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CFD Analysis of Exhaust Manifold of Multi Cylinder SI Engine to Determine Optimal Geometry for Reducing Emissions

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1. ABSTRACT

Exhaust manifold is one of the most critical components of an IC Engine. The designing of exhaust manifold is a complex procedure and is dependent on many parameters viz. back pressure, exhaust velocity, mechanical efficiency etc. Preference for any of this parameter varies as per designers needs. Usually fuel economy, emissions and power requirement are three different streams or thought regarding exhaust manifold design. In any multi-cylinder IC engine, an exhaust manifold (also known as a header) collects the exhaust gases from multiple cylinders into one pipe. This header is connected to these cylinders through bends. It is attached downstream of the engine and is major part in multi- cylinder engines where there are multiple exhaust streams that have to be collected into a single pipe.

Exhaust gases comes out of this Header as a single stream of hot exhaust gases through single outlet. This work comprehensively analyzes eight different models of exhaust manifold and concludes the best possible design for least emissions and complete combustion of fuel to ensure least pollution. The main objective of this investigation is to design an exhaust manifold by using CATIA V5 R20 software and also find out pressures and velocities at various mass flow rates in the exhaust manifolds with Long Bend Side Exit (LBSE), Long Bend Middle Exit (LBME) and Reducer and find out the performance of the exhaust manifold with various modifications in its design or adding a component for the exhaust manifold to increase its effectiveness. In the current analysis mass flow rates considered in the exhaust manifold are 2 kg/s, 4 kg/s, 6 kg/s, 8 kg/s ,10 kg/s, 12 kg/s in all the various modification ns in the exhaust manifolds.

1. INTRODUCTION

1.1 Exhaust manifold:

The exhaust manifold is a pipe, receives the exhaust gases from the combustion Chamber and leaves it to the atmosphere. Exhaust manifolds are mounted to the cylinder head. V- Type engines have two exhaust manifolds, and an in-line engine usually has one. When intake and exhaust manifolds are on opposite sides of an in-line engine, the head is called a cross-flow head. This design improves breathing capacity of an engine. Exhaust manifolds are typically made of cast iron or steel, although some latest-model cars use stainless steel manifolds.

Cast iron is a good material for exhaust manifolds. Like the frying pan on a stove, it can tolerate fast and severe temperature changes. Exhaust gas temperature is related to the amount of load on the engine.

Fig.1.1 A typical diagram of exhaust manifold

1.2 Types of turbo manifolds:

1.21 Log manifold:

The log type manifold is the most economical manifold on the market. They are almost bullet proof when it comes to reliability and they are the most compact manifolds available. Most manifolds you find on factory turbocharged cars are log type manifolds.

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This is understandable when you manufacturer is all about reliability. When it comes to performance, a log manifold will leave you wanting. This hurts the turbo's performance and hurts the motors performance as well being that a log manifolds common plenum is so close to the other cylinders, it causes a lot of back flow of exhaust.

2. Literature Survey

Jafar M Hassan et.al. [1] In his paper they analyzed the performance of the manifolds with a tapered longitudinal section.

M.Usan et.al. [2] In their research paper theyhad applied a multi-disciplinary optimization approach for the exhaust system, exhaust manifold and catalytic converter, in highly integrated concurrent engineering software framework.

HessamedinNaemi et.al. [3] In their research they had employed numerical simulations (CFD methods) for estimating the flow loss coefficient in manifolds.

Masahiro Kanazaki [4] In their research paper they have developed a multi-objective optimization method for the exhaust manifold by using Divided Range Multi-objective Genetic Algorithm.

Hong Han-Chi et.al. [5] In their research paper they used GT-Power, 1-dimensional software, for estimating the engine performance of a single cylinder IC engine.

Taner Gocmez et.al.[6] in their "Designing Exhaust Manifolds Using Integral Engineering Solutions" focused on the development of a reliable approach to predict failure of exhaust manifolds and on the removal of structural weaknesses through the optimization of design.

Martinez-Martinez et.al. [7] In their paper theyhad performed CFD analysis to estimate the performance of the exhaust manifold while placing the catalytic converter near to it (Close-Coupled Catalytic Converter).

