# NUMERICAL INVESTIGATION OF A DIVERGENT EXHAUST DIFFUSER OF A GAS TURBINE ENGINE

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## ABSTRACT
This paper mainly deals with the numerical analysis of 3D model of adivergent exhaust diffuser of a gas turbine engine, which is developed to study the co-efficient of pressure recovery, exit velocity, static pressure and dynamic pressure. The variation in divergent exit diameters of an exhaust diffuser are 242.25mm, 247.25mm, 252.25mm and the inlet diameter value as 140mm and the methodology affects the flow through an exhaust diffuser. Results of CFD analysiswill give the optimum value of co-efficient of pressure recovery of a divergent exhaust diffuser. The maximum value of co-efficient of pressure recovery will leads to improve the performance and efficiency of a turbine. It also verifiedthat the CFD is a convenient tool for designing and analysing the flow through a divergent exhaust diffuser.

**KEYWORDS:** Computational Fluid Dynamics; Co-efficient Of Pressure Recovery (CPR); Numerical Simulation.

## INTRODUCTION
The divergent exhaust diffuser is a major component of a gas turbine engine. It basically decreases the fluid velocity which is discharging from the low pressure turbine stage and increases the static pressure. Hence it will increase the pressure ratio across the turbine section. As the exhaust diffuser increasing the pressure, the pressure gradient will reduces at the exit of the exhaust diffuser.

Generally a fluid can be more easily ejected from the turbine of a gas turbine engine in the absence of an exhaust diffuser. When the fluid is ejecting from the turbine stage the atmospheric air pressure will tends to drive the fluid back into the turbine only. This will results in initiating the backflow condition. Due to this there is a decrease in the performance of a turbine will takes place. Hence the use of exhaust diffuser will supports in the dismissal of the exhaust gases.

By inserting the exhaust diffuser component into a gas turbine engine, the backflow condition can be made absent. Because of this the useful work carried by turbine will increases, thereby increasing the performance and efficiency of the turbine of a gas turbine engine system.

A short discussion of the previous studies of authors who have attempted to focus on the design and analysis of a divergent exhaust diffuser by some design parameters are presented here. Kouichi Ishizaka [1], in this paper it found that they have conducted an industrial gas turbine conical exhaust diffuser by CFD analysis. The main aim was to improve the performance of the gas turbine exhaust diffuser by considering the distortion of the flow at the turbine exit and to verify the accuracy of the CFD.Singh et al [2], this paper has conducted the CFD analysis of an annular exhaust diffuser of different geometries by keeping inlet half cone angle as same. Finally they have reported that the performance of an annular exhaust diffuser having the parallel diverging hub and casing has been improved over the swirl. Hoffman [3], this paper has proved that the pressure recovery of an exhaust diffuser can be increased by increasing the inlet turbulence intensity. The turbulence intensity of an exhaust diffuser can be varied for improving the pressure recovery of the diffuser. P A C Okwuobi [4], this paper proposed an experimental study on the structure of a turbulence in a conical exhaust diffuser. They showed that the turbulent energy rate will approximately reaches a maximum value at the edge of the wall layer, which is extending to the point of maximum fluctuation. The turbulent kinetic energy balance showed that the magnitude of the energy convective diffusion due to the pressure effects and kinetic effects are comparable with that of the energy production.

SJ Kline [5], this paper has showed that the performance and efficiency of an exhaust diffuser can be determined by the equations by co-relating the total pressure and static pressure at the inlet and outlet and also by using the global parameters.

The main objective of this project is to carry out the numerical simulation of a divergent exhaust diffuser in order to obtain a maximum value of CPR with an optimized geometry having a half cone angle of $7^0$, resulting in improving the performance and efficiency of the turbine. To analyze the effect of inlet and divergent exit diameters with an optimized half cone angle of $7^0$.

## MATHEMATICAL FORMULATION

## THE PHYSICAL MODEL OF A DIVERGENT EXHAUST DIFFUSER

The internship work is carried out with a divergent exhaust diffuser geometry dimensions are as shown in figure 2.1, whichis taken from P A C Okwuobi [4]. Three models are created by varying the divergent exit diameter values i.e the divergent exit diameters are 242.25mm, 247.25mm and 252.25mm and one more model is created by varying the inlet diffuser diameter value i.e the inlet diffuser diameter is 140mm. The other parameters like half cone angle value as $7^0$ and Outlet diffuser diameter value as 210.75mm are same in all geometrical models.

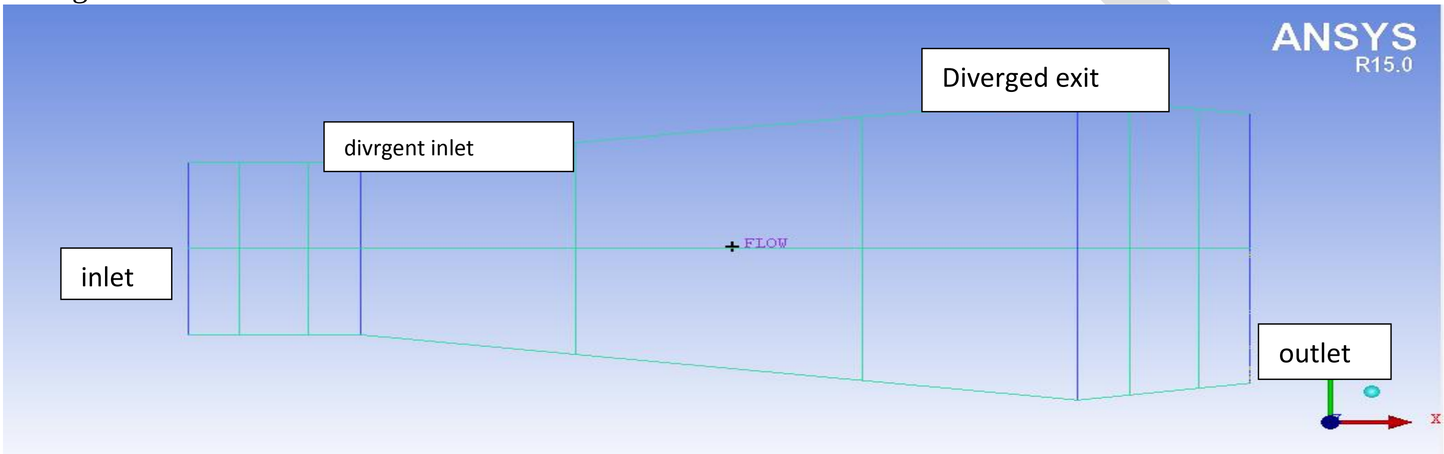


**Fig.2.1 3D Divergent Exhaust Diffuser.**

## MESHING

- ✓ The model is created using ICEM CFD software.
- ✓ The whole model is divided into different parts namely inlet, divergent inlet section, divergent exit section, outlet and wall.
- ✓ Global Mesh parameters are defined which gives information regarding type of mesh. The global element seed size, part parameters are setup and mesh is computed which gives the mesh information regarding total number of elements.
- ✓ Anstructured hexahedral mesh is generated in order to perform computations with the Octree approach. After setting up part parameters for various parts, a mesh is generated.

