Optimization of Silencer - An Integrated Approach of Acoustic Performances & Backpressure

N. V. Pujari, Mahajan S.R., Mohite Y.B.

Abstract— A pollutant of concern to the mankind is the exhaust noise in the internal combustion engine. However this noise can be reduced sufficiently by means of a well designed silencer. The suitable design and development will help to reduce the noise level, but at the same time the performance of the engine should not be hampered by the back pressure caused by the silencer. With the stringent legislative requirements for noise in automobiles, the concern for properly designed s for specific applications is increasing .Optimized design of requires an integrated study of acoustical and engine performance viz. backpressure. However, the Backpressure loss itself depends upon engine characteristics geometry indicated by the transmission loss, flow induced noise, type of - reactive, absorptive, hybrid, etc. Most of the work till date covers the acoustical and engine performance in isolation rather than in an integrated fashion due to the multidisciplinary nature of the problem. The objective of this study is to develop an integrated methodology to predict the performance of the at the design stage resulting in an optimized time and cost effective design. In the present study, the acoustical and engine performance of was predicted using CFD techniques. Using the integrated approach, it was possible to optimize the design and meet the two conflicting requirements and reduce the design cycle time.

Index Terms—silencer, Acoustic, Backpressure, CFD.

I. INTRODUCTION

Noise legislation for automotive vehicles has led to the development of properly designed exhaust silencer. Basically, there are five different design criterion of silencers design. These are Acoustical Criterion, Aero dynamical Criterion, Mechanical Criterion, Geometrical Criterion and Economical Criterion. Among above Criterion we are selected for the study work Acoustical Criterion with the Engine Performance viz. Backpressure.

The main contributor to vehicle pass-by noise is the exhaust system. With the pass-by noise becoming stringent in India, there is an urgent need to optimize the silencer design. Today's modern silencers are no longer simple, but highly complicated with noncircular shapes and absorptive material to meet pass by noise requirements. The new trend in the silencer design process is to use as much as possible the Computer Aided Engineering (CAE) tools to simulate its behaviour for several attributes in order to reduce both time and cost involved in the development process. Although experimental tests will be always the final answer, CAE process can help to reduce the number of intermediate tests.

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In the design of the exhaust system for an engine the attributes to be considered are emissions, power loss, noise, space, durability, temperature distribution and cost. The most dominant factors in the silencer design criteria are exhaust noise and engine power loss due to backpressure. There are several papers dealing with acoustic and backpressure performance of silencer [1-5]. Most of the papers deal the acoustics and backpressure performance in isolation rather than in consolidated form due to the complexity involved in the design of silencer.

In recent past, silencer design and development has been largely empirical guided by practical experience. However, such an approach is often expensive and time consuming as each modified system must be fabricated and tested before its performance can be assessed. Such considerations have led to the development of more rationally based acoustic design strategies. For acoustical analysis, commercial codes like LAMPS, WAVE, AVL BOOST and GT POWER are available which are based on one-dimensional plane wave theory. They use transfer matrix approach for the acoustical analysis. These 1-D codes also include gas dynamics codes to simulate the complete engine intake to exhaust tail pipe. These codes give the source impedance of the engine required to predict the insertion loss of the silencer; however this is a complicated task, as it requires large number of inputs. In general, 1- D codes give good first approximation of transmission loss within short time compared to the 3-D tools like Finite Element Method (FEM) and Boundary Element Method (BEM). However these codes are good for silencer with simple geometry. 1-D codes are not able to take into accounts the higher order modes (3-D effects) and complex geometries and hence lead to inaccurate solutions. The modern day silencers can be designed using the advanced numerical techniques like FEM and the BEM accurately. FEM is widely used for acoustical analysis of silencer, where the domain can be non-homogenous in terms of flow, temperature gradient and material. In BEM, the above non-homogeneities cannot considered and require high computational time, even though it requires less modelling effort as compared to FEM as surfaces are modelled, instead of acoustic cavity. In the prediction of backpressure, there are several studies which use empirical relations obtained from steady state flow experiments on each silencer element [1, 4]. But these relations do not give valid backpressure for actual silencers due to the pulsating and turbulent flow in silencers.