Benny Paul et.al. [8] In this research paper he conducted CFD simulations on manifold of direct injection diesel engine. They had used the RANS (Reynolds Averaged Navier Stokes) solver approach with RNG k-ε turbulence model for the simulations. The flow inlet for the manifolds was modeled using 'pressure-inlet'.

MohdSajid Ahmed et.al. [9] In his research paper theyhad applied CFD methods to identify the optimum exhaust manifold for a 4-stroke 4-cylinder SI engine.

I.P. Kandylas et.al. [10] In this paper theyhad developed an exhaust system heat transfer model that included the steady state and transient heat conduction as well as convection and radiation.

Bin Zou et al. [11] in their research paper they have discussed the impact of temperature effect on exhaust manifold modal analysis by mapping temperature field from the CFD software and then heat conduction process is analyzed in FEM software with the temperature field boundary conditions.

P.L.S.Muthaiah et.al. [12] He has analyzed the exhaust manifold in order to reduce the backpressure and also to increase the particulate matter filtration.

K.S. Umesh et.al. [13] In their research paper they worked on eight different models of exhaust manifold were designed and analyzed to improve

Vivekananda Navadagi et.al. [14] In their research paper they analyzed the flow of exhaust gas from two different modified exhaust manifold with the help of Computational fluid dynamics.

Kulal et.al. [15]In their research work they comprehensively analyzes eight different models of exhaust manifold and concluded the best possible design for least fuel consumption.

Simon Martinez-Martinezet.al. [16] In their paper they had performed CFD analysis to estimate the

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performance of the exhaust manifold while placing the catalytic converter near to it (Close-Coupled Catalytic Converter).

Gopaal et.al [17] in his paper he note that the exhaust pulse, created due to the release of high pressure exhaust gas from the cylinder to the exhaust manifold, would have three pressure heads – high, medium and low.

K.H. Park et.al. [18] in their paper“Modeling and Design of Exhaust Manifold Under Thermo mechanical Loading “, had proposed a thermal stress index (TSI) for designing the exhaust manifold.

J.David Rathnaraj et.al [19] in his work “Thermo mechanical fatigue analysis of stainless steel exhaust manifolds” had proposed a model based on Isothermal data. Thermal fatigue analysis should be considered in the design process of the exhaust manifold.

S.N.Ch.Dattu.V et.al. [20] In his paper heperformed thermal analysis for the tubular type ICEngine exhaust manifold for various operating conditions.

3.3.1. GEOMETRIC MODELLING

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Assault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Assault Systems product lifecycle management software suite.