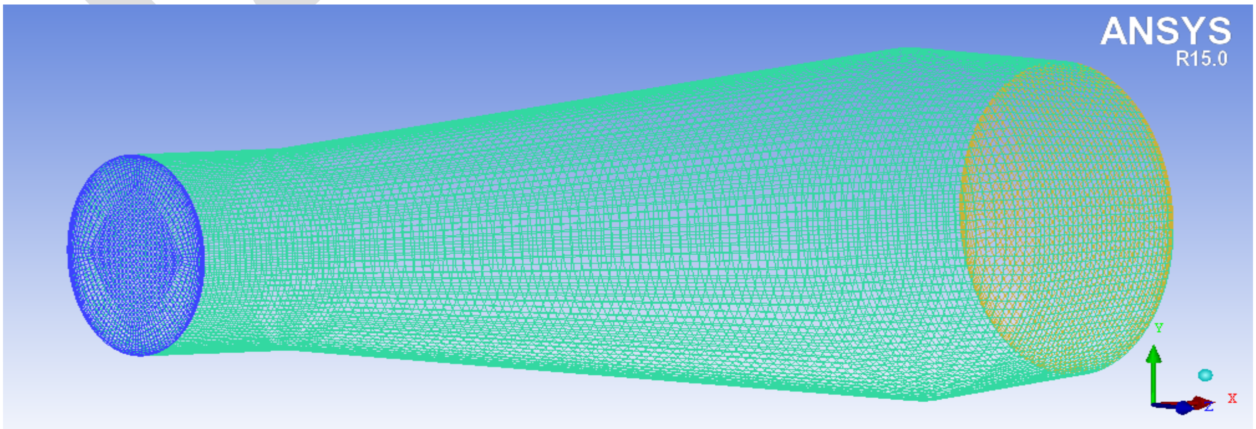


**Fig.3.1 Meshed model of a divergent exhaust diffuser with inlet diffuser diameter as 135mm.**

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## BOUNDARY CONDITIONS

The relevant boundary conditions for the computation of the divergent exhaust diffuser are as follows:

- ✓ Inlet: The inlet parameter is defined as inlet-velocity and the value at the inlet of a conical exhaust diffuser set as 45m/s.
- ✓ Outlet: At the outlet section the parameter is defined as pressure-outlet and the value is set as 101325 Pascal.
- ✓ Wall: The stationary wall with no slip condition is defined. Also the smooth surface is assumed i.e the roughness height and the roughness constants are set to be zero.

## CODE VALIDATION

The problem is solved using ANSYS CFX and the code is validated with the results of a research paper [4] for, it is found that it agrees well with the results of the published work as shown in figures 5.1, 5.2, 5.3, 5.4 and 5.5. The table 5.1 gives the validation data obtained by CFD analysis.

