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CFD Analysis of Exhaust Manifold of A Multi-Cylinder Engine

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ABSTRACT: *The present scenario, the main objective the engine designer's try to achieve is the best performance with lowest possible emissions. Exhaust Manifold is one of the crucial components that have an influence on this objective. The designing of Exhaust Manifold is one of the complex procedures and relies on many variables like back-pressure, flow velocity, mechanical efficiency, volumetric efficiency, etc. In the present work, three different exhaust manifold models are considered with various pipe diameters. All three models differ from each other in geometry. Computational fluid dynamics simulation has been carried out with the help of ANSYS Fluent at three different speeds. The pressure contours and velocity streamlines are obtained for all the three models. The work is further extended by modeling two other models and the performed analysis results are validated with journal data. Manifold model 3 considered is yielding the least backpressure and indicates possible design proposals for manifold.*

Nomenclature : CFD – Computational Fluid Dynamics; SBSE - Short Bend Side Exit Model; LBCE - Long Bend Center Exit Model; MM1 - Manifold Model 1; MM2 - Manifold Model 2; MM3 - Manifold Model 3

I. INTRODUCTION

The design of exhaust manifolds are developed for several years, as engines are improved thus have exhaust manifolds, early manifold are lot less economical than present days exhaust manifolds. Design did not contribute to a smooth flow in early times, the back pressure built up was much higher, and this increased the work done by the particular piston at the exhaust stroke. Large quantity of residual gas remains in the combustion chamber which, as a consequence, leads to increase in temperature. Sometimes when working at full loads the manifolds were turning red hot. So in order to protect the paint, asbestos are used which is a highly heat resistant fibrous silicate. Now exhaust manifold designs are transformed completely. In order to boost earlier configurations, designers have come up with completely different styles that decrease the flow resistance by employing a lot of improved pipe layout and increasing the average exhaust velocities of the gases, which leads to increase in the power output. The collector has also been modified throughout the years through the utilization of various geometries for achieving better flow efficiency. Later, to improve the efficiency of engine, turbochargers are fitted at the end of exhaust manifold to draw more air into the cylinder for better and to complete the combustion process which would deliver more power and reduce the exhaust gas emissions.

A. Exhaust Manifold

An exhaust manifold is a series of pipes that are usually connected directly on the engine cylinder head. It is an integral part of the exhaust system. Hot exhaust gases from the exhaust ports on the cylinder head is passed through the pipes and into a single collector pipe. Exhaust manifolds is a necessary part of the exhaust system. Their design is optimized to ensure exhaust gases go with the flow efficiently from the engine combustion chamber without any back pressure. Depending on the type engine, a vehicle will have either one or two exhaust manifolds connected to it. An inline engine usually has one exhaust manifold. The sizable majority of contemporary automobile engines are V-fashioned, requiring one manifold for each of cylinder banks. Exhaust manifolds are either made from cast iron or any one form of steel. The vast majority of exhaust

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manifolds are constituted of cast iron, as it is reasonably low priced and lasts a very long time. The drawbacks to CI manifolds are that they are usually heavy and tend to get brittle with age and exposure to the heat cycles of an engine. Tubular steel exhaust manifolds are known for having higher exhaust flow and are, consequently, discovered on many performance vehicles. Stainless steel exhaust manifolds are the more expensive, however are rust-resistant and totally long lasting.

I. METHODOLOGY

B. Model Description

There are five different types of exhaust manifold modeled with the help of CAD software SOLIDWORKS. All models having four inlets and one outlet pipe.

The five different types of models considered here are

1. Short Bend Side Exit Model
2. Long Bend Center Exit Model
3. Manifold Model 1
4. Manifold Model 2

Wherein the first two models, i.e., Short Bend Side Exit Model as shown in Figure 1 and Long Bend Center Exit Model as shown in Figure 2 are reconstructed from data obtained in K.S. Umesh et al. [1] for validation purpose.