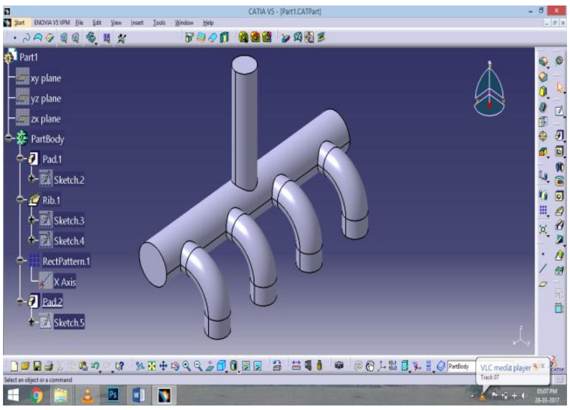

Fig no.3.1 Long Bend Centre Exit

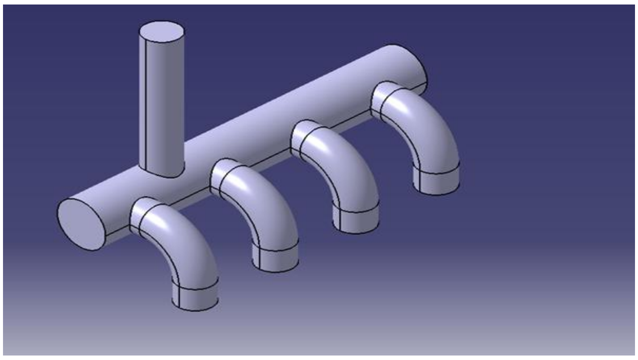

Fig no. 3.2 Long Bend Side Exit

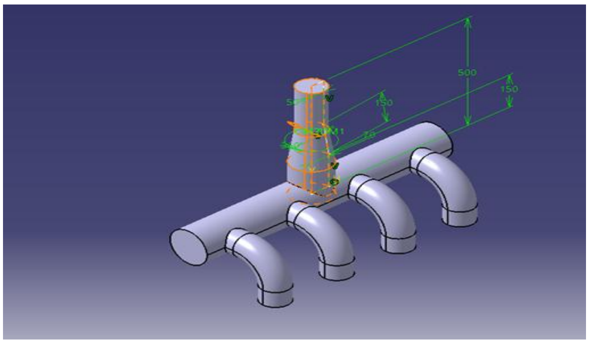

Fig 3.3 Long Bend Centre Exit with Reducer (LBCER)

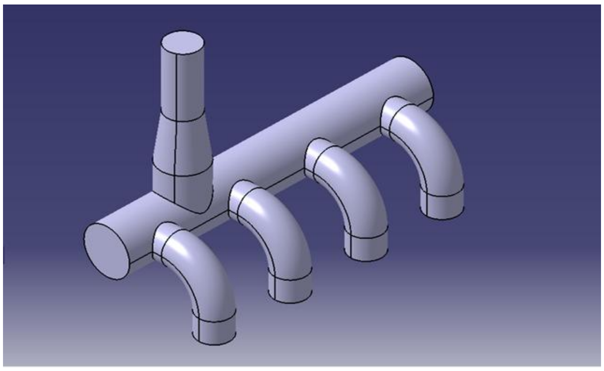

Fig 3.4 Long bend side exist with reducer

4.Steps involved in analysis using ANSYS

The ANSYS program has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis.

A typical ANSYS analysis consists of the following steps:

- Build the model using key points, lines, areas and volume commands.
- Giving material properties.
- Choosing proper element.
- Meshing the model to discritise it into elements.

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- Applying the given loads.
- Applying the boundary conditions.
- Running the solution phase.

Fig 4.1 Review the results using the post processor.

