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A Comparison of Fiber Wheel Liners on Two Different Vehicles

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ABSTRACT

Identical fiber wheel liners were installed on two different mid size vehicles in order to compare the noise reduction for each vehicle. The fiber liners represented material in current production. A baseline noise level was established with the existing plastic wheel liners and then comparisons were made with fiber wheel liners. Noise levels were compared in the wheel well and in the interior for similar vehicle operating conditions. For both vehicles, significant tire noise reduction at the source was measured with fiber liners compared to plastic liners. One of the vehicles also demonstrated noise reduction in the passenger cabin with fiber liners. Insight into potential explanations for these differences was provided by comparing the noise levels at different locations within the vehicles. The results show how fiber liners are an additional tool to reduce the noise in a vehicle and how the NVH design for the balance of the vehicle can leverage the NVH impact of these parts.

INTRODUCTION

Tire noise can be one of the major contributors to interior noise in a vehicle. The mechanisms of tire noise are complex and include the pumping of air in and out of the tread, the interaction of the tread with the road surface, and the vibrations of the tread and side wall [(1)]. Tire noise has its most pronounced effect at speeds from 50 to 110 kph [(2)]. Below 50 kph, noise from tire pavement interaction can also be significant because the engine speed in revolution per minute (rpm) is low. However, these low speeds include start and acceleration conditions where engine noise from high rpm is a greater part of interior noise than tire noise. Above 110 kph, wind noise from turbulent air flow over and around the vehicle is present and, in most vehicles, is the largest contributor to interior noise [(3)]. Because a majority of highway driving and cruising occurs at speeds from 80 to 100 kph, reduction of tire noise becomes a primary concern and tests for interior tire noise are most often conducted at steady speeds within this range [(4)].

One strategy to reduce tire noise without the expense of redesigning the tire is to provide sound absorption near the tire. This added absorption reduces the source strength before noise propagates outward or into the vehicle. Sound absorption in the exterior space around the tire can be provided with molded fiber wheel liners in place of hard plastic wheel liners. These fiber liners absorb sound in the reverberant space around the tire.

On two separate occasions, fiber wheel liners were installed and tested on vehicles as replacements to the current plastic liners.[(5,6)] The purpose of this study was, therefore, to compare the noise reduction between vehicles with and without fiber wheel liners and to evaluate their effectiveness as a component of the NVH package.

FIBER WHEEL LINERS

Fiber wheel liners are found on a wide range of vehicles, from entry level vehicles to luxury vehicles. In a recent market survey, 48 vehicles were identified with fiber

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liners either for the rear wheels, for the front wheels, or for both front and rear wheels. While the construction and performance of these fiber wheel liners differ based on manufacturer, one common feature of a fiber liner is a weight reduction over the plastic liner it replaces. The weight reduction can be as high as 650 grams per wheel. This helps reduce the gross vehicle weight and contributes to improved fuel economy.

Market studies of fiber wheel liners have shown that only a few of the commercially available fiber liners can also be classified as acoustical wheel liners. Acoustical wheel liners have high sound absorption compared to the plastic liners they replace. For a fiber wheel liner to be considered an acoustical liner, the average sound absorption should be 50% or more for the individual measurements at 500, 1000, 2000, and 4000 Hz when the material is tested in a reverberation room with a 10 mm air space. The 10 mm air space is intended to represent minimum mounting conditions on the vehicle. A deeper air space would provide even greater sound absorption.

Some fiber liners have a thin barrier membrane in the center of a fiber sandwich and do not function as sound absorbers. The performance advantage of an acoustical fiber liner over a plastic liner will be shown in the subsequent data.

The fiber wheel liners tested in this study represent a material in production on a mid size vehicle. This material was developed to meet targets for high sound absorption required by the vehicle manufacturer. The construction includes two layers of engineered fiber. The top layer of fiber is an abrasion resistant and water repellant nonwoven facing. The backing layer is a fiber blend engineered for molding, stiffness, and sound absorption.

