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Muffler Design Development and Validation Methods

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ABSTRACT
Noise from an automobile exhaust is one of the major components of sound pollution. Exhaust systems are developed to reduce the noise. This paper deals with a practical approach to design, develop and test muffler particularly reactive muffler for exhaust system, which will give advantages over the conventional method with shorten product development cycle time and validation.

Keywords: Noise, pollution, Exhaust systems, muffler design, back pressure.

1. Introduction
Since the invention of the internal combustion engine in the latter part of the nineteenth century, the noise created by it has been a constant source of trouble to the environment. Significantly, the exhaust noise in terms of pressure is about 10 times all the other noises (structural noise) combined. So the problems of reducing engine noise consist, mainly in attenuating exhaust noise. The design of mufflers has been a topic of great interest for many years and hence a great deal of understanding has been gained. Most of the advances in the theory of acoustic filters and exhaust mufflers have come about in the last four decades. Hence good design of the muffler should give the best noise reduction and offer optimum back pressure for the engine. Moreover, for a given internal configuration mufflers have to work for a broad range of engine speed. Usually when mufflers are designed by well established numerical techniques like boundary element method or finite element method, the numerical model generation is time consuming often limiting the user to try various other possible design alternates. The process might be lengthy and laborious as it involves a more iteration with different prototypes. Mufflers have been developed over the last ninety years based on electro- acoustic analogies and experimental trial and error. Many years ago Stewart used electro – acoustic analogies in deriving the basic theory and design of acoustic filters [1]. Later Davis et al. published results of a systematic study on mufflers [2]. They used traveling wave solutions of the one-dimensional wave equation and the assumption that the acoustic pressure p and acoustic volume velocity v are continuous at changes in cross sectional area. An important step forward in the analysis of the acoustical performance of mufflers is the application of two- port network theory with use of four –pole parameters. Igarashi and his colleagues calculated the transmission characteri stics of mufflers using equivalent electrical circuits [3-4]. Parrot later published results for the certain basic elements such as area expansions and contractions. Sreenath and Dr. Munjal gave expression for the attenuation of mufflers using the transfer matrix approach [5]. The expression they developed was based on the velocity ration concept. Later, Dr. Mujal modified this approach to include the convective effects due to flow [6]. Young and Crocker used the finite element method to predict four-pole parameters and then the transmission loss of complex shaped mufflers for the case of no flow [7]. Ying-change, Long-Jyi used optimized approach of maximal STL and muffler dimension under space constraints throughout the graphic analysis as well as computer aided numerical assessment [8]. Middlberg, J.M. and Barber T.J. present different configurations of simple expansion chamber mufflers, including extended inlet or outlet pipes and baffles have been modeled numerically using CFD in order to determine their

acoustic response [9]. However, most of the research studies based on formulation of mathematical equation and trial and error 2 methods. The scope of our work is to establish a design methodology to make design process simpler and less time consuming by making use of acoustic theories [10, 11] and experience, in short practical approach to get better design. Also this

approach will predict design quality at earlier stage of muffler design, evaluate quality of design, set targets for proto design and improves the same throughout the product design steps and reduce cost of proto development. This paper deals with a practical approach to design, develop and test muffler particularly reactive muffler for exhaust system, which will give advantages over the conventional method with shorten product development cycle time and validation. This paper also emphasis on how modern CAE tools could be leveraged for optimizing the overall system design balancing conflicting requirements like Noise and Back pressure.

2.0 Design Methodology

Design Methodology the properly designed muffler for any particular application should satisfy the often – conflicting demands of at least five criteria simultaneo usly. The acoustic criterion, which specifies the minimum noise reduction, required from the muffler as a function of frequency. The operating conditions must be known because large steady- flow velocities or large alternating velocities (high sound pressure levels) may alter its acoustic performance. The aerodynamic criterion which specifies the maximum acceptable average pressure drop through the muffler at a given temperature and mass flow. The geometrical criterion, which specifies the maximum allowable volume and restrictions on shape. The mechanical criterion, which may specify materials from which it is durable and requires little maintains. The economical criterion is vital in the marketplace. [3, 8] The Muffler Design methodology for a given engine involves 7 steps. Following are the broad steps followed to arrive at a good design of muffler making use of practical experimental data figure 1.