In the present study, the base silencer was modelled and analyzed to give Acoustic level (db) and backpressure was predicted using Computational Fluid Dynamics (CFD) approach, which will take into account the turbulence. Optimization of the existing design based on simulations was carried out. The aim of the present study is to adopt a multidisciplinary approach to achieve the optimized design configuration of silencer to meet

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the overall requirements both in terms of noise and engine performance of the vehicle.

II. METHODOLOGY

Initially, geometric models are created with appropriate dimensions. CATIA V5R20 is used as a preprocessor for creating the geometric models. The surface and volume mesh of fluid domain are formed using HYPERMESH. The completed meshes are imported to the respective numerical solvers where the simulation setup of a model is implemented.

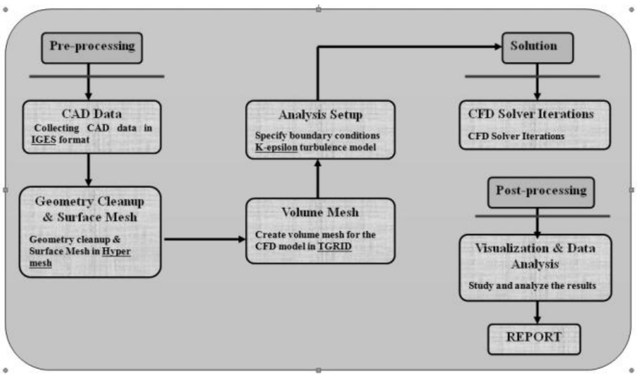

Fig 1-Methodology for the Silencer analysis-flow chart

The simulation setup includes essential steps such as assigning the Geometrical Shape & Size, boundary conditions and numerical schemes. The methodology for the Silencer analysis is as shown in figure 1.

III. GEOMETRY

The Silencer has complex geometry inside.

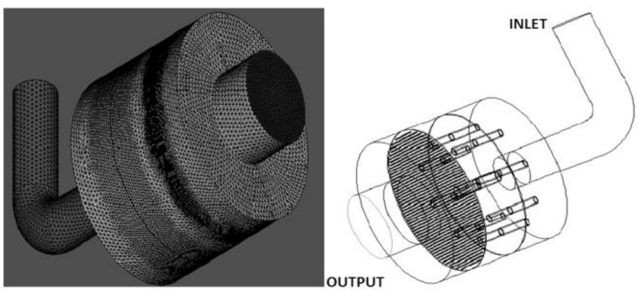

Fig 2-Surface Mesh Model of Silencer (Hyper mesh)

Inside of silencer there are two plates one of that having one centre and eight peripheral pipes of different dimensions and the second plate having the perforated plate having 4 mm holes in all over.

The geometry created in CATIA NX5R20 software.

IV. COMPUTATIONAL MESH

The surface mesh is created using triangular elements by HYPERMESH. For the Silencer geometry, unstructured mesh has to be created and triangular element is good choice for unstructured mesh.

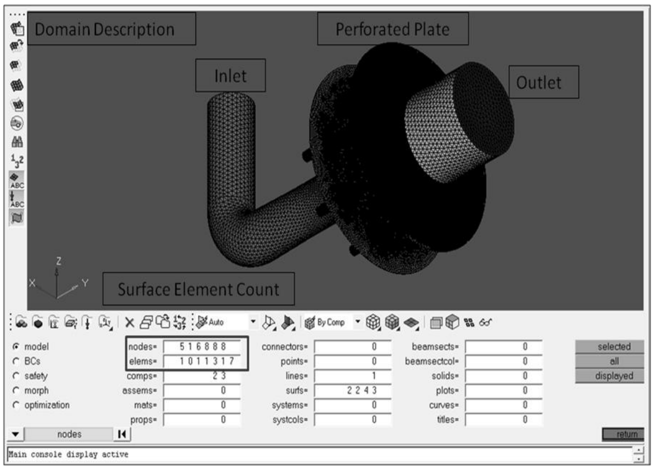

Fig 3: surface mesh of Silencer Using HYPERMESH.

Above fig. shows the Surface Mesh inside geometry of silencer having perforated plate & another plate having small peripheral eight pipes with center pipe. The volume mesh is created using tetrahedral cells by TGRID.

