# Prediction and Control of Motorcycle Engine Noise under Combustion Load

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**Abstract:**

Engine is a major source of noise in a motorcycle. Combustion induced vibrations are transferred from the powertrain to engine casings and radiate noise. In this paper, the acoustic analysis of a single cylinder motorcycle engine under combustion load is presented. Engine surface acceleration obtained from vibration analysis is used as input for acoustic analysis. These nodal accelerations are then interpolated to map it as per the engine skin mesh data. In this method, nodal acceleration input was taken from the external '.csv' file format. This process has to be repeated at each frequency step (~40 steps). Thus, process automation is carried out using Java script. Far field SPL is calculated for each frequency at 0.5m distance from engine. Results of acoustic analysis helped to identify critical frequencies with high SPL and areas of engine structure responsible for high noise radiation. SPL vs. Frequency plot and sound intensity plots from acoustic analysis are compared with test results. Structural modifications in engine are then implemented to achieve noise reduction.

**Keywords:** NVH, engine noise, combustion noise, far field, PML

## 1. Introduction

In the motorcycle development process, it is important to achieve reduction in noise levels to meet regulations and to satisfy customer demands of quieter products. Noise radiated from automotive engine is one of the major contributors to overall vehicle noise in motorcycles because it is not enclosed unlike in cars where the engine is packaged in an enclosed chamber. In motorcycle engines there are many sources of noise such as valve train, piston slap, intake, exhaust, gear whine, and combustion noise etc. Rapid rise of combustion pressure inside the combustion chamber of engine produce engine structural vibrations. Combustion induced vibrations are transferred from the powertrain to engine casings through bearings and radiate noise. Noise radiated from engine under combustion excitations is dominant in certain frequency range as compared to other noise sources of engine.
Acoustic radiation analysis of IC engine can be carried out by using structural and acoustic modelling methods. These methods help in identifying the areas of engine structure contributing to noise. Modifications in engine structure can be implemented in the development phase itself to reduce noise. With this approach, substantial savings in terms of cost and reduction in product development time can be achieved.

## 2. Procedure for noise prediction

The methodology to predict noise radiation of IC engine can be divided in three steps [1]. First step is to predict the excitation forces by carrying out Multi body dynamic (MBD) simulation. MBD simulation is carried out at a specified operating condition of the engine and takes into consideration the effect of combustion pressure and inertia forces of engine powertrain. Second step is to build the FE model for the engine and carry out vibration analysis under combustion load. Major components of engine are assembled to build FE model. Excitation forces from MBD simulation are applied to FE model of the engine to carry out vibration analysis and thus predict response on the engine outer surface. In the third step, nodal accelerations obtained from vibration analysis is used as an input to carry out acoustic analysis. SPL is predicted at a specified distance from the engine for the desired frequency range. The present work focuses on acoustic radiation analysis of a single cylinder motorcycle engine using acoustic module of COMSOL multiphysics ®.

## 3. Use of COMSOL Multiphysics

Acoustic analysis of the engine is explained in detail in this section. Firstly, the outer surface of engine, referred here as engine skin, is extracted from FE model of the engine. Engine skin is enclosed inside a computational domain defined by a Cartesian perfectly matched layer (PML) as shown in Figure 1. PML closely represents an open and non-reflecting infinite domain and dampens all outgoing waves with minimal or no reflections. Computational mesh size is decided based on the criteria of 6 elements per wavelength in order to provide sufficient resolution of the waves.

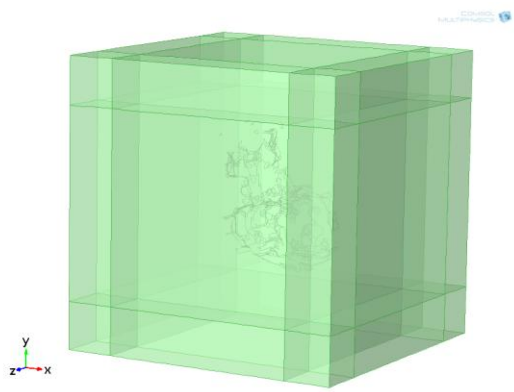

**Figure 1**. Engine skin enclosed by PML

The output of vibration analysis i.e. engine surface acceleration data is required as input for acoustic analysis. These nodal accelerations are interpolated to map on the engine skin mesh using the Interpolation function in COMSOL. Interpolation obtained in COMSOL matches well with results of vibration analysis as shown in Figure 2.

