Internal Flow Simulation of a Multi-Chamber Flow Splitting Muffler

Dharni Vasudhevan Venkatesan, Mohanraj Murugesan, Harish Kumar Navaroj, Jijith Radhakrishnan, and Sanal Kumar.V.R

***Abstract*—**In this paper authors made an attempt to simulate the internal flow features of a multi-chamber flow splitting muffler with different geometric and fluid dynamic options for its design optimization. The entry area ratio of inlet channels is taken as 1.7. With this geometry different combinations of nozzle holes are tried based on the given envelop. Through various parametric analytical studies the authors observed that the multi-chamber flow splitting muffler with the given area ratio and different combinations of nozzle holes the muffler designer could reduce the sound level of any automotive vehicle on the order of 5 - 7 % compare to the existing Flow-master muffler with the same operating conditions. Authors comprehended that any exhaust system designer can further achieve reduction in the sound level through prudent design options, viz., optimized impingement angle, optimised inlets area ratios and suitable aerodynamic contours.

***Keywords*—**Particle impingement muffler, Flow splitting Muffler, Noise suppression, Silencer.

I. Introduction

The muffler is engineered as an acoustic soundproofing device designed to reduce the loudness of the sound pressure created by the engine by way of acoustic quieting [1]-[10]. It is well known that mufflers are installed within the exhaust system of most internal combustion engines. The majority of the sound pressure produced by the engine is emanated by the vehicle, using the same piping used by the silent exhaust gases. These gases are absorbed by a series of passages and chambers, lined with roving fiberglass insulation and/or resonating chambers. These are harmonically tuned to cause destructive interference wherein opposite sound waves cancel each other out. An unavoidable side effect of muffler use is an increase of back pressure which decreases engine efficiency. This is because the engine exhaust must share the same complex exit pathway built inside the muffler as the sound pressure that the muffler is designed to mitigate.

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In most motorcycles all or most of the exhaust system is visible and may be chrome plated as a display feature. Aftermarket exhausts may be made from steel, aluminum, titanium, or carbon fiber. Motorcycle exhausts come in many varieties, depending on the type of engine and its intended use. A twin cylinder may flow its exhaust into separate exhaust sections, such as seen in the Kawasaki EX250 (also known as the Ninja 250 in the US, or the GPX 250). Or, they may flow into a single exhaust section known as a two-into-one (2-1). Larger engines that come with 4 cylinders, such as Japanese super sport or superbikes (such the Kawasaki ZX series, Honda's CBR series, Yamaha's YZF series, also known as R6 and R1, and Suzuki's GSX-R series) often come with a twin exhaust system. Admittedly all these exhaust systems produce reasonable sound level, which warrant for further sound isolation. Design of mufflers is a complex function that affects noise characteristics, emission and fuel efficiency of engine. Therefore muffler design becomes more and more important for noise reduction. Traditionally, muffler design has been an iterative process by empirical technique. However, in the recent past the theories and science that has undergone development of muffler, has given a way for an engineer to cut short the trial and error design technique.

Noise isolation, is isolating noise to prevent it from transferring out of one area, using barriers like deadening materials to trap sound and vibration energy. An acoustic Scientist can provide many ways to quieting the machine. The challenge is to do this in a practical and inexpensive way. The Scientist might focus on changing materials, using a damping material, isolating the machine, running the machine in a vacuum, or running the machine slower. During acoustic decoupling, certain parts of a machine can be built to keep the frame, chassis, or external shafts from receiving unwanted vibrations from a moving part. Literature review reveals that Volkswagen has registered a patent for an "acoustically decoupled underbody for a motor vehicle (U.S. Patent 5,090,774). Also, Western Digital has registered a patent for an "acoustic vibration decoupler for a disk drive pivot bearing assembly (U.S. Patent 5,675,456). Dharni Vasudhevan et al., [1] made an attempt, to design a Muffler with multi-chamber, facilitated for engine exhaust flow splitting and mixing, for patenting. Note that, aforesaid authors' patent is inherently different than the existing Muffler design, owing to the fact that its design is unique and the particle impingement theory and the noise suppression method behind the design is cogent. This is the first generation of such type of silencer and this technology can be made use for any industrial exhaust system for noise suppression. Nevertheless, design optimization of the multi-chamber muffler is still a daunting task. In this connected paper authors made an attempt, to simulate the internal flow features of a multi-chamber flow splitting muffler with different geometric and fluid dynamic options for its design optimization.

