Vibration Analysis and Experimental Testing of Existing 3-Wheeler Automotive Muffler Using Modal and FFT Analyzer

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Abstract: *A muffler is a device used to reduce the noise and vibration of gas emitted by internal combustion engine. So, it become a necessary equipment in automobile to have a proper emission of gases to surrounding. Due to improper design some muffler decreases the mass flow rate due to which there is increase in fuel consumption, large pressure drops across its cross section and higher knock sensitivity. In present project existing 3-wheeler vehicle muffler is experimentally tested with FFT analyser (Impact Hammer Test) technique to determine the mode shapes, natural frequencies and thermal heat flux analysis and FEA analysis is performed in ANSYS software to validate the experimental results.*

Keywords: Modal Analysis, Exhaust system, Structural Dynamics, Finite Element Method, FFT Analyzer.

I. INTRODUCTION

Mufflers are installed within the exhaust system of most internal combustion engines. The muffler is engineered as an acoustic device to reduce the loudness of the sound pressure created by the engine by acoustic quieting. The noise of the burning-hot exhaust gas exiting the engine at high speed is abated by a series of passages and chambers lined with roving fiberglass insulation and resonating chambers harmonically tuned to cause destructive interference, wherein opposite sound waves cancel each other out. The function of a Muffler or a Silencer in Vehicle is to cool the exhaust gases by expansion through it and to reduce the noise of outgoing gases. The exhaust gases must be discharged into the atmosphere with minimum restriction. The restriction in flow of exhaust gases causes back pressure.

An unavoidable side effect of this noise reduction is restriction of the exhaust gas flow, which creates back pressure, which can decrease 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. Modern engine architectures do require gas flow handling on small space. At Ford, an advanced boosting concept has been investigated where two turbo chargers are served via two separate integrated exhaust manifolds. This boosting system has been applied to the EU Horizon 2020 Project 'GasOn', where four automobile manufacturers and more than 20 suppliers and research partners are going to demonstrate the efficiency potential of compressed natural gas (CNG) as fuel. There are four types of mufflers found mentioned below,

1.1 Types of Mufflers

1. Multiple Baffle Silencers

In a multiple baffle silencer, the exhaust gas escapes through holes that are punched in the walls of the silencer tube. This results in muffling the sound via pulse reflection. These are fairly restrictive.

2. Turbo Silencers

Turbo silencers have an S-shaped path that allows gas to enter the silencer prior to being forced out into the tube. These are restrictive and have poor gas flow.

3. Straight-Through Silencers

Straight-through silencers make use of a perforated tube. Here, the gas is enforced from the inlet of the silencer to the outlet. This happens with little flow restriction. The holes in the pipe lets the gas release silently.

4. Performance Silencers

Performance silencers change how your car sounds by using their resonating chamber in order to amplify and tune the existing exhaust note. These types of silencers often result in a deeper and more aggressive sound in comparison to standard mufflers.

1.2 Selection of Muffler

In this case we have used exhaust muffler of 3-Wheeler vehicle. Durable exhaust system design, development and manufacturing is mandated for the vehicle to be competitive and comparative. Material selection for the exhaust system plays a vital role due to the increased warranty requirements and regulatory compliances. Physical, chemical and mechanical characteristics of the materials used for conventional and special applications are compared. Exhaust system materials should possess high temperature oxidation resistance, thermomechanical vibration resistance, external salt corrosion resistance and internal acid/base corrosion resistances. Internal components such as inner cones, baffle plates, retainer rings, perforated pipes and external components such as hanger rod, outer shell, heat shield, end caps outer cones, flex tube, manifold etc. should be able to withstand high thermal impact and vibrations caused by road load, thermal load and engine load. The effect of additives such as Ti, Mo, Mn and Si to the base steel material is presented. Properties of mild steel, stainless steel and aluminized steel are compared. Applications of special materials such as Inconel, FeCr Alloy, 18CrCb and A286 are discussed in detail.

Fig. 1: Existing 3-wheeler muffler

Mufflers are installed within the exhaust system of most internal combustion engines. The muffler is engineered as an acoustic device to reduce the loudness of the sound pressure created by the engine by acoustic quieting. The noise of the burning-hot exhaust gas exiting the engine at high speed is abated by a series of passages and chambers lined with roving fiberglass insulation and resonating chambers harmonically tuned to cause destructive interference, where in opposite sound waves cancel each other out.

An unavoidable side effect of this noise reduction is restriction of the exhaust gas flow, which creates back pressure, which can decrease 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. Modern engine architectures do require gas flow handling on small space. At Ford, an advanced boosting concept has been investigated where two turbo chargers are served via two separate integrated exhaust manifolds. This boosting system has been applied to the EU Horizon 2020 Project 'Gas On', where four automobile manufacturers and more than 20 suppliers and research partners are going to demonstrate the efficiency potential of compressed natural gas (CNG) as fuel.

Today, finite element and other numerical models are used very commonly for predicting deflections and stresses of structures. However, analysts validate very few of the results or even the assumptions. Convenient but unrealistic values are often chosen because many properties of the physical structure are very difficult to measure. For example, deflections are often specified to be zero (fixed boundary conditions) at attachment points. Unrealistic boundary conditions lead to inaccurate modal properties. Based on modal properties, one can calculate the response (stresses, deflection, etc.) of the structure to forces.

Thus, wrong boundary conditions may lead to dangerously misleading dynamic calculations. Damping factors or loss factors are required in FE modelling to predict deflections and stresses caused by dynamic loads. Finite element modelers often have to pick damping factors at random because damping is impossible to obtain accurately from material properties and geometry alone. Away from resonant frequencies of the structure, incorrect damping factors do not cause serious errors in dynamic response computation.

However, near or at resonance frequencies, incorrect damping factors are likely to result in gross miscalculation in lightly damped structures such as the car exhaust. Furthermore, in such structures responses near resonance are much more severe than responses away from resonance. Thus, EMA is necessary in creating realistic FEM.

II. Problem Statement

Experimental and numerical analysis of existing 3-wheeler muffler to study the effect of deformation, mode shapes, natural frequencies and thermal heat flux using ANSYS software and FFT technique.

2.1 Objective

- Experimental and numerical modal and thermal analysis of existing and modified 3- wheeler muffler.
- FEA analysis of existing and modified 3- wheeler muffler to determine mode shapes, natural frequencies and thermal heat flux across it using modal, thermal analysis in ANSYS software.
- Experimental analysis of modified 3-wheeler muffler using FFT analyser technique (impact hammer test) to determine mode shapes, natural frequencies.
- Validation of experimental and numerical results.

2.2 Methodology

- Modelling of existing 3-wheeler muffler in CATIA software.
- Numerical analysis in ANSYS software to determine the mode shapes, natural frequencies and thermal heat flux across 3-wheeler muffler.
- Experimental analysis of modified 3-wheeler muffler using FFT analyser technique (impact hammer test) to determine mode shapes, natural frequencies.
- Comparison of results obtained by experimental and numerical analysis by FFT and FEA results.

III. Literature Review

1. OPTIMAL AUTOMOBILE MUFFLER VIBRATION AND NOISE ANALYSIS, Sujit Kumar Jha and Ajay Sharma, International Journal of Automotive and Mechanical Engineering (IJAME) ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online); Volume 7, pp. 864-881, January-June 2013

In this paper it is discussed about the muffler is the main part of the Automobile Exhaust System, consisting of fibrous and porous materials to absorb noise and vibrations. The exhaust gas mass coming from the engine can produce resonance, which may be the source of fatigue failure in the exhaust pipe due to the presence of continuous resonance. The modes on the muffler should be located away from the engine's operating frequencies in order to minimise the resonance. The objective of this paper is to determine the frequencies that appear at the modes, which have the more adverse effect during the operation of the automobile. An impact test has been conducted by applying the force using a hard head hammer, and data generated have been used for plotting a graph of the transfer functions using MATLAB. Six points have been selected, namely 1, 2, 3, 4, 7, and 11 on the muffler for the impact test. The collected data from theses six points have been analysed for the addition of damping. Results suggests that increasing the mass increases the damping and lowers the modes of the transfer function. Further research will identify higher strength materials that can withstand the higher gas temperatures as well as the corrosion and erosion by the gas emitted from the engine. An effort has made to review the various techniques used for the measurements of noise and vibrations of an automobile. This research conducted experiments to analyse a muffler system with impact testing. The impact force has been applied by a hammer and an accelerometer has been used to determine the output response. According to the test results, the muffler design can be changed based on the resonant frequencies of the system. MATLAB has used to determine the resonance frequency and to plot a graph of the transfer functions for each data point labelled on the muffler. From the collected data sets in Table 2, five peaks have occurred at 120, 240, 560, 730, and 880 Hz, which were identified as prospective resonance frequencies to be eliminated from the muffler system. Furthermore, the resonance frequencies can be minimised by adding damping to the system.

2.Acoustic attenuation performance of perforated dissipative mufflers with empty inlet/outlet extensions F.D. Dania, _, A. Selametb, F.J. Fuenmayora, R. Kirby, Journal of Sound and Vibration 302 (2007) 1000–1017

In these articles it presents the acoustic behaviour of perforated dissipative circular mufflers with empty extended inlet/outlet is investigated in detail by means of a two-dimensional (2D) axisymmetric analytical approach that matches the acoustic pressure and velocity across the geometrical discontinuities, and the finite element method (FEM). The complex characteristic impedance, wavenumber, and perforation impedance are taken into account to evaluate the axial wavenumber in the fibrous material and the central perforated pipe. Two different analytical procedures are presented that allow the computation of the modal wave coefficients for the muffler sections. Benchmarking against FE calculations exhibited an excellent agreement. Both approaches are also compared with experimental work for further validation. Several effects are examined, including the extended inlet/outlet ducts, absorbent resistivity, the porosity of the perforations, and the muffler dimensions, and compared with muffler configurations of earlier studies, such as reactive extended inlet/outlet expansion chambers, dissipative mufflers without extensions, and mufflers with absorbent-filled extensions. It is shown that the use of empty extensions leads to quarter-wave resonances providing an improved acoustic performance of the muffler at low to mid frequencies. Also, the presence of sound-absorbing material partially retains the desirable behaviour of the dissipative mufflers at higher frequencies. As the resistivity of the absorbing material increases, this advantage is gradually reduced. In addition, the presence of a sound-absorbing material in the central chamber of the muffler with empty extended inlet/outlet ducts allows partial retention of the good properties of the dissipative mufflers at higher frequencies, avoiding the TL collapse of purely reactive chambers. The presence of perforated surfaces with reduced porosity produces a detrimental effect on the acoustic performance. Finally, the consideration of larger mufflers leads to a strong effect associated with the propagation of higher-order modes. The attenuation becomes more irregular and a higher number of peaks can be found as the radius is increased.