Figure 1 shows the sound absorption for this material measured with a 10 mm air space in a reverberation chamber.[5] The average sound absorption coefficient for the octave bands from 500 to 4000 Hz is 53%.

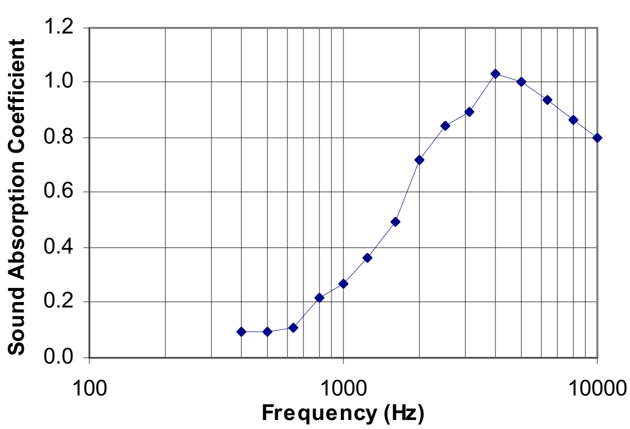

Figure 1 – Random incidence sound absorption coefficient for fiber wheel liner with 10 mm air space

For both vehicles in this study, prototype fiber liners were constructed of the exact shape and size as the existing plastic liners on each vehicle. Table 1 shows the weight for the plastic and fiber rear wheel liners for both vehicles. Since the surface weight of the fiber liners was equal, the difference in weight of the fiber liners for these two vehicles is due to different sizes and surface areas for the parts. The fiber liner (and plastic liner) on vehicle B is therefore 13% smaller than the liner on vehicle A.

Continuing this comparison, the plastic liner on vehicle B is 8% heavier than the part on Vehicle A. Therefore, the 13% smaller and 8% heavier plastic liner on vehicle B represents a 24% heavier surface weight for the plastic liner on vehicle B compared to vehicle A. There is no information to confirm that heavier plastic is of acoustic benefit for this part. It simply shows a weight penalty for the plastic parts compared to fiber parts. By comparison, a pair of fiber wheel liners provided weight savings of 1200 to 1560 grams for these vehicles.

Table 1 – Wheel liner weights, rear wheel

Rear liner	Vehicle A	Vehicle B
Plastic (g) – one wheel	1250	1345
Fiber (g) – one wheel	650	565
Weight savings 2 parts (g)	1200	1560

VEHICLES

The vehicles chosen for this study were mid size luxury vehicles from two different manufacturers. Both vehicle manufacturers place a premium on customer satisfaction through innovative design and low noise levels. The vehicle weights, wheelbases, and tire sizes are shown in Table 2.

Table 2 – Properties of the vehicles used in this study

	Vehicle A	Vehicle B
Weight (kg)	1712	1759
Wheel base (m)	3.048	2.936
Tire size	P215/65R17	P225/60R16

No attempt was made to standardize tires or to normalize tire source strength between the two vehicles. Rather, the goal was to establish a baseline for each vehicle and then look at changes that occurred when the fiber wheel liners were installed.

VEHICLE TESTING

A simple, quick, and thorough test procedure was developed to evaluate the in-place performance of wheel liners.[5] For vehicle A, road tests were conducted at 50, 75, and 100 kph on a smooth road and on a rough road. Noise levels were measured with microphones mounted at 3 locations in the vehicle. These locations were:

1. Exterior wheel liner
2. Binaural head in front seat, passenger side
3. Binaural had in rear seat, driver side

Figure 2 shows the sound pressure levels (SPL) at the rear seat for the left ear of the binaural head for vehicle A at speeds of 50, 75, and 100 kph. Figure 3 shows the SPL at the wheel liner for the same operating conditions.

The results in Figures 2 and 3 show an increase in SPL with speed for both interior and exterior measurements. Furthermore, the transfer function between the SPL at the tire and for the interior is very consistent at each speed.