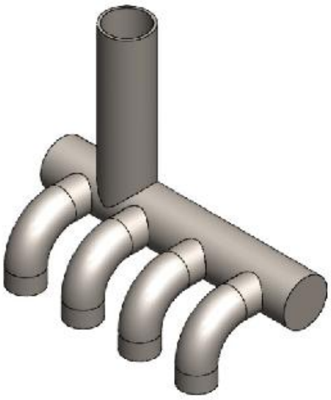

Fig. 1 Short Bend Side Exit Model

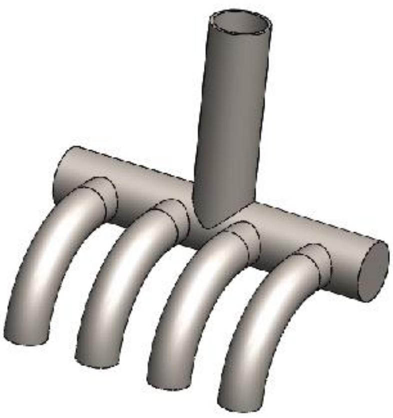

Fig. 2 Long Bend Center Exit Model

The short bend side exit model and long bend center exit model have a header length of 335mm, ID is 52.48mm and OD is 60.3. The length of the outlet pipe is 220mm. The bend pipes of inlet have ID of 35.08mm and OD is 42.46mm.

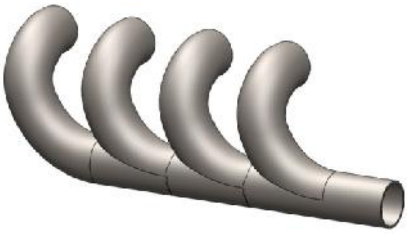

Fig. 3 Manifold Model 1

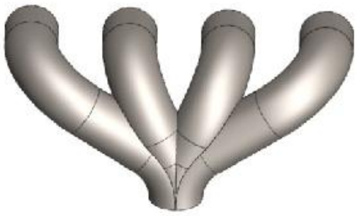

Fig. 4 Manifold Model 2

Figure 3 represents Manifold Model 1, Figure 4 represents, Manifold Model 2 and Figure 5 represents Manifold Model 3.All three models have three sub models of 40 mm, 45 mm and 50 mm pipe diameter.

Meshing

Altair HYPERMESH was the meshing tool used for mesh generation.

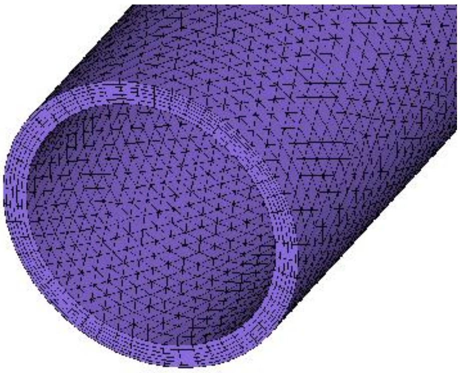

Fig. 6 (a) Boundary layers generated

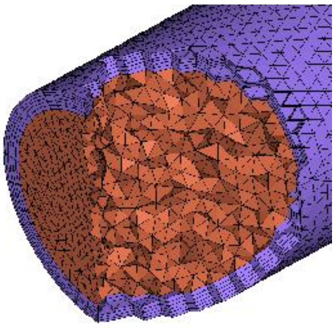

Fig. 6 (b) Solid tetramesh with boundary layers

The boundary layers generated and the solid tetramesh with boundary layers are indicated in Figure 6 (a) and Figure 6 (b) respectively.

Fluid Properties

The fluid properties considered for the CFD simulation are tabulated in Table 1

Table 1. Fluid Properties

Density (Kg/m3)	1.045
Viscosity (Pa-s)	3.0927e-5
Specific Heat (J/Kg-K)	1056.64
Thermal Conductivity (W/m-K)	0.0250

Boundary Conditions

At the inlet, mass flow rates are evaluated for three different speeds, i.e., 1000rpm, 3000rpm and 6000rpm. At outlet, pressure is taken as gauge pressure for all models

Assumptions:

1. Mass flow rate at inlet is equal to mass flow rate at outlet.
2. Volumetric efficiency as 90%
3. The flow is considered to be turbulent.
4. K-Є model is considered with RNG scheme.

The mass flow rates at inlet are listed in Table 2 and the values are taken from K.S. Umesh et at. [1] which are evaluated at 1500 rpm at different loading condition. The mass flow rates are taken for validation of Short Bend Side Exit (SBSE) model and Long Bend Center Exit (LBCE) model.