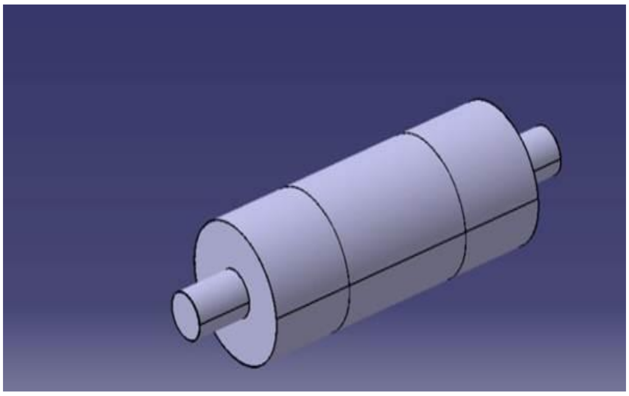

Fig 2.1 Geometry generated based upon experimental data

Step 1 Objectives framing and benchmarking: Benchmarking is a core component of continuous improvement programs; it is a key component of quality assurance and process improvement. The role of benchmarking in process improvement is similar to that of the Six Sigma process improvement methodology.

Step 2 Calculation of targeted data (frequencies): After benchmarking exercise, one needs to calculate the target frequencies to give more concentration of higher transmission loss. For calculating the target frequencies engine max power rpm is required.

Step 3 Muffler volume calculation: Based on the experience and theory of acoustics for muffler design for various Engines

Step 4 Internal configuration and concept design: Based on the benchmarking transmission loss and the target frequencies, designer draws few concepts of internal configuration that meets the packaging dimension within the volume mentioned above. Each concept and internal configuration is then formulated to the best possible configuration so as to achieve best acoustic performance and least back pressure.

Step 5 Virtual simulation: Based on above mentioned approach, different concepts will be arrived with optimum combinations of different elements inside volume of the silencer. Finalized concepts will be verified virtually by calculating transmission loss and back pressure.

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Step 6 Prototype manufacturing: All the above stages combined with the packaging of the engine evolve the design of the prototype muffler and those; can be taken up for manufacturing.

Step 7 Experimental testing and design finalization for prototype: The experimental determination of backpressure on engine and transmission loss on two source method for different concepts of verified. The prototypes of all concepts that are made at the above step are tested for the transmission loss to verify the target value**.**

3. Results and Discussions: After the construction of exhaust muffler model it is analyzed. The analysis is carried out by considering two types of inlet boundary conditions.

1. Velocity inlet 2. Pressure inlet

Parameter	Units Value
Area (m2)	0.003051
Temperature (K)	470
Viscosity (kg/m-s)	$2.7X10^{-05}$
Enthalpy (J/kg)	749575.3
Density (kg/m3)	0.696
Length (mm)	500
Velocity(m/s)	80
Ratio of specific heats	1.4

4.1: Initial values for velocity inlet as the inlet boundary condition

Parameter	Units Value
Area (m2)	0.003051
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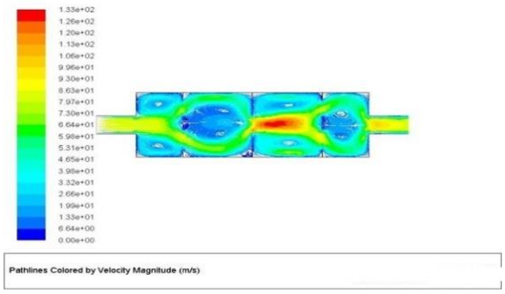
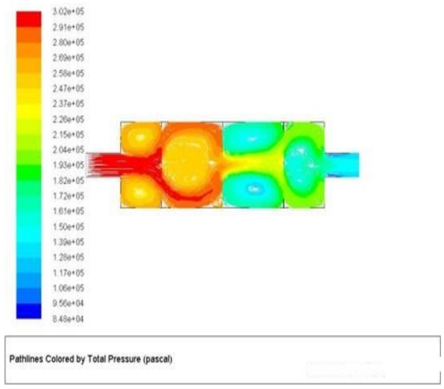
Table 4.2: Initial values for pressure inlet as the inlet boundary condition

The mean flow performance of the muffler considered in the flow analysis has been assessed. The results of the simulated muffler models obtained with the use of CFD modeling are very encouraging.