II. Numerical Methodology

Numerical simulations have been carried out with the help of a three-dimensional standard k–omega model. This turbulence model is an empirical model based on model transport equations for the turbulence kinetic energy and a specific dissipation rate. This code solves standard k–omega turbulence equations with shear flow corrections, using a coupled second-order-implicit unsteady formulation. In the numerical study, a fully implicit finite volume scheme of the compressible, Reynolds-averaged, Navier–Stokes equations is employed. Compared to other available models, this model could well predict the turbulence transition in duct flows and has been validated through benchmark solutions.

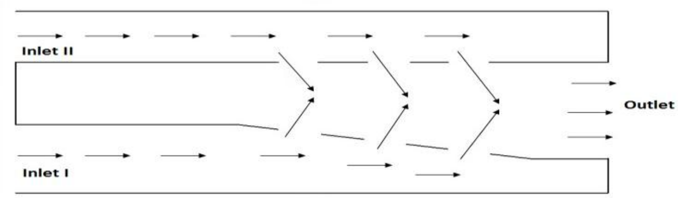

Fig. 1 The idealized physical model (upper half) of a multi-chamber flow splitting Muffler

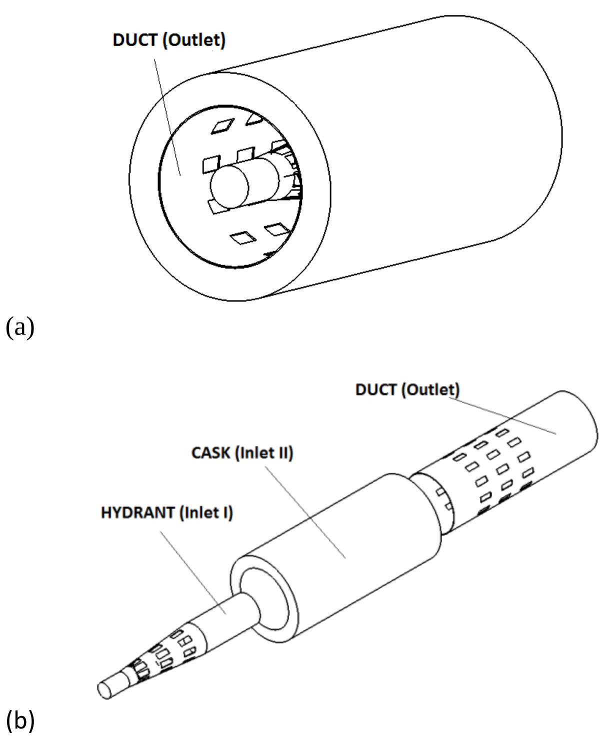

Fig. 2(a-b) show assembled and exploded view of the multi chamber flow splitting muffler.

The physical model of the multi-chamber flow splitting muffler is shown in Fig.1. Figures 2(a) & (b) show assembled and exploded view of the multi chamber flow splitting muffler.

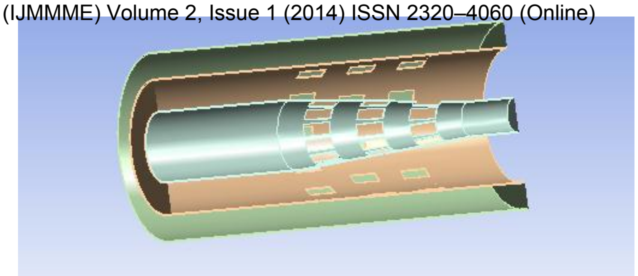

Fig. 3 Cut section view of the multi chamber flow splitting muffler.

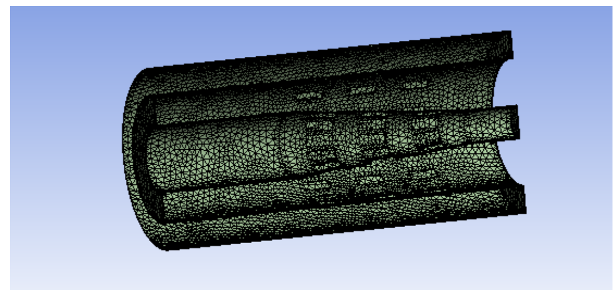

Fig. 4 Typical 3D grid system in the computational domain

As a first step, the authors made an attempt to compare the acoustic level of 2D and 3D model for the proposed and existing cases. We have found that it is varying marginally at the outlet. Therefore, we have taken 2D model of the proposed muffler for comparison with the existing model. This is done for reducing the computational time. However, we have generated 3D results for the proposed model, as well. Figure 3 shows the cut session view of the multi chamber flow splitting muffler. Typical 3D grid system in the computational domain is shown in Fig. 4. The grids are clustered near the solid walls using suitable stretching functions. At the solid walls a no-slip boundary condition is imposed. The Courant–Friedrichs–Lewy number is suitably chosen and ideal gas is selected as the working fluid. The muffler geometric variables and material properties are known *a priori*. In this paper, the authors further made attempts for the geometrical as well as fluid dynamic optimization of the multi-chamber muffler, by varying the length to diameter ratio. This is done for facilitating different angles of jet impingement to achieve best results.