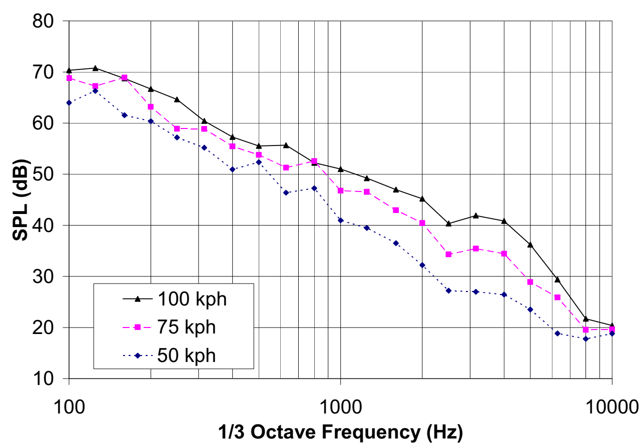

Figure 2 – Vehicle A with plastic wheel liner, rear seat driver side, left ear, three speeds

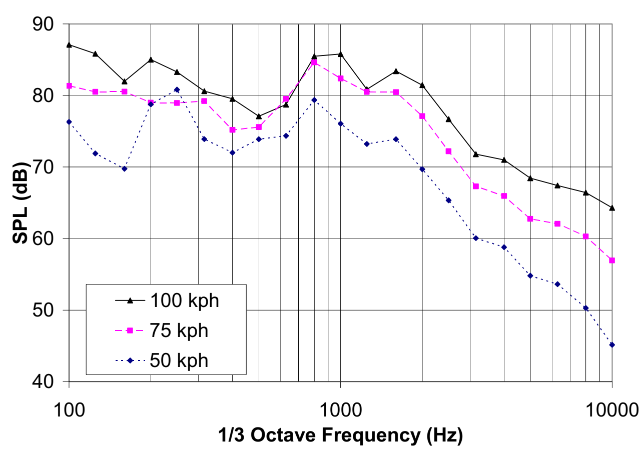

Figure 3 – Vehicle A with plastic wheel liner, wheel liner microphone, three speeds

To focus on the performance of the wheel liner rather than the influence of speed or road surface, a decision was made to isolate tire noise and run all future tests at 83 kph on a smooth road surface. Therefore, all tests for vehicle B were conducted at one speed, 83 kph, and on a smooth road. In fact, the smooth road surface used for tests on vehicles A and B represented the same highway but at one year intervals.

Since tests for vehicle A were conducted only at speeds above and below 83 kph, it was necessary to synthesize data at 83 kph to make comparisons with vehicle B at 83 kph. Therefore, data for vehicle A was synthesized at 83 kph at each microphone location by the following relationship

$$L_{83} = L_{75} + (L_{100} - L_{75})*0.33$$

where L_x = the noise level at x kph

The synthesized data at 83 kph for vehicle A represents an interpolation between 75 and 100 kph.

BASELINE COMPARISONS

Baseline noise levels in vehicles A and B were measured with plastic rear wheel liners that are standard features on each vehicle. Figure 4 shows the SPL for vehicle A at the rear seat location, driver side, for the left (outboard) and right (inboard) ear. The level at the left ear is about 3 to 5 db above the level at the right ear. This is because the left ear is closer to the glass and to the rear tire. The outboard ear will be used for comparisons.

Figure 5 shows the baseline SPL for the two vehicles at the front seat, passenger side, for the outboard ear. The results indicate similar levels and frequency content for the two vehicles with vehicle B having slightly lower noise levels.

