assuming no loss in the duct=34.086MW,

Actual power required by the compressor=34.714MW, Power required when using the new design=34.188MW

Therefore Power saved by the new design=526KW

Power Consumed by the compressor=  $m \cdot C_v \cdot (T_2 - T_1)$

Where,

$m$  = mass flow rate= 112.1 kg/sec

$C_v$  = Ideal gas specific heat capacities of air =0.721 kJ/kg.k

$T_2$  = Temperature at the exit of duct =736K

$T_1$  = Initial Temperature = 313K

=  $112.1 \cdot 0.721 \cdot (736 - 313)$  ( KJ/Sec=KW)

= 34188 KW = 34.188 MW

#### Calculation for Material Selection

Weight of duct in **mild steel** material, Density of mild steel = 8000Kg/m<sup>3</sup>, Wt of duct =  $L \cdot B \cdot \text{density} \cdot \text{thickness}$

=  $16613 \cdot 3278 \cdot 0.00000785 \cdot 3$ , = 1306.97793 Kg (60Rs. \*1282.47) = **76,948Rs**, Wt of transition duct =  $2540 \cdot 2540 \cdot 0.00000785 \cdot 3$

= **151.93518 Kg \* 60 = 9115.8Rs**. Mild steel bars =  $1.2 \cdot 2.5$  (qty 10) = 30m<sup>2</sup>, 60\*30= **1800 Rs**.

Total cost of mineral wool =  $3.278 \cdot 2.540 = 8.32612$  m<sup>2</sup>

( 250 Rs./Sq M \* 8.32612) = **2081.53 Rs**

**Total cost of duct =89,945Rs.**

Weight of duct in **stainless steel** material ,Density of mild steel = 8000Kg/m<sup>3</sup> Wt of duct =  $L \cdot B \cdot \text{density} \cdot \text{thickness}$

=  $16613 \cdot 3278 \cdot 0.00000800 \cdot 3$ , = 1306.97793 Kg (300Rs. \*1306.977) = **39,2093Rs**, Wt of transition duct =  $2540 \cdot 2540 \cdot 0.00000800 \cdot 3$

= **154.83518 Kg \* 300 = 46440 Rs**.,stainless steel bars =  $1.2 \cdot 2.5$  (qty 10) = 30m<sup>2</sup>,300\*30=900Rs.

Total cost of mineral wool =  $3.278 \times 2.540 = 8.32612 \text{ m}^2$

( 250 Rs./Sq M \* 8.32612) = **2081.53 Rs**

**Total cost of duct = 4, 41,514 Rs.**

Weight of duct in **Aluminum 6061** grade material ,Density of mild steel =  $2790 \text{ Kg/m}^3$ , Wt of duct =  $L \times B \times \text{density} \times \text{thickness}$

=  $16.613 \times 3.278 \times 2790 \times 3^{-3}$ , =  $455.8085552 \text{ Kg}$  (102Rs.\* 455.8085552) = **46,492Rs**, Wt of transition duct =  $2.540 \times 2.540 \times 2790 \times 3^{-3}$

= **54 Kg \* 102 = 5507.988Rs.**, stainless steel bars =  $1.2 \times 2.5$  (qty 10) =  $30 \text{m}^2$

$102 \times 30 = 3060 \text{ Rs.}$

Total cost of mineral wool =  $3.278 \times 2.540 = 8.32612 \text{ m}^2$

( 250 Rs./Sq M \* 8.32612) = **2081.53 Rs**

**Total cost of duct = 57,140Rs.**

Table No 5.1 The cost Analysis of the design No.1

Material	Total Cost
Mild Steel 60 Rs/Kg	89,945Rs.
Stainless steel 304 300 Rs./Kg	4, 41,514 Rs.
Aluminium grade 6061 series 102 Rs/Kg	57,140Rs.