Table 2. Mass flow rates at inlet for SBSE and LBCE models

Load (Kg)	**Mass Flow Rate (Kg/s)**
2	0.001696
4	0.003392
6	0.005088
8	0.006784
10	0.008480
12	0.010176

The mass flow rates for Manifold Model 1 (MM1), Manifold Model 2 (MM2) and Manifold Model 3 (MM3) are listed in Table 3

Table 3. Mass flow rates at inlet for MM1, MM2 and MM3 models.

RPM	Mass Flow Rate (Kg/s)
1000	0.0156
3000	0.0469
6000	0.0939

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II. Results and Discussion

The CFD analysis is performed using ANSYS Fluent for all models by varying the mass flow rates at inlet and finally after the solution converged, the pressure Contours and velocity streamlines are plotted for all models.

Short Bend Side Exit Model (SBSE)

The 'Short Bend Side Exit Model' is modeled and analyzed as per work carried out by K.S. Umesh et al. [1]. The amount of backpressure and the velocity of flow of fluid/exhaust gas inside the manifold for 1500 rpm at different loading conditions is tabulated in Table 4 and the results obtained are compared with K.S. Umesh et al. [1] and the error obtained are well within the admissible value

Table 4. Pressure and Velocity of Short Bend Side Exit Model

Load	**Parameters**	**K.S. Umesh** et al. [1]	**Present Result**	**% error**
2 Kg	Pressure (pa)	1020	1011.84	0.8
	Velocity (m/s)	18.1	17.88	1.2
4 Kg	Pressure (pa)	1071	1063.51	0.7
	Velocity (m/s)	18.6	18.61	0.05
6 Kg	Pressure (pa)	1098	1091.42	0.6
	Velocity (m/s)	19.1	18.96	0.73
8 Kg	Pressure (pa)	1113	1106.30	0.6
	Velocity (m/s)	20.2	19.6	2.9
10 Kg	Pressure (pa)	1132	1126.38	0.5
	Velocity (m/s)	21.6	20.41	5.5
12 Kg	Pressure (pa)	1172	1165.59	0.54
	Velocity (m/s)	23.5	21.86	6.9

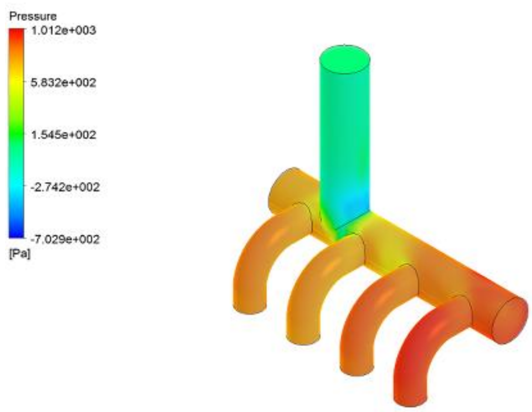

Fig. 7(a) Pressure Contour at 2 kg loading of SBSE model

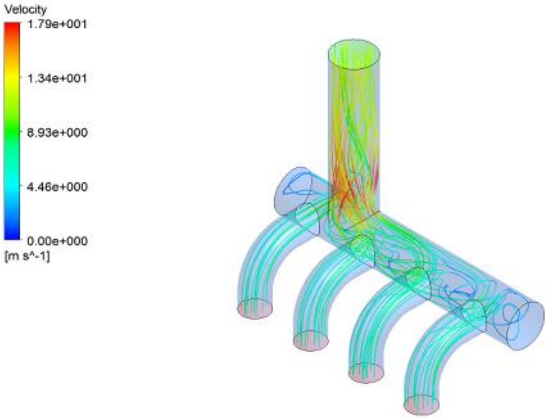

Fig. 7(b) Velocity Streamline at 2 kg loading of SBSE model

The amount of backpressure produced by Short Bend Side Exit model at 2 kg loading is found to be 1011.84 Pa and is represented in Figure 7(a) and the velocity of flow is found to be 17.88 m/s which is represented in Figure 7(b).