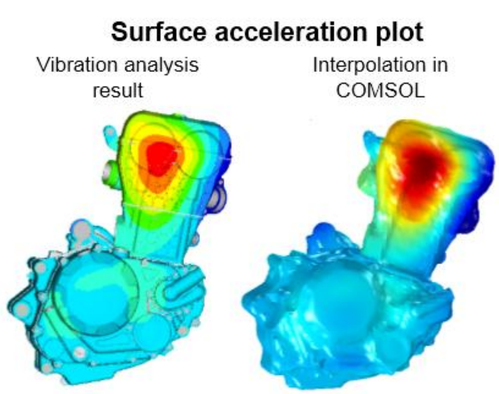


**Figure 2.** Interpolation in COMSOL

Normal acceleration boundary condition is applied to boundaries of engine skin as shown in Figure 3.

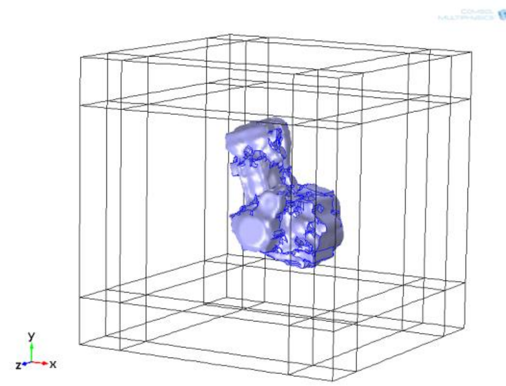

**Figure 3**. Boundaries of engine skin

Equation used for acoustic analysis [2] is as follows

$$n \cdot \left(\frac{1}{\rho_0}(\nabla p) + n \cdot a_0\right) = 0 \qquad (1)$$

Where, n is a unit vector in normal direction, $\rho_0$ is fluid density of medium, p is fluid pressure in the medium, $a_0$ is fluid mass acceleration $a_0 = (i_x\, a_x + i_y\, a_y + i_z\, a_z)$ in which $a_x$, $a_y$, $a_z$ are the complex nodal acceleration components in X, Y and Z direction respectively.

$$\nabla = operator = \left(i_x \frac{\partial}{\partial x} + i_y \frac{\partial}{\partial y} + i_z \frac{\partial}{\partial z}\right)$$

$i_x$, $i_y$, $i_z$ are the unit vectors in X, Y and Z direction respectively.

In the present case, the microphone location where the SPL is measured in testing lie outside the boundaries of computational domain. Thus, far field calculation feature in COMSOL is used to calculate pressure outside computational domain. This feature uses the Helmholtz-Kirchhoff (H-K) integral [2] given by Equation 2. H-K integral calculates the acoustic field at any point outside the computational domain. In order to get a precise evaluation of the far-field variable, the evaluation of the H-K integral must be accurate. This requires having a good numerical estimate of the normal derivative of the pressure on the far-field calculation surface (adjacent to the

PML layer). Thin layer of boundary layer mesh is used for accurate evaluation of the far-field variable. Far-field boundaries selected in the computational domain are shown in Figure 4.

$$p(\boldsymbol{R}) = \frac{1}{4\pi} \int \frac{e^{-ik\,|\boldsymbol{r}-\boldsymbol{R}|}}{|\boldsymbol{r}-\boldsymbol{R}|} \left( \nabla p(\boldsymbol{r}) + p(\boldsymbol{r})\, \frac{(1 + ik\,|\boldsymbol{r} - \boldsymbol{R}|)}{|\boldsymbol{r} - \boldsymbol{R}|^2}\, (\boldsymbol{r} - \boldsymbol{R}) \right) \cdot n\, dS \qquad (2)$$

