

Powerplant NVH Decision Making Using Combined Airborne and Structureborne Noise Sources

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ABSTRACT

Powerplant NVH decisions are sometimes made looking only at how the change impacts either the source radiated noise level or the source vibration. Depending on the engine configuration, those can be good approximations, but they can also be very misleading. By combining both noise sources into a vehicle equivalent noise level a much better analysis can be made of the impact of any proposed design change on the customer perceived loudness.

This paper will investigate several different scenarios and identify how the airborne and the structureborne paths combine for I4, V6 and V8 engine configurations. Similar relationships will be shown for path as well as the source contributions.

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INTRODUCTION

Historically, Powerplant (Engine + Transmission) Radiated Noise has been the focus of vehicle noise reduction. The Engine Sound Level Measurement Procedure, SAE J1074, was first issued in 1974. For certain engine configurations like V8's, the radiated noise is the dominant source of engine contribution to vehicle interior noise. Actions taken to reduce the radiated noise from these engines will have a significant and direct effect on the engine contribution to vehicle interior noise, what the customer hears.

For other engine configurations, like I4's, the link between engine radiated noise and vehicle interior noise is not as direct. For these engines there is a significant Structureborne contribution due to vibration at the mounts. This is the less straight forward path for vehicle interior noise, and there is no SAE standard for the measurement of Powerplant Mount Vibration.

This paper will try to define the relative magnitude of the contributions of the Airborne path (Powerplant Radiated Noise) and the Structureborne path (Powerplant Mount Vibration related Noise) for different engine configurations and what the combined, or Vehicle Level Equivalent Noise, is. Using the Vehicle Level Equivalent Noise level approach, different Powerplant Noise and Vibration reductions will be studied to quantify the relative effect on different engine configurations and help with cost effective decision making.

AIRBORNE PATH

Powerplant Radiated Noise

Powerplant Radiated Noise used in this paper is defined as the 4-mic. summation, as shown in Equation 1, using the SAE J1074 procedure. The microphone locations are as shown in Figure 1.

$$4 - \text{Mic. Sum} = 10 * \log_{10}(10^{(\text{front}/10)} + 10^{(\text{top}/10)} + 10^{(\text{right}/10)} + 10^{(\text{left}/10)}) \quad (1)$$

4-Microphone Measurement Locations

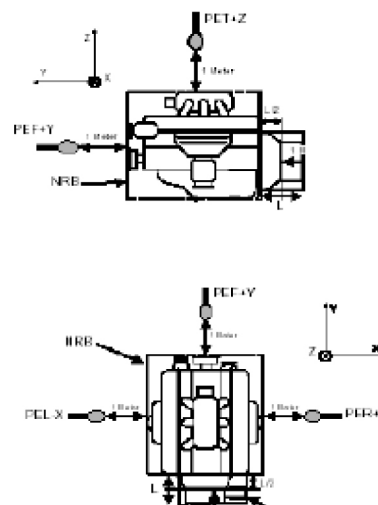


Figure 1. Microphone Locations in SAE J1074 Test Procedure

The result of the J1074 test at Full Engine Load is a curve of the 4-mic. summation expressed in dB(A) vs. the Engine Speed as shown in [Figure 2](#).