Long Bend Center Exit Model (LBCE)

The 'Long Bend Center Exit Model' is modeled and analyzed as per work carried out by K.S. Umesh et al. [1]. The amount of backpressure and the velocity of flow of fluid/exhaust gas inside the manifold for 1500 rpm at different loading conditions is tabulated in Table 5 and results obtained are compared with K.S. Umesh et al. [1]

Table 5. Pressure and Velocity of Long Bend Center Exit Model

Load	**Parameters**	**K.S. Umesh** et al. [1]	**Present Result**	**% error**
2 Kg	Pressure (pa)	850	842.85	0.84
	Velocity (m/s)	20.22	19.98	1.18
4 Kg	Pressure (pa)	863	856.21	0.78
	Velocity (m/s)	21.33	20.21	5.2
6 Kg	Pressure (pa)	894	887.74	0.7
	Velocity (m/s)	22.07	21.06	4.5
8 Kg	Pressure (pa)	923	919.02	0.43
	Velocity (m/s)	23.52	22.60	3.9
10 Kg	Pressure (pa)	984	978.46	0.56
	Velocity (m/s)	23.98	23.61	1.54
12 Kg	Pressure (pa)	1012	1006.88	0.5
	Velocity (m/s)	24.77	24.08	2.78

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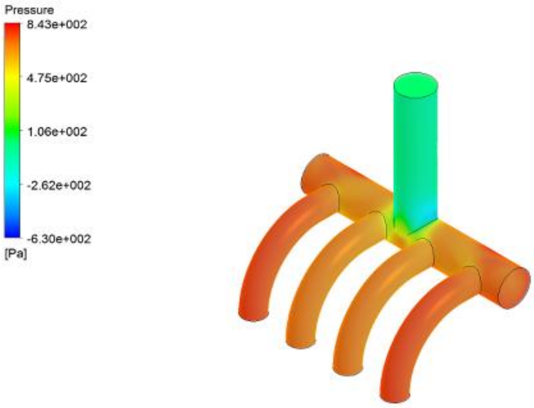

Fig. 8(a) Pressure Contour at 2 kg loading of LBCE model

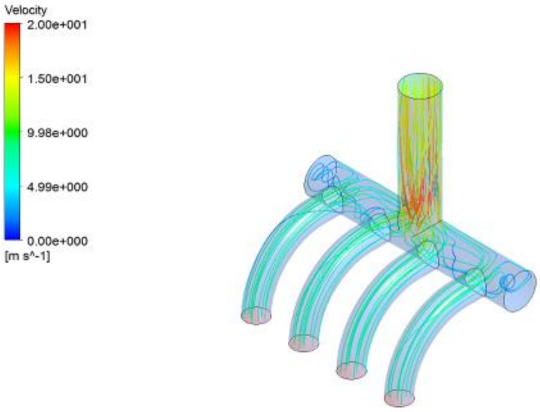

Fig. 8(b) Velocity Streamline at2 kg loading of LBCE model

The amount of backpressure produced by Long Bend Center Exit model at 2 Kg. loading is found to be 842.85 Pa and is represented in Figure 8(a) and the velocity of flow is found to be 19.98 m/s which is represented in Figure 8(b).

Manifold Model 1

The results of pressure and velocity obtained for Manifold Model 1 for three different rpm's and three different diameter is tabulated in Table 6

Manifold Model - 2		**40mm**	**45mm**	**50mm**
1000 rpm	Pressure (Pa)	488.35	306.29	203.01
	Velocity (m/s)	31.65	25.13	20.63
3000 rpm	Pressure (Pa)	3821.24	2392.69	1582.21
	Velocity (m/s)	89.27	70.83	58.28
6000 rpm	Pressure (Pa)	14527.27	9090.22	6005.77
	Velocity (m/s)	174.79	138.69	114.14

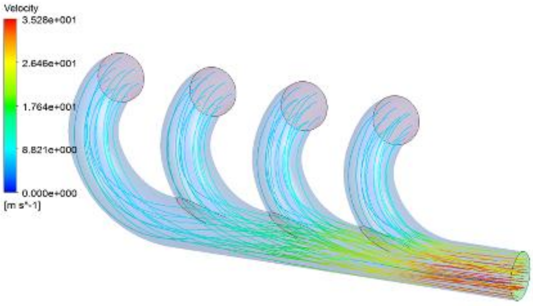

Fig. 9(a) Pressure Contour of 40mm dia. at 1000 rpm

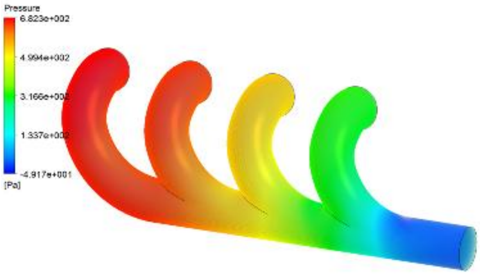

Fig. 9(b) Velocity Streamline of 40mm dia.at 1000 rpm

The backpressure of manifold model 1 of 40mm diameter for 1000 rpm is found to be 682.29 Pa and is represented in Figure 9(a) and the velocity of flow is found to be 35.28 m/s which is represented in Figure 9(b).