V. CFD SIMULATION SETUP

In the CFD Simulation, We Considering The numerical solver of pressure-based approach was developed for low-speed incompressible flows. As the flow in Silencer is turbulent, the realizable k-ε turbulence physical model is selected with standard wall function. The realizable k-ε model contains a new formulation for the turbulent viscosity and also provides superior performance for flows involving rotation, boundary layers under strong adverse pressure gradients, separation, and recirculation.

The fluid model is comprised of gas (air). The important properties of air used in this simulation are **Density** -1.225 Kg/m^3, **Dynamic viscosity-** 1.789×10^{-5} Kg/ms. The operating conditions for the CFD analysis are set to the standard atmospheric pressure conditions i.e. 101325 Pascal. When solving the Navier-Stokes equation and continuity equation, appropriate initial conditions and boundary conditions need to be applied. A wide range of boundary conditions types permit the flow to enter and exit the solution domain:

– General: Velocity inlet, pressure outlet.
– Incompressible flow: velocity inlet, outflow.
– Compressible flows: mass flow inlet, pressure far-field.
– Special: inlet vent, outlet vent, intake fan, exhaust fan.

Pressure-velocity coupling algorithms are used to derive equations for the pressure from the momentum equations and the continuity equation. The most commonly used algorithm is the SIMPLE. The strength of the SIMPLE method is that together with implicit time treatment of the flow variables, steady state solution can be obtained efficiently.

VI. RESULTS AND DISCUSSION

In the present study, various modifications on the geometry of base silencer were tried out to optimize the Acoustic performances and backpressure. The base model is a three-pass silencer, which consists of three chambers, One Solid plate & one perforated plate and Solid Plate consist of one Central tube & Eight Peripheral tubes (Fig. 2). The perforated Plate is having Hole

Size of 4mm. The strategy adopted during the study was to reduce the backpressure & the Acoustic performance.

VII. STRATEGY FOR DESIGN OPTIONS:

In this optimization study of silencer, Four options were tried out to find the sensitivity of geometrical attributes like perforations, tube diameters, baffles, and chamber lengths on the silencer performance. Parametric studies were initiated with existing silencer as the base geometry and progressively varying its different geometrical attributes. In the process of iterations, the latest option at stage of iteration considered the positive attributes of the earlier option. The modifications tried on existing silencer were: providing unequal chambers (Option 1), Change in inlet pipe Shape. (Option 2), and increase in perforations on plate (Option 3) Combination Of above option which gives the best Result (Option 4). In all these options, total volume was equal to that of base silencer and cross section was selected due to space constraints.

A. Baseline Model

Following Fig Shows, the Base model Of Silencer. In that, there are 3 equal Chamber. Between chamber 2 & 3 there are one Central & eight Peripheral tubes. Perforated plate nearby Chamber 3 with hole size of 4 mm.

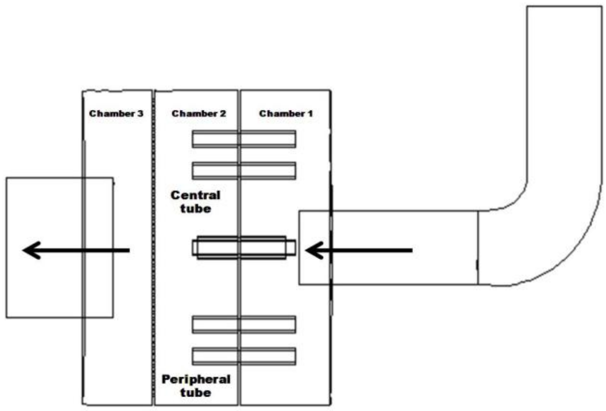

Fig 4: Base Model Of silencer.

CFD analysis shows that backpressure up to 9367.06 pa and Acoustic level is at inlet 118.56 db & 124.87 db at outlet.

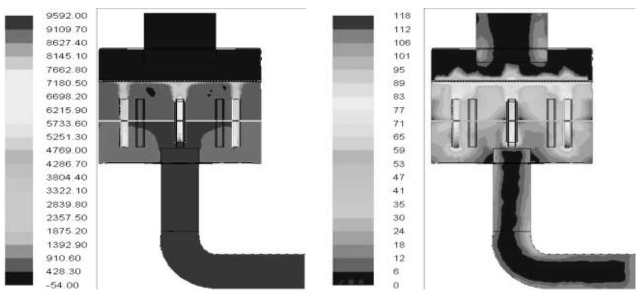

Fig 5: Pressure Drop & Acoustic Level (db) of base model.