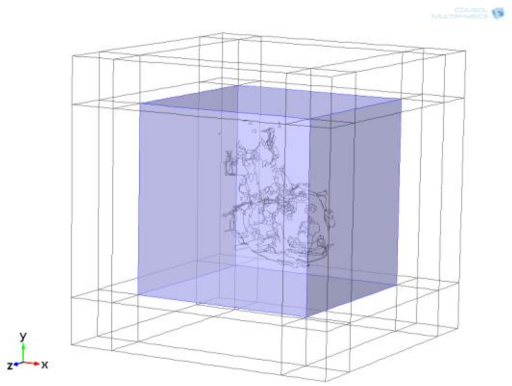


**Figure 4.** Far field boundaries

### 3.1 Process Automation

Acoustic analysis is carried out for frequencies up to 2000Hz in steps of 50Hz. The acoustic model has to be solved for each frequency step, in this case, 40 steps. Every step requires the nodal acceleration data of the vibration analysis to be read and interpolated on engine skin as input to carry out acoustic analysis. In this method, nodal acceleration input was taken from the external '.csv' file format. To reduce the overall solution time, process automation is carried out using java script. COMSOL batch mode is used to carry out acoustic analysis.

## 4. Noise Measurement

Noise measurement set up is as shown in Fig 5. Vehicle was operated on the vehicle dynamometer in quiet room of NVH laboratory. Engine was operated at full load, constant RPM at which engine delivers peak power. Noise was measured with microphone located in front of the engine side cover at a distance of 0.5m as shown in Figure 5.

**Figure 5.** Noise measurement set-up

## 5. Sound Pressure Level (SPL) correlation

Noise radiation from engine structure under combustion load is dominant in the frequency range of 800 Hz to 2000 Hz. Thus, for test correlation, one third octave data of engine noise signal from 800 Hz to 2000 Hz is presented here. Figure 6 shows the comparison of noise data obtained in test and analysis for one third ocatve bands. One third octave data from simulation show good match with test data. From the noise data shown in Figure 6, it is observed that highest SPL occurs in 1250 Hz band.

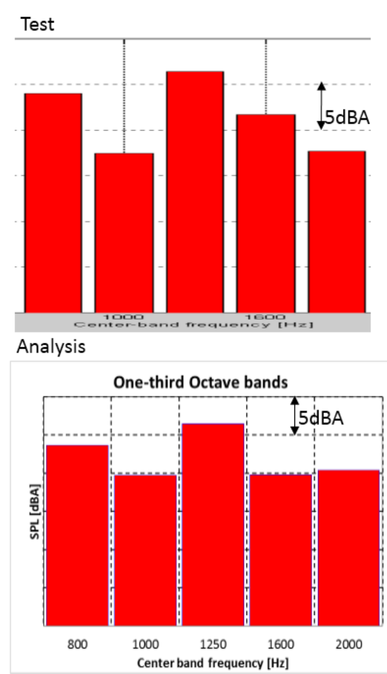


**Figure 6.** Sound pressure level correlation with test data (One third octave bands)

## 6. Sound intensity plots correlation

In addition to SPL measurement, sound intensity of the engine is also measured at the same operating conditions. Sound intensity plots show the area on the engine structure which radiates more noise. Comparison of sound intensity plots from test and surface SPL plot obtained from acoustic analysis at 1250 Hz is shown in Figure 7. It is observed that areas highlighted in simulation for high noise radiation match well with the test plots.