3. Modal Analysis of Exhaust System, Marcus Myrén, Jörgen Olsson, Research gate

In this paper a modal analysis was performed on a Volvo S/V 70 exhaust system. Finite element models were correlated with experimental models. It was shown that a rather simple finite element model was sufficient for describing the dynamic behaviour of the exhaust systems studied. Beam elements, rigid elements and mass elements were used. For the assembled system the agreement between theoretical and experimental natural frequencies was within approximately 10 % for the first eleven modes. This type of finite element model is therefore probably sufficient also for most other exhaust systems of similar type. For parts of the exhaust system, it was more difficult to achieve good agreement. Furthermore, it was found that further studies on some components having nonlinear characteristics are necessary if these components are to be included in the analysis in a more realistic way. If the flexible unit in the front part of the exhaust system will be included. In this work this unit was modelled by a beam element that is stiffer than the uncompressed bellows. To achieve reliable models both theoretical and experimental modal analyses should be performed, so that finite element and test models can be compared and successively improved. Free-free boundary conditions are recommended for the first models. At an early stage of the product development process the boundary conditions that the exhaust system will have under operation are not always known. By using free-free boundary conditions it is still possible to develop FE-models of the exhaust system, or parts of it, which correspond well with measurements. For example, stiffness values of connections etc. can be found. As the product development process proceeds the FE-models can then be analysed with other boundary conditions. For a good free-free hanging, many hanging points and rubber bands with low stiffness should be used.

4. Experimental Modal Analysis of Automotive Exhaust Structures, SAE TECHNICALPAPER SERIES 2001-01-0662

In these paper experimental modal analysis (EMA) is performed on many parameters that are required in numerical modelling of dynamic and vibratory behaviour of structures. This paper discusses EMA on an exhaust system of an off-road car. The exhaust structure is tested under three boundary conditions: free-free, supported with two elastomeric mounts, and mounted to the car. The free-free modal parameters are compared to finite element results. The two-mount tests are done with the mounts fixed to a rigid and heavy frame. The rigidity of the frame is verified experimentally. The on-car test is done with realistic boundary conditions, where the exhaust structure is fixed to the engine manifold as well as the two elastomeric mounts. The two-mount and the on-car tests result in highly complex mode shapes. Details discussed in the paper include obtaining the measurement point coordinates, a method to attach triaxial accelerometers to align with coordinate axes, methods to ensure rigidity of the mounting frame, and the effects of non-proportional damping from the elastomeric mounts. Results from EMA provide data and validation to numerical models such as finite element models.

5. Vibration Analysis of Muffler by using FEM and FFT Analyzer

Mr. Tushar Chindha Jagtap, Prof.Sunil S. Raut Prof. Arvind. Ambesange, IJARIIE-ISSN(O)-2395-4396, Vol-4 Issue-2 2018

In this article it represents the various types of failures and cracks are seen in mufflers due to vibration from engine and road excitations. These vibrations cause localized stresses in muffler. The natural frequency and stresses are analysed by finite element method. Hence in order to increase the natural frequency and reduce the induced stresses, the structural modification in muffler is proposed and subsequent analysis is carried out. Modal analysis is performed to evaluate natural frequency of the muffler. The baffles, perforated pipes, body are the mounting parts tend to vibrate as the excitation frequency of the source (engine). This vibration failure occurs due to resonant frequencies occurring in defined frequency range. The 'frequency match' could lead to a response detrimental to the life of the structure. FEA techniques are used in this work to avoid resonance. Physical experimentation is performed on using FFT analyser. The aim of this project is to study the existing industrial Muffler. From modal analysis, it has been observed that, by comparing first two natural frequencies of vibration of exhaust muffler by FEA and FFT analyser. The natural frequencies obtained from both the methods are agreeing with each other which are useful for designing of exhaust muffler to avoid the resonance. Modified muffler is safe from resonance because natural frequencies of modified muffler are greater than exiting muffler. Harmonic analysis was done for both models using FEA. Acceleration is reduced from 23.251 m/s2 to 4.4456 m/s2 at first natural frequency by changing the thickness and hole diameter of baffle plate.

6. Transmission loss prediction on a single-inlet/double-outlet cylindrical expansion-chamber muffler by using the modal meshing approach, Applied Acoustics 69 (2008) 173–178

In this research it is discussed about the acoustical performance prediction on a single-inlet/double-outlet cylindrical expansion-chamber muffler. Expressions for the transmission loss (TL) of the muffler are formulated by using the modal meshing approach and the plane wave theory, respectively. The parametric influence upon the values of TL for this kind of muffler is numerically analysed for various cases of length–diameter ratio, and the computed results of TL are compared to present the higher order mode effects. The results by the modal meshing approach are also compared with the finite element method to verify its accuracy**.** In this paper, a theoretical model has been developed to predict the transmission loss of a single-inlet/double-outlet rigid-walled cylindrical expansion-chamber muffler. On the basis of the method, the numerical studies show that the higher-order mode effects as the main factors cause manifest differences between the computed TL values and those calculated by the plane wave theory, especially for the acoustical short chambers. To understand and consider these effects is very important in designing practical expansion-chamber mufflers.

7. Vibrational Analysis of Muffler, Mr. Anmol Rathan Simon, Dr. K. Ashok Reddy, B. Prashanth, ISSN: 2455-2631, February 2017 IJSDR | Volume 2, Issue 2

In this paper it is about the component that reduces the intensity of the sound or decrease the intensity of the pressure pulse is called a muffler. There are various designs that are available today in market. However, there are two major types of the design in mufflers. Reactive type or Absorptive two main types of mufflers that are in employed in major day to day applications. In this study we've considered the various geometries of the mufflers that have been designed using Genetic Algorithm and would study their behaviour at varying frequency of 10-600 HZT. In the low-frequency range, reactive damping prevails. Therefore, resistive damping is not included in the model and would suggest the best configuration in use today. The geometry is modelled Catia and the effect would be studied using the processor Ansys and Hypermesh would be used as pre and post processor and suggest the optimal design conditions and suited materials for the muffler designs. The genetic algorithm is employed to optimize the muffler model for better results.

8. "Experimental Modal Analysis of Automotive Exhaust Muffler Using Fem and FFT Analyzer" Sunil, Dr Suresh P M, International Journal of Recent Development in Engineering and Technology, (ISSN 2347-6435(Online) Volume 3, Issue 1, July 2014) 185

In this literature it refers to experimental modal analysis, also known as modal analysis or modal testing, deals with the determination of natural frequencies, damping ratios, and mode shapes through vibration testing. The exhaust muffler in an automobile plays an integral role in reducing the sound of the automobile, as well as the ride itself. In order to maintain a desired noise and comfortable ride, the modes of a muffler need to be analysed. Modal analysis is done both experimentally through FFT analyser and finite element analysis. The natural frequencies obtained by both the methods agree with each other. This is useful while designing of exhaust muffler to avoid the resonance. The summaries of modal analysis of exhaust muffler under free condition were carried out using MSC NASTRAN and experimental test was conducted using Impact testing machine. The first six frequencies were nil frequency which indicates rigid body motion. The next six frequencies ranged from 313 to 701 Hz. These frequencies are the natural frequencies. From experimental modal analysis, the natural frequencies ranged from 306 to 674 Hz.

Topology and Shape Optimization of Ford Applications using Tosca Fluid by Dr. Anselm Hopf, Ford Motor Company, Aachen, Germany.

Modern engine architectures need compact designs driven by vehicle package constraints. Furthermore, an engine should fit into several vehicle applications and parts have to be modified to match all package configurations. The optimization of the individual parts and the system by Computational Fluid Dynamics (CFD) may help to minimize or even delete these drawbacks. Meanwhile, there are several powerful optimization methods for three-dimensional flows on the market. While comparing their strengths and weaknesses, efficiency and easy handling are also important for engineers in research and product development. In this paper, several Ford applications have been presented showing the optimization of three-dimensional flow problems of engine parts. The proposed solution is a combined optimization strategy using CFD topology optimization with Tosca Fluid and a following shape optimization with the Adjoint Solver (bionic design). It is easy to setup and post-process the optimization runs. The CFD engineer may generate an initial design of a new CFD optimized part and give it to the designer. So, the designer may start with an optimized design solution. The new surfaces of the parts may also serve as an idea generator of new flow shapes, which may help to extend the parameter set for parametric optimizations. In the age of additive manufacturing, a 3D print of the parts is quickly possible. For Ford, this new optimization workflow is highly efficient, reduces development time, improves result quality, and may reduce the number of expensive and time-consuming test-rig measurements.

9. Integration of exhaust manifold with engine cylinder head towards size and weight reduction by M.A. Neshan, A. Keshavarz, K. Khosravi.