From Figure 4 it has been observed that for a velocity inlet boundary condition in model 1, the exhaust from the engine enters the muffler at a velocity of 80 m/s and increases to a magnitude of about 133 m/s in the expansion chamber once it passes through the opening. This is observed as a result of decrease in the flow area the pressure increases and subsequently the velocity increases. After this the gases get spread in the chamber and they enter the next chamber from the other two splits. Then on hitting the baffle they swirl and come out of the exhaust at an increased speed of about 106 m/s.



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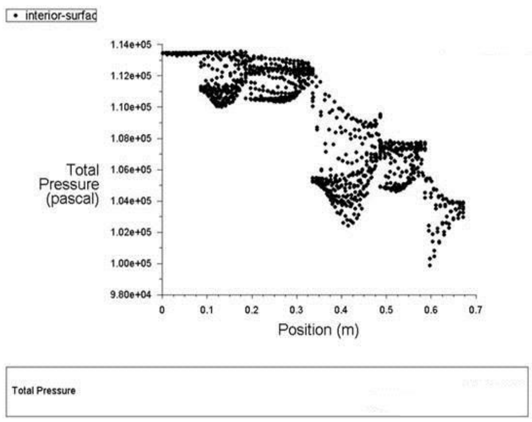
Also from figure 9 it is observed that for a pressure inlet boundary condition in model 1, the gases enter the muffler at a pressure of 3.02 bar and hit the baffle. On making the impact the exhaust recedes a bit and swirls are observed in that particular entrance chamber. The swirls have the pressure magnitude of about 2.47 bar. The gases enter the second chamber from the baffle openings at top and bottom and hence it has been observed that the pressure intensity is more near the walls in this chamber and has a magnitude of about 2.8 bar. This is because of the fact that due to the presence of the slits or openings near the top and the bottom of the baffle, the pressurized gas or exhaust is directed towards the walls of the muffler and on hitting them the exhaust comes away from the walls.

From the second chamber the exhaust enters the third chamber through an opening at the center of a baffle and hence it is observed that there is a 2.26 bar pressure region almost throughout the center of the chamber and the rest has a swirl region with a pressure of 1.5 bar. This is due to the reason that as the area decreases the pressure increases and the velocity decreases. So as the pressure is more hence there is a constant or maintained region in the chamber. Again the gases hit the baffle and enter the next chamber with a similar effect as it was observed in the second chamber but with a reduced pressure intensity of about 1.93 bar near the walls. Finally the exhaust gases come out of the outlet pipe at a pressure of 1.61 bar.



In model 2 as evident from figure 6 it has been observed that the gases enter the inlet pipe at a pressure of 3.01 bar and on hitting the baffle there occurs a swirl region in the first chamber which has a pressure intensity of 2.9 bar. The flow of the gases was more or less similar as that in model 1 but due to the changed arrangement of the baffles more intensity of pressure was observed near the walls. The velocity magnitude over this region is nearly 310 m/s according to figure 17.

Due to the reduction in the flow area the velocity of the gases increase and reach a maximum intensity of 620 m/s. The flow pattern remains similar to that of model 1 further and the gases come out of the outlet pipe at a speed of 372 m/s and a pressure of 1.64 bar. Even though the second model displayed a similar behavior, there was a more significant drop in the pressure of the exhaust gases in the first case than the second. The drop in the pressure of the exhaust gases in the first model was about 57 % whereas the drop in the second model was nearly 51 %.

4.3 Pressure Inlet Boundary Condition for Model 1

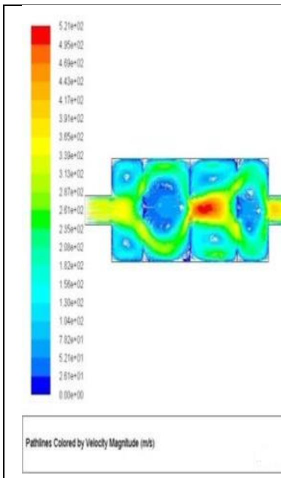


Figure 4.5: Velocity field cut plot

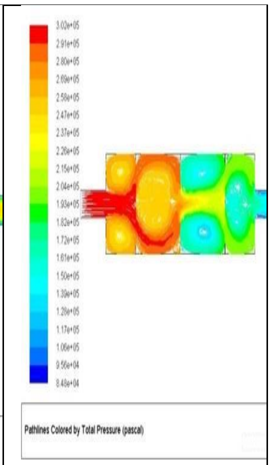


Figure 4.6 Pressure field cut plot

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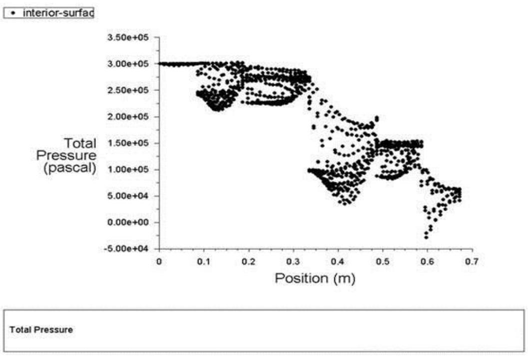