### 5.5 Design N0 2

In the next design the position of the panel was arranged horizontally instead of vertically and having two turning panels in the elbow instead of one.

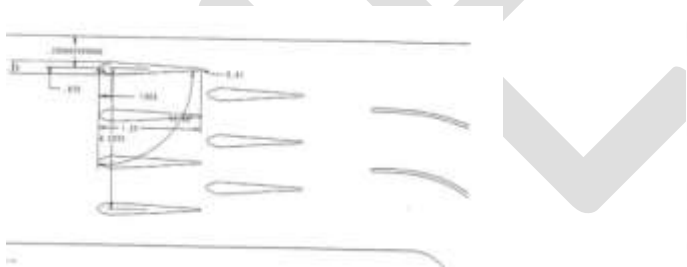


Fig No.5.6 shows the arrangement of panels



Fig No.5.7 shows the 3D model

### 5.6 Result of design no.2

The Pressure plot result is shown in below figure, which shows that the pressure loss further reduced to  $426 \text{ N/m}^2$ .

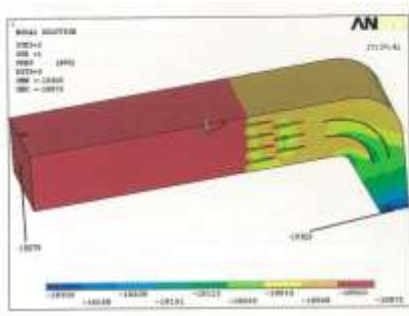


Fig No.5.8 Pressure Result of design 2

By using new design Power Consumed by the compressor is =34.179 MW (1MW = 1000KW)

Actual power required by the compressor = 34.714 MW

Therefore the power saved by change in the design = 534.38KW

Table No 5.2 The cost Analysis of the design No.2

Material	Total Cost
Mild Steel 60 Rs/Kg	89,945Rs.
Stainless steel 304 300 Rs./Kg	4, 41,514 Rs.
Aluminum grade 6061 series 102 Rs/Kg	57,140Rs.

### 5.7 Design No.3

Another possibility in the design changes is that the thickness of the panels be reduced so as to gap in between each of the panel is increased. thickness of the panel reduced by 100mm.



Fig No 5.9 Shows 3D Model Of the design No.3

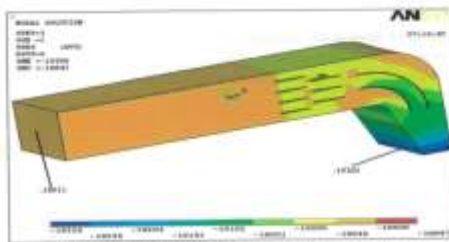


Fig No 5.10 Shows the pressure plot result of design no. 3

### 5.6 Result of design no.3



After modeling meshing is done and the load is applied. The pressure distribution plot is done. Following figure shows that the design comes out with the result of **394 N/m<sup>2</sup>**, this is the less than previous design.

Power saved by design no.3 is 540.95KW

Total cost of duct in mild steel material is =89,005Rs. , Total cost of duct in stainless steel material= 4, 45,114 Rs.

Total cost of duct in Aluminum 6061 grade material = 55,611Rs. ,

Table No 5.3 The cost Analysis of Design No.3

Material	Total Cost
Mild Steel 60 Rs/Kg	<b>80,945Rs.</b>
Stainless steel 304 300 Rs./Kg	<b>3, 99,794 Rs.</b>
Aluminum grade 6061 series 102 Rs/Kg	<b>56,140Rs.</b>

### 5.8 Design No.4

In design no 4 the new arrangement of panel was designed. Which is shown in figure.