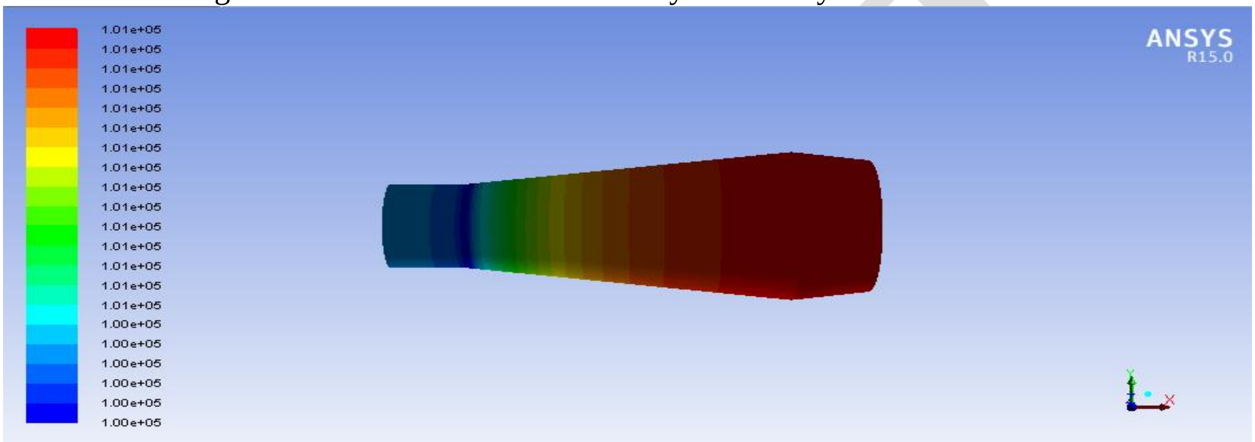


**Fig 5.1. Contour of static pressure with inlet diffuser diameter 135mm.**

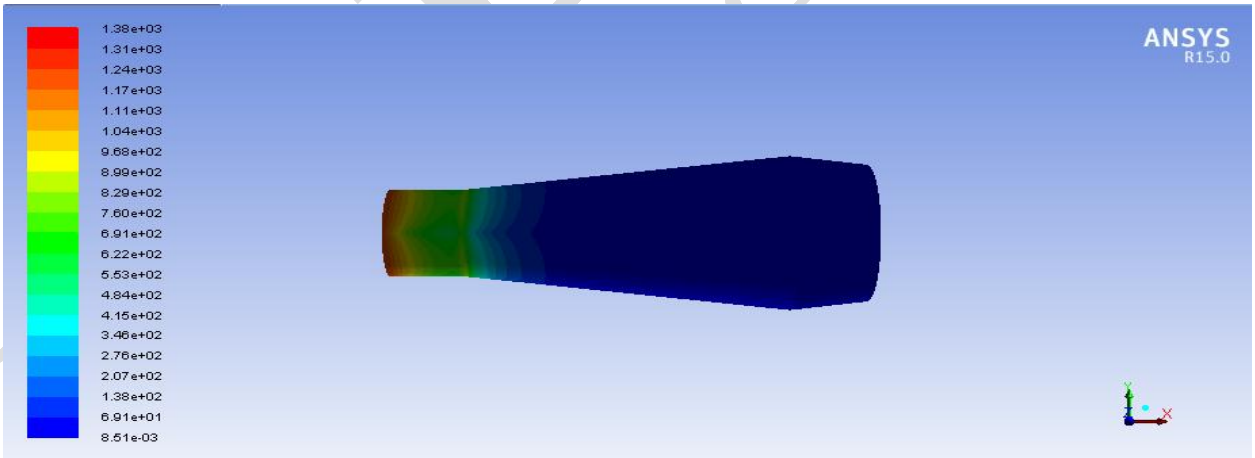


**Fig 5.2. Contour of dynamic pressure with inlet diffuser diameter 135mm.**


**Fig 5.3. Contour of velocity magnitude at inlet and exit sections with inlet diffuser diameter 135mm.**

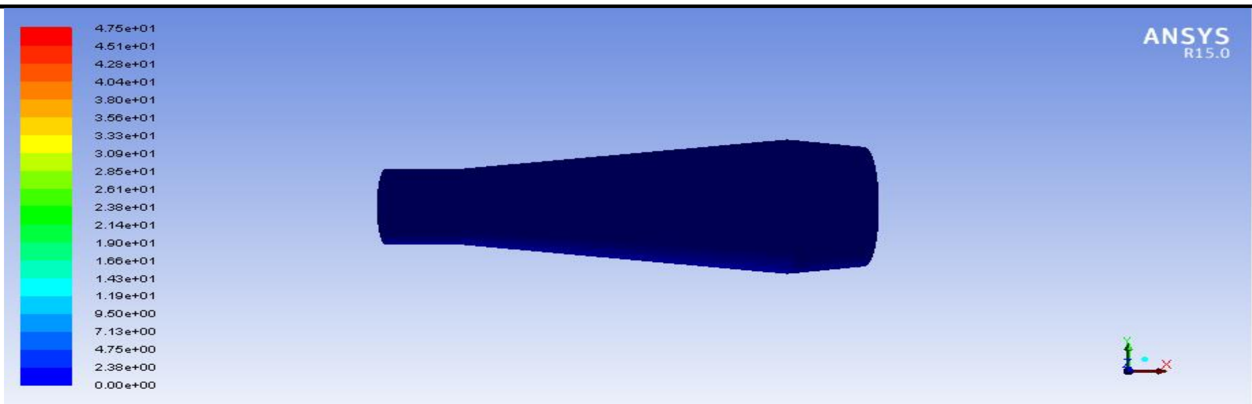


**Fig 5.4. Contour of velocity magnitude with inlet diffuser diameter 135mm.**

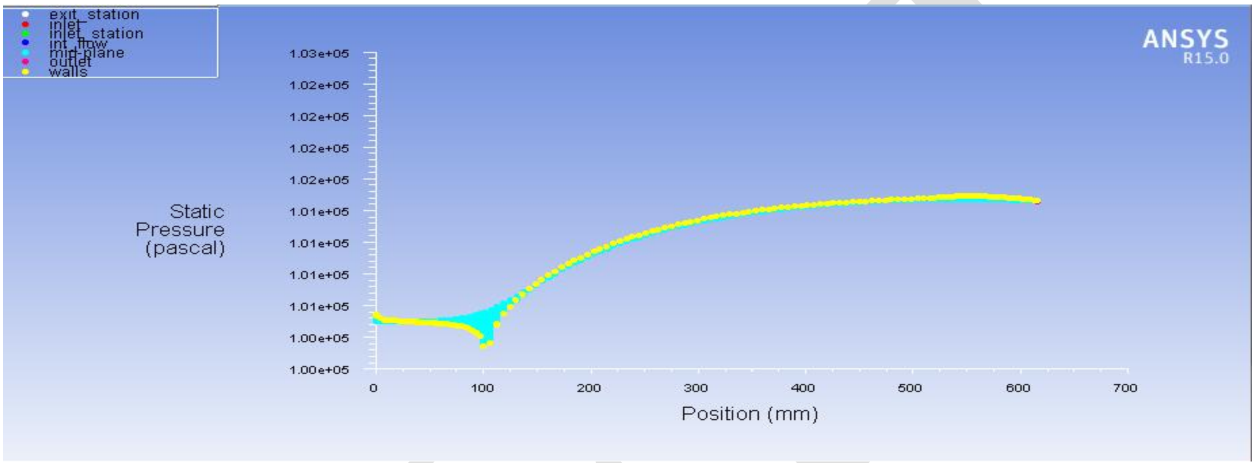


**Fig 5.5.Variation of static pressure along the length of diffuser.**

**Table 5.1. Data obtained from CFD analysis.**

| Location | Static Pressure(Pa) | Dynamic Pressure(Pa) | Velocity(m/s) | CPR |
|---|---|---|---|---|
| **Inlet** | 100386.29 | 1241.63 | 45 | |
| **Outlet** | 101325 | 216.193 | 18.45 | 0.75602 |

## 5.1 MEASUREMENT CO-EFFICIENT OF PRESSURE RECOVERY

The value of CPR can be calculated by using the formula:

$$CPR = (P_x - P_i)/ q_i$$

Where $P_x$ is the average static pressure at any station x, $P_i$ is the static pressure at the diffuser inlet and $q_i$ is the dynamic head available at the inlet of the diffuser.

The value of CPR which is calculated should be maximum in order to get better performance and efficiency.

## PRESENT RESULTS AND DISCUSSIONS

In the present study the design parameters such as diffuser inlet diameter, divergent inlet section diameter, divergent exit section diameter, diffuser outlet diameter and half cone angle, which are affecting the value of CPR can be studied. It aims to optimize the geometry of a divergent exhaust diffuser to obtain the maximum CPR value. The following designs parameters are considered for analysis:

**Case-I:** A 3D divergent exhaust diffuser with the following dimensions is generated; inlet diffuser diameter = 135mm, divergent inlet diameter = 135mm, divergent exit diameter = 242.25mm, outlet diffuser diameter = 210.75mm and a half cone angle of $7^0$.