B. Option – 1 providing unequal chambers

In this option chamber lengths for 1 and 3 were made unequal and middle chamber length was unchanged. Chamber 3 was moved by 60 mm towards outlet to prevent the accumulation of fluid pressure (Fig.6).

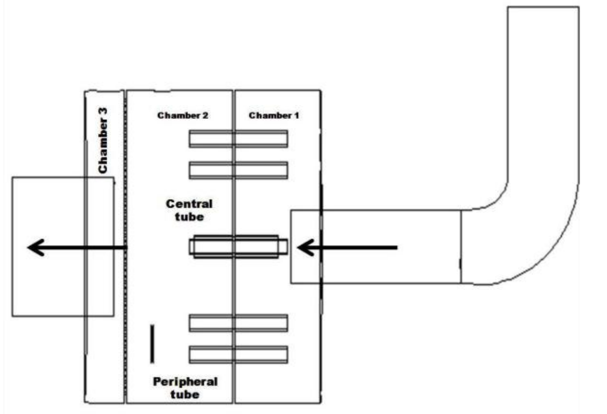

Fig 6: Chamber 3 plate moved by 60 mm towards outlet.

CFD analysis showed that backpressure was reduced by 126.75 pa from base simulation (Table I). Simulated Acoustic results vary up to 13.1% from base model.

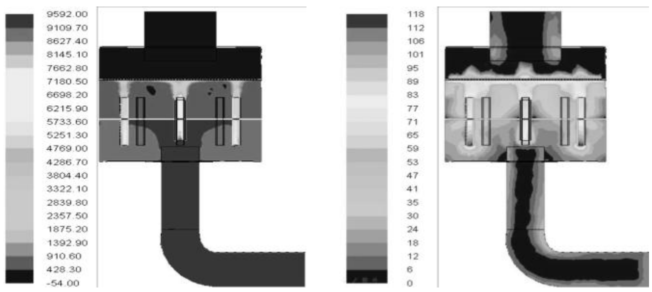

Fig 7: Pressure Drop & Acoustic Level (db) of unequal chamber silencer.

C. Option 2: Change in inlet pipe Shape.

In option 2, the Shape of the inlet pipe was Change from the base silencer and other geometry details are the same as of Base model. The pressure losses are proportional to the square of fluid velocity [1] and therefore the increase in diameter would reduce backpressure.

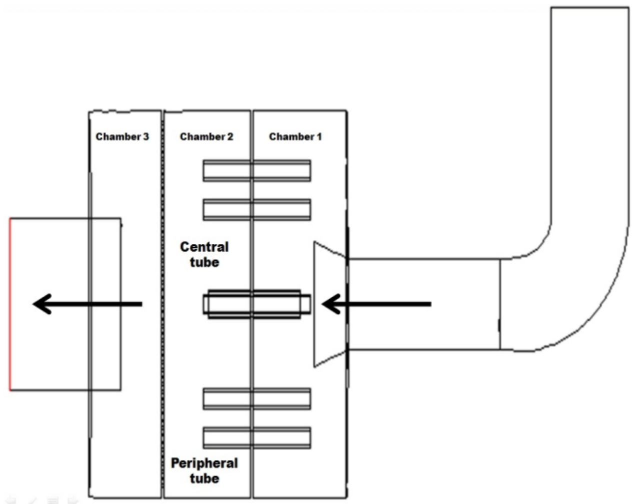

Fig 8 : Chang e in inlet pipe Shape of Silencer.

CFD analysis showed that backpressure was reduced by 245.57 pa from base simulation (Table I). Simulated Acoustic results vary up to 7.9% from base model (Table-II).

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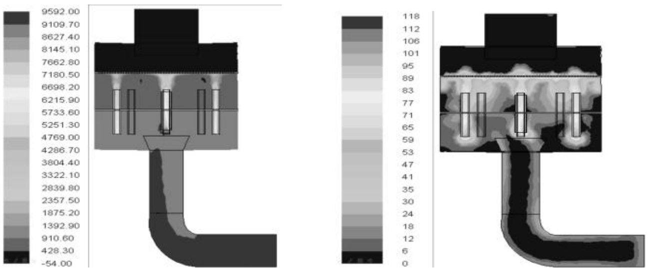


Fig 9: Pressure Drop & Acoustic Level (db) of Increase the inlet pipe diameter silencer.