Figure 4.7: XY plot (Total pressure vs position)

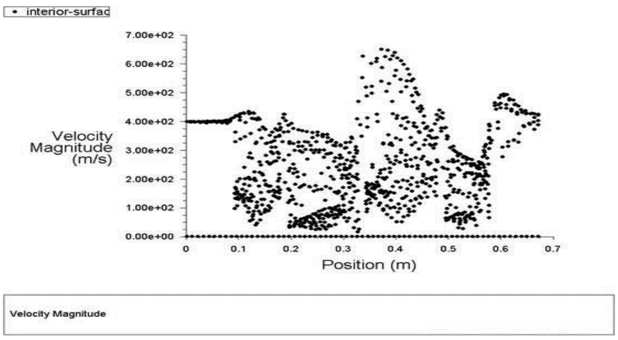

Figure 4.8: XY plot (Velocity magnitude vs position)

4.4 Velocity Inlet Boundary Condition for Model 2

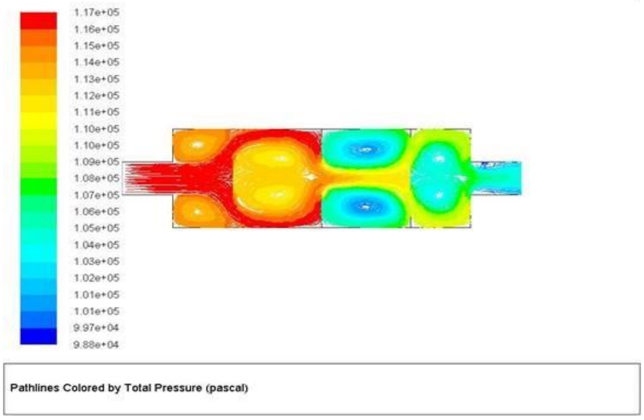

Figure 4.9: Pressure field cut plot

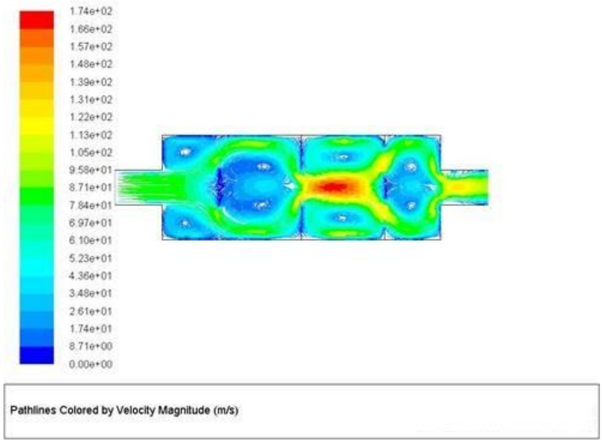

Figure 4.10: Velocity field cut plot

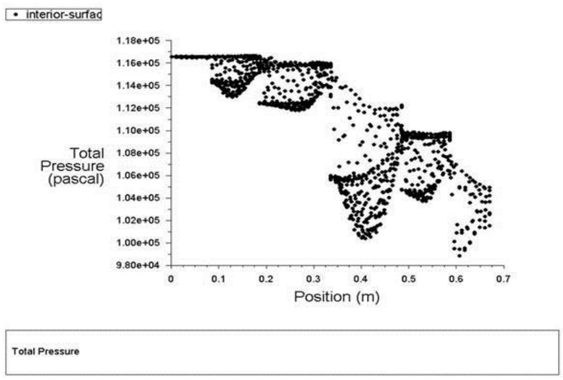

Figure 4.11: XY plot (Total pressure vs position)