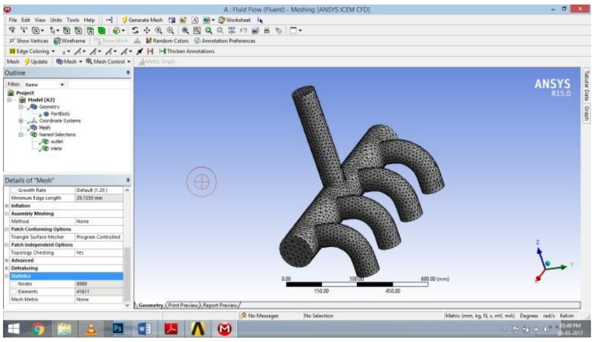

Fig 4.1Coarse mesh

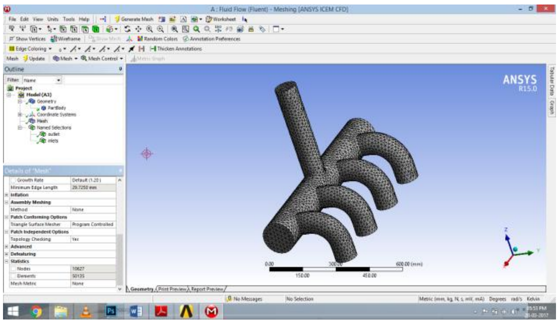

Fig 4.2Fine meshed

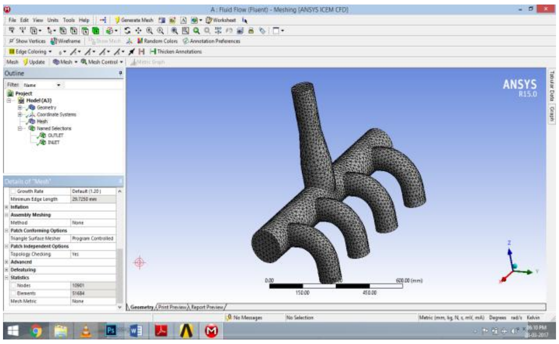

Fig 4.3meshed exhaust manifold

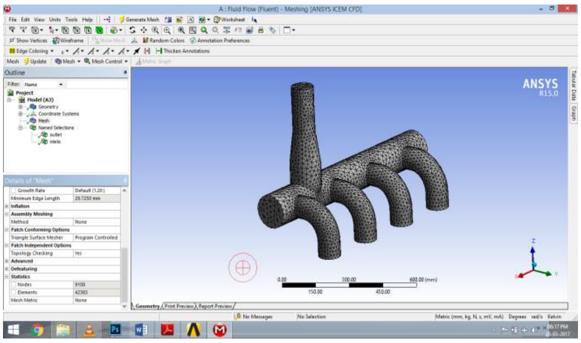

Fig 4.4COARSE meshed

5. RESULTS AND DISCUSSIONS

The main objective of this investigation is to find out pressures and velocities at various mass flow rates in the exhaust manifolds with Long Bend Side Exit (LBSE), Long Bend Middle Exit (LBME) and Reducer and find out the performance of the exhaust manifold with various modifications in its design or adding a component for the exhaust manifold to increase its effectiveness.

In the current analysis mass flow rates considered in the exhaust manifold are 2 kg/s, 4 kg/s, 6 kg/s, 8 kg/s ,10 kg/s, 12 kg/s in all the various modifications in the exhaust manifolds.

Case-1: Pressure and Velocity Variations in Exhaust Manifold with LBSE

The exhaust manifold with LBSE is considered for this analysis at different mass flow rates in turbulent region. In this analysis five mass flow rates are considered and analysed. The mass flow rates were considered randomly and entire analysis depends on the mass flow rate considered.

Mass Flow Rate: 2 kg/s

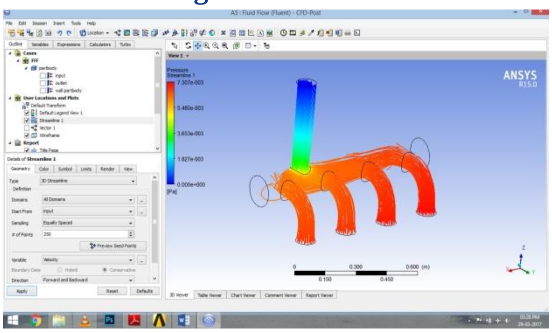

Fig 5.1 Streamlines of Pressure Drop in Exhaust Manifold

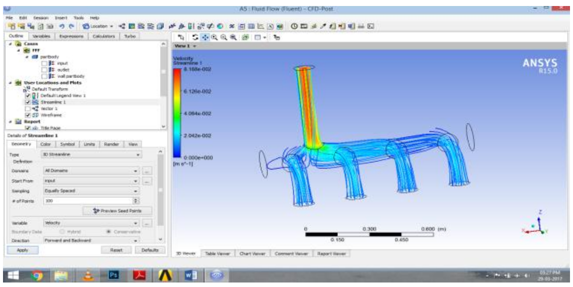

Fig 5.2 Streamlines of Velocity in Exhaust Manifold

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Here in this case the fluid which is flowing in the Exhaust Manifold is shown in the above figures. As we know that the pressure drop increases with increase in Reynolds number as both of them are directly proportional to each other. Here mass flow rate of the fluid flowing is taken as 2kg/s. Depending on the mass flow rate the Reynolds number and pressure also changes. The minimum and maximum pressure drop and velocities in the exhaust manifold listed below. Here in this case also change in pressure of the liquid is clearly shown in the form of both vectors and streamlines the liquid moves in the exhaust manifold .Greater pressures may damage the manifold as greater vibrations were created which in turn decreases the performance of the manifold.