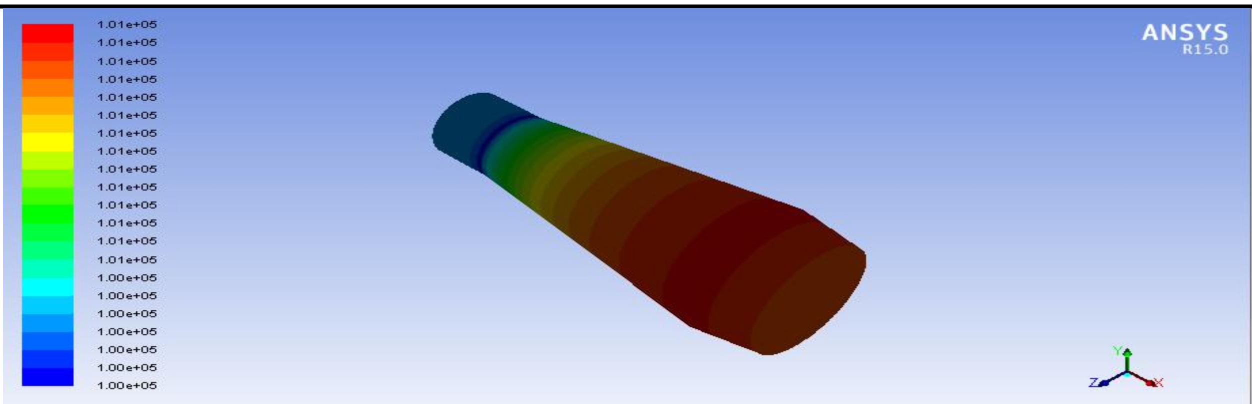


**Fig 6.1.1 Contour of static pressure with divergent exit diameter of 242.25mm.**

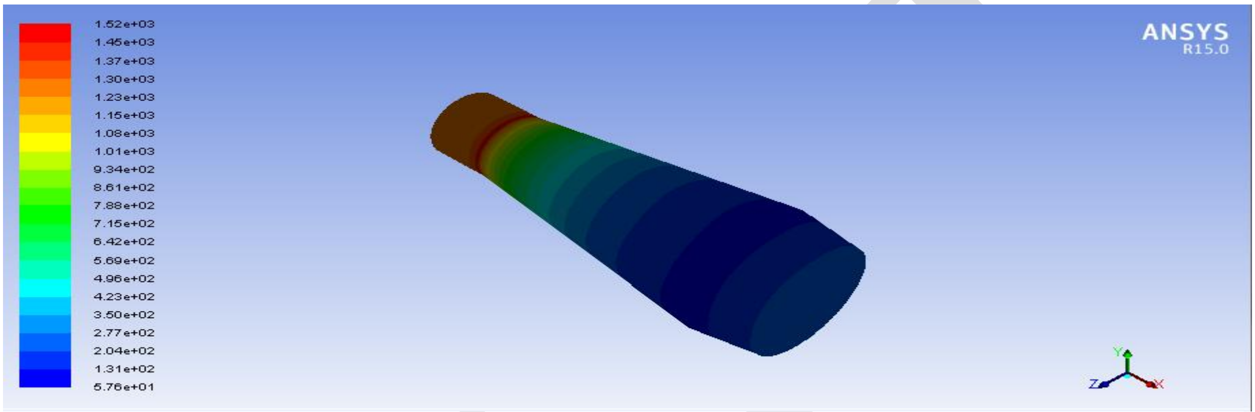


**Fig 6.1.2. Contour of dynamic pressure with divergent exit diameter of 242.25mm.**

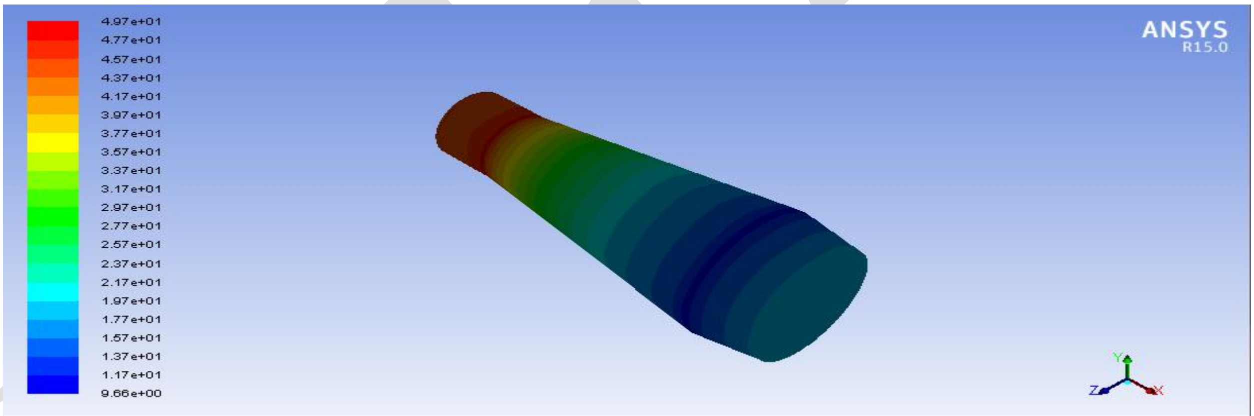


**Fig 6.1.3 Contour of velocity magnitude with divergent exit diameter of 242.25mm.**

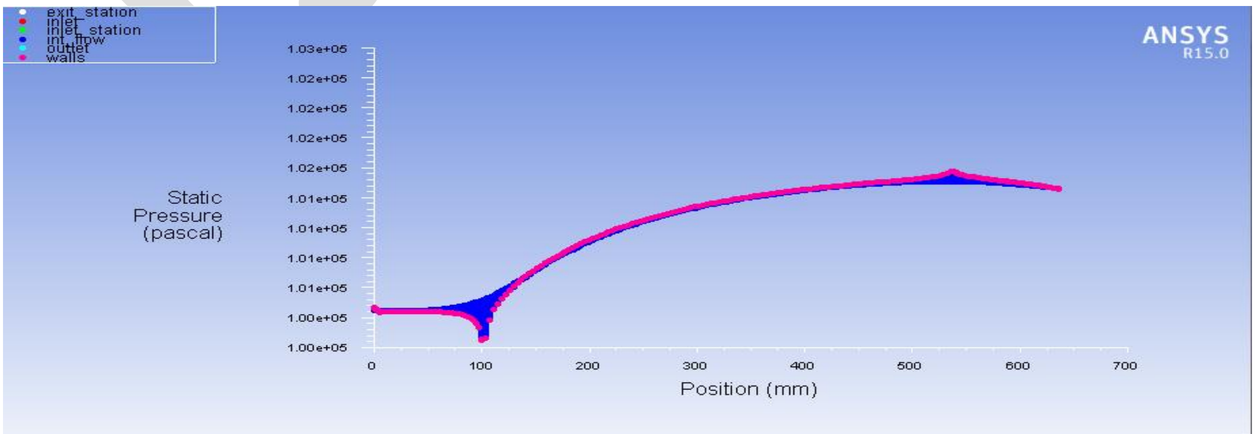


**Fig 6.1.4.Variation of static pressure along the length with divergent exit diameter of 242.25mm.**

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**Case-II:** A 3D divergent exhaust diffuser with the following dimensions is generated; inlet diffuser diameter = 135mm, divergent inlet diameter = 135mm, divergent exit diameter = 247.25mm, outlet diffuser diameter = 210.75mm and a half cone angle of $7^0$.