In this research, a new exhaust manifold and its cooling jackets is first designed for the integrated exhaust manifold into cylinder head (IEMCH) for a turbocharged engine. Then, the gas exchange and flow analysis is carried out numerically to evaluate the proper conditions for the exhaust gas and the coolant stream respectively. Finally, the entire engine parts are thermally analysed to assure their acceptable temperature. The obtained results are compared to the base engine conditions, indicating that the new engine with IEMCH may well satisfy all its thermal limitations. It is essential to cool the exhaust runners made of aluminium in the IEMCH, in order to provide an acceptable strength and durability for the materials against high temperature gases and thermal stresses in the exhaust manifold. The water jacket of cylinder head extends to the area of exhaust runners to maintain the materials in an acceptable temperature level. The paper concludes that, Emissions reduction due to the exhaust gas leakage prevention and improvement of catalyst performance. 1.Higher heat transfer coefficient around the exhaust valves. 2.Lower coolant heat transfer coefficient in the cylinder head. 3.An improved water pump, a larger radiator and fan are required. 4.The Maximum temperature of the exhaust gas at full load decreases about 55oC. 5.The inner wall temperature of the exhaust manifold reduces from 790oC to 160oC. 6.More heat flux to the coolant. 7.There is a weight reduction of 3.2 kilograms and better layout condition for IEMCH. 8.Lower manufacture cost because of the elimination of expensive alloy, exhaust manifold gasket, bolts, and nuts. 9.Economical fuel consumption. 10.Emissions reduction due to the exhaust gas leakage prevention and improvement of catalyst performance.

10. Exhaust System Muffler Volume Optimization of Light Commercial Vehicle Using CFD Simulation by C.P. OM ARIARA GUHANa, G. ARTHANAREESWARAN, K.N. VARADARAJAN, S. KRISHNAN.

Nowadays, the automotive industry is focused on weight reduction. Main advantage of this weight reduction is improving the fuel economy. Specific fuel consumption can be improved if we focus on vehicle with light weighting. Light weighting can be done by changing material or by changing the size (dimensions) of components. In the present work we have focused on weight reduction of existing exhaust system by optimizing muffler volume with the help of 3D design tool CATIA V5 and computational fluid dynamics commercial tool ANSYS CFX. Back pressure, noise level, sound quality and exhaust gas temperature are the key important parameters for design verification. Result of this present study, existing muffler volume has been reduced by 15 % and weight reduced by 2 %. Existing muffler has been analysed and then compared with vehicle level test observation data. Noise level and pressure drop have been optimized for new muffler design. Flow properties have been analysed by using CFD for the new optimized design. Based on optimization, prototype has been built and physical test has been conducted in vehicle level. The physical test results have been validated against CFD results. The key functions of automotive engine exhaust system are carrying out hot noxious exhaust gases from engine to atmosphere and significantly attenuating noise output from the engine through muffler, quickly and efficiently. Exhaust gases originate in pulses. This is elliptical in shape with baffles placed in between We have opted to down size this muffler along its length or width or both simultaneously. It is difficult to down size the muffler along minor axis because of pipe construction and position. CFD analysis with the help of ANSYS CFX tool has been carried out for existing muffler and multiple newly designed mufflers. Results of existing muffler and final design concept of muffler are discussed; Final design concept of muffler with increased no of holes is mentioned as down sized muffler in upcoming discussion are showing the 3D geometry and cross-sectional view of existing muffler respectively.

11. Methods for evaluating in-duct noise attenuation performance in a muffler design problem by Jong Kyeom Lee, Kee Seung Oh, and Jin Woo Lee.

In this study, methods for evaluating the noise attenuation performance **Methods for evaluating in-duct noise attenuation performance in a muffler design problem by Jong Kyeom Lee, Kee Seung Oh, and Jin Woo Lee.** Of a muffler in a muffler design problem are investigated, and a proper evaluation method is suggested for actual noise reduction in a duct when an optimally designed muffler is mounted on a duct. Mathematical expressions of the transmission loss, insertion loss, and level difference for a simple expansion chamber muffler are developed from basic acoustic equations. The effects of the locations of the measurement points, tailpipe length, and impedance at the end of the duct on the noise attenuation performance calculated using the three evaluation methods are discussed. The TL and IL maximization problems formulated using topology optimization are solved for a muffler unit, and the noise attenuation performances of the optimally designed mufflers are compared when mounted on a duct. In this work, three methods (TL, IL, and LD) to evaluate the noise attenuation performance of a muffler were theoretically and computationally investigated for decreasing the discrepancy between the noise attenuation performances of an optimal muffler unit and an optimal muffler mounted on a duct. Mathematical expressions for the TL, IL, and LD described the effects of the locations of the measurement points, tailpipe length, and impedance at the duct on the noise attenuation performance calculated using the three evaluation methods. Because the LD was strongly affected by the locations of the measurement points as well as the tailpipe length and impedance at the duct end, the noise attenuation performance of a muffler unit could not be objectively evaluated. To confirm the accuracy of optimal mufflers designed using the IL, a partition volume minimization problem with a moderate IL value in the target frequency range was formulated, and the noise attenuation performance of a muffler designed optimally for broadband noise reduction was validated experimentally. These research results will contribute to reducing the discrepancy between the noise attenuation performances of a muffler unit and a muffler mounted on a duct. If they are combined with the precise calculated flow analysis results, they can be applied to duct noise reduction problems in the field of HVAC.

A Nonlinear Quasi-3D Approach for the Modelling of Mufflers with Perforated Elements and Sound-Absorbing Material by G. Montenegro, A. Della Torre, A. Onorati, and R. Fairbrother.

Increasing demands on the capabilities of engine thermo-fluid dynamic simulation and the ability to accurately predict both performance and acoustics have led to the development of several approaches, ranging from fully 3D to simplified 1D models, quasi-3D approach is proposed as a compromise between the time-demanding 3D CFD analysis and the fast 1D approach; it allows to model the acoustics of intake and exhaust system components, used in internal combustion engines, resorting to a 3D network of 3D cells. Due to its 3D nature, the model predicts high-order modes, improving the accuracy at high frequencies with respect to conventional plane-wave approaches, conservation equations of mass and energy are solved at cell centres, whereas the momentum equation is applied to cell connections including specific source term to account for the of sound-absorbing materials and perforated elements, quasi-3D approach has been validated by comparing the predicted transmission loss to measured data for a number of standard configurations typical of internal combustion engine exhaust systems: a reverse flow chamber and series chambers with perforates and resistive material. In this paper a general quasi-3D method for the acoustic modelling of silencers has been presented. the aim of this work was to show the potentialities of a quasi-3D approach for the prediction of simple and complex muffler performances with sound absorbing material and perforated elements, model has been validated on three different muffler configurations, namely a reverse chamber, an expansion chamber with one perforated pipe and an expansion chamber with sound absorptive material. The comparison between the calculated TL and the measured data has pointed out the capabilities of the model in predicting of the acoustic phenomena occurring in these mufflers. In particular, the model is able to predict the frequencies of the quarter wave resonances associated to inlet and outlet extensions, the peaks associated to perforated elements, and the dissipative effect produced by the absorptive material. The presented model is based on the pure geometrical reconstruction the mufflers and does not require the creation of an acoustically equivalent model. Moreover, due to the coarse level of mesh adopted, the computational burden of the simulations is very low if compared to other 3D CFD methods, allowing the adoption of DOE for fast muffler optimization.

Modification of Muffler design to increase exit velocity by Nagisetty Lokhesh Kumar* and K. Veladri .

The Muffler is the most predominant part of an automobile exhaust system. The function of the Muffler is to evacuate the exhaust gases from the combustion chamber, attenuating the sound created by the engine. Any minute change in the Muffler can alter the performance of the engine. The main objective of this work is to increase the exit velocity of the Muffler. A Maruti alto 800cc muffler was taken, examined and a 3d model was created. This model was analyzed for velocity at the outlet of the muffler using CFD. Alternate designs had been developed and were analyzed. Results were compared to obtain an optimized model. Modelling was done in UG NX 11.0, the analysis was carried out in CFX (fluent) Workbench 18.0. A Maruti Alto 800cc muffler was taken for this project. The outer wrapping of the muffler was removed and required dimensions were noted down. A 3D model was developed in UG NX 11.0 The first expansion chamber consists of an inlet pipe for exhaust gases and holes are drilled in the inlet pipe. Some of the gases come out through these holes and travel inside the first expansion chamber, as more gases come out space gets reduced and sound waves get cancelled out due to friction. The sound waves with more intensity travel further into the second expansion chamber. Here sound waves collide with each other and to the wall and get cancelled. The waves with the highest intensity pass through both the expansion chambers and enter into a Helmholtz resonator. In this sound waves hit the wall and come back with same frequency. This action makes them cancel out each other. Now, these gases are made to travel into the third expansion chamber, here the noise is reduced further due to friction. Now, these gases from the third expansion chamber flows out into the atmosphere through the tailpipe with considerably low noise levels and harm. The proposed designs were modelled and analyzed. This was done in order to choose the best proposed design. And accordingly design 4 was selected to be the best design as it gives an increase of exit velocity by 17.42% when compared with the existing model.

12. Enhancement of Engine Performance through analyzing internal part design on Modenas CT115s exhaust using CFD Simulation by Efi N E, Shahriman A B, Rojan M A, I Zunaidi1, Z M Razlan, W K Wan, M S M Hashim, N S Kamarrudin, A Harun, I Ibrahim and Azizul Aziz I.

Exhaust is made to make a way that guide and expel exhaust gasses far from the engine. Inside exhaust system, there are four noteworthy parts which are muffler, perforation, resonator chamber, inlet and outlet. For mechanical performance of perforated resonator can be controlled by size of holes. The aim of this paper is to analyzing internal part geometry of exhaust muffler in order to increase Modenas CT115s performance by using Ansys software as a programmed to calculate the velocity magnitude and the flow rate of exhaust muffler. Consequently, high proficiency inside the exhaust system will create a brilliant execution and high-quality performance. From the simulation shows that decreasing the size of holes give ultimately impact to performance of exhaust. Increasing the size of hole in exhaust make a huge different in simulation result. For the mass flow rate result at improvement design B show that the mass flow is 0.15644 kg/s which is the highest compared to the others design. Different result shows at the existing design result which is 0.03256 kg/s much lower than improvement design B. For velocity magnitude design B also improve from 1.876e2 m/s for existing design to 6.192e2m/s. Based on the research and analysis that had been done for internal part of exhaust which focusing on redesign the perforated tube in the muffler, the size of hole give ultimately impact to the performance of gases flow out to the surrounding. In this research, diameter of hole is decreasing 0.5mm from existing value. From the simulation result clearly shows that smaller the size of holes gives higher performance in term of mass flow rate and velocity. For this research, conclusion can be made as lower the value of diameter for perforated tube will contribute to higher performance of exhaust. Therefore, for the future work, the optimum value for size of hole and number of holes are suggested to be investigate in detail for general small engine.

