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Front Engine Diesel Motorhomes: Issues and Opportunities

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Motorhomes, also known as recreational vehicles (RV's) pose many interesting design challenges for acoustical engineers. Some of these were published in a previous paper[1]. This paper mainly dealt with issues in the acoustical design of luxury rear engine diesel coaches. Now, front engine diesel coaches are being designed and produced with the same acoustical goals as the rear engine units. Typically, front engine coaches are lower cost, or utilize a gasoline engine which is much quieter than a diesel engine. With many coaches being 40 feet in length, the front engine design places the main noise source, the engine, about 30 feet closer to the primary receiver. This paper reviews the challenges faced with designing a front engine coach to be as quiet as a rear engine model, and provides recommendations for achieving an overall quieter coach.

1 INTRODUCTION

Motorhomes come in many different shapes and sizes. They range in size from conversion van type units to 13.7 m (45 ft) luxury coaches. Typical motorhomes are categorized as Class A, B, or C. Class A units are the most luxurious and are built on a specially design chassis. Costs for these units can range from about $125,000 to over $1,000,000. Most models offer complete self-containment. An on-board generator, large water and holding tanks, large batteries and a propane supply make these units livable for extended periods. For some, this type of vehicle can serve as their permanent residence. A photo of a typical Class A coach is provided in Figure 1.

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Class B and C units are built on chassis that have been adapted for motorhome use. Class B units are constructed on a van chassis and Class C units are constructed on a truck chassis. These units cost typically below $100,000 and have lower Noise Vibration and Harshness (NVH) expectations. This is because these are typically entry level units and the OEM's do not have control over NVH design since the chassis are "borrowed" from other types of vehicles. Photos of typical Class B and C coaches are provided in Figures 2 and 3.

The motorhomes studied for this paper are front engine diesel engine powered Class A units. These are typically 9.1–12.2 m (30-40 ft) in length with prices ranging from about $125,000 to about $250,000. Traditionally, luxury Class A motorhomes were designed with a diesel engine in the rear of the coach and entry level Class A motorhomes were designed with a gasoline engine in the front of the coach. The front engine diesel coach provides a bridge between a high end gasoline unit and a lower end rear engine diesel coach. The customer NVH expectation is for the front engine diesel coaches are high: no louder than the gasoline powered unit with a desire to be as quiet as the rear engine luxury units. Having the diesel engine in the front of the coach offers various NVH challenges as the source levels are much higher than the more conventional front engine gasoline powered units. In addition, sound not typically dominant towards the rear of the diesel coach, such as tire noise, is now clearly audible.

This paper presents the results of numerous motorhome studies and reviews issues and recommendations for making front engine coaches as quiet as rear engine units.

2 MEASUREMENTS

The most common acoustical measurements involve measuring the sound pressure levels at "typical" occupant locations inside the motorhome, simulating common operating conditions such as 88 km/h (55 mph) on a smooth road or at idle. Measurements are made at approximately 15 cm (6 inches) to the right of the driver's right ear, and approximately 15 cm to the left of a passenger's left ear when seated in the lounge. The one-third octave band sound pressure level, A-weighted sound level, un-weighted sound level, and Articulation Index are calculated based on multiple 5-second measurements and the results averaged.

OEM's do not have prototypes or engineering coaches, so measurements must be done on-road instead of on a chassis dynamometer. Although additional measurements, such as full throttle acceleration and deceleration would be useful, these types of measurements can be difficult, if not impossible on public roadways.

2.1 Benchmarking

Over the past few years, studies have been performed on more than 35 Class A motorhomes from 10 major OEM's, representing a large percentage of the market. Test models ranged in price from about $100,000 to $800,000 and included front engine gasoline and diesel pullers and rear engine diesel pusher models. Results showing the average, minimum, and maximum values for the A-weighted sound level and other metrics at the Driver are provided in Tables 1-3. As expected, the sound levels in the driver area are lowest in the rear engine diesel coaches.