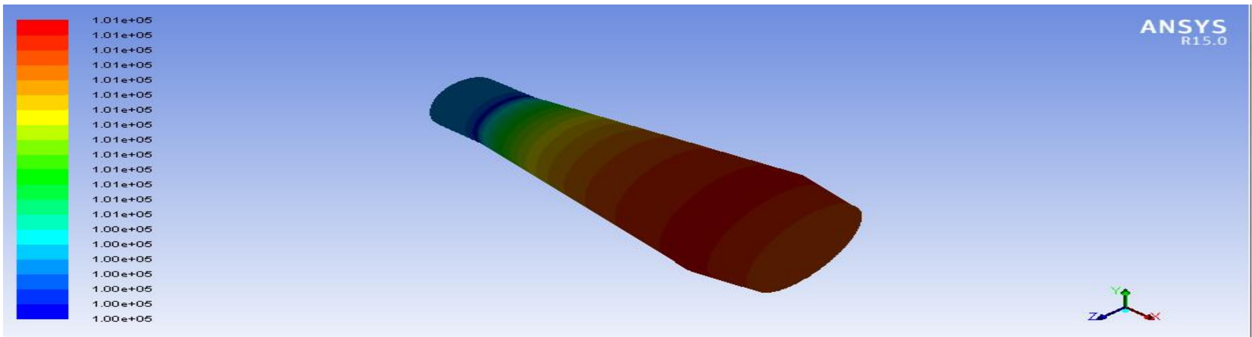


**Fig 6.2.1. Contour of static pressure with divergent exit diameter of 247.25mm.**

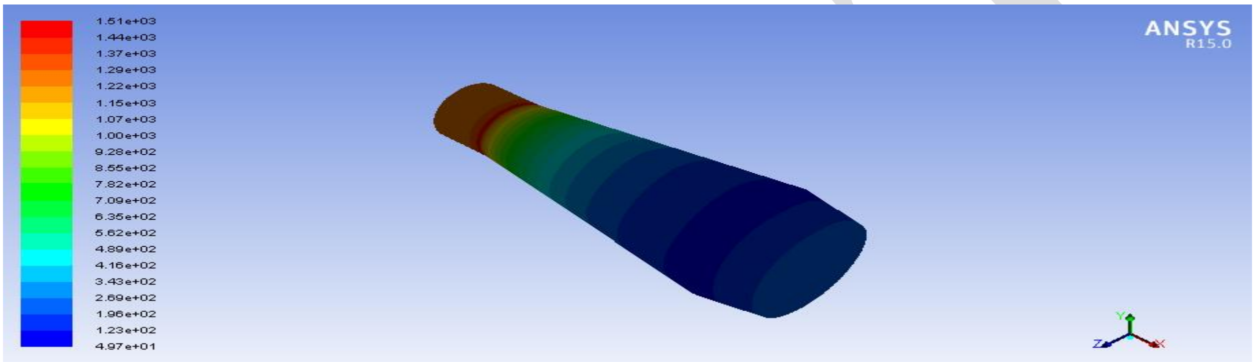


**Fig 6.2.2. Contour of dynamic pressure with divergent exit diameter of 247.25mm.**

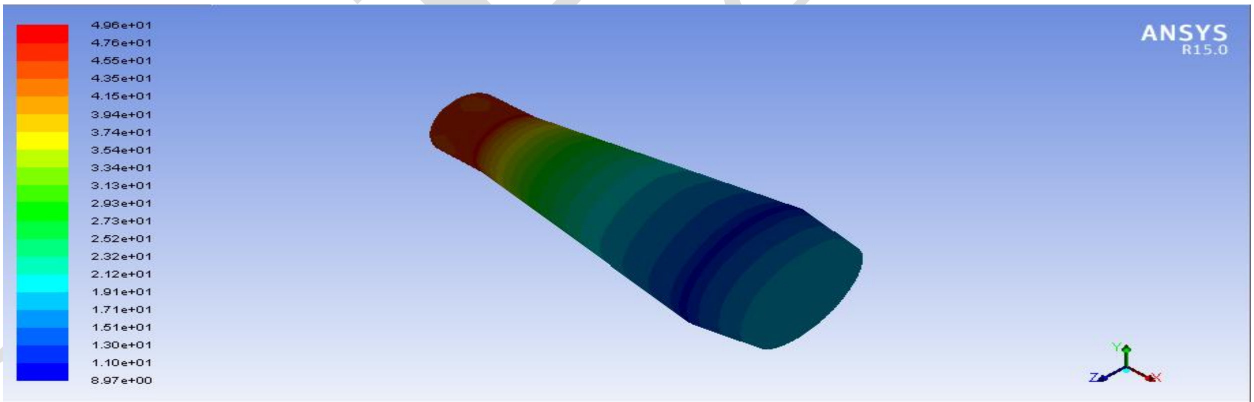


**Fig 6.2.3. Contour of velocity magnitude with divergent exit diameter of 247.25mm.**

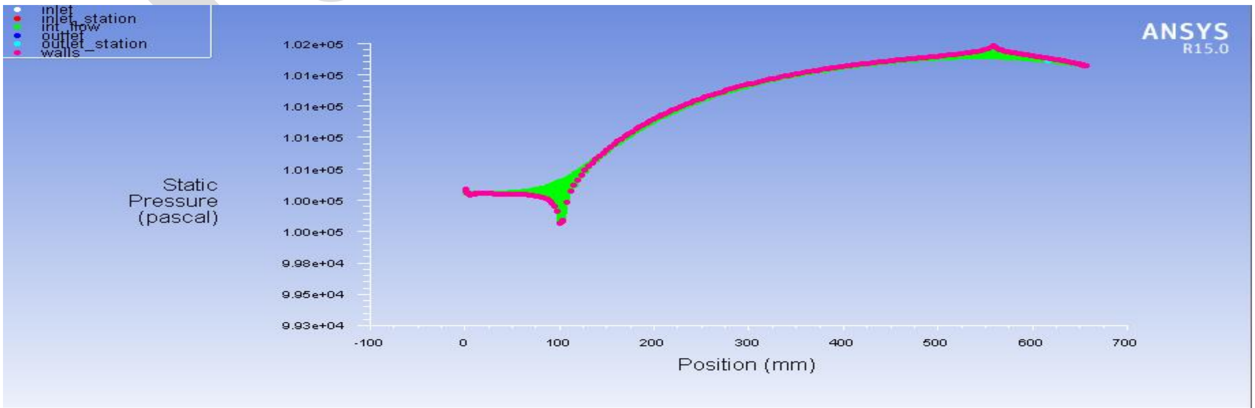


**Fig 6.2.4.Variation of static pressure along the length with divergent exit diameter of 247.25mm.**

**Case-III:** A 3D divergent exhaust diffuser with the following dimensions is generated; inlet diffuser diameter = 135mm, divergent inlet diameter = 135mm, divergent exit diameter = 252.25mm, outlet diffuser diameter = 210.75mm and a half cone angle of $7^0$.

