Transfer Path Analysis Using Engine Radiated Sound And Mount Vibration

Nikolina Samardzic, and Colin Novak
Dept. of Mechanical, Automotive and Materials Engineering, University of Windsor, 401 Sunset Ave.; Windsor, Ontario

INTRODUCTION

One of the main areas of consideration in defining vehicle customer satisfaction is vehicle interior sound and vibration. Engine radiated sound and mount vibration are significant contributors to vehicle interior sound and vibration. Characterizing their contribution requires a detailed and methodical analysis that may be used to establish baseline levels, identify manufacturing deficiencies, and influence design changes for baseline improvements of vehicle interior sound and vibration. Component-level testing such as engine sound and vibration testing is performed frequently because it is more practical and less costly compared to similar vehicle-level testing. Thus, estimating vehicle performance based on engine performance can potentially provide cost reduction benefits at all stages of vehicle design and manufacturing. The objectives of this study are to:

1. Develop a vehicle interior sound and vibration numerical estimation method based on engine radiated sound and mount vibration and verify the estimations by actual vehicle interior sound and vibration measurements at all operating conditions under investigation.
2. Evaluate the contribution of individual engine air-borne and structure-borne sources of sound and vibration to the total vehicle interior sound and vibration.

DATA ANALYSIS METHODS

The vehicle interior sound and vibration is a combination of air-borne and structure-borne transfer paths. The behaviour of principal sources of sound and vibration is dependent on the vehicle design and its operating conditions. Examples of vibroacoustic sources include wind and road, powertrain, intake and exhaust systems and others. The total sound and vibration level in the vehicle interior is a sum of partial pressures and accelerations caused by all air-borne and structure-borne delivery paths from the sources of sound and vibration.

The Transfer Path Analysis (TPA) is an experimental technique used to establish the effect of individual air-borne and structure-borne paths on the interior sound and vibration. The TPA method requires the vibroacoustic source and the transfer function data. A target response due to a single path, $r(\omega)$, is a combination of frequency response function, $H(\omega)$, and the magnitude of the source or excitation, $s(\omega)$, as shown in equation:

$$r(\omega) = H(\omega) \cdot s(\omega) \quad (2.2)$$

The total receiver sound pressure level, $R(\omega)$, is the sum of *n* partial pressures of the individual transfer paths, *i*:

$$R(\omega) = \sum_{i=1}^{n} \frac{r(\omega)}{s_i(\omega)} \cdot s_i(\omega)$$

Figure 1 illustrates an overview of vehicle interior sound and vibration numerical estimation method used in this study.

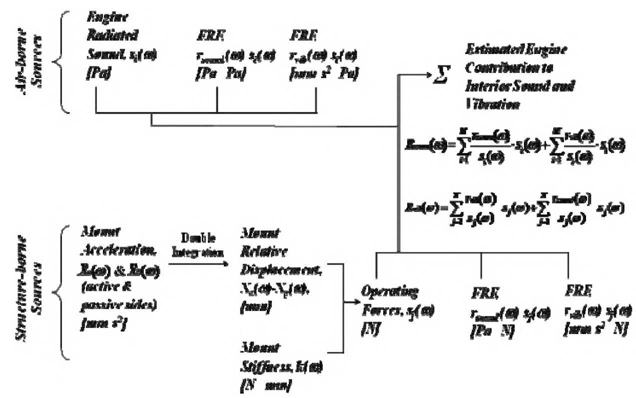

Fig. 1: Vehicle Interior Sound and Vibration Numerical Estimation Method Overview.

The modal analysis was performed to estimate the sound and vibration transmission characteristics from the engine compartment to vehicle interior. It included acoustic and mechanical excitation of the frame and body assembly of a light truck. The calculated frequency response functions are then combined with frequency based source data (engine radiated sound and forces transmitted through the mounts) to estimate the response at the receivers. The response was characterized as the binaural sound pressure and driver's seat track triaxial acceleration. The results were verified by actual vehicle interior sound and vibration measurements.

EXPERIMENTAL DETAILS

The engine radiated sound is a source of air-borne contributions to interior sound and vibration. In order to calculate these contributions it is necessary to quantify acoustical radiation from exterior surfaces of the engine by recording time domain sound data at each operating condition (rpm).

The forces transmitted through engine mounts resulting from engine operation are structure-borne sources of interior sound and vibration. The relative displacement across the engine mounts was required to calculate structure-borne engine operating forces transmitted through the mounts. The relative displacements are proportional to the forces transmitted through the mounts and into the vehicle body at each operating condition and frequency. The proportionality constant is the frequency-dependent, manufacturer-specified mount stiffness. Initially, the acceleration time data was obtained from the mount vibration test. This acceleration spectra was then calculated for both the active and body sides of the mounts and integrated twice to obtain the displacements. The engine acoustic inputs used to measure FRF's were simulated using white noise input through the loudspeakers. The engine force input through the frame was simulated by impact hammer excitation of the frame, with the engine removed. The interior sound and vibration were measured using binaural head and triaxial accelerometer, respectively at the same five receiver locations used in the FRF measurements.

RESULTS AND DISCUSSION

The results indicate a close correlation between the estimated results and actual measurements (see examples in Figures 2 and 3). This verified the effectiveness of the acoustic and impact excitation methods used in the study to simulate the air-borne and structure-borne engine inputs and the transfer paths for the operating conditions considered.