Manifold Model - 3		**40mm**	**45mm**	**50mm**
1000 rpm	Pressure (Pa)	364.94	229.32	154.70
	Velocity (m/s)	25.86	20.36	16.58
3000 rpm	Pressure (Pa)	2720.65	1698.21	1117.72
	Velocity (m/s)	73.56	58.29	47.12
6000 rpm	Pressure (Pa)	10616.69	6625.07	4342.87
	Velocity (m/s)	147.76	117.16	94.85
Manifold Model - 3		**40mm**	**45mm**	**50mm**
1000 rpm	Pressure (Pa)	364.94	229.32	154.70
	Velocity (m/s)	25.86	20.36	16.58
3000 rpm	Pressure (Pa)	2720.65	1698.21	1117.72
	Velocity (m/s)	73.56	58.29	47.12
6000 rpm	Pressure (Pa)	10616.69	6625.07	4342.87
	Velocity (m/s)	147.76	117.16	94.85

Table 7. Pressure and Velocity of Manifold Model 2 for different speed and diameters

Manifold Model 2

The results of pressure and velocity obtained for Manifold Model 2 for three different rpm's and three different diameter is tabulated in Table 7

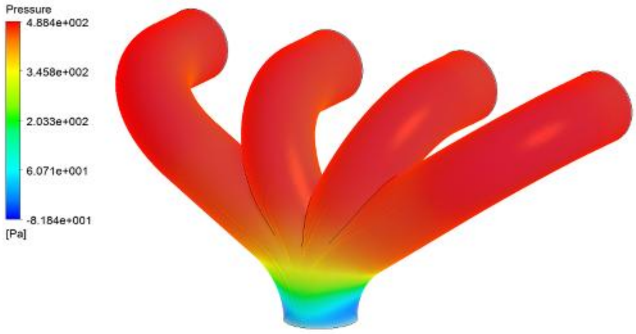

Fig. 10(a) Pressure Contour of 40mm dia.at 1000 rpm

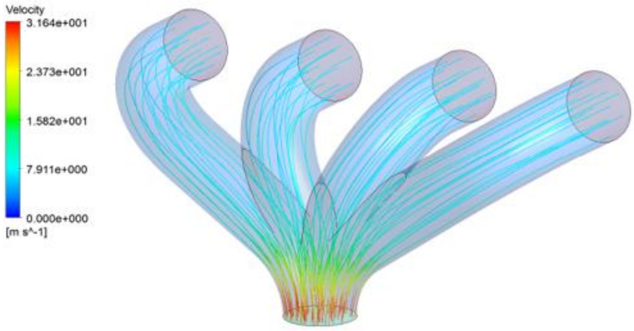

Fig. 10(b) Velocity Streamline of 40mm dia. at 1000 rpm

The backpressure of manifold model 2 of 40mm diameter for 1000 rpm is found to be 488.35 Pa and is represented in Figure 10(a) and the velocity of flow is found to be 31.64m/s which is represented in Figure 10(b)

III. Conclusion

The results obtained in the preliminary study on Short Bend Side Exit model and Long Bend Center Exit model from K.S. Umesh *et al.* [1]which was considered for validation purpose are very much matching with the journal data [1].Manifold model 3 considered, is yielding the least backpressure compared to other models and indicates a possible design proposal for manifolds. Exhaust manifold selection is a tricky thing where we need to have narrow pipes as possible with least back pressure. If wider pipes are selected, no doubt that there will be low backpressure, but will be losing power because there will be no good exhaust flow. So recommendation is that, if engine power band lies somewhere around 2000-3000 rpm, narrow pipes are good, whereas if it lies somewhere around 6000rpm, wider pipes lead to better performance.

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