IV. Design

4.1 CAD PART OF 3-WHEELER MUFFLER IN CATIA SOFTWARE

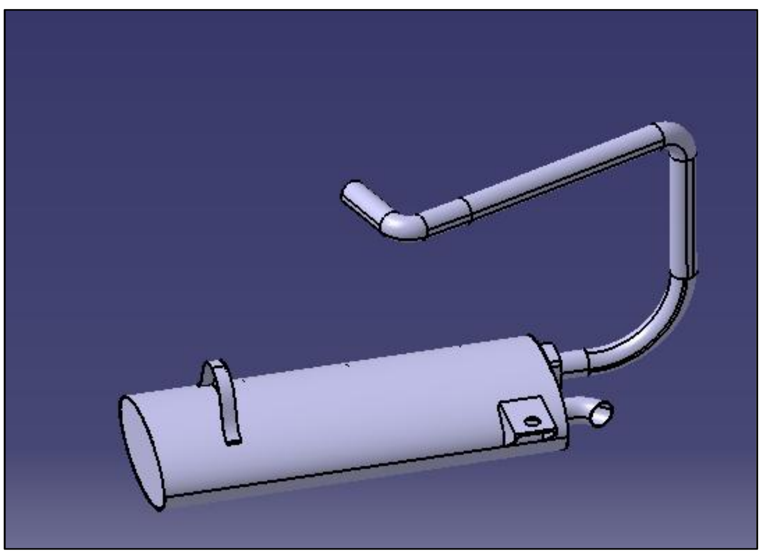

Fig. 2: CATIA model of existing 3-wheeler muffler

CAD:

Computer-aided design (CAD) is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations.

Its use in designing electronic systems is known as electronic design automation (EDA). In mechanical design it is known as mechanical design automation (MDA) or computer-aided drafting (CAD), which includes the process of creating a technical drawing with the use of computer software.

CAD software for mechanical design uses either vector-based graphics to depict the objects of traditional drafting, or may also produce raster graphics showing the overall appearance of designed objects. However, it involves more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions.

CAD may be used to design curves and figures in two-dimensional (2D) space; or curves, surfaces, and solids in three-dimensional (3D) space.

CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals, often called DCC digital content creation. The modern ubiquity and power of computers means that even perfume bottles and shampoo dispensers are designed using techniques unheard of by engineers of the 1960s. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry.

The design of geometric models for object shapes, in particular, is occasionally called *computer-aided geometric design* (*CAGD*)

Uses:

Computer-aided design is one of the many tools used by engineers and designers and is used in many ways depending on the profession of the user and the type of software in question.

CAD is one part of the whole Digital Product Development (DPD) activity within the Product Lifecycle Management (PLM) processes, and as such is used together with other tools, which are either integrated modules or stand-alone products, such as:

- Computer-aided engineering (CAE) and Finite element analysis (FEA)
- Computer-aided manufacturing (CAM) including instructions to Computer Numerical Control (CNC) machines
- Photorealistic rendering and Motion Simulation.
- Document management and revision control using Product Data Management (PDM).

CAD is also used for the accurate creation of photo simulations that are often required in the preparation of Environmental Impact Reports, in which computer-aided designs of intended buildings are superimposed into photographs of existing environments to represent what that locale will be like, where the proposed facilities are allowed to be built. Potential blockage of view corridors and shadow studies are also frequently analysed through the use of CAD.

CAD has been proven to be useful to engineers as well. Using four properties which are history, features, parameterization, and high-level constraints. The construction history can be used to look back into the model's personal features and work on the single area rather than the whole model. Parameters and constraints can be used to determine the size, shape, and other properties of the different modelling elements. The features in the CAD system can be used for the variety of tools for measurement such as tensile strength, yield strength, electrical or electromagnetic properties. Also, its stress, strain, timing or how the element gets affected in certain temperatures, etc.

TYPES

There are several different types of CAD, each requiring the operator to think differently about how to use them and design their virtual components in a different manner for each.

There are many producers of the lower-end 2D systems, including a number of free and open-source programs. These provide an approach to the drawing process without all the fuss over scale and placement on the drawing sheet that accompanied hand drafting since these can be adjusted as required during the creation of the final draft.

3D wireframe is basically an extension of 2D drafting (not often used today). Each line has to be manually inserted into the drawing. The final product has no mass properties associated with it and cannot have features directly added to it, such as holes. The operator approaches these in a similar fashion to the 2D systems, although many 3D systems allow using the wireframe model to make the final engineering drawing views.

3D "dumb" solids are created in a way analogous to manipulations of real-world objects (not often used today). Basic three-dimensional geometric forms (prisms, cylinders, spheres, and so on) have solid volumes added or subtracted from

them as if assembling or cutting real-world objects. Two-dimensional projected views can easily be generated from the models. Basic 3D solids don't usually include tools to easily allow motion of components, set limits to their motion, or identify interference between components.
There are two types of *3D Solid Modelling*

1. *Parametric modelling* allows the operator to use what is referred to as "design intent". The objects and features created are modifiable. Any future modifications can be made by changing how the original part was created. If a feature was intended to be located from the centre of the part, the operator should locate it from the centre of the model. The feature could be located using any geometric object already available in the part, but this random placement would defeat the design intent. If the operator designs the part as it functions the parametric modeler is able to make changes to the part while maintaining geometric and functional relationships.
2. *Direct or Explicit modelling* provide the ability to edit geometry without a history tree. With direct modelling, once a sketch is used to create geometry the sketch is incorporated into the new geometry and the designer just modifies the geometry without needing the original sketch. As with parametric modelling, direct modelling has the ability to include relationships between selected geometry (e.g., tangency, concentricity).

Top end systems offer the capabilities to incorporate more organic, aesthetics and ergonomic features into designs. Freeform surface modelling is often combined with solids to allow the designer to create products that fit the human form and visual requirements as well as they interface with the machine.

4.2 FEA (Finite Element Analysis)

The finite element method (FEM), is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The analytical solution of these problems generally require the solution to boundary value problems for partial differential equations. The finite element method formulation of the problem results in a system of algebraic equations. The method yields approximate values of the unknowns at discrete number of points over the domain. To solve the problem, it subdivides a large problem into smaller, simpler parts that are called finite elements.
In the first step, the element equations are simple equations that locally approximate the original complex equations to be studied, where the original equations are often partial differential equations (PDE). The process, in mathematical language, is to construct an integral of the inner product of the residual and the weight functions and set the integral to zero. In simple terms, it is a procedure that minimizes the error of approximation by fitting trial functions into the PDE. The residual is the error caused by the trial functions, and the weight functions are polynomial approximation functions that project the residual. The process eliminates all the spatial derivatives from the PDE, thus approximating the PDE locally with

- A set of algebraic equations for steady state problems,
- A set of ordinary differential equations for transient problems.

These equation sets are the element equations. They are linear if the underlying PDE is linear, and vice versa. Algebraic equation sets that arise in the steady state problems are solved using numerical linear algebra methods, while ordinary differential equation sets that arise in the transient problems are solved by numerical integration using standard techniques such as Euler's method or the Runge-Kutta method.
FEM is best understood from its practical application, known as finite element analysis (FEA). FEA as applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements, as well as the use of software program coded with FEM algorithm. In applying FEA, the complex problem is usually a physical system with the underlying physics such as the Euler-Bernoulli beam equation, the heat equation, or the Navier-Stokes equations expressed in either PDE or integral equations, while the divided small elements of the complex problem represent different areas in the physical system.
In present research for analysis ANSYS (**An**alysis **Sys**tem) software is used. Basically, its present FEM method to solve any problem. Following are steps in detail

1. Geometry
2. Discretization (Meshing)

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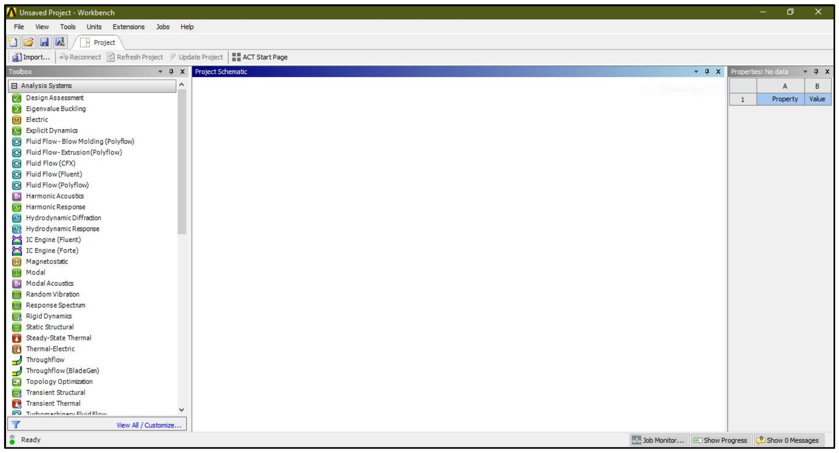
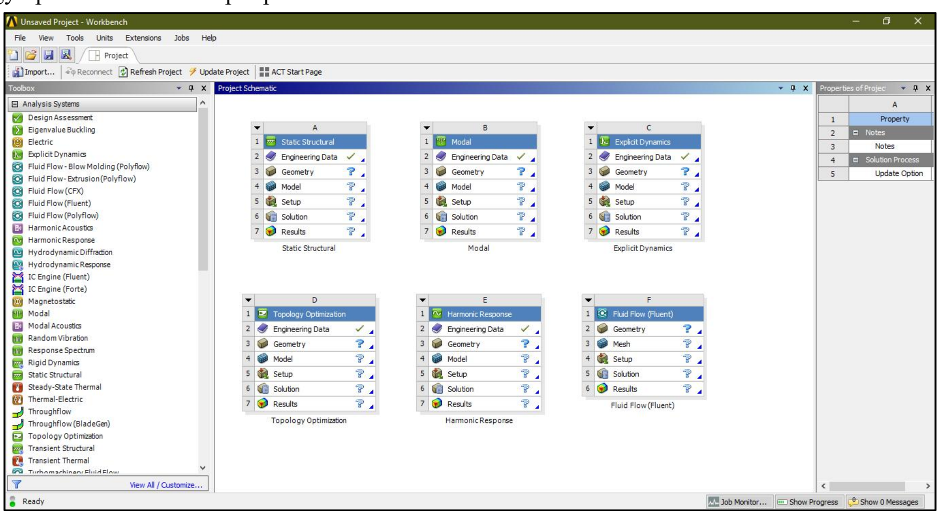
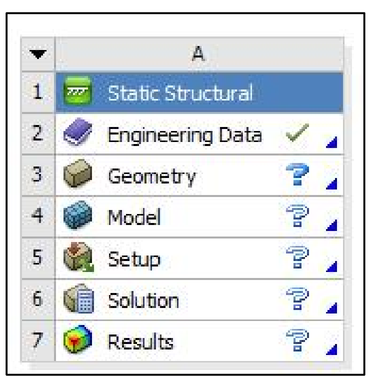
1. Boundary condition
2. Solve (Solution)
3. Interpretation of results