III. Results and Discussion

The job description of a muffler is simple, viz., noise reduction; but its design optimization is a challenging task. Once internal combustion takes place, the engine expels exhaust gasses in the form of high pressure pulses. These high pressure pulses create very powerful sound waves, and the muffler is tasked with reducing this powerful sound to a tolerable level. While the job description is simple, the way in which a muffler performs its main task is more varied and complicated. Ideally, an aftermarket muffler will provide a good performance exhaust tone without creating too much power-stealing backpressure. Depending on the style, a muffler uses some combination of baffles, chambers, perforated tubes, and/or sound deadening material to achieve this goal.

In this paper, the authors essentially focused on the geometrical as well as the fluid dynamic aspect of noise suppression. Accordingly, design optimization has been carried out using a three dimensional k-omega model.

The entry area ratio of inlet channels ($A_{\text{hydrant inlet}}/A_{\text{cask inlet}}$) is taken as 1.7. With this geometry different combinations of nozzle holes are tried, based on the given envelop. For demonstrating the merits of this invention, the inventors have conducted a case study using a computational fluid dynamics model and compared the sound level with one of the typical Flow-master mufflers. Figures 5 and 6, shows the acoustic level comparison of both existing, and the proposed mufflers. Figure 7 shows a graph comparing the acoustic levels of both existing and proposed muffler. The line of reference is shown. A steep rise is noticed in the acoustic levels due to the recirculation of the flow. It is evident from Figs. 5-7 that the proposed multi-chamber flow splitting muffler is superior to the exiting muffler. Therefore, the authors made an attempt for the hot internal flow simulation of multi-chamber flow splitting muffler using the 3D turbulence model.

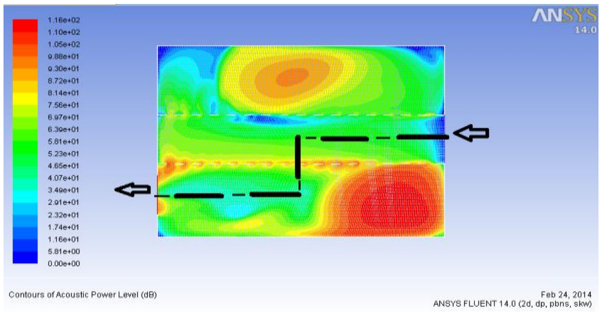

Fig. 5 Demonstrating the acoustic level of 2d existing case (FLOW MASTER)

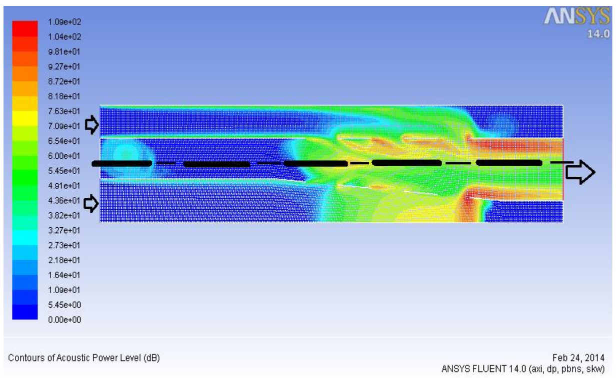

Fig. 6 Demonstrating the acoustic level at various inner locations of the proposed multi-chamber flow splitting muffler unit.

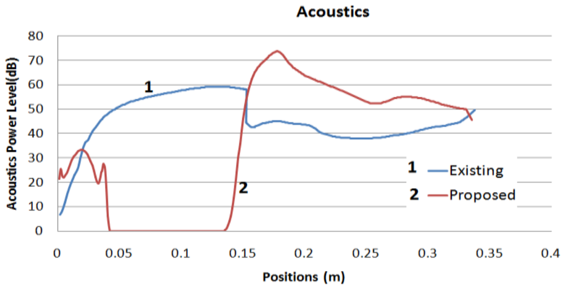

Fig. 7 Comparison of the acoustics levels of the existing and the proposed multi-chamber flow splitting muffler, corresponding to the line of reference shown in Figures 5 & 6.