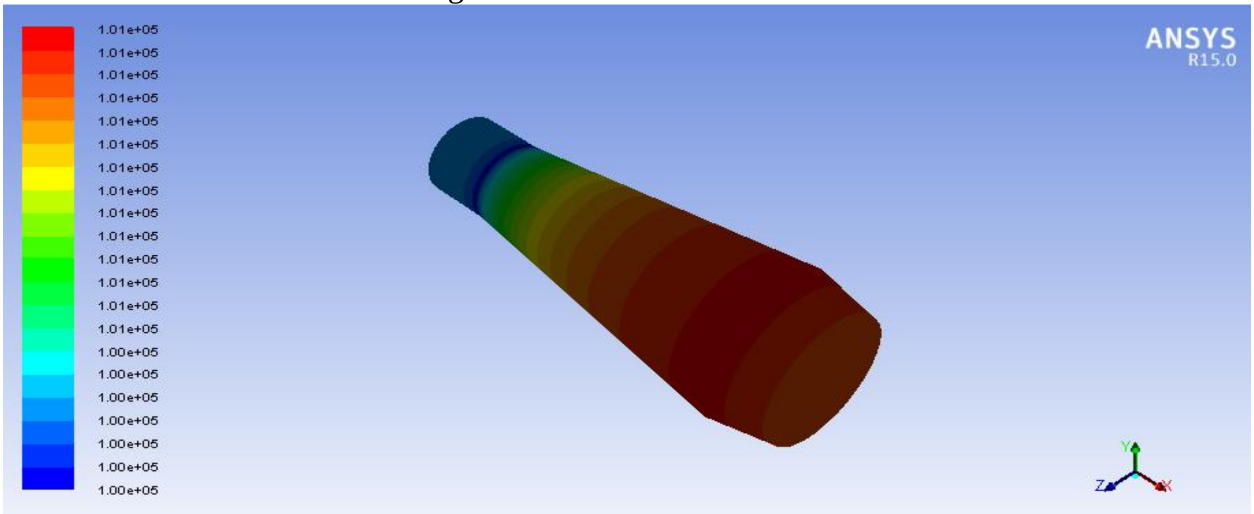


**Fig 6.3.1. Contour of static pressure with divergent exit diameter of 252.25mm.**

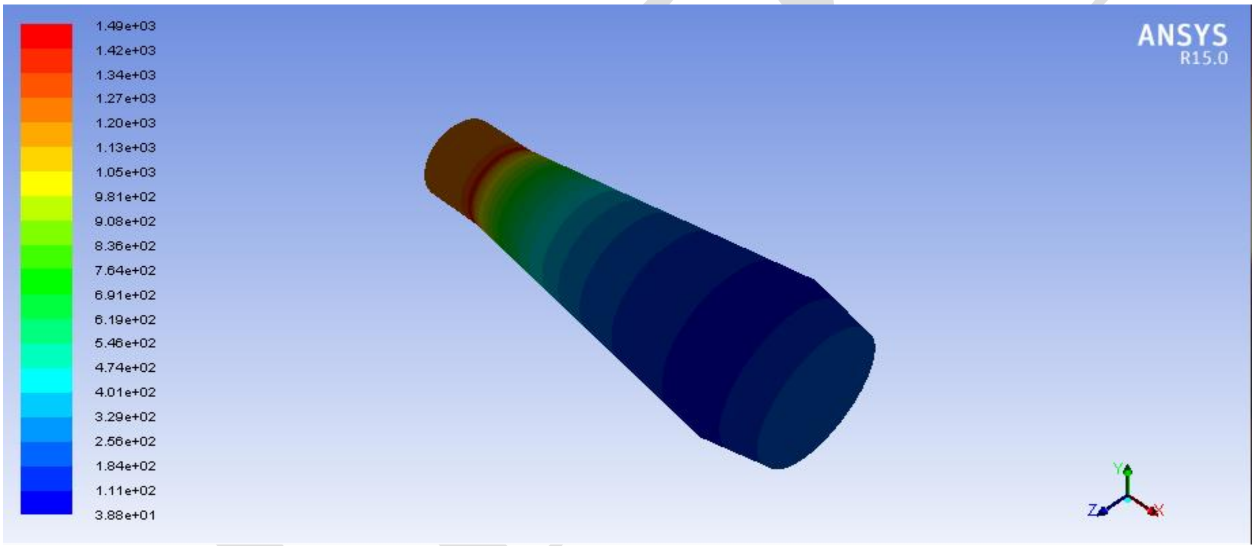


**Fig 6.3.2. Contour of dynamic pressure with divergent exit diameter of 252.25mm.**

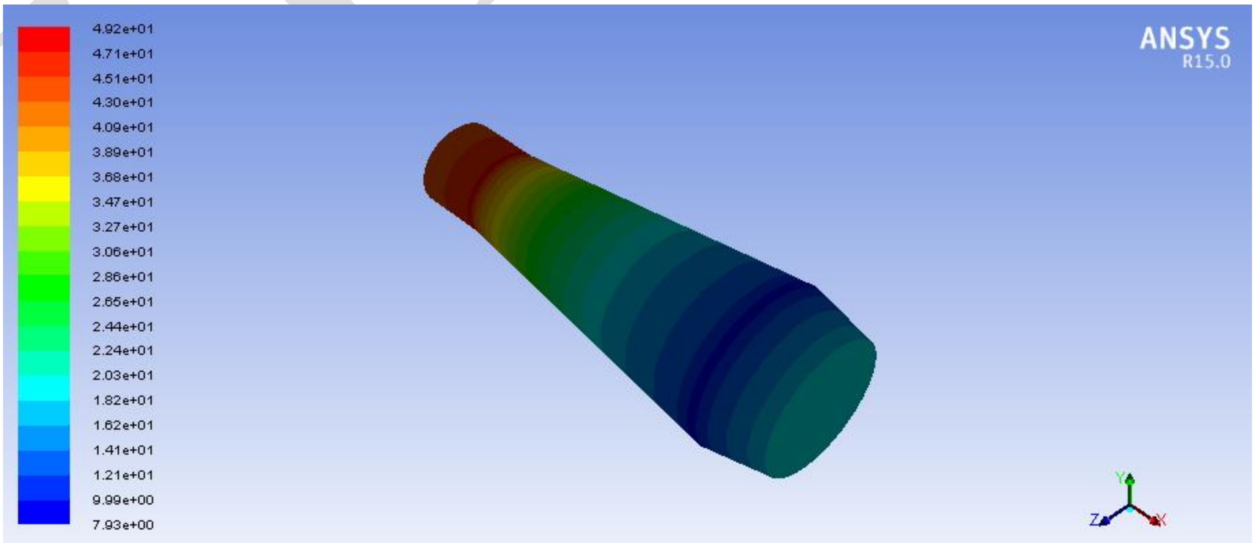


**Fig 6.3.3. Contour of velocity magnitude with divergent exit diameter of 252.25mm.**

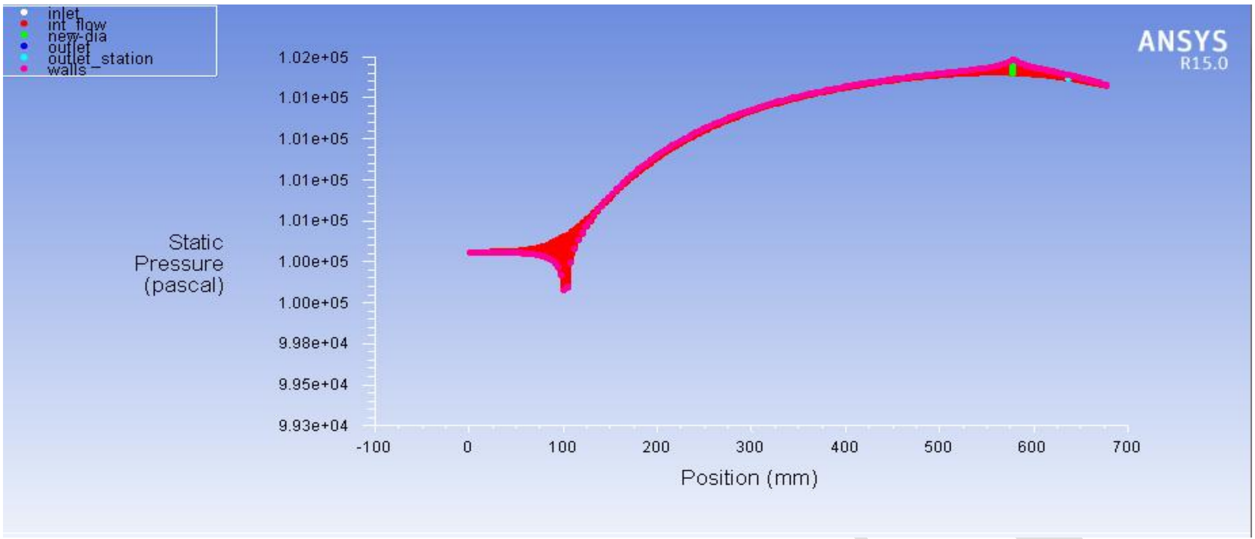


**Fig 6.3.4.Variation of static pressure along the length with divergent exit diameter of 252.25mm.**

**Case-IV:** A 3D divergent exhaust diffuser with the following dimensions is generated; inlet diffuser diameter = 140mm, divergent inlet diameter = 140mm, divergent exit diameter = 237.25mm, outlet diffuser diameter = 210.75mm and a half cone angle of $7^0$.