Table 5.1 pressure and velocity

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	7.307e-003	0.00e+00	8.168e-0.002	0.00e+00

Mass Flow Rate: 4 Kg/S

Table 5.2 pressure and velocity drop

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	2.126e-0.002	-3.675e-0.005	1.536e-0.001	0.00e+00

5.3 Mass Flow Rate: 6 Kg/S

Table 5.3

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	4.099e-002	-1.216e-004	2.187e-001	0.00e+00

Mass Flow Rate:8Kg/s

Table 5.4 Pressure and velocity drop calculations

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	6.583e-002	-5.737e-004	2.781e-001	0.00e+00

Mass Flow Rate:10 Kg/s

Table 5.5 pressure and velocity drop

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	9.584e-002	-506e-003	3.367e-001	0.00e+00

Mass Flow Rate:12 Kg/s

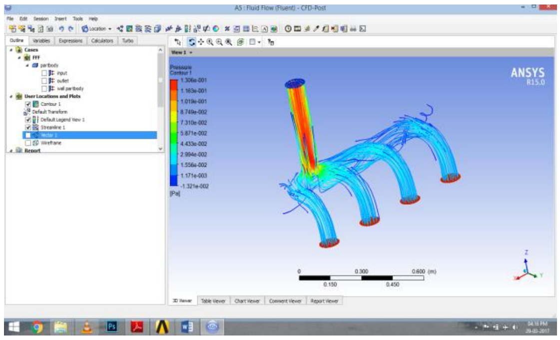


Fig.5.3 Pressure drop in streamlines

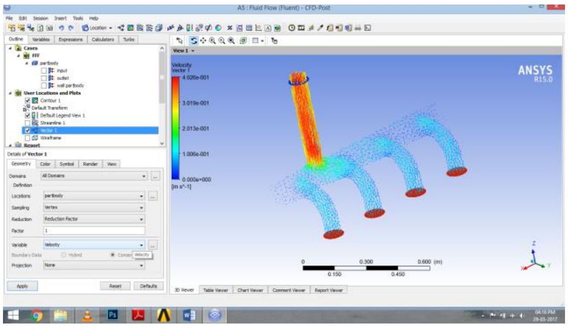


Fig.5.4 Velocity drop in stream lines

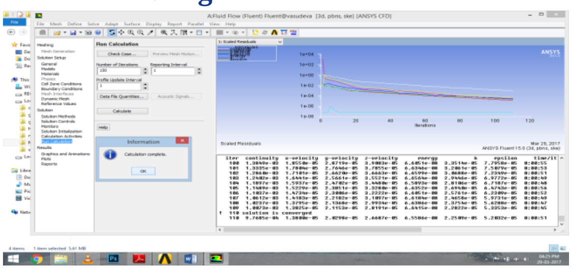
Table 5.6

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	1.306 e-001	-1.321e-002	4.026e-001	0.00e+00

Case-2: Pressure and Velocity Variations in Exhaust Manifold with LBCE

The exhaust manifold with LBCE is considered for this analysis at different mass flow rates in turbulent region. In this analysis five mass flow rates are considered and analyzed. The mass flow rates were considered randomly and entire analysis depends on the mass flow rate considered.