D. Option 3 (Perforated Baffles):

In previous options, the fluid flow path was restricted due to solid baffles, which cause pressure accumulation in the First & Second chamber. In order to facilitate uniform flow distribution across the chambers, perforated baffles were introduced (Fig. 10).

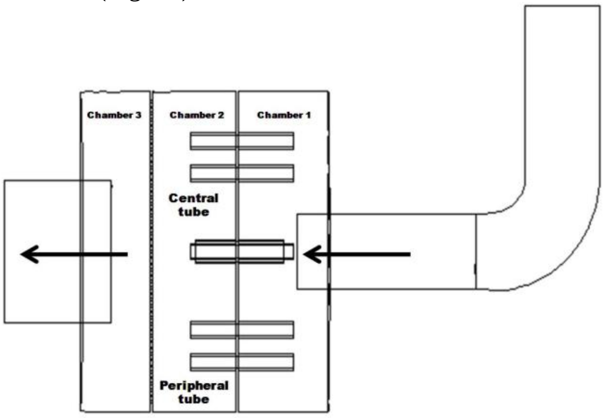


Fig 10 : Perforated Baffles of Chamber 3 plate.

The CFD results show there is a reduction in backpressure by 251.62 pa From Base model (Table I). The predicted Acoustic results vary up to 20.1% from base model (Table-II).

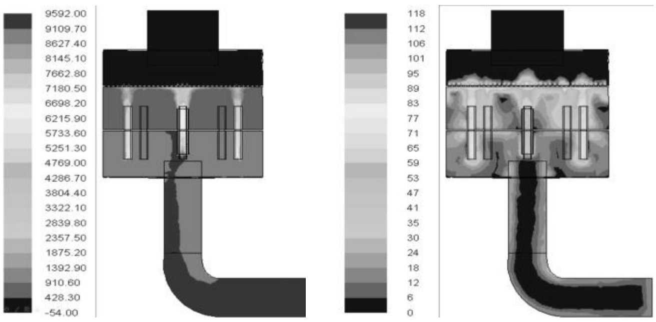


Fig 11: Pressure Drop & Acoustic Level (db) of Increase the diameter of perforate Baffles silencer.

E. Option 4: Option 2 + Option 3

It was observed in options 3 that, increase of perforation percentage and Change Shape of inlet pipe in option 2 gives good reduction of backpressure. Option 4 is built with increase in perforation and diameter of inlet pipe, similar to the design changes in option 2 and 3.

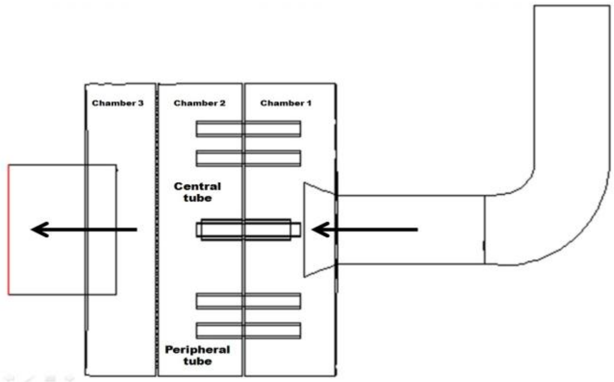


Fig 12: Increase of Perforation Percentage and Change Shape of Inlet Pipe.

Reduction of 245.57 pa was observed from CFD results in option 2 (Table-I). Compared to reduction of 251.62 pa in option 3, this option gives reduction backpressure up to 454.47 pa From Base model (Table-II). Acoustic results vary up to 44.6% from base model. This indicates that sensitivity of two parameters - porosity and tube diameter is creating a lot of difference.