The average sound levels for front engine gas units are very similar to the front engine diesel units for the cruise test condition, 88 km/h (55 mph). This was surprising as consumers report front engine diesel units to have objectionable sound levels. With both types of coaches the engine is in a similar location and similar acoustical treatments are often used. Diesel engines are typically louder than gas engines so we expected higher levels on-road. A possible explanation for this is that at cruise, other sound sources and paths are more dominant than the engine. For example, wind noise and road noise inputs are often more prevalent than the engine at highway speeds.

At idle, the engine is the primary noise source and a large difference can be seen in the average sound level metrics for the three different types of coaches (Table 4). Here the A-weighted sound level and speech interference levels for the front engine diesel are significantly higher than in the front engine gas or rear engine diesel units. The consumer's first impression of the sound of a coach occurs at idle, after the engine is started. If the consumer does not perceive the engine to be running smoothly or quietly, they may find the idle noise to be annoying, particularly if they are used to a front engine gas or a rear engine diesel unit.

Another possible explanation is the higher sound levels found during acceleration with front engine diesel powered units. During a hard acceleration, the engine is again the dominant noise source and the higher sound and vibration levels from the diesel engine are evident. Currently, data supporting this theory is limited; however, acceleration noise studies in an acoustics laboratory are scheduled for later this year.

A survey conducted in 2005 at the Family Motor Coach Association (FMCA) rally in Perry, GA, showed that low sound levels were important to most of the survey respondents[2]. Noise complaints heard during on-road operation were squeak and rattle from doors and slide-outs, wind noise, and engine noise. At the same time, respondents said that hearing the engine, especially when it shifted, was an important sound to them. While the motorhome owner wants to hear the engine to be able to diagnose any potential issues during operation, they don't want the sounds to be annoying or disruptive.

3 NOISE REDUCTION CHALLENGES

As with any vehicle, noise reaches the interior of the coach through structure-borne and airborne paths. For many RV manufactures, the structure-borne isolation is subcontracted to the chassis manufacturer. The chassis is purchased as a package that includes engine, transmission, exhaust system, and tires. The RV is then constructed on the chassis and treatments to reduce airborne noise transmission may be added. A few RV manufacturers design and construct their own chassis, giving them greater control of the final product.

For the front engine diesel, treatments need to take into account the higher airborne and structure-borne sound generated by the diesel engine. Typical underhood sound levels for a diesel engine and a gasoline engine at cruise and at idle are provided in Figure 4. Note that although diesel engines are typically characterized as having more low frequency content, the gasoline engine actually generates higher sound levels below 400 Hz and the diesel engine airborne component peaks around 2,000 Hz.

The typical interior noise spectrum gives a different story. A comparison of average front engine diesel and front engine gas units at idle is provided in Figure 5. In order to produce a front engine diesel coach that is as quiet as a front engine gasoline unit at idle, significantly improved vibration isolation is required along with acoustical treatments providing at least 15 dB greater noise reduction for the engine cover, floor, and front of dash area. This requires treatments that utilize a decoupling layer of 12 to 25 mm (½" to 1") and barrier weights from 3.9 to 9.8 kg/m^2 (0.8 to 2.0 lb/ft^2). In some cases, sound absorptive treatments in the engine compartment and damping of lightweight panels are recommended. Fortunately, the chassis used for front engine diesel coaches are not as weight sensitive as some of the gasoline models.

With a front engine coach, the tailpipe is still located near the rear of the coach. If it is not designed properly, resonances at various engine orders can be accentuated instead of being reduced. An example is provided in Figure 6. This is a measurement in the bedroom at 88 km/h in a front engine diesel coach. The peak at 125 Hz, matches the 3rd engine order (firing frequency of the engine).

For manufacturers not having design control or the ability to select a tire manufacturer, this can add additional noise issues. Spectra measured in the lounge of an RV at 88 km/h near the rear tires is shown in Figure 7 with two different tire designs. The tire from Manufacturer A has a strong tonal component that is audible throughout the RV. A tire selected from Manufacturer B would not have this issue.