Workbench contain analysis of different types namely static, modal, harmonic, explicit dynamics, CFD, ACP tool post, CFX, topology optimization etc. as per problem defined.





Step 1: Details of material namely copper, steel, grey cast iron, composite material, fluid domain material is defined in engineering data. i.e., ANSYS default material is structural steel.

Step 2: Import of geometry created in any CAD software namely CATIA, PRO E, SOLIDWORK, INVENTOR etc. in geometry section. If any correction is to be made it can be created in geometry section in Design modeller or space claim.

Step 3: In model section after import of component

- Material is assigned to component as per existing material
- Connection is checked in contact region i.e., bonded, frictionless, frictional, no separation etc. for multi body components.
- Meshing or discretization is performed i.e., to break components in small pieces (elements) as per size i.e. preferably tetra mesh and hexahedral mesh for 3D geometry and for 2 D quad or tria are generally preferred.

Step 4: Boundary condition are applied as per analysis namely in fixed support, pressure, force, displacement, velocity as per condition.

Step 5: Now problem is well defined and solve option is selected to obtain the solution in the form of equivalent stress, strain, energy, reaction force etc.

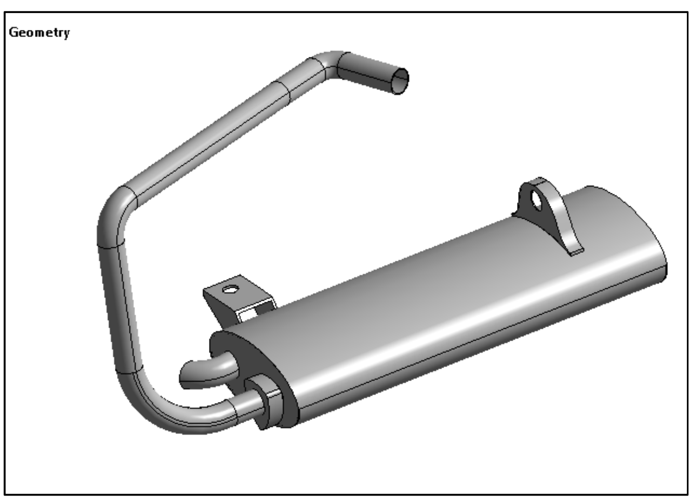
ENGINNERING DATA – STRUCTURAL STEEL

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
6	Isotropic Elasticity		
7	Derive from	Young's Modulus and Poi...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

Fig. 2: Details of structural steel material

4.3 GEOMETRY OF 3-WHEELER MUFFLER



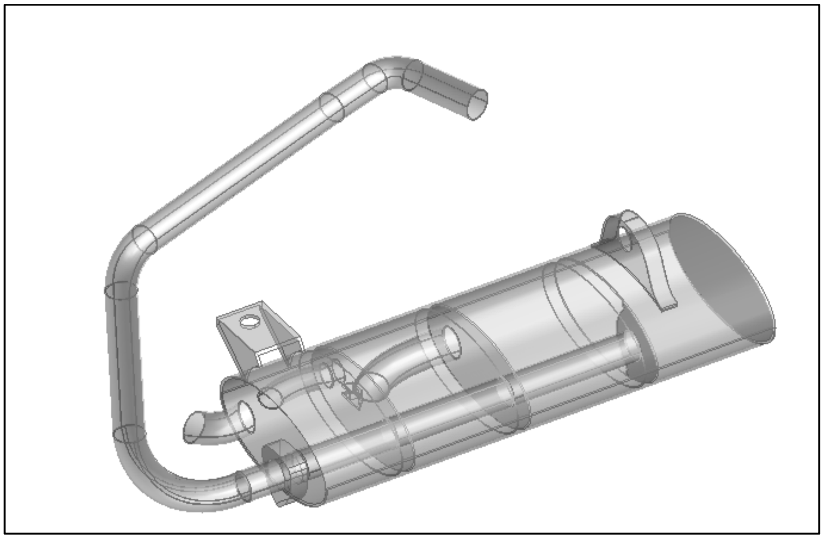
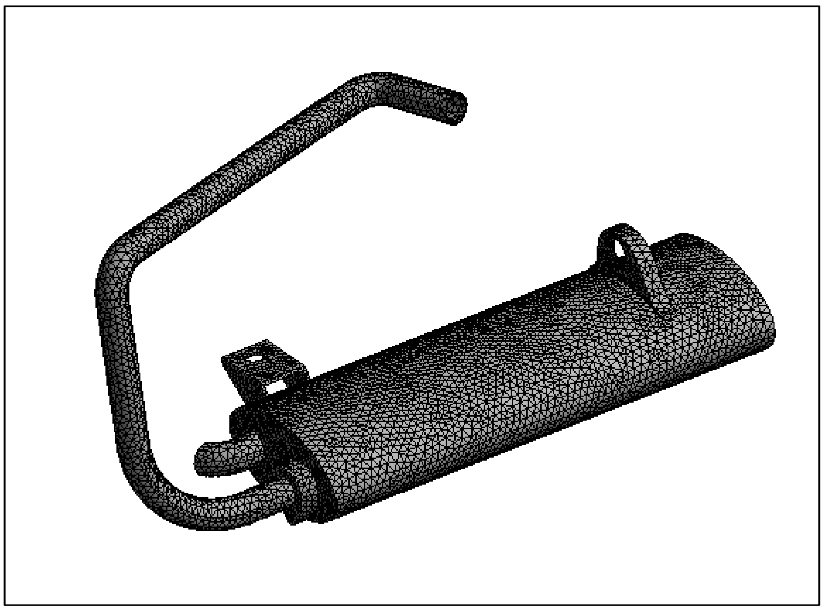


Fig. 3: Geometry of muffler imported in ANSYS

4.4 MESHING



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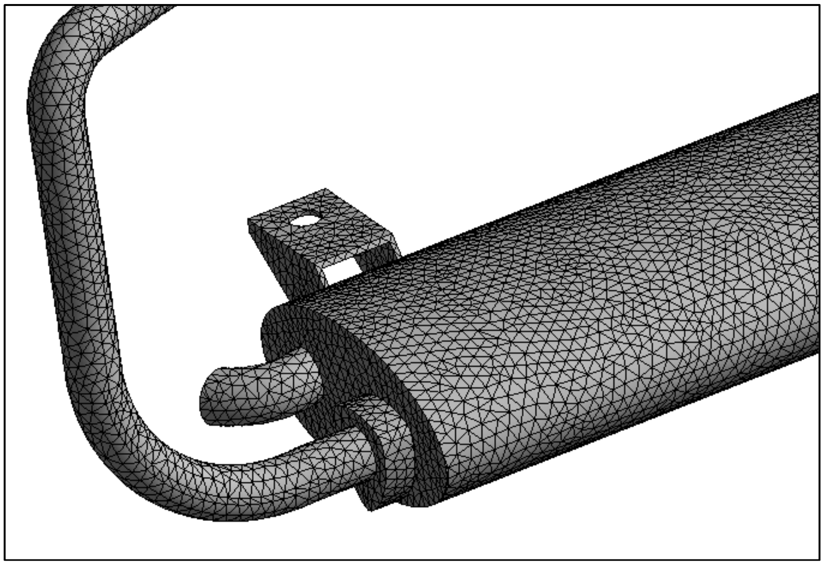

Details of "Body Sizing" - Sizing	
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Type	Element Size
Element Size	6.0 mm