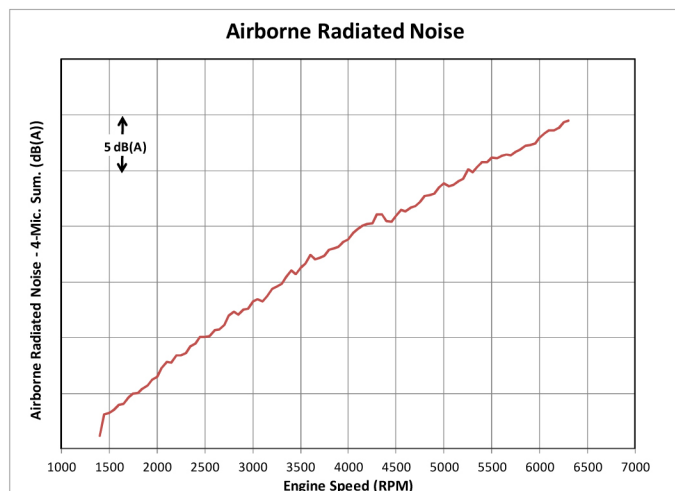


Figure 2. Engine Radiated Noise

Airborne Transfer Function

The Noise as shown in [Figure 2](#) is not the noise level heard in the interior of the vehicle; it is the Noise level inside the semi-anechoic test cell. To predict the in-vehicle noise level the J1074 Noise needs to be multiplied by the Airborne Transfer Function [1-2]. This transfer function represents the difference between the Vehicle Interior Noise resulting from the Powerplant Radiated noise and the Powerplant Radiated Noise source level.

The transfer function used in this paper is Noise Attenuation vs. Frequency for a generic vehicle body. The Airborne Transfer Function is shown in [Figure 3](#).

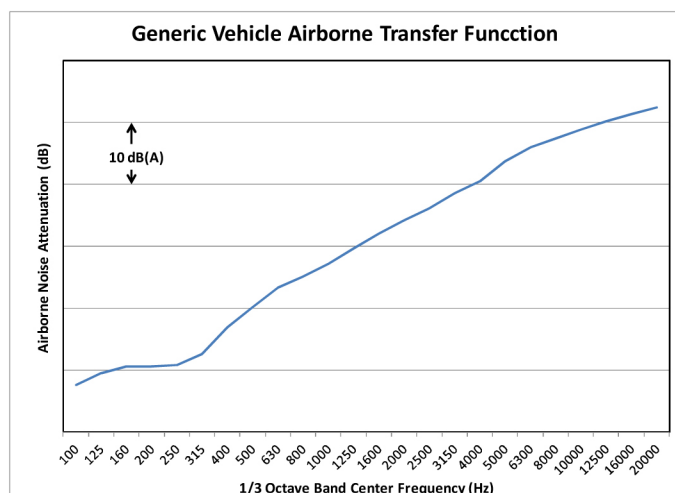


Figure 3. Generic Vehicle Airborne Transfer Function

Vehicle Interior Equivalent Airborne Noise

When this Transfer Function is applied to the Powerplant Source Radiated Noise there is a significant reduction in noise level. Since the attenuation in [Figure 3](#) is a function of frequency, the magnitude

of change varies over the speed range as shown in [Figure 4](#). Here the average reduction was 34 dB(A), but the range of reduction vs. Engine Speed varied from 31 to 37 dB(A).

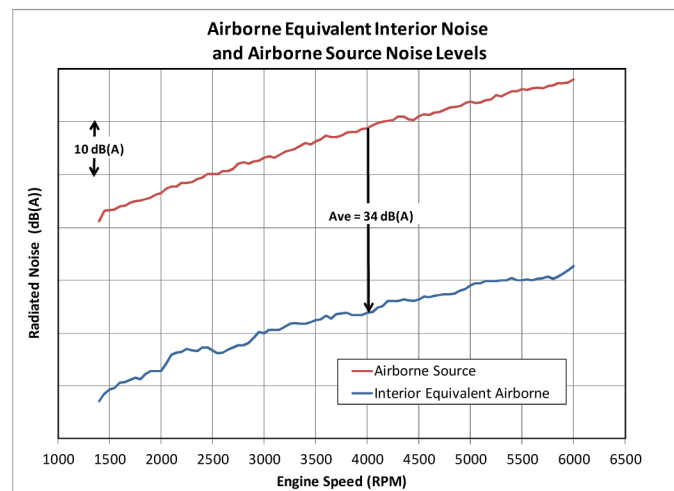


Figure 4. Airborne Equivalent and Source Noise Levels

STRUCTUREBORNE PATH

Powerplant Mount Displacement

The Structureborne noise path starts with the Powerplant Mount Vibration.