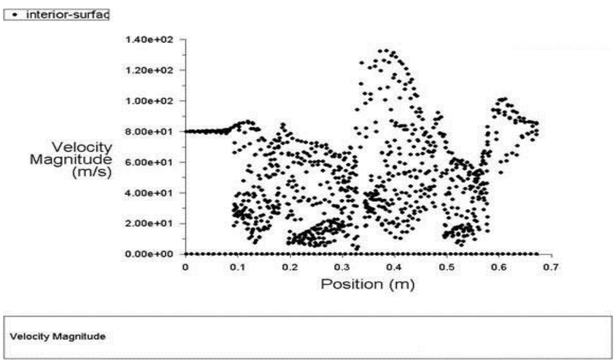

Figure 4.12: XY plot (Velocity magnitude vs position)

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4.5 Pressure Inlet Boundary Condition for Model 2

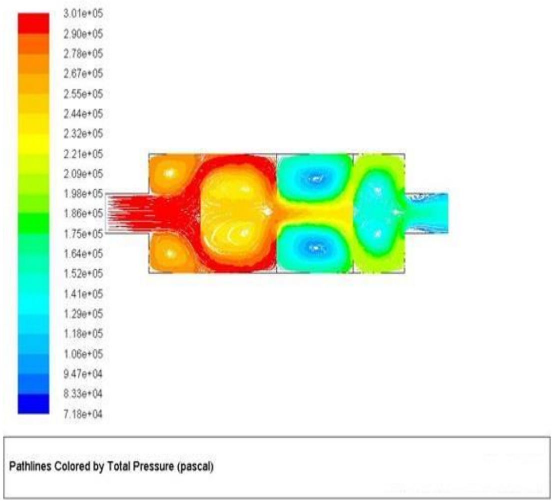

Figure 4.13: Pressure field cut plot

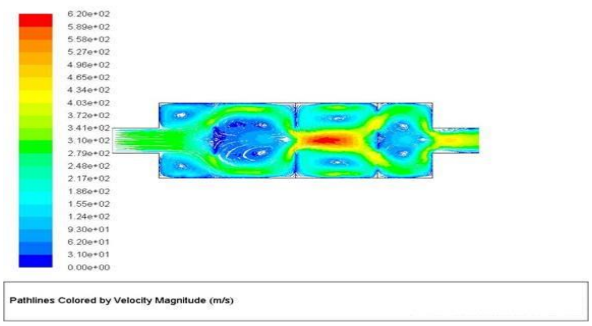

Figure 4.14: Velocity field cut plot

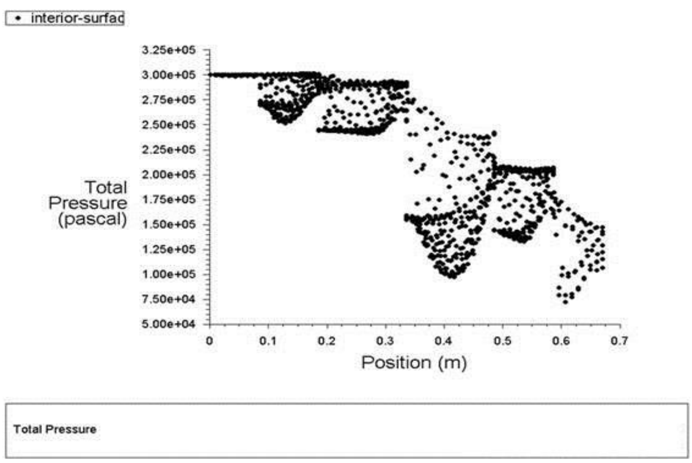

Figure 4.15: XY plot (Total pressure vs position)

5.0 Conclusions

In this work two different models of a muffler have been designed for the engine output of an LCV diesel engine and the flow has been simulated using ANSYS. The flow characteristics obtained through the simulation were promising. On comparing the results and performances of the two models, we observe that though both the models have same similar design parameters, the second model was more effective in reducing the exhaust pressure than the second one because of its internal baffle arrangement.

1. Maximum velocity in model 1 for velocity inlet boundary condition is 133 m/s

2. Maximum velocity in model 2 for velocity inlet boundary condition is 176 m/s

3. Exhaust pressure reduction in model 1 is 53.82

4. Exhaust pressure reduction in model 2 is 57.14

The reduction in pressure of exhaust in model 1 is 53.82 % whereas the reduction in exhaust pressure in model 2 is 57.14 %. Hence we conclude that model 2 is more efficient in reducing the exhaust pressure when compared to model 1.

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