4 CONCLUSIONS

Front engine diesel motorhomes offer additional noise reduction challenges. Using the benchmarking data, manufacturers will be able to use objective data to design quiet coaches and determine how their vehicle compares to others in the industry. As OEM's continue to produce what they feel are the best units available in this highly competitive market, interior noise levels and, more importantly, coach sound quality will become an important selling feature. This will force noise issues to be considered early in the design process. Quantifying the noise in a manner that yields information that can be related to the consumer's perception will be key to this process.

5 REFERENCES

1. Kunio, Jason, and Charles Moritz, Motorhome Acoustical Issues: An Overview, SAE Transactions, Journal of Passenger Cars: Mechanical Systems Section 6, page 1800-1810, 2003.
2. Shaw, Jennifer A. and Charles T. Moritz, "Acoustical Considerations for Luxury Motorhomes", *J. Acoust. Soc. Am.*, **124**(4), 2440, (2008).

Figure 1 - Example of a Class A motorhome.

Figure 2 - Example of a Class B motorhome.

Figure 3 - Example of a Class C motorhome.

Table 1 - Benchmark Data for Front Engine Gasoline Powered Coaches – 88 km/h.

	dBA	dB	SIL (dB)	AI (%)
	Driver's Ear Measurement Location			
Best Performing Coach	66.6	87.5	55.9	58
Average	**70.4**	**95.9**	**60.1**	**46**
Worst Performing Coach	72.6	104.2	65.4	28

Table 2 - Benchmark Data for Rear Engine Diesel Powered Coaches – 88 km/h.

	dBA	dB	SIL (dB)	AI (%)
	Driver's Ear Measurement Location			
Best Performing Coach	63.8	90.0	50.6	77
Average	**66.8**	**96.8**	**55.3**	**62**
Worst Performing Coach	72.2	106.2	60.0	50

Table 3 - Benchmark Data forFront Engine Diesel Powered Coaches – 88 km/h.

	dBA	dB	SIL (dB)	AI (%)
	Driver's Ear Measurement Location			
Best Performing Coach	69.4	87.1	58.8	50
Average	**70.9**	**89.3**	**61.5**	**41**
Worst Performing Coach	72.9	91.7	63.5	35

Table 4 - Benchmark Data for Coaches at Idle.

	dBA	dB	SIL (dB)	AI (%)
	Driver's Ear Measurement Location			
Rear Engine Diesel	49.9	81.6	34.6	96
Front Engine Diesel	56.4	79.8	46.4	86
Front Engine Gas	47.3	70.4	34.7	99