Statistics	
Nodes	112109
Elements	56422

Fig. 4: Details of meshing

BOUNDARY CONDITIONS

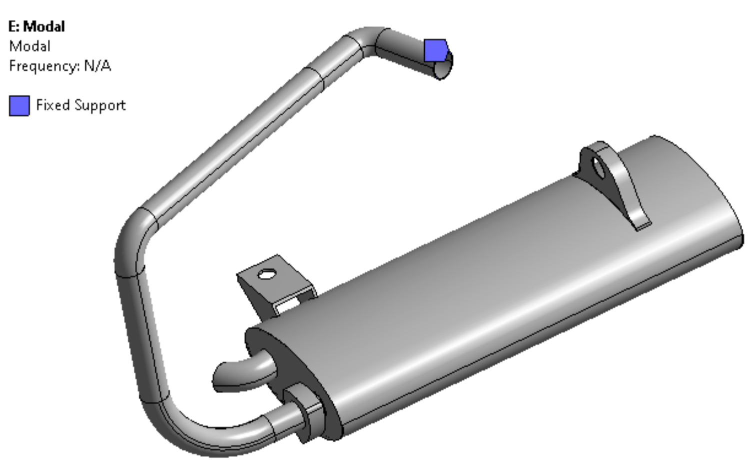

Fig. 5: Boundary condition for muffler

- Fixed support is applied at bolting joint as per existing condition

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RESULTS OF MODE SHAPES

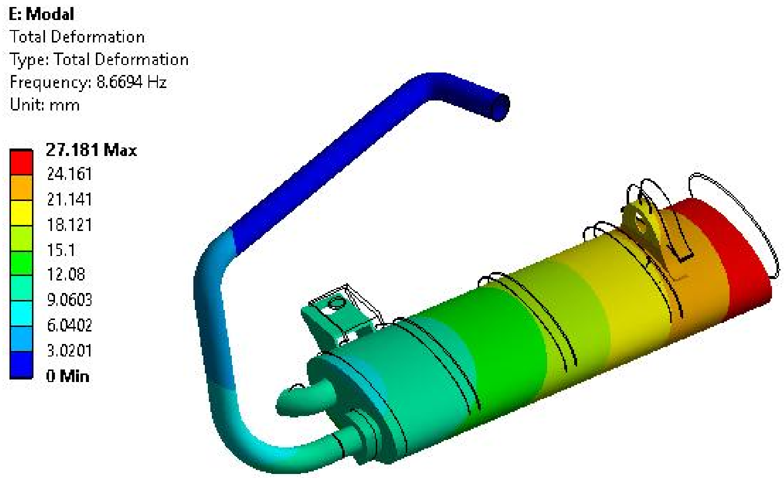

Fig. Mode shape 1

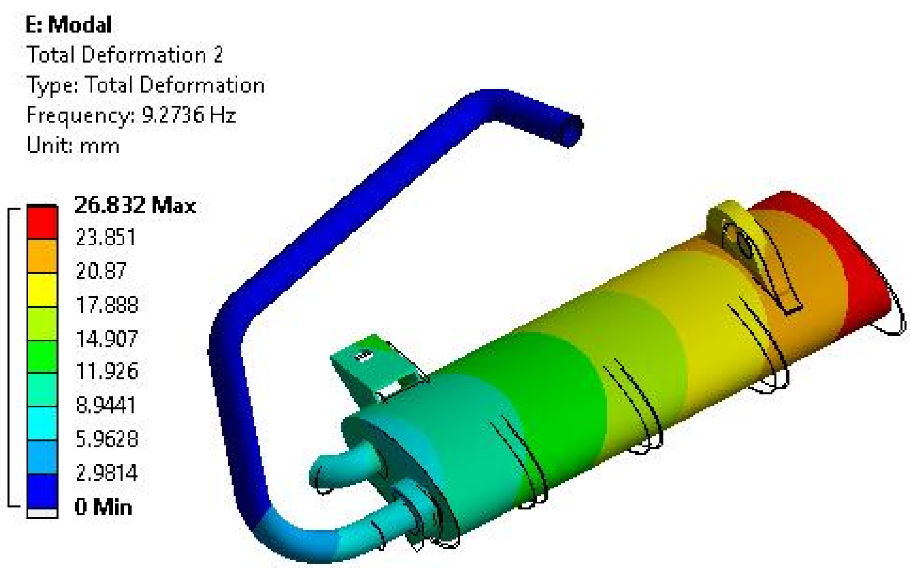

Fig. Mode shape 2

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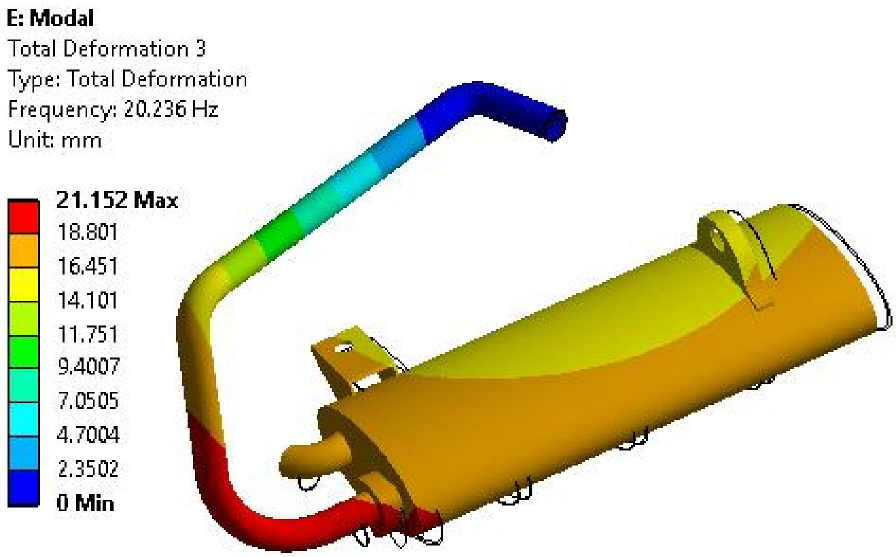

Fig. Mode shape 3

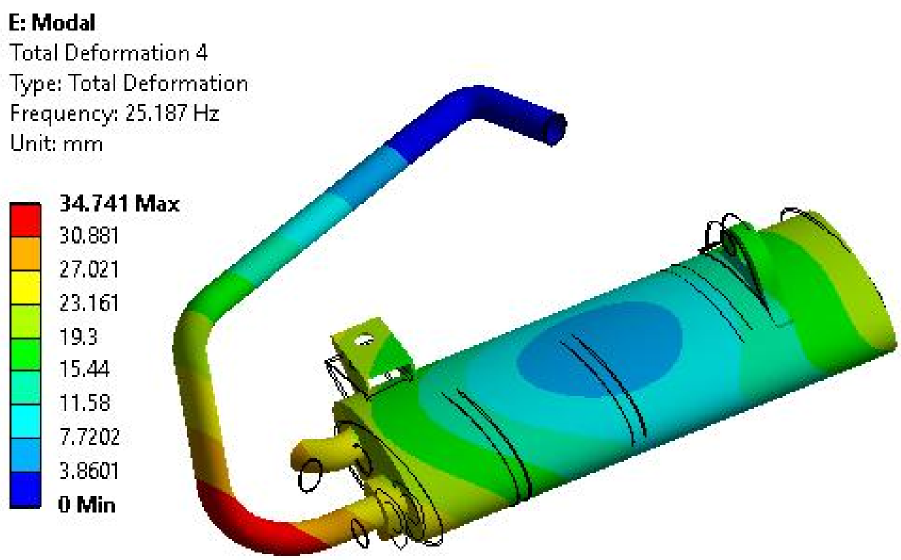

Fig. Mode shape 4

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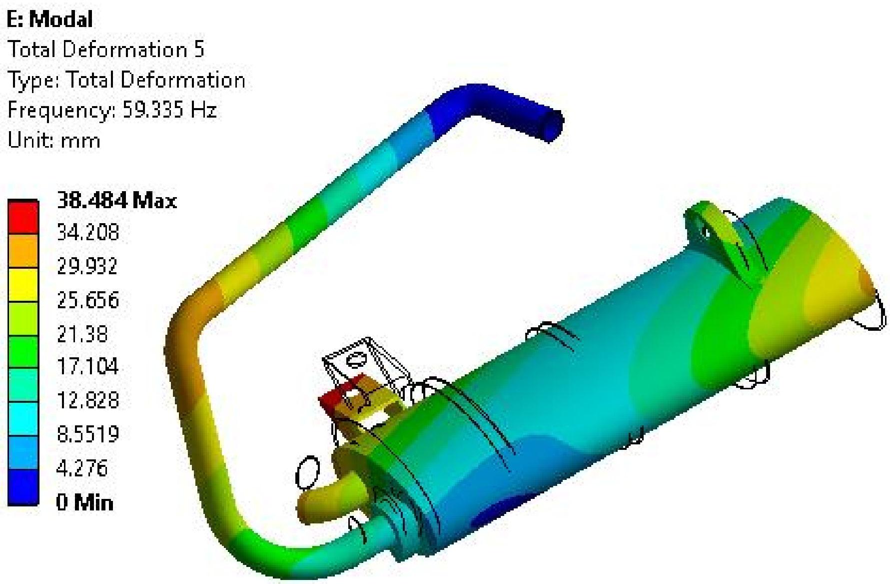
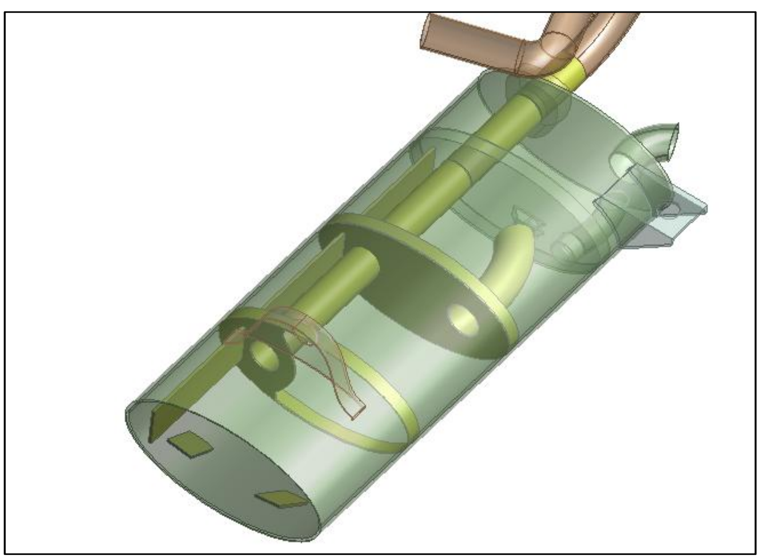


Fig. Mode shape 5

	Mode	Frequency [Hz]
1	1.	8.6694
2	2.	9.2736
3	3.	20.236
4	4.	25.187
5	5.	59.335
6	6.	80.816