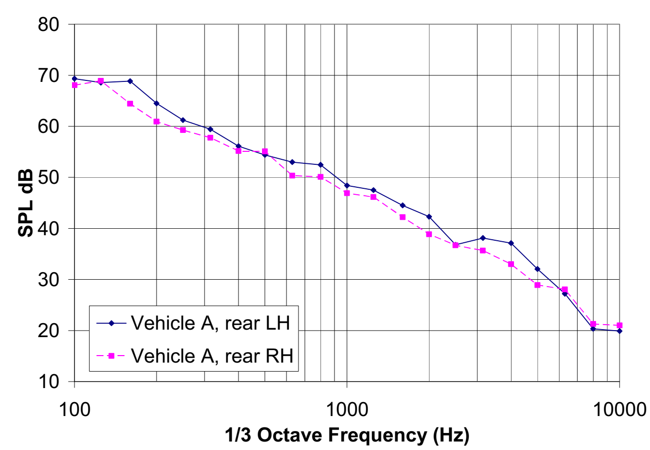

Figure 4 – Vehicle A, plastic liners, rear seat, driver side, left and right ear

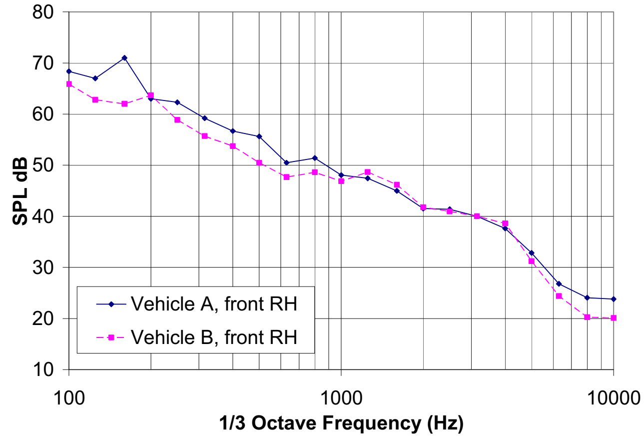

Figure 5 - Baseline vehicles A and B with plastic wheel liners, front seat, passenger side, right ear

Figure 6 shows the baseline noise levels for the two vehicles at the rear seat, driver side, for the outboard ear. The results indicate similar levels and frequency content for the two vehicles with vehicle B again having slightly lower noise levels.

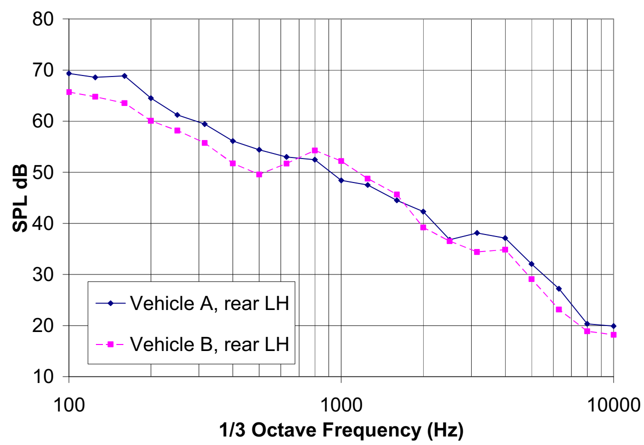

Figure 6 – Baseline vehicles A and B with plastic wheel liners, rear seat, driver side, left ear

A previous study showed that the Articulation Index was the best of four different single number ratings to compare measured results against subjective response when vehicle modifications were made.[6] Low noise levels result in high AI levels. Table 3 shows the AI for these baseline cases.

Table 3 – Articulation Index for vehicles A and B

Plastic liners	**Vehicle A**	**Vehicle B**
Front seat, pass, RH ear	79.7	79.4
Rear seat, driver, LH ear	78.7	82.0

Based on AI calculations, vehicles A and B have comparable front seat noise levels but vehicle B has a higher AI (or lower SPL) for the rear seat. Comparisons will later be made between vehicles A and B with fiber liners.

No attempt was made to identify the reasons for the different SPL between vehicles or to identify the noise sources that contributed to these sound levels. These measurements serve mainly as a baseline against which to compare changes due to fiber wheel liners. The relative importance of tire noise and the contribution that fiber wheel liners can make to attenuate this noise were examined next.

Figure 7 shows the noise levels at the rear wheels for both vehicles. Microphone mounting considerations did not allow identical microphone placement between vehicles. While the frequency distribution of the noise is similar, level differences up to 8 dB between the two vehicles are evident with vehicle A having lower measurements. It could not be determined whether this difference was due entirely to microphone placement or due to tire differences.