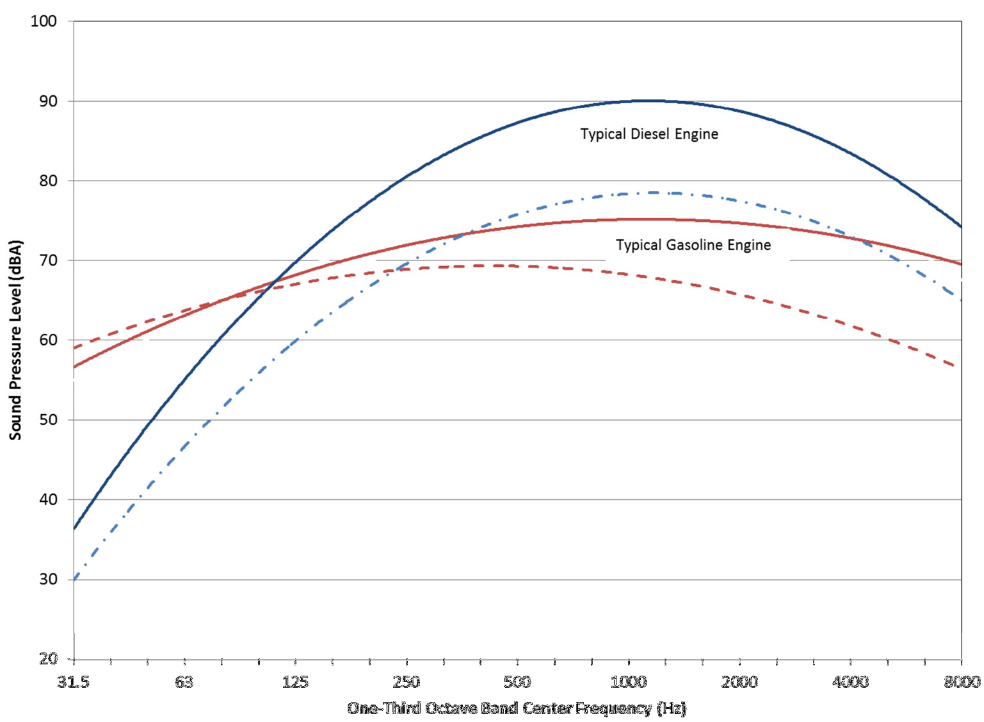

Figure 4 - Typical underhood gasoline and diesel engine sound levels at cruise (solid line) and at idle (dashed line).

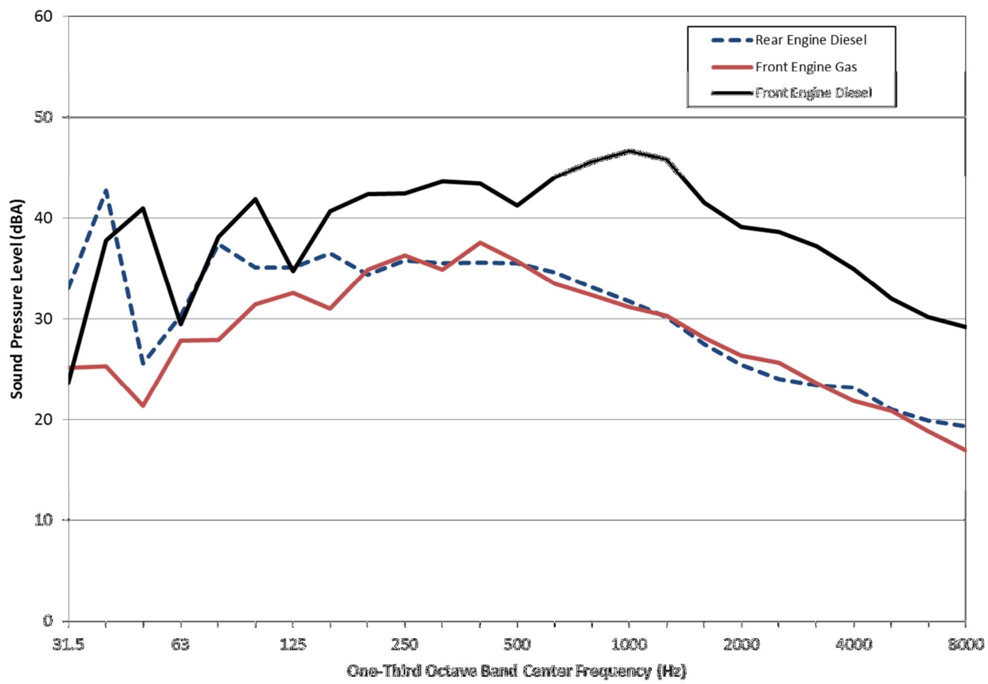

Figure 5 - Typical driver's ear sound levels at idle for gasoline and diesel powered coaches.