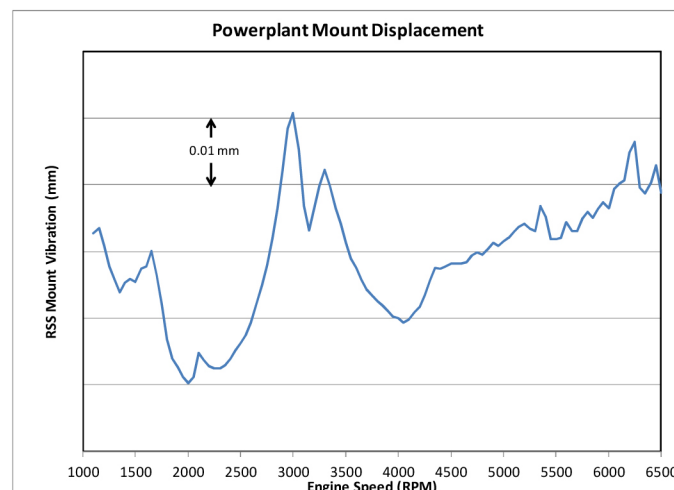


Figure 5. Powerplant Mount Displacement

The Mount Displacement curve shown in [Figure 5](#) is a square root of the sum of the squares summation of the motion measured at the active side of each of the Powerplant mounts. How this displacement relates to the vehicle interior noise is the next step in the process.

Structureborne Transfer Function

The displacements (as a function of frequency) on the active side of the Powerplant Mount can be multiplied by an equivalent Mount Stiffness curve to generate a body input force. The assumption inherent with this approach is that the displacement of the body side attachment of the mount is $\ll$ the active side.

The body input force, also a function of frequency, generates noise in the vehicle interior. The combination of the mount stiffness (Force/Displacement) and the vehicle structure transfer function (Pressure/Force) gives a Structureborne Noise TF [3-4] (Pressure/Displacement).

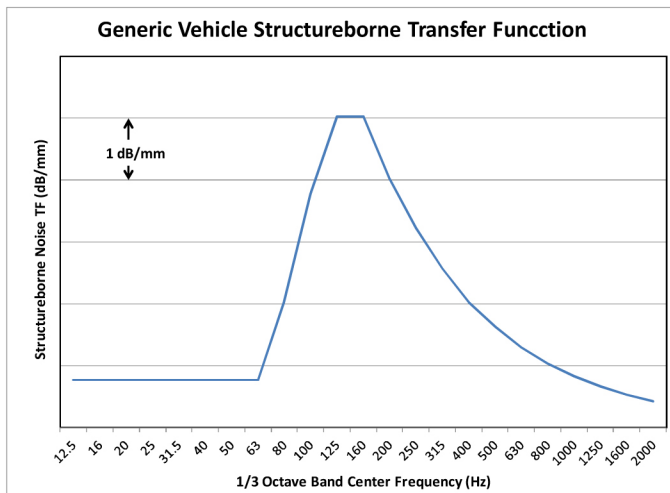


Figure 6. Generic Vehicle Structureborne Noise Transfer Function

Vehicle Interior Equivalent Structureborne Noise

When the Transfer Function in Figure 6 is multiplied by the Powerplant Mount Displacement in Figure 5, the resulting Vehicle Interior Equivalent Noise is as shown in Figure 7.

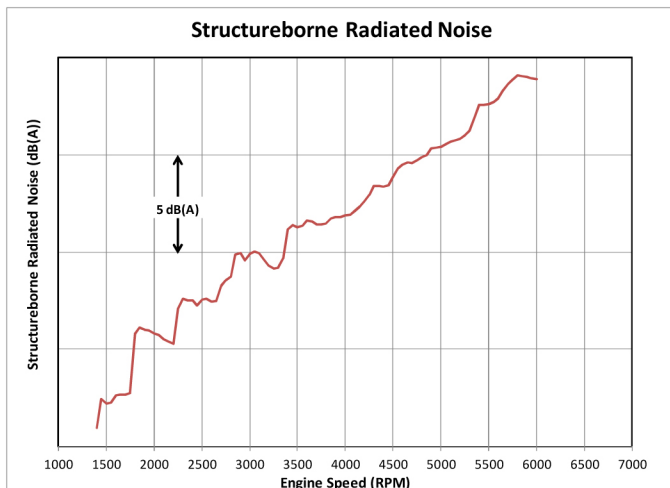


Figure 7. Structureborne Equivalent Noise Level

TOTAL EQUIVALENT INTERIOR NOISE

The Total Equivalent Interior Noise is the summation of the Airborne and the Structureborne Paths. The data is shown in Figure 8.