Mass Flow Rate:2Kg/s



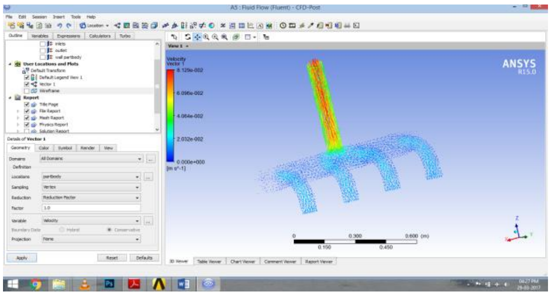


Fig.5.5 Velocity drop in stream lines

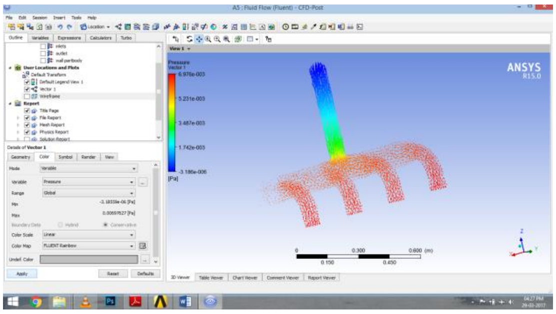


Fig 5.6 pressure drop in streamlines

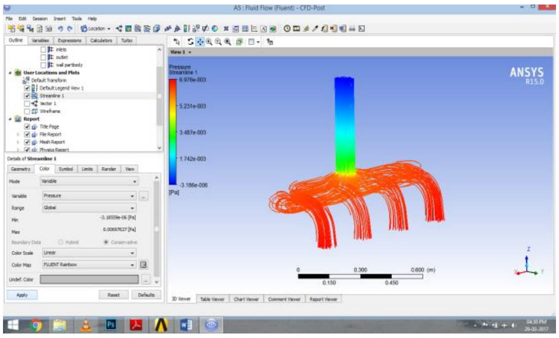


Table 5.7 Pressure and velocity drop

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	6.976e03	-3.18e05	8.129e002	0.00e+000

Mass Flow Rate:4Kg/s

Table 5.8 Pressure and velocity drops

S.No	Pressure Drop		Velocity	
	Max	Min	Maxim	Minimum
1	2.032e-002	-4.066e-005	1.520e-001	0.00e+000

5.9 Mass Flow Rate:6Kg/s

Table 5.9 Pressure and velocity drops

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	-1.095e-004	3.926e-002	2.185e-001	0.000e+00

Mass Flow Rate: 8Kg/s

Table 5.10 pressure and velocity drop

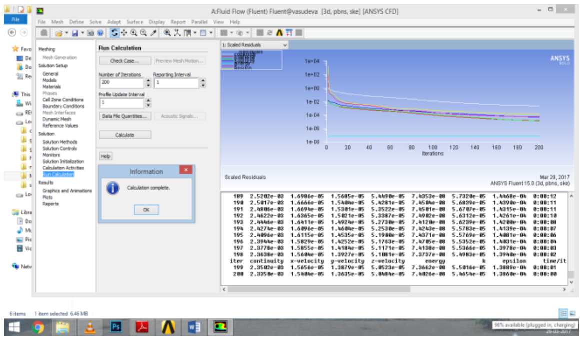
S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	6.322e-002	1.244e-003	2.805e-001	0.00e+000

Mass Flow Rate:10 Kg/s

Table 5.11 Pressure and velocity drops

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	9.205e-002	-7.623e-003	3.396e-001	0.000e-000

Mass Flow Rate: 12 Kg/s



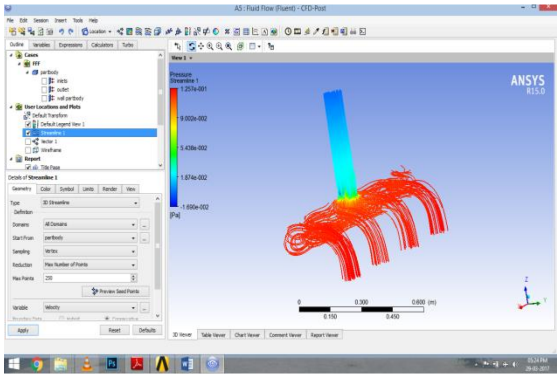


Fig.5.8 Pressure drop in stream lines

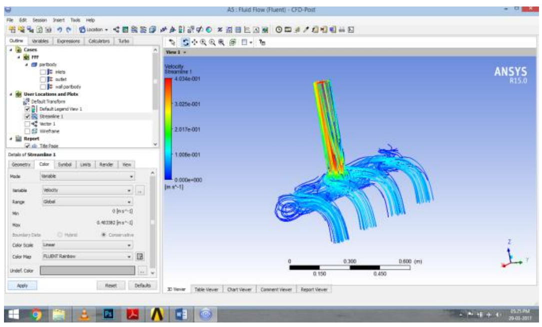
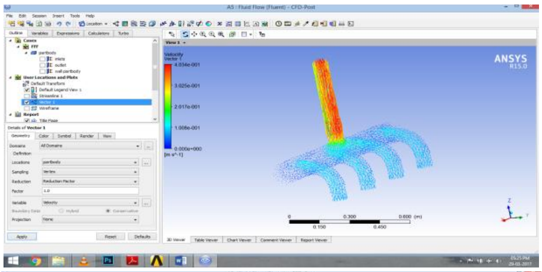