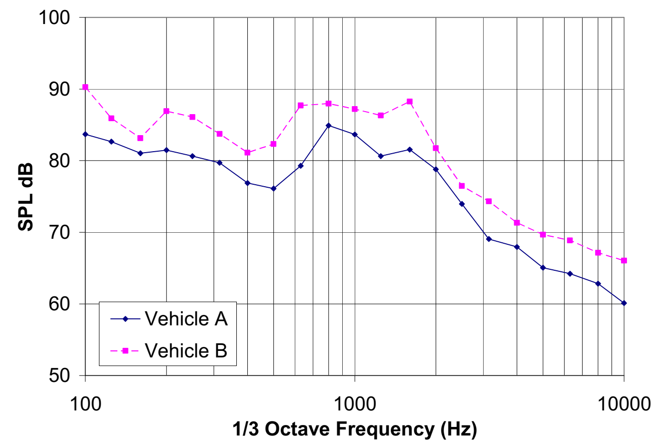

Figure 7 – Wheel liner microphones, vehicles A and B with plastic liners

TESTS WITH FIBER WHEEL LINERS

Prototype fiber wheel liners in the weight and construction described earlier were fabricated for each vehicle. These fiber wheel liners represented the exact shape, size, and mounting conditions as the plastic liners that they replaced. Vehicle road tests and noise measurements were conducted as described for the baseline measurement and comparisons were made at 83 kph.

Figure 8 shows the SPL at the tire of Vehicle A with plastic liners and then with fiber liners. The fiber liners reduced the source strength from 2 dB to 6 dB from 800 Hz to 10,000 Hz.

Figure 9 shows the SPL at the tire of Vehicle B with plastic liners and then with fiber liners. Here, the fiber liners reduced the source strength from 4 dB to 8 dB from 630 Hz to 10,000 Hz.

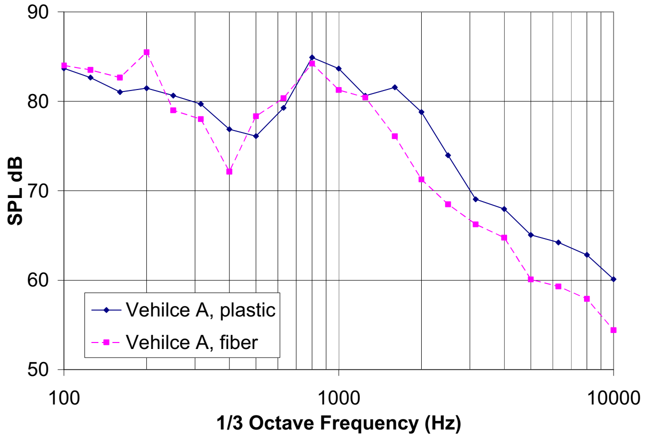

Figure 8 – Wheel liner microphone, vehicle A with fiber liners replacing plastic liners

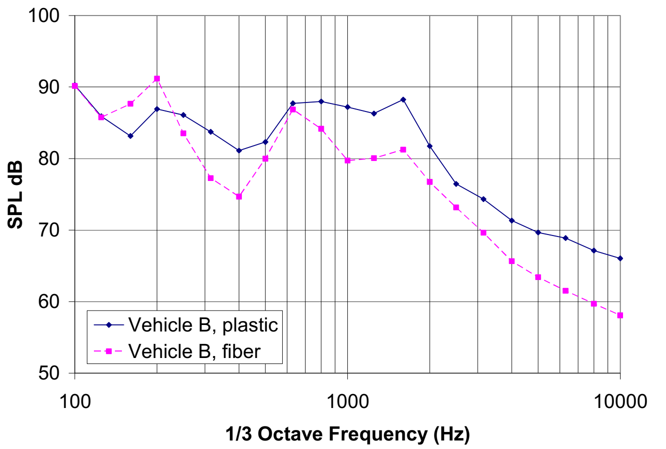

Figure 9 – Wheel liner microphone, vehicle B with fiber liners replacing plastic liners

These figures show that identical fiber liners are delivering similar tire noise reduction on different vehicles. Differences in noise reduction across the spectrum can be caused by the different air gaps behind the fiber liner. Since the fiber liner is a porous material, any air gap behind the material will enhance the performance, especially at low frequencies. The air space behind the wheel liner was not measured over the entire surface. However, this performance increase with added air space highlights an effective design tool to improve absorption without an increase in cost or weight.