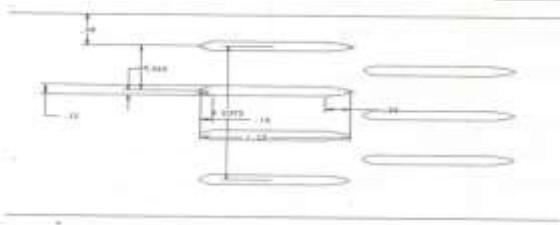


Fig No. 5.11 New Arrangement of panels

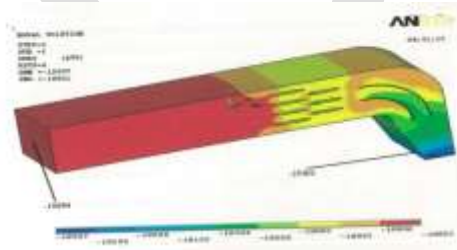


Fig No. 5.12 shows the pressure plot result

Table No 5.4 The cost Analysis of Design No.4

Material	Total Cost
Mild Steel 60 Rs/Kg	<b>84,005Rs</b>
Stainless steel 304 300 Rs./Kg	<b>4, 40,114 Rs.</b>
Aluminum grade 6061 series 102 Rs/Kg	<b>50,611Rs.</b>

### 5.9 Design No.5

The losses in the silencer section could not be reduced anymore it was decided to concentrate on reading the losses in the elbow. to achieve this it was decided to reduce the panel size so that the losses due to friction in the elbow section will be come down.

Following Fig shows the new shape of the panel and the pressure plot result

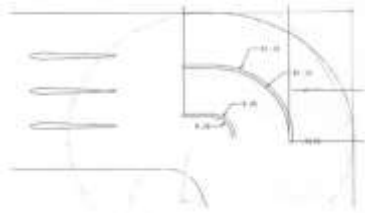


Fig No. 5.13 New shape of panels in the elbow

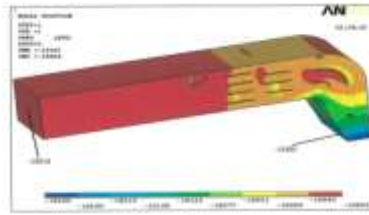


Fig No. 5.14 New shape of panels in the elbow

As the power loss in the new design = 387 N/m<sup>2</sup>

Therefore Power saved by the new design=543.46 KW

Total cost of duct in mild steel material =89,005Rs.

Weight of duct in stainless steel material

**Total cost of duct in stainless steel material is = 4, 45,114 Rs.**

**Total cost of duct in Aluminum 6061 grade material = 55,611Rs.**

Table No 5.5 The cost Analysis of Design No.4

Material	Total Cost
Mild Steel 60 Rs/Kg	<b>89,005Rs</b>
Stainless steel 304 300 Rs./Kg	<b>4, 45,114 Rs.</b>
Aluminum grade 6061 series 102 Rs/Kg	<b>55,611Rs.</b>

Analysis is done by changing the design of panels, and their arrangement. From below table it is clear that the least loss occurs in design no. 5 with aluminum Material and total pressure loss is 387 N/m<sup>2</sup>.

Design	Material Cost	Total Pressure Loss	Power Saved
Old Design	5,50,999 Rs(in MS)	2986 N/m <sup>2</sup>	628 Kw
Design No.1	57,140Rs	710 N/m <sup>2</sup>	475.9Kw
Design No.2	57,140 Rs	426 N/m <sup>2</sup>	534.38 Kw
Design No. 3	55,611Rs	394 N/m <sup>2</sup>	540.95 Kw
Design No.4	57,140Rs	411 N/m <sup>2</sup>	537.46 Kw
Design No. 5	55,611Rs	387 N/m <sup>2</sup>	543.6 Kw

From the above table it can be clearly seen that the minimum pressure losses occurs in design no. 5 cost of the material in mild steel is also very less than other design according simplification of the design no 5 the mineral wool in that shape of the panels can be cut, and attach with the panels.

## 6 Conclusion:

This design proposed to the company and they have decided to manufacture, Before the company can start manufacturing and marketing this designs they have to build prototype model of the design.

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