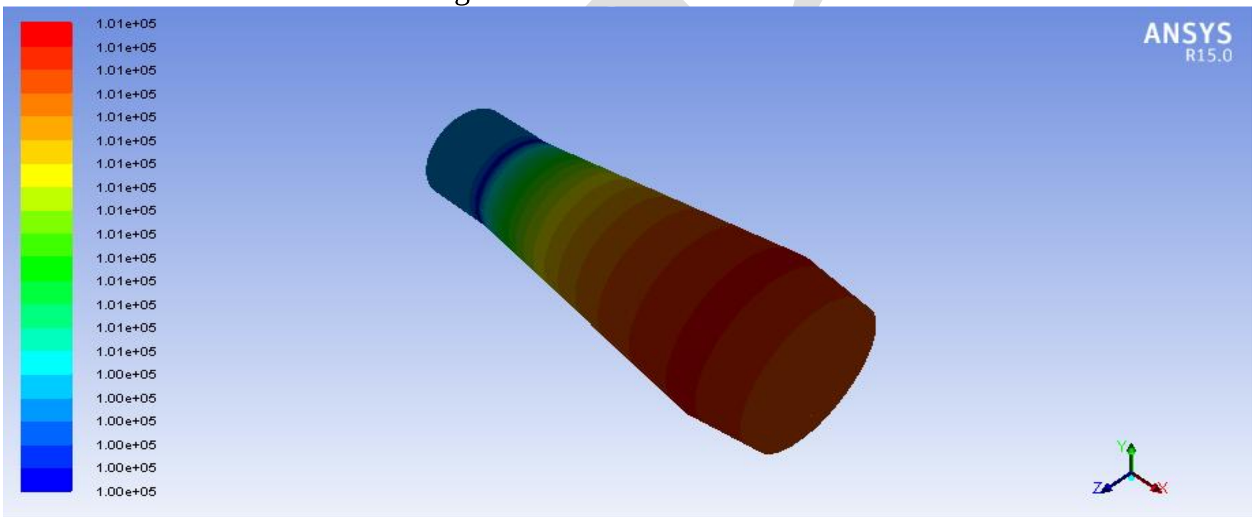


**Fig 6.4.1. Contour of static pressure with diffuser inlet diameter of 140mm.**

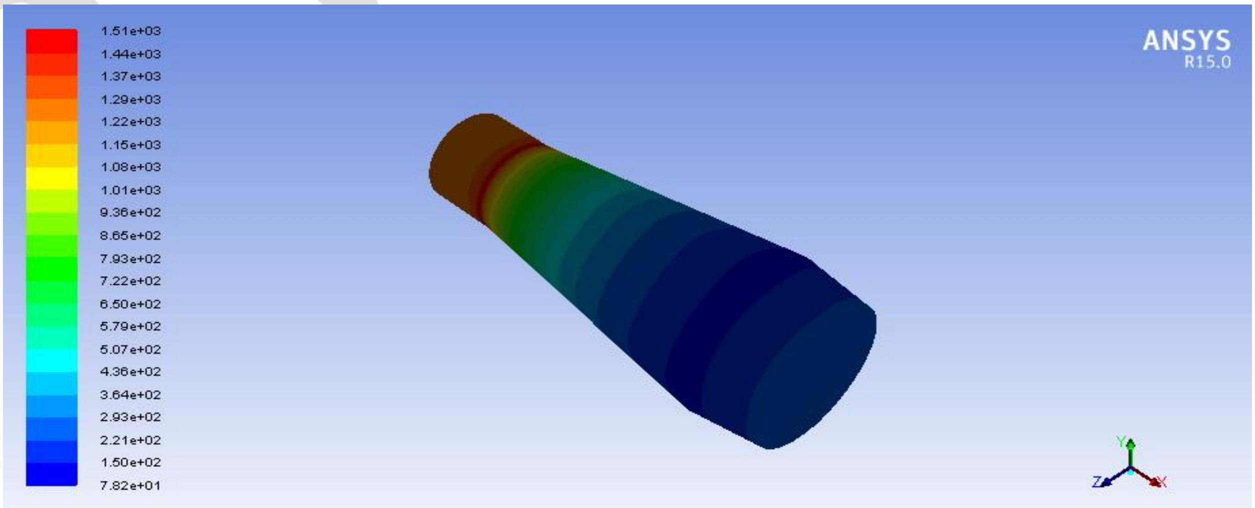


**Fig 6.4.2. Contour of dynamic pressure with diffuser inlet diameter of 140mm.**

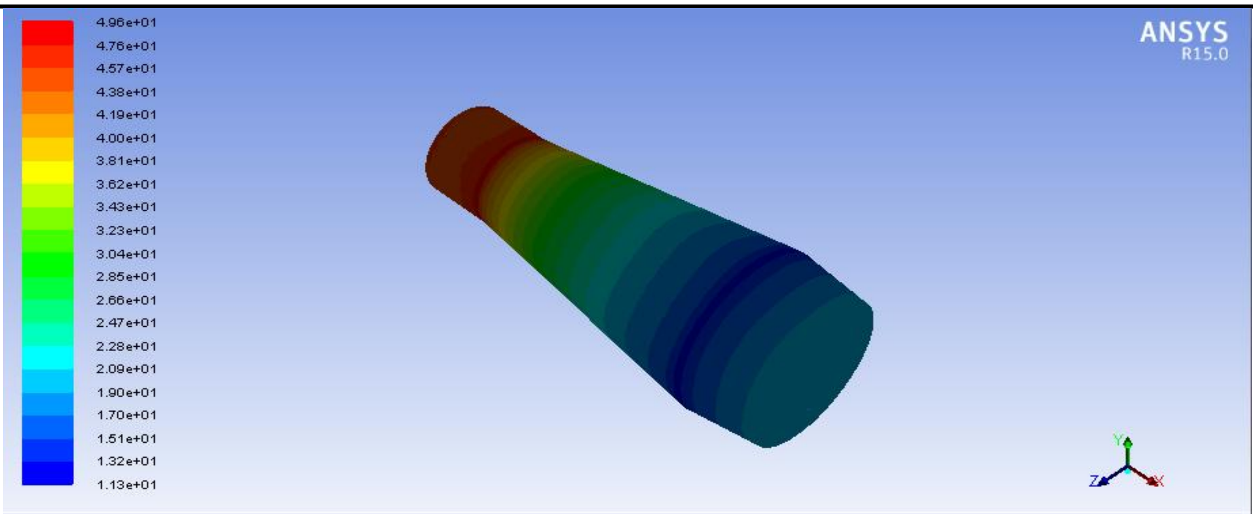


**Fig 6.4.3. Contour of velocity magnitude with diffuser inlet diameter of 140mm.**

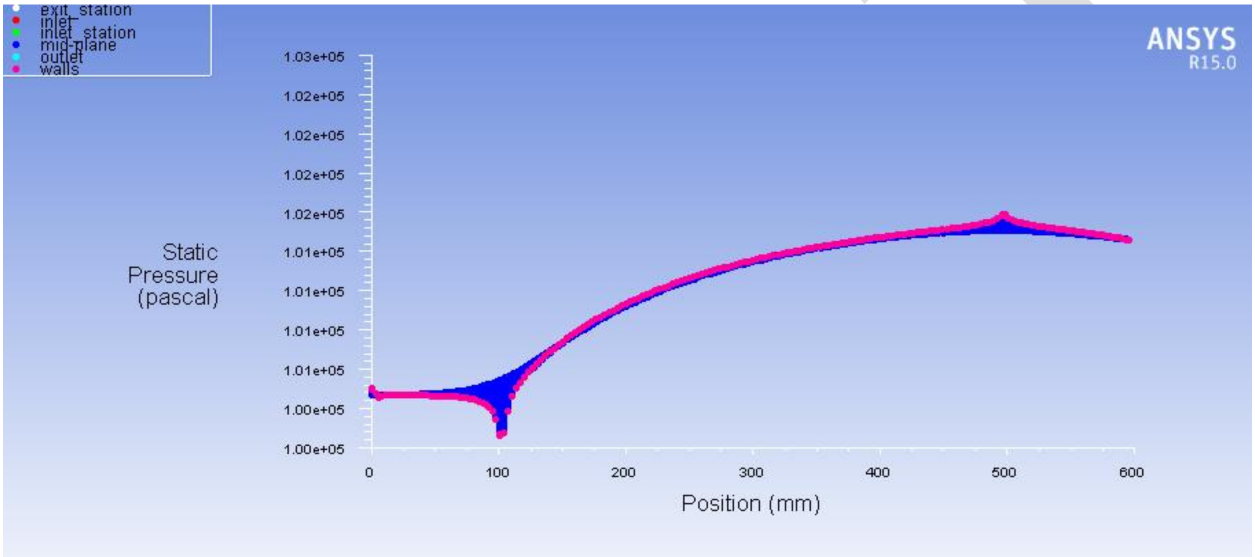


**Fig 6.4.4.Variation of static pressure along the length, with diffuser inlet diameter of 140mm.**

The numerical investigation of a divergent exhaust diffuser by CFD for different geometrical cases will give the contours of static pressure, contours of dynamic pressure, contours of velocity magnitude and the variation of static pressure along the length of a divergent exhaust diffuser.

## DISCUSSIONS:

**Table 6.1 Data obtained from CFD analysis of diffuser with divergent exit diameter =242.25mm.**

| **Conical angle-7$^0$** | **Diffuser inlet diameter =135mm** | **Divergent inlet diameter=135mm** | **Divergent exit diameter=242.25mm** | **Diffuser exit diameter=210.75mm** |
|---|---|---|---|---|
| **Location** | **Static Pressure(Pa)** | **Dynamic Pressure(Pa)** | **Velocity(m/s)** | **CPR** |
| Inlet | 100305.54 | 1241.88 | 45 | |
| Outlet | 101325 | 210.4014 | 18.53406 | 0.8209 |
| Exit Station | 101369.7 | 167.6066 | 16.54 | 0.8568 |
| Divergent Exit Section | 101415.4 | 120.9059 | 14.655 | 0.8936 |

**Table 6.2 Data obtained from CFD analysis of diffuser with divergent exit diameter =247.25mm.**

| **Conical angle-$7^0$** | **Diffuser inlet diameter =135mm** | **Divergent inlet diameter=135mm** | **Divergent exit diameter=247.25mm** | **Diffuser exit diameter=210.75mm** |
|---|---|---|---|---|
| **Location** | **Static Pressure(Pa)** | **Dynamic Pressure(Pa)** | **Velocity(m/s)** | **CPR** |
| Inlet | 100306.6 | 1241.88 | 45 | |
| Outlet | 101325 | 210.9233 | 18.5569 | 0.82 |
| Exit Station | 101375.4 | 162.5687 | 16.2896 | 0.8606 |
| Divergent Exit Section | 101424.8 | 112.1621 | 13.4543 | 0.9 |

**Table 6.3 Data obtained from CFD analysis of diffuser with divergent exit diameter =252.25mm.**

| **Conical angle-$7^0$** | **Diffuser inlet diameter =135mm** | **Divergent inlet diameter=135mm** | **Divergent exit diameter=252.25mm** | **Diffuser exit diameter=210.75mm** |