Fig.5.9 Velocity drop in stream lines



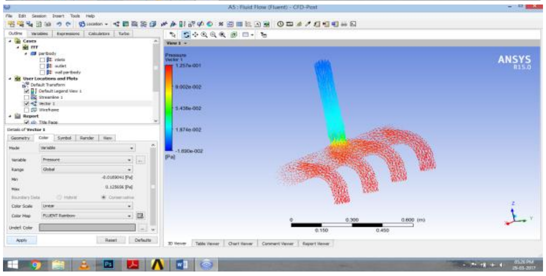


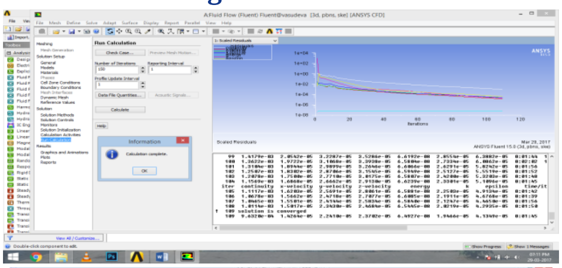
Table 5.12 Pressure and velocity drops

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	1.257e-001	-1.690e-002	4.034e-001	0.000e+000

Case-3: Pressure and Velocity Variations in Exhaust Manifold with Reducer

The exhaust manifold with reducer is considered for this analysis at different mass flow rates in turbulent region. In this analysis five mass flow rates are considered and analysed. The mass flow rates were considered randomly and entire analysis depends on the mass flow rate considered.

Mass Flow Rate: 2 Kg/s



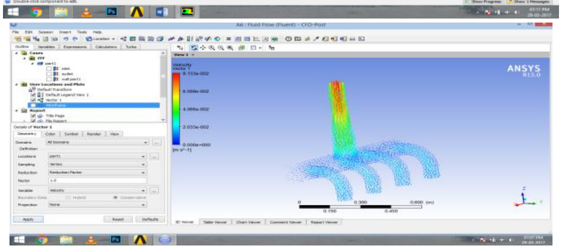


Fig.5.11 Velocity drop in stream lines

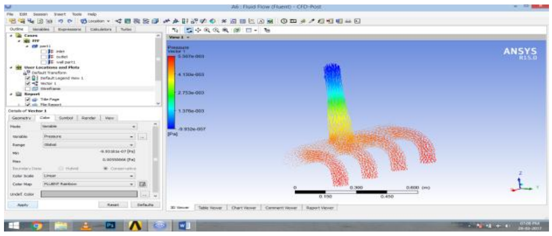
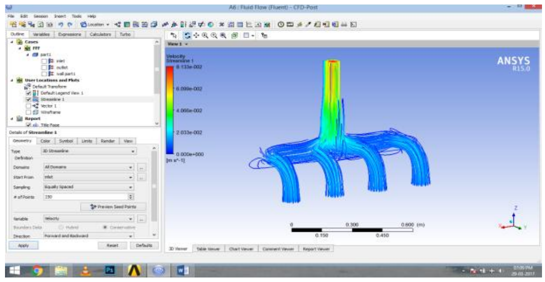


Fig.5.12 Pressure drop in streamlines



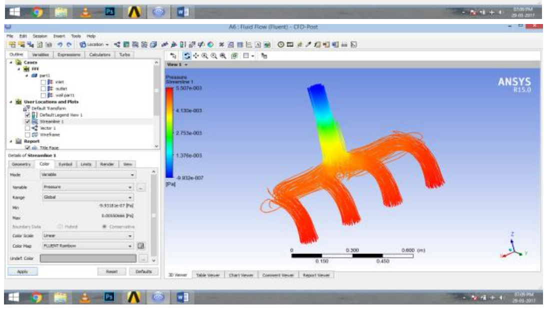


Table 5.13 Pressure and velocity drops

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	5.507e-003	-9.932e-007	8.133e-002	0.000e+000

Mass Flow Rate:4 Kg/s

Table 5.14

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	1.606e-002	0.000e+000	1.497e-001	0.000e+000