Table. Tabular data of natural frequency

4.5 MODIFIED DESIGN OF MUFFLER WITH STIFFNERS



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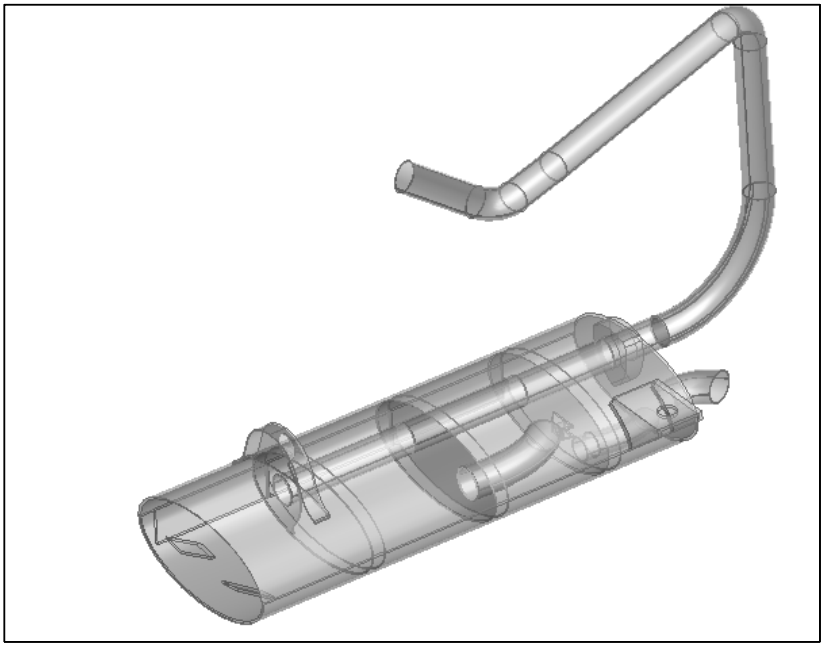
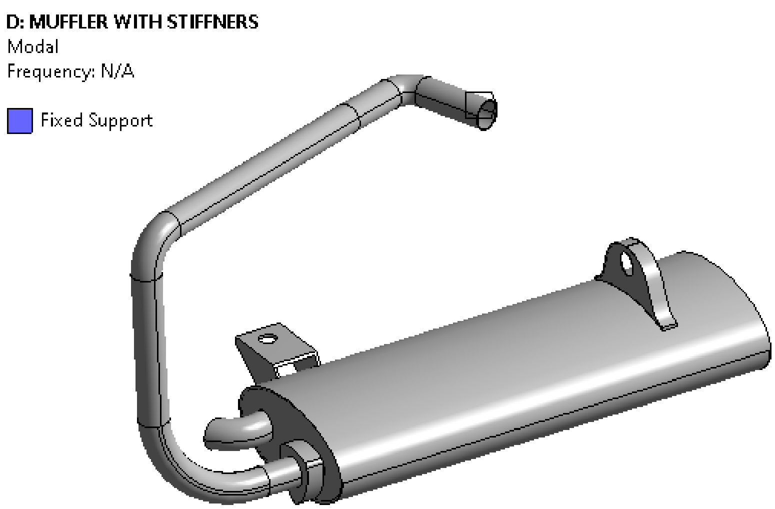
- Stiffeners are used to absorb vibration as well in present research it must not disturb the exhaust flow of gases so rectangular plate with preferable location are mounted to study the effect on existing natural frequency





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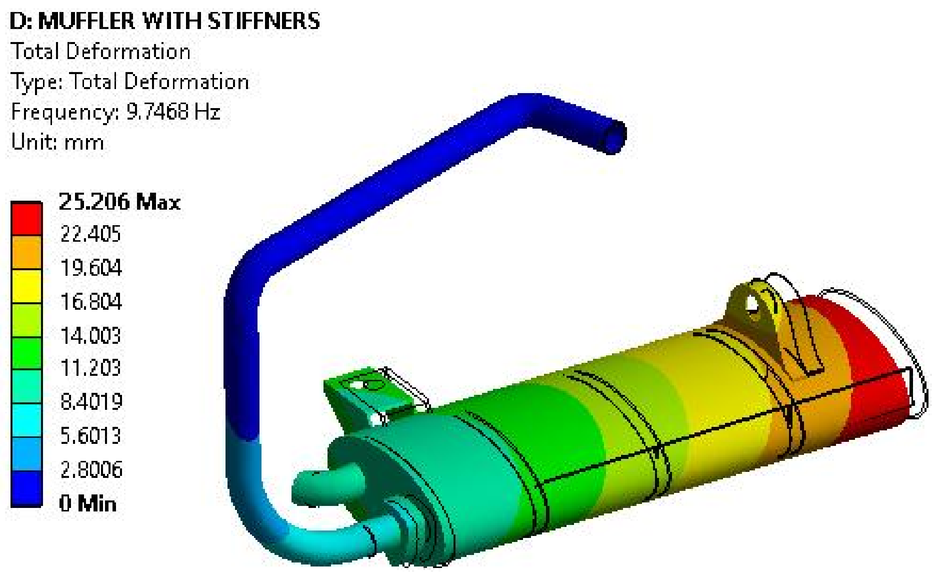