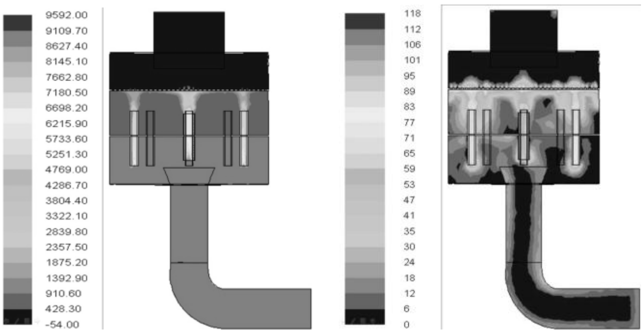
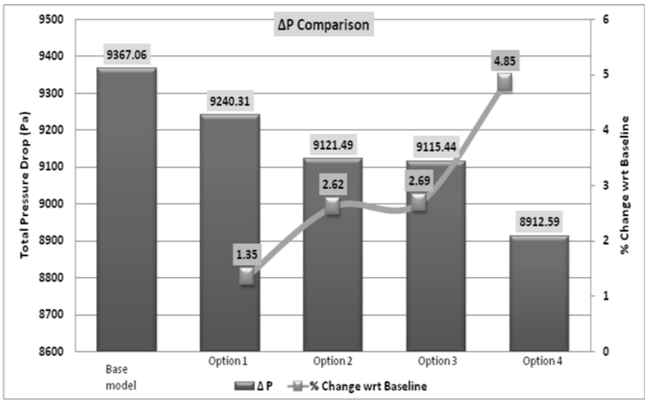


Fig 13: Pressure Drop & Acoustic Level (db) of Increase the diameter of perforate Baffles & inlet pipe silencer.

The Total Pressure Drop Summarise Results with All the Option Changes in the Geometry Are Shown In Below,

Table I: Total Pressure Drop of All the Silencer

Total Pressure Drop				
Cases	**Pressure Inlet (pa)**	**Pressure Outlet (pa)**	**Δ Pressure (pa)**	**% Change with respect to Base model**
Baseline	**9392.85**	**25.79**	**9367.06**	
Option 1	**9291.78**	**51.46**	**9240.31**	**1.35%**
Option 2	**9147.99**	**26.50**	**9121.49**	**2.62%**
Option 3	**9142.94**	**27.50**	**9115.44**	**2.69%**
Option 4	**8940.75**	**28.16**	**8912.59**	**4.85%**

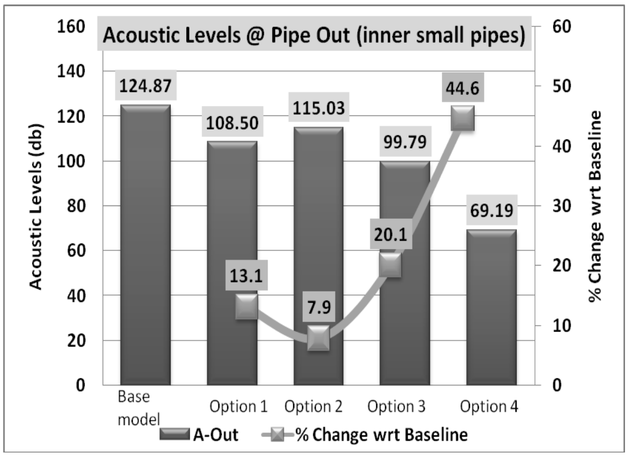


Graph 1: Total Pressure Drop of All the Silencer

The Total Pressure Drop Summarise Results with All the Option Changes in the Geometry Are Shown In Below,

Table II: Acoustics Level At Pipe Inlet-Outlet of Silencer.

Acoustics Level At Pipe Inlet-Outlet				
Cases	Acoustics Level Inlet (db)	Acoustics Level Outlet (db)	Δ Acoustics Level (db)	% Change with respect to Base Model
Baseline	118.56	124.87	-6.32	
Option 1	103.27	108.50	-5.23	13.1%
Option 2	109.15	115.03	-5.88	7.9%
Option 3	97.48	99.79	-2.31	20.1%
Option 4	59.14	69.19	-10.05	44.6%



Graph 2 : Acoustics Level At Pipe Inlet-Outlet of Silencer.

VIII. CONCLUSION

Option 4 was the best optimized design achieved using integrated methodology, which meets the acoustic as well as backpressure target requirements. This study presents a benchmark methodology for the optimized design of silencer, which takes into account the noise as well as the backpressure constraints and finds the performance parameters like Acoustic performance (db) and backpressure, which form the basis for the design of silencer. This methodology helps the manufacturer as well OEMs to reduce the design cycle time for silencer.

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