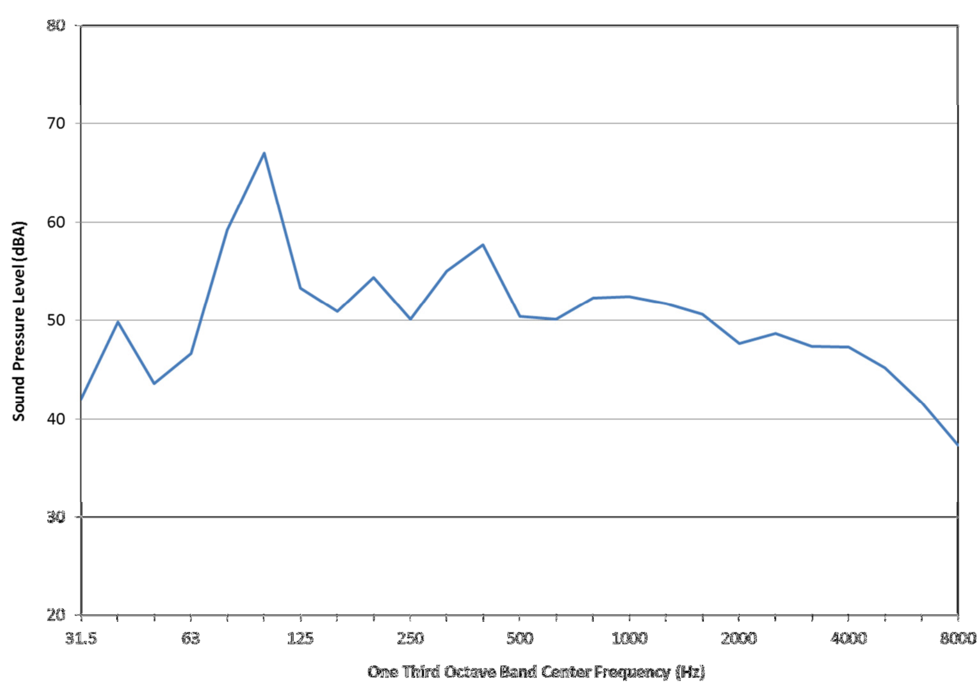

Figure 6 - Example spectra for exhaust noise in a coach – 88 km/h.

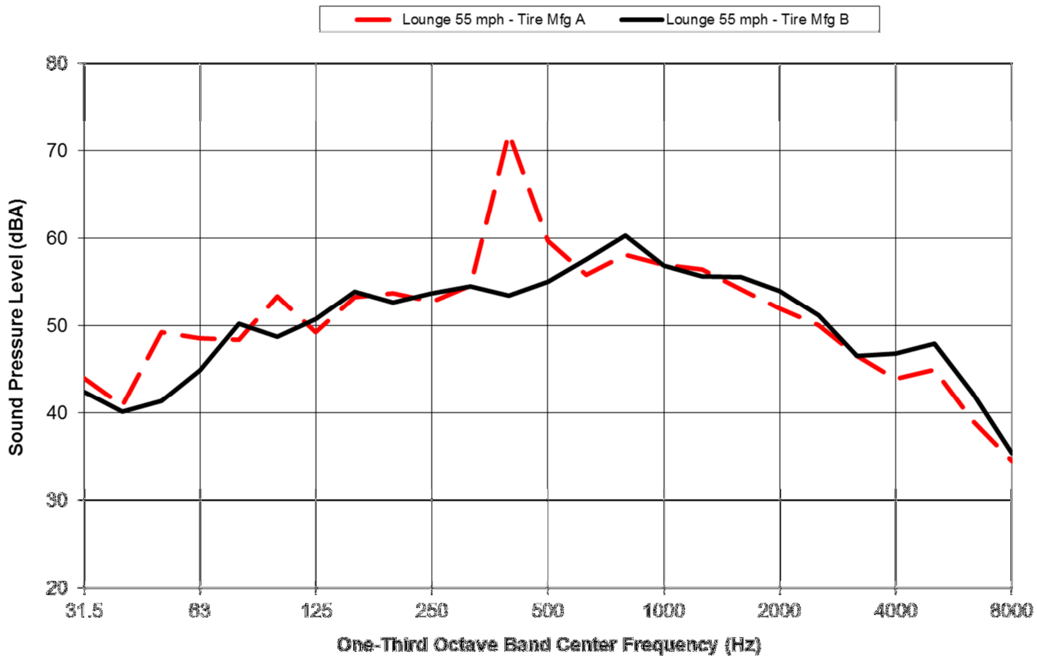

Figure 7 - Example spectra for tire noise in a coach – 88 km/h.