Mass Flow Rate: 6 kg/s

Table 5.15 Pressure and velocity drop

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	3.063e-002	0.000e+000	2.123e-001	0.000e+000

Mass Flow Rate:8 kg/s

Table 5.16 Pressure and velocity drop

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	4.951e-002	0.000e+000	2.709e-001	0.000e+000

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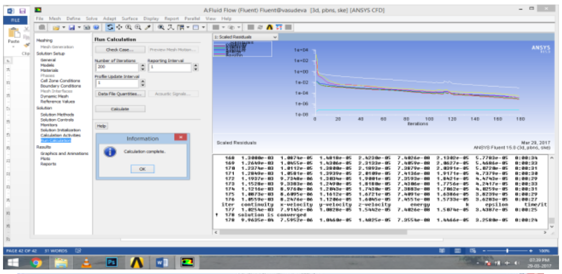
Mass Flow Rate:10 kg/s

Fig.5.17 Pressure and velocity drop

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	7.180e-002	0.000e+000	3.273e-001	0.000e+000

Mass Flow Rate:12 kg/s



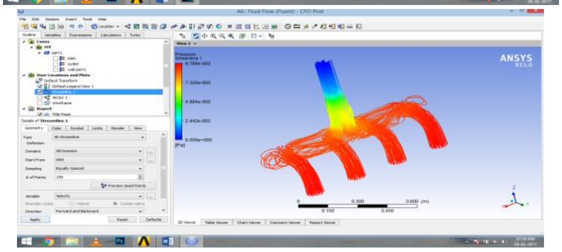


Fig.5.13 Pressure drop in stream lines

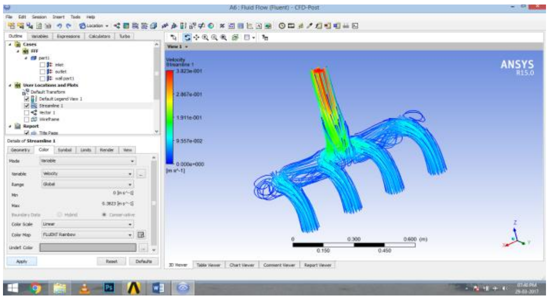
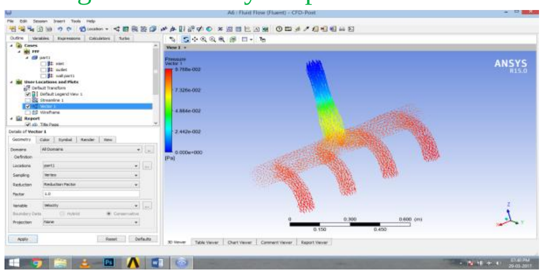


Fig.5.14 Velocity drop in streamlines



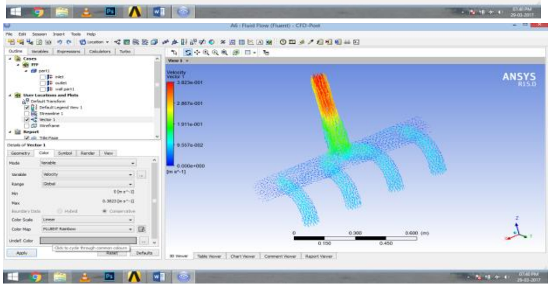


Fig.5.15 Pressure and velocity drop

S.No	Pressure Drop		Velocity	
	Max	Min	Max	Min
1	9.768e-002	0.000e+000	3.823e-001	0.000e+000

6. CONCLUSION

In this thesis the investigation is to find out pressures and velocities at various mass flow rates in the exhaust manifolds with Long Bend Side Exit (LBSE), Long Bend Middle Exit (LBME) and Reducer and find out the performance of the exhaust manifold with various modifications in its design or adding a component for the exhaust manifold to increase its effectiveness.

In the current analysis mass flow rates considered in the exhaust manifold are 2 kg/s, 4 kg/s, 6 kg/s, 8 kg/s ,10 kg/s, 12 kg/s in all the various modifications in the exhaust manifolds.

From the above investigations it is found that Long Bend Middle Exit (LBME) with Reducer is giving the better performance.

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