|---|---|---|---|---|
| **Location** | **Static Pressure(Pa)** | **Dynamic Pressure(Pa)** | **Velocity(m/s)** | **CPR** |
| Inlet | 100307.9 | 1240.312 | 45 | |
| Outlet | 101325 | 211.4148 | 18.5783 | 0.82 |
| Exit Station | 101381.5 | 157.1601 | 16.0124 | 0.8655 |
| Divergent Exit Section | 101433.4 | 103.903 | 12.916 | 0.9074 |

**Table 6.4 Data obtained from CFD analysis of diffuser with inlet diameter =140mm.**

| **Conical angle-$7^0$** | **Diffuser inlet diameter =140mm** | **Divergent inlet diameter=140mm** | **Divergent exit diameter=237.25mm** | **Diffuser exit diameter=210.75mm** |
|---|---|---|---|---|
| **Location** | **Static Pressure(Pa)** | **Dynamic Pressure(Pa)** | **Velocity(m/s)** | **CPR** |
| Inlet | 100336.9 | 1241.856 | 45 | |
| Outlet | 101325 | 242.7121 | 19.9063 | 0.796 |
| Exit Station | 101368.9 | 200.6557 | 18.0988 | 0.831 |
| Divergent Exit Section | 101416.7 | 152.1722 | 15.70294 | 0.8695 |

The data obtained after the CFD analysis for different cases of a divergent exhaust diffuser are as shown in the above tables.

## CONCLUSION

The CFD Analysis of a divergent exhaust diffuser is carried out to obtain an optimized geometry and to get a maximum CPR value. A divergent exhaust diffuser having the four sections on it, they are diffuser inlet, divergent inlet section, divergent exit section and diffuser outlet. As divergent exit diameter and the diffuser inlet diameter is the defining parameter, the model is varied with divergent exit diameters as 342.25mm, 247.25mm and 252.25mmmm and the diffuser inlet diameter as 140mm. The CFD analysis is carried out for all the four cases to find out the maximum co-efficient of pressure recovery (CPR) value which improves the performance and efficiency of the turbine. From the results and discussions it is found that the divergent exhaust diffuser with a diverging exit diameter of 252.25mm gives the maximum CPR value of 0.8655 and an exit velocity of 18.5783 m/s with a half cone angle of $7^0$and is proving to be the most efficient.

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