Figure 10 compares the SPL in vehicle A for the outboard ear at the rear seat location for plastic liners and for fiber liners. The noise reduction with fiber liners at the rear seat is less than the noise reduction at the tire as shown in Figure 8.

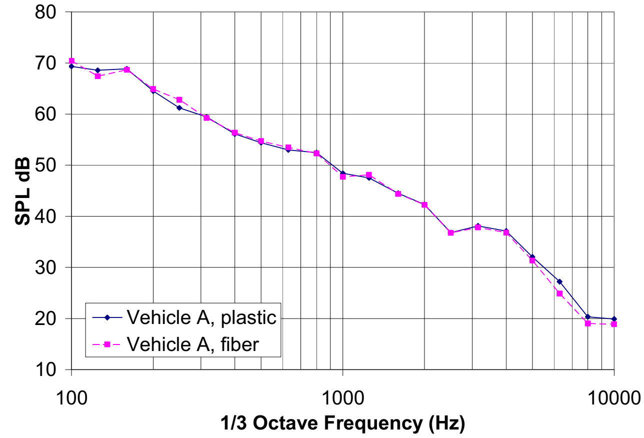

Figure 10 – Vehicle A with plastic and fiber liners, rear seat, driver side, left ear

A difference in performance is seen on vehicle B. Figure 11 compares the SPL in vehicle B for the outboard ear at the rear seat location for plastic liners and fiber liners. The noise reduction at the rear seat is slightly greater than the reduction for vehicle A. The results show a uniform 2 dB to 3 dB reduction in noise from 500 Hz to 4000 Hz with fiber liners.

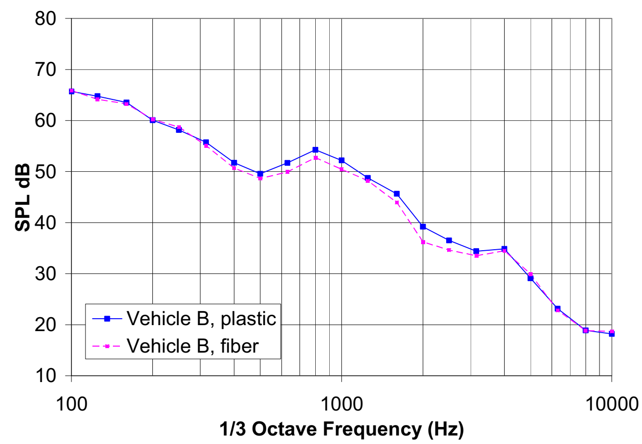

Figure 11 – Vehicle B with plastic and fiber liners, rear seat, driver side, left ear

The reason why greater noise reduction with fiber liners is achieved in vehicle B and not in vehicle A can be partially explained by the measurements at the front seat.

Figure 12 shows the SPL at the front seat for vehicle A with plastic and fiber liners. In this case, there is no difference between the levels with plastic and fiber liners. For vehicle A, with the current tire, it can be concluded that

- tire noise is low enough that it is hardly noticeable in the front seat of the vehicle, with or without fiber liners, OR
- other noises within the vehicle are significantly louder than the tire noise and override tire noise at the front seat, with or without the fiber wheel liners