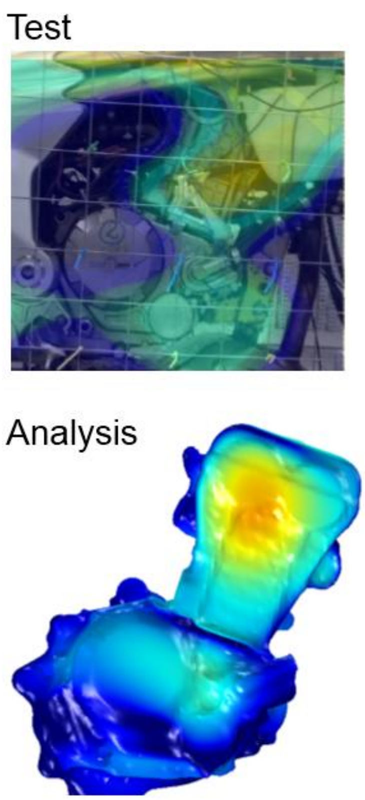


**Figure 7.** Comparison of surface SPL plot with test data

## 7. Modifications

Results of modal and frequency response analysis along with 3D surface SPL plots are studied at the critical frequencies. Based on this study, modifications such as increasing rib height, wall thickness and strengthening the mounting location are done in cylinder head and block as shown in Figure 8. With these modifications, SPL is reduced at target frequency band of 1250Hz and two other frequency bands as shown in Figure 9. Increase in SPL is observed in 1000Hz and 1600Hz band. However, the SPL at 1000Hz and 1600Hz frequency band is less than the maximum SPL for baseline design at all frequency bands. Thus, with these modifications, overall SPL is reduced by 3 dBA.

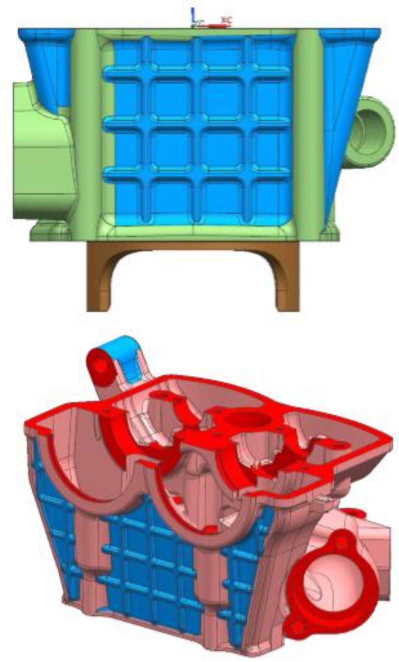

**Figure 8.** Modifications in cylinder head and block

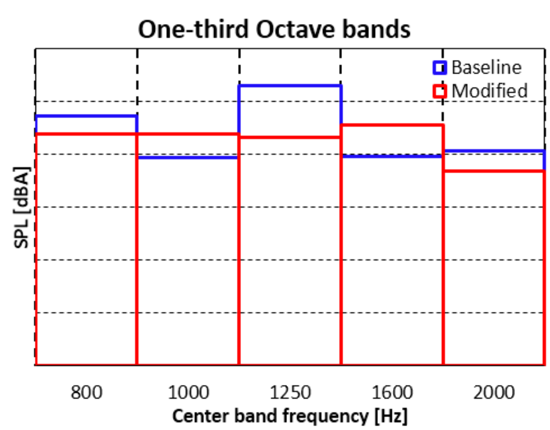


**Figure 9.** Sound pressure level comparison – Baseline vs. Modification

## 8. Conclusions

A method to predict motorcycle engine noise under combustion load is presented. Engine surface acceleration data is used as input for acoustic analysis. Process automation is carried out using java script to interpolate nodal acceleration data on the engine skin and to solve the acoustic model for each frequency step. With process automation, time required for acoustic analysis is substantially reduced. Acoustic analysis data for SPL and sound intensity plots of the engine show a reasonably good correlation with the test data. Structural modifications can be carried out in engine structure in the initial design phase to achieve overall noise reduction. This approach can thus lead to substantial savings in terms of cost and reduction in product development time.

## 9. References


1. U.Mohite, et.al. ,"An Approach for Prediction of Motorcycle Engine Noise under Combustion Load," SAE Technical Paper 2015-01-2244, 2015, doi:10.4271/2015-01-2244

2. COMSOL Multiphysics Manual, Acoustic Module