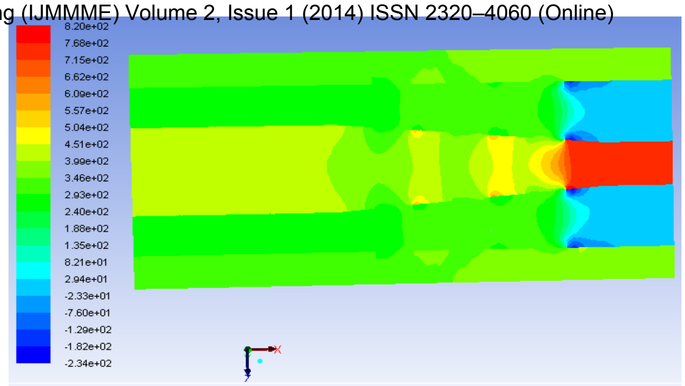

Fig. 8 Demonstrating the pressure level at various inner locations of the entire unit.

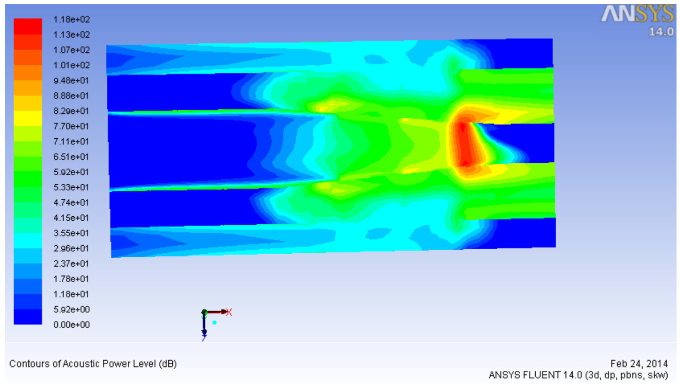

Fig. 9 Demonstrating the acoustic level of the multi-chamber flow splitting muffler.

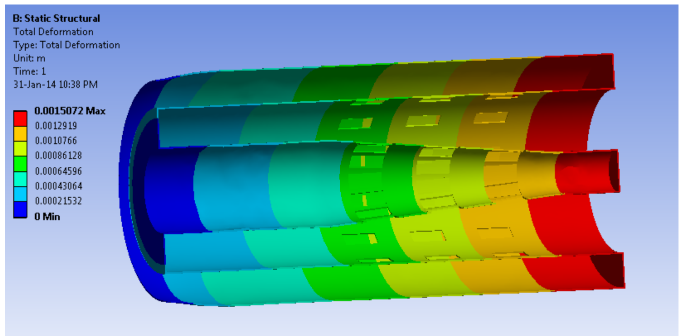

Fig. 10 Demonstrating the temperature level at various inner locations of the multi-chamber flow splitting muffler.

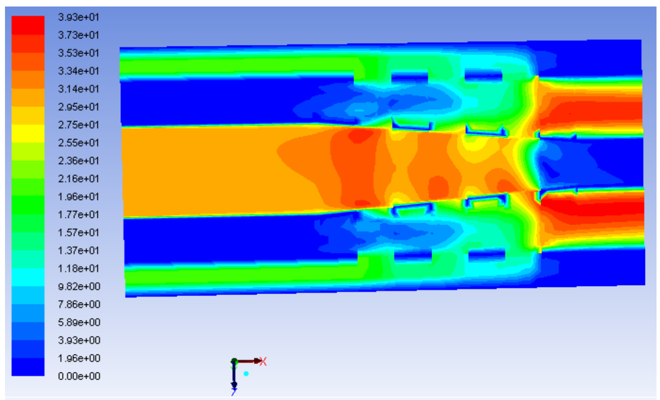

Fig. 11 Demonstrating the velocity level at various inner locations of the multi-chamber flow splitting muffler.