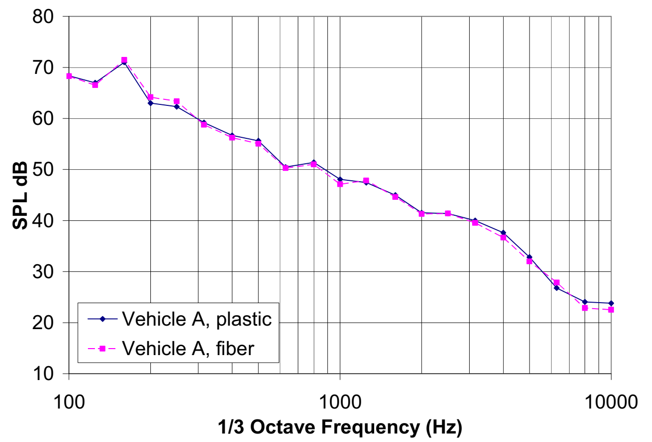

Figure 12 – Vehicle A with plastic and fiber liners, front seat, passenger side, right ear

In this case, weight savings (600 g per wheel) are realized for a fiber wheel liner but no additional acoustical benefits from the acoustical liner are realized. The reason is that other noise sources are greater concerns than tire noise. Further NVH improvements on vehicle A must be directed on areas other than the tires. However, a different tire with a higher noise level may completely change this focus and strategy.

Figure 13 shows the SPL at the front seat for vehicle B with plastic and fiber liners. In this case, an improvement was seen in the front seat as well as the rear seat. Comparing Figure 13 to Figure 11, 2 to 3 dB noise reduction from 630 to 4000 Hz is evident at both the front and rear seats. While not all of the noise reduction seen at the tire (Figure 9) is realized for the interior, this comparison shows that the other noise sources in Vehicle B have been successfully managed. For vehicle B, with the current tire, it can be concluded that

- rear seat SPL for the baseline condition with plastic liners is lower in vehicle B than in vehicle A (Figure 6)
- at the rears seat, other noises within the vehicle have been managed to a low enough level so that tire noise must now be considered as an equal contributor to the interior noise level, OR
- at the rear seat, tire noise is noticeable in the vehicle and tire noise reduction due to fiber liners is noticeable. (If the higher tire noise from vehicle B in Figure 7 is due more to tire pavement interaction than to microphone position differences from vehicle A, then the benefit of a fiber liner for tire noise reduction at the source and within the vehicle is evident.)

In this case, both weight savings (780 g per wheel) and acoustical benefits are realized for a fiber wheel liner. Therefore, on vehicle B a focus on tire noise will pay a dividend for the interior.

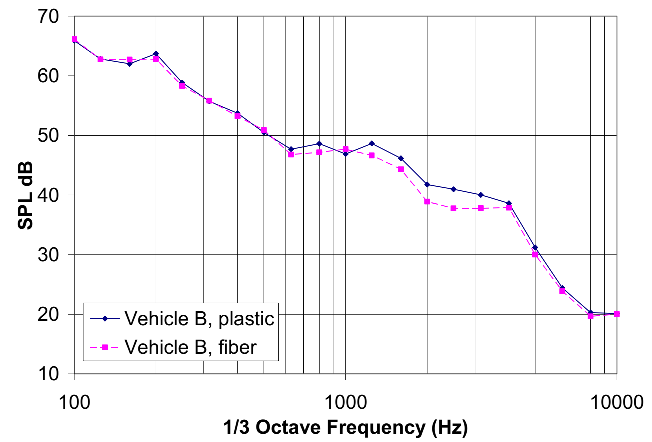

Figure 13 – Vehicle B with plastic and fiber liners, front seat, passenger side, right ear

Table 4 shows the AI for these same conditions with fiber liners. For vehicle A, no difference in AI was seen between the front and rear seat. For vehicle B, an improvement in AI was seen at the rear seat, which is closer to the rear tire. Therefore, when tire noise contributes to the total interior noise, the fiber wheel liner is an effective means to attenuate this noise.

Table 4 – Articulation Index for vehicles A and B

Fiber liners	Vehicle A	Vehicle B
Front seat, pass, RH ear	77.8	82.3
Rear seat, driver, LH ear	77.4	86.6

A summary of the changes in AI from Table 3 and Table 4 is shown in Figure 14. For vehicle B, the AI improved 3% for the front and 