In this example the interior noise level is predominantly from the Structureborne path. In the region between 1500 and 3000 RPM the Airborne Noise source is 5 dB less than the Structureborne source, so the Total Noise is dominated by the Structureborne source. At higher speeds the Airborne Noise level approaches the level of the

Structureborne Noise as seen by the increasing separation between the Total Noise and the Structureborne Noise, but in this example it is always less.

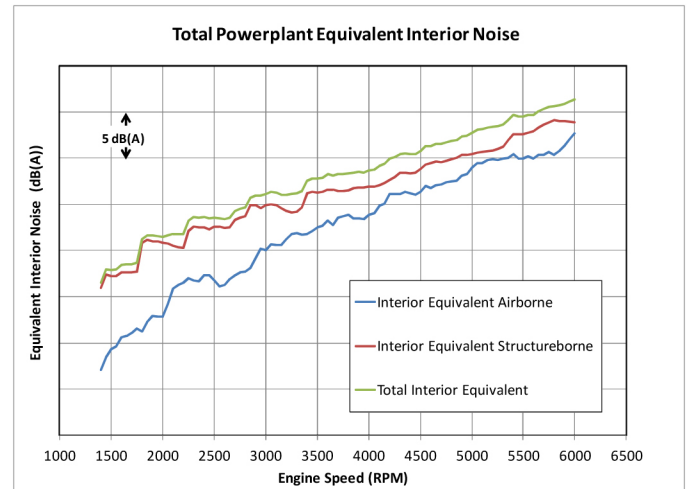


Figure 8. Total Equivalent Noise Level

Impact of Noise Reduction Actions

Assume now that 2 different noise reduction actions are available; one that reduces the Airborne Noise and one that reduces the Structureborne Noise. If both actions have an equal reduction on the source content, say 2 dB, we can compare the effect of each on the Total Noise level.

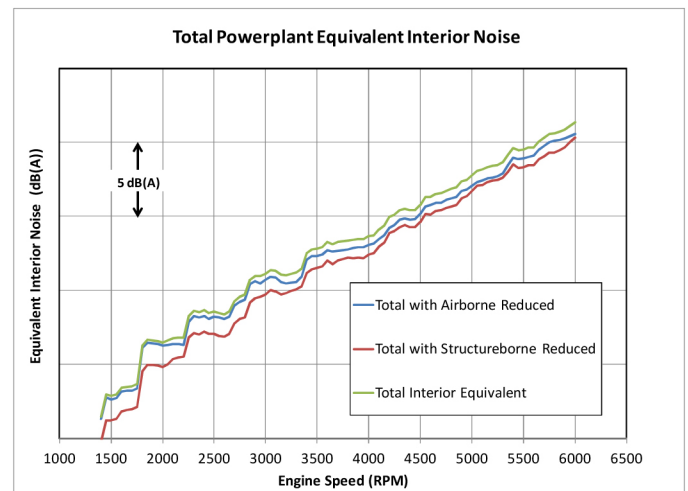


Figure 9. Reduction of Total Equivalent Noise Level

Figure 9 shows how these 2 equal source reduction actions impact the Total Noise Level. Because the Structureborne Noise contribution is larger than the Airborne Noise contribution, the Structureborne Noise reduction action has a greater effect on the Total Noise. The Airborne Noise reduction action goes from having almost no impact on the Total Noise at low speed to having a small impact at higher speeds. At all speeds the impact of the Airborne Noise reduction is less than the impact of the Structureborne Noise reduction. So if the need is to reduce the Total Noise level, the Structureborne reduction is the clear choice.