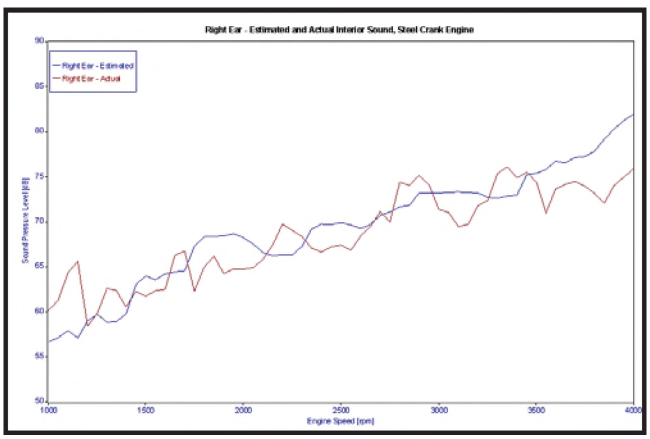

Fig. 2: Estimated and Actual Interior Sound, Right Ear.

The interior sound and vibration are functions of individual contributions of source sound and vibration as well as operating conditions. The transfer path contributions to receivers were calculated for each operating condition and example results are shown in Figure 4.

The contributions of individual engine air-borne and structure-borne paths of sound and vibration to total vehicle interior sound and vibration were evaluated and a ranking method was used for rapid identification of significant paths. The paths were ranked in terms of their average overall contribution to each receiver (Table 1). Common paths of significance included the X-direction of the right mount (consistently the least significant path) and front radiated sound (one of the most significant paths). Table 1 also shows a comparison between transfer path contribution associated with a steel and a cast crank engine. Any differences in transfer path contributions between the different engines may be used as part of a future interior vehicle sound quality assessment.

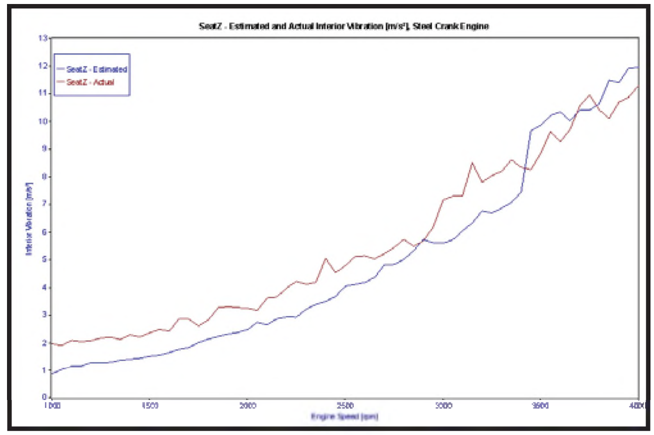

Fig. 3: Estimated and Actual Interior Vibration, Z-direction.

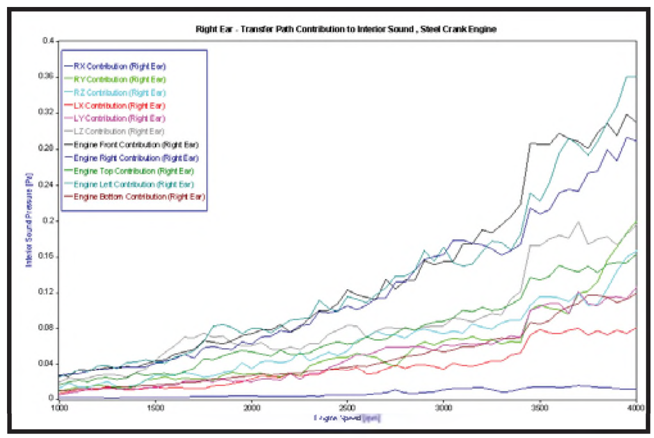

Fig. 4: Transfer Path Contribution to Interior Sound, Right Ear.

Tbl. 1: Transfer Path Contribution Ranking.

		Interior Sound				Interior Vibration					
		Right Ear		Left Ear		X-dir		Y-dir		Z-dir	
		Steel Crank	Cast Crank	Steel Crank	Cast Crank	Steel Crank	Cast Crank	Steel Crank	Cast Crank	Steel Crank	Cast Crank
Air-borne Sources	Front, X-dir	2	1	3	3	1	1	1	1	1	1
	Right, Y-dir	3	3	4	4	4	5	4	4	4	5
	Top, Z-dir	5	7	5	8	5	7	5	5	5	6
	Left, Y-dir	1	2	1	2	2	3	2	2	2	2
	Bottom, Z-dir	9	9	2	1	3	2	3	3	3	4
Structure-borne Sources	Right Mount, X-dir	11	11	11	11	11	11	11	11	11	11
	Right Mount, Y-dir	7	6	8	7	6	9	6	8	6	8
	Right Mount, Z-dir	6	5	7	5	7	4	8	7	7	3
	Left Mount, X-dir	10	10	9	9	10	10	10	10	10	10
	Left Mount, Y-dir	8	8	6	6	9	6	7	6	8	7
	Left Mount, Z-dir	4	4	10	10	8	8	9	9	9	9

Significant:	1 - 4	(orange)
Moderately Significant:	5 - 7	(grey)
Insignificant:	8 - 11	

REFERENCES

[1] N. Samardzic, "Vehicle Interior Sound and Vibration Numerical Estimation Method Based on Engine Radiated Sound and Mount Vibration", Master's Thesis, University of Windsor, 2005.