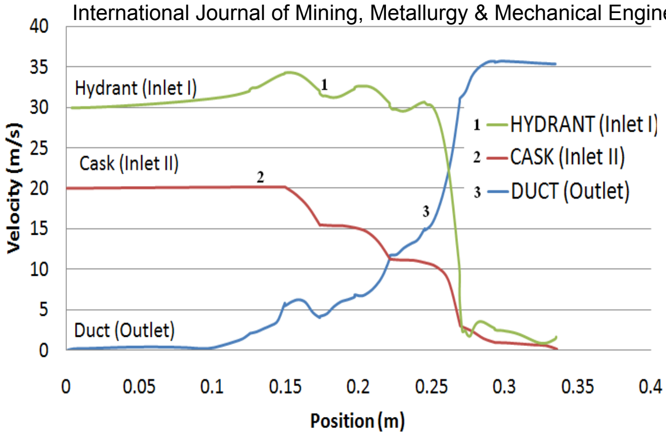

Fig. 12 Demonstrating the axial velocity variations of both inlets and outlet of the multi-chamber flow splitting muffler.

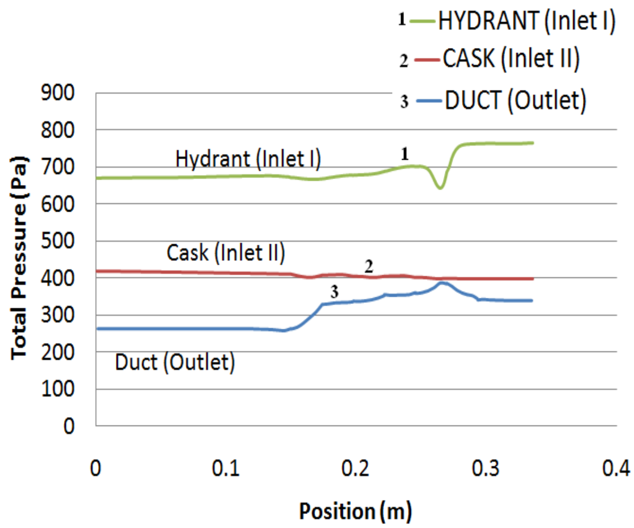

Fig. 13 Demonstrating the pressure level variations at the axial locations of both inlets and outlet of the multi-chamber flow splitting muffler.

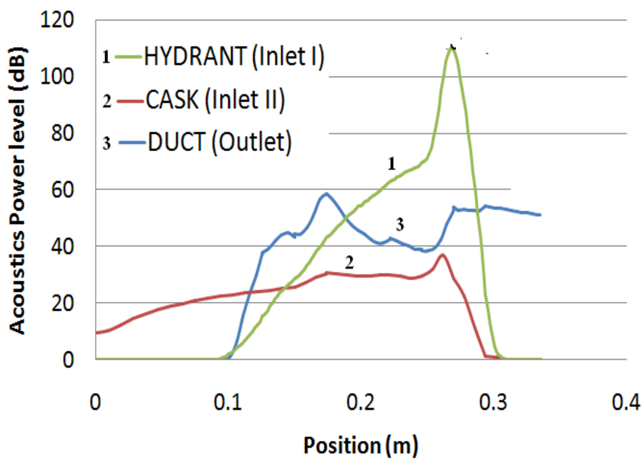

Fig. 14 Demonstrating the acoustics level variations at the axial locations of both inlets and outlet claiming the damping of sound at the outlet of the multi-chamber flow splitting muffler.

Figures 8-14 show the said computational results, for establishing the facts that the multi-chamber flow splitting muffler using the particle impingement technique is superior for sound reduction than the existing mufflers. In the analysis inlet velocities are taken as 20 m/s (Inlet 1) and 30m/s (Inlet 2) and corresponding inlet pressures are 43 MPa and 30 MPa respectively. Inlet temperature is taken as 650 K.

IV. Concluding Remarks

The multi-chamber flow splitting muffler is more efficient and lucrative than the existing mufflers, owing to the fact that the present system is entirely utilizing the particle impingement theory for the self noise suppression. With the given inlet channel area ratio and 36 numbers of nozzles in the outlet, we could reduce the sound level on the order of 5-7 % compare to the existing Flow-master muffler with the same operating conditions. Additionally, one could reduce the total weight of the unit by 50 % leading to the reduction of the total material cost. Through various parametric analytical studies, the authors observed that the multi-chamber flow splitting muffler with the given area ratio and different combinations of nozzle holes any automotive vehicle could reduce the sound level on the order of 5-7 % compare to the existing Flow-master muffler with the same operating conditions. Authors comprehended that any automotive muffler designer or industrial exhaust system designer can further achieve reduction in the sound level, through prudent design options, viz., optimized impingement angle, optimized inlets area ratios and suitable aerodynamic contours.

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