Fig. Mode shape 1

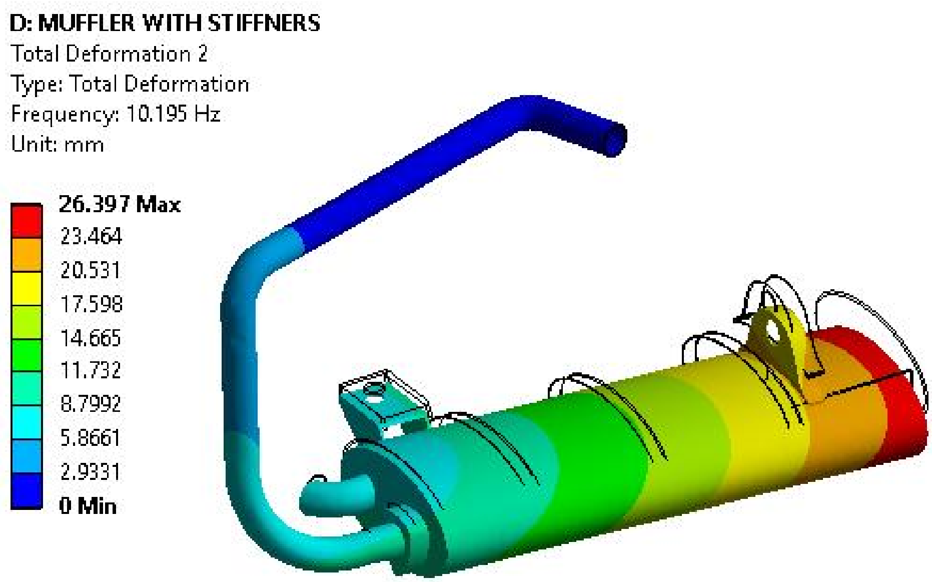

Fig. Mode shape 2

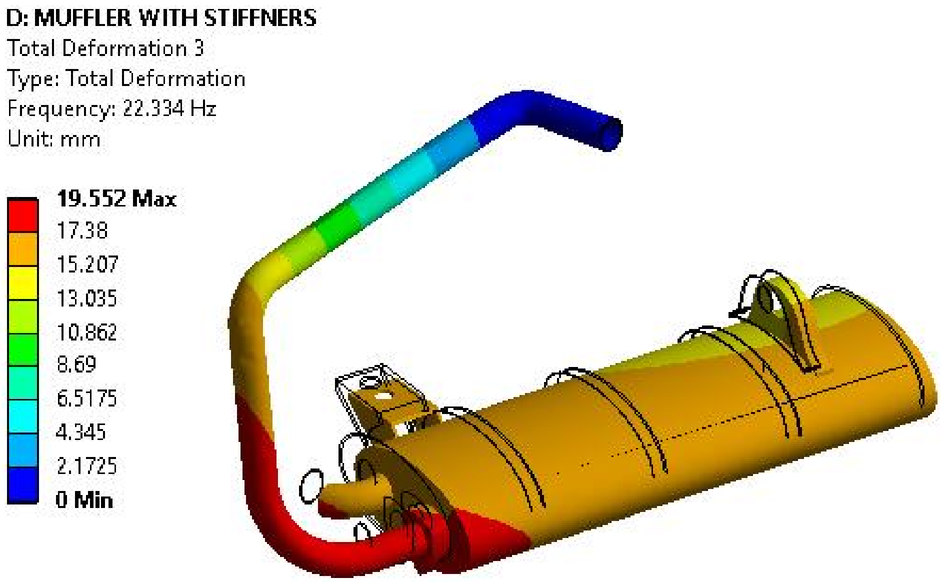

Fig. Mode shape 3

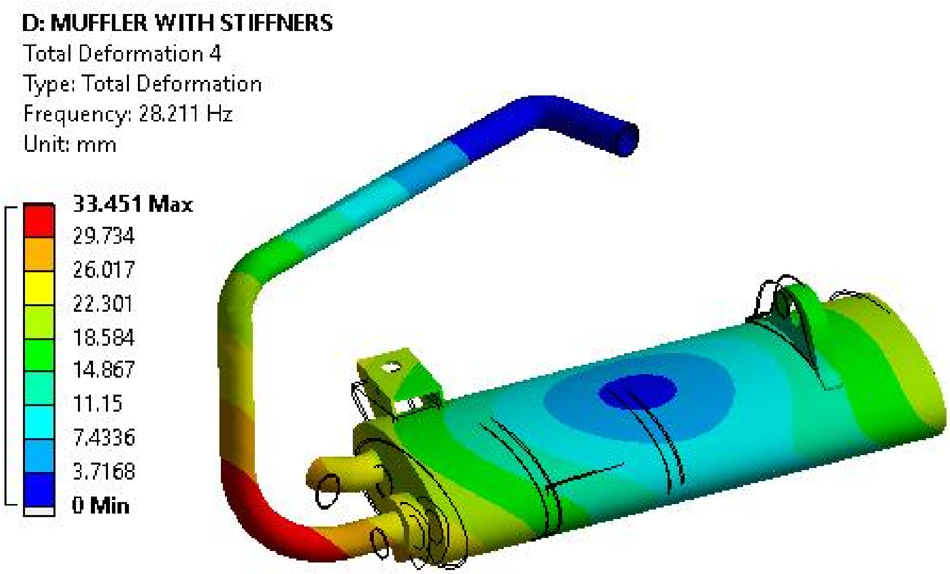

Fig. Mode shape 4

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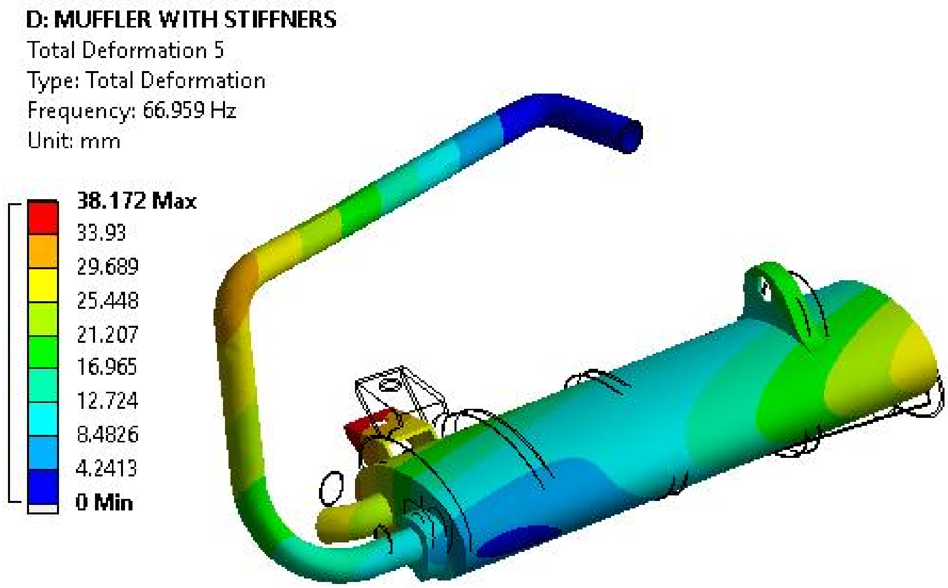

Fig. Mode shape 5

Tabular Data

	Mode	Frequency [Hz]
1	1.	9.7468
2	2.	10.195
3	3.	22.334
4	4.	28.211
5	5.	66.959
6	6.	90.394

- It is observed from graph that addition of stiffeners has increased natural frequency

Manufacturing

- In existing muffler is cut down with the help of grinder with grinding wheel and after gap is created then with chisel it is separated apart for stiffeners operation.
- In present study existing 3-wheeler muffler is selected to study the effect of stiffener on muffler.
- It is observed that existing muffler exhaust pipe is straight and pressure of hot gas emitting through get collected in last chamber and have more pressure due to which it makes create a lot of noise and affect the inner surface.
- In present research to enhance the existing natural frequency of system stiffener of rectangular plate (25 mm x 100mm x 3 mm) is mounted in between chamber at edge to not disturb the existing flow of exhaust gases.
- It effect is observed in FEA analysis with addition of stiffeners natural frequency have been improved compared to existing muffler.

Fig. Existing 3 wheeler muffler with open section view

V. EXPERIMENTAL TESTING

5.1 Fast Fourier Transform

FFTs were first discussed by Cooley and Tukey (1965), although Gauss had actually described the critical factorization step as early as 1805 (Bergland 1969, Strang 1993). A discrete Fourier transform can be computed using an FFT by means of the Danielson-Lanczos lemma if the number of points N is a power of two. If the number of points N is not a power of two, a transform can be performed on sets of points corresponding to the prime factors of N which is slightly degraded in speed. An efficient real Fourier transform algorithm or a fast Hartley transform (Bracewell 1999) gives a further increase in speed by approximately a factor of two. Base-4 and base-8 fast Fourier transforms use optimized code, and can be 20-30% faster than base-2 fast Fourier transforms. prime factorization is slow when the factors are large, but discrete Fourier transforms can be made fast for $N=2$, 3, 4, 5, 7, 8, 11, 13, and 16 using the Winograd transform algorithm.

The experimental validation is done by using FFT (Fast Fourier Transform) analyzer. The FFT spectrum analyzer samples the input signal, computes the magnitude of its sine and cosine components, and displays the spectrum of these measured frequency components. The advantage of this technique is its speed. Because FFT spectrum analyzers measure all frequency components at the same time, the technique offers the possibility of being hundreds of times faster than traditional analog spectrum analyzers.

Fourier analysis of a periodic function refers to the extraction of the series of sines and cosines which when superimposed will reproduce the function. This analysis can be expressed as a Fourier series. The fast Fourier transform is a mathematical method for transforming a function of time into a function of frequency. Sometimes it is described as transforming from the time domain to the frequency domain. It is very useful for analysis of time-dependent phenomena.

5.2 Impact Hammer Test

Impact excitation is one of the most common methods used for experimental modal testing. Hammer impacts produce a broad banded excitation signal ideal for modal testing with a minimal amount of equipment and set up. Furthermore, it is versatile, mobile and produces reliable results. Although it has limitations with respect to precise positioning and force level control, overall its advantages greatly outweigh its disadvantages making it extremely attractive and effective for many modal testing situations.

The use of impulse testing with FFT signal processing methods presents data acquisition conditions which must be considered to ensure that accurate spectral functions are estimated. Problems stem from the availability of only a finite duration sample of the input and output signals. When a structure is lightly damped the response to the hammer impact may be sufficiently long that it is impractical to capture the entire signal. The truncation effect manifests itself in terms of a spectral bias error having the potential to adversely affect the estimated spectra. The signal truncation problem is further compounded in practice by the computational and hardware constraints of the FFT processing equipment. Typically the equipment has a limited number of data capture lengths or frequency ranges which are available for an operator to select. Normally a user is more concerned with useable analysis frequencies and less with the data capture length. Therefore, it is conceivable that an inappropriate data capture duration could be used which truncates the vibration signal and introduces errors in the estimated spectra. To suppress the truncation a common practice is to artificially force: it to decay within the data capture window [1,2,3]. This artificial reduction is obtained by multiplying the slowly decaying vibration signal by an exponential function. However, the application of the exponential window must be considered carefully since it may also adversely affect the estimated spectra.

A phenomena commonly encountered during impact testing is the so called "double hit". The "double hit" applies two impulses to the structure, one initially and one time delayed. Both the temporal and spectral characteristics of the "double hit" input and output are significantly different than a "single hit". The input force spectrum for the "double hit" no longer has the wide band constant type characteristics of a single hit. The purpose of this paper is to examine the use of impact vibration testing in relation to the constraints imposed by typical FFT' signal processing techniques. The characteristics of the impact testing procedure are examined with analytical time and spectral functions developed for an idealized test: a single degree of-freedom system excited by a half sine impact force. Once an understanding of the fundamental characteristics is developed it is applied to examine the specific situations encountered in structural impact testing. The relationship of the system's parameters with respect to data capture requirements is evaluated. The effects of exponential windowing are developed to examine the effects on the estimated spectra and modal parameters. Finally, the "double hit" phenomena is examined by combining the results from the single degree-of-freedom system excited by two impulses, one of which is time delayed. The results from these related studies are combined to provide insight into data acquisition guidelines for structural impact testing.

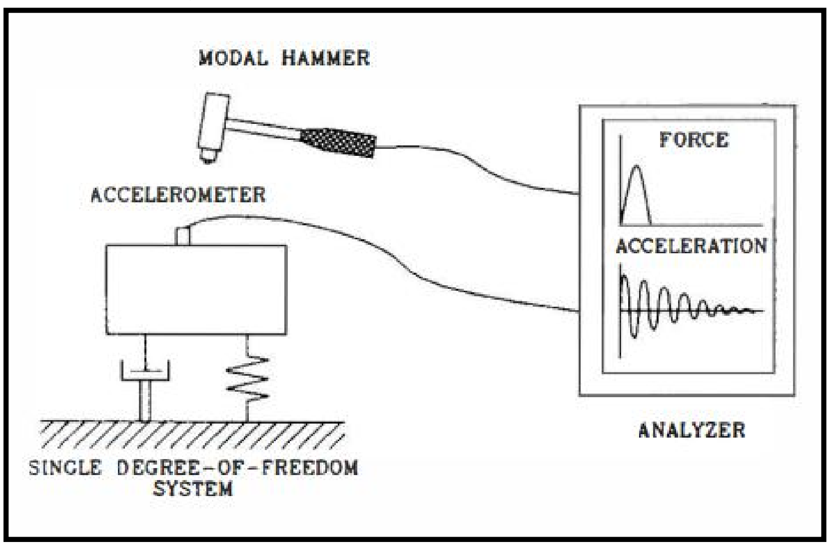

Fig 15: FFT construction

VI. Experimental Procedure

- Initially fixture is designed according to existing boundary condition as per FEA results.
- FFT consists of impact hammer, accelerometer, data acquisition system in which each supply is applied to DAS and laptop with DEWSOFT software to view FFT plot.

- Accelerometer is mounted at edge as per high deformation observed in FEA results along with initial impact of hammer is placed for certain excitation to determine frequency of respective mode shapes.
- After impact FFT plot are observed on laptop and comparison of FEA and experimental results are analysed.

VII. Conclusion

- In this report we completed literature survey on the muffler vibration problem and define problem statement and objectives
- We design the 3D model of the muffler using CATIA software
- Complete the vibration analysis on the existing muffler using ansys software.
- Perform the modal analysis on the muffler and find out the natural frequency on the muffler
- A mode shape of 3-wheeler muffler is calculated with the help of modal analysis in ANSYS software with different natural frequencies.
- It is observed from graph that addition of stiffeners have increased natural frequency.

Tabular Data

	Mode	Frequency [Hz]
1	1.	9.7468
2	2.	10.195
3	3.	22.334
4	4.	28.211
5	5.	66.959
6	6.	90.394

Table. final results of Tabular data of natural frequency.

Acknowledgement

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