

Obtaining Structure-borne Input for Hybrid FEA/SEA Engine Enclosure Models through a Simplified Transfer Path Analysis

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ABSTRACT

Structure-borne inputs to hybrid FEA/SEA models could have significant effects on the model prediction accuracy. The purpose of this work was to obtain the structure-borne noise (SBN) inputs using a simplified transfer path analysis (TPA) and identify the significance of the structure-borne and airborne contributions to the spectator sound power of an engine with enclosure for future modeling references. Force inputs to the enclosure from the engine were obtained and used as inputs to a hybrid engine enclosure model for sound prediction.

CITATION: Zhen, J., Copley, D., Londhe, N., and Fredrickson, S., "Obtaining Structure-borne Input for Hybrid FEA/SEA Engine Enclosure Models through a Simplified Transfer Path Analysis," *SAE Int. J. Commer. Veh.* 8(2):2015, doi:10.4271/2015-01-2349.

INTRODUCTION

Large engines in off-highway machines can be a major contributor to exterior noise emissions. To meet regulatory and market sound requirements, sound-suppressed enclosures are used to balance the needs of noise control with that of machine operations including required airflow, physical protection etc.

With the availability of more and more powerful computing devices, virtual product development tools (VPD, aka CAE/CAD) have become popular and reliable, but the success of VPD still relies on the accuracy of the models compared to the physical systems (car, machine, or anything else) and the accuracy of the input loads to drive the models. Fortunately, the commercially available modelling tools are capable of representing the complex physical systems, and the data acquisition tools and techniques are further capable of acquiring accurate input data for model validation.

VPD plays an important role in product development to help meet the sound goals of many products including the engines. Statistical Energy Analysis (SEA) [1, 2, 3, 4, 5] is one of the popular techniques used to predict the sound power of an engine enclosure system; it is used in conjunction with supplemental empirical and analytical approximations and works well for panels with high modal density. SEA predictions of enclosure support structures with lower modal density may be distorted. A hybrid model with high modal density panels modelled using SEA and low modal density frame structures modelled using Finite Element Analysis (FEA) can take advantage of the benefits of both methods when combined in one model [6, 7, 8, 9, 10].

In such a model, it is required to have certain measurements for material characterization, system (panels) damping loss factors, and load excitations as inputs to the model. Among the input loads, engine sound power is considered as one of the major air-borne noise (ABN) sources, and the force inputs from the engine to the support frame are the structure-borne noise (SBN) sources. For mid-high frequency, the ABN is dominant and for low-mid frequency, the SBN contribution can be significant and therefore cannot be neglected.

This paper presents a case study of (a) obtaining the SBN inputs using a simplified transfer path analysis (TPA) for a hybrid model to predict the sound power emission from an enclosed diesel powered engine and (b) identifying the significance of the SBN and ABN contributions to the spectator sound power for reference, in designing an improved sound-suppressed enclosure.

ABN AND SBN SOURCES

The subject work consists of an enclosed diesel engine mounted on a frame. The engine was elastically mounted using four rubber mounts while the sheet metal enclosure was rigidly mounted. [Figure 1](#) shows the enclosure with the engine. [Figure 2](#) is a schematic representation of the unit with its major systems of noise emissions and control.

The major air borne noise sources are the engine, intake and exhaust. The engine was water cooled by a separate system, which eliminated the need for a fan and heat exchangers even though those systems are physically built in the test rig. The exhaust was discharged through the engine muffler and routed out through the assembly on top of the enclosure. The exhaust and intake are the only noise source located outside of the enclosure. All these major systems rest on a frame structure made of thick metal beams.

The enclosure was designed on the engine to suppress the noise inside from radiating out. It consisted of large thin sheet metal panels fastened together as required on the frame structure. The large panels may radiate significant noise into the environment when excited by engine forces, which are considered as SBN inputs.



Figure 1. Engine test rig in a hemi-anechoic sound chamber

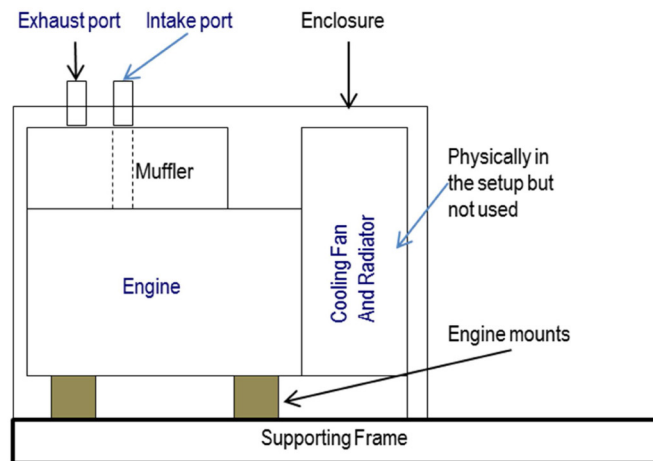


Figure 2. Schematic representation of the engine and the sound suppressed enclosure

THE HYBRID ENCLOSURE MODEL

A hybrid model was built using the commercially available VA-One code. In this hybrid model, the thin enclosure panels were constructed as SEA panels and the thick supporting frame beams were constructed as FE sub-systems as shown in Figure 3. The sound power emitted from the engine and the other systems were the target to predict.

As discussed in the previous section, there are two kinds of inputs to the hybrid model: ABN sources and SBN sources.

Figure 4 shows the interior acoustic cavity of the enclosure that is used as the ABN excitation to the model which includes the engine sound, cooling fan sound and the exhaust sound.

The SBN inputs are the forces transmitted to the frame from the engine.

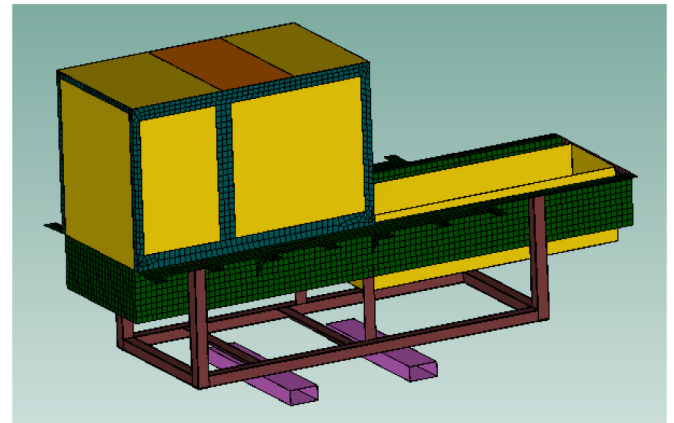


Figure 3. Hybrid enclosure model: SEA panels and FE frames

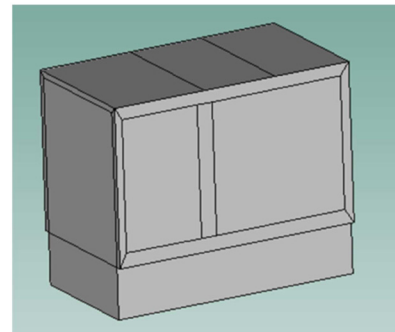


Figure 4. Interior acoustic cavity

SIMPLIFIED TPA FOR SBN INPUTS

There are a few ways to find the force inputs to a structure (receiver) from another structure (source) via elastic or rigid connections: 1) direct force measurement, 2) mount stiffness method, and 3) inverse matrix determination.

Direct force measurement is the most straightforward method. It can be done by placing a load cell at the mounting location or building in strain gauges in the mounting bracket and measuring the forces during machine operations. However, these methods pose practical limits. The choice of the load cells that can be used without significantly increasing in the mounting height is limited. Similarly, there may be difficulties constructing strain gauge mounting brackets that do not break during testing conditions.

The mount stiffness method requires the relative displacements across the mounts that can be derived from measured accelerations and the dynamic mount stiffness for the interested frequency range as shown in Equation 1:

$$\{F\}_N = [K]_{N \times 1} (\{X\}_{1,N} - \{Y\}_{1,N}) \quad (1)$$

The disadvantage for this method is that the dynamic stiffness of the mount may not be readily available and it is difficult to test the mounts in the higher frequency (greater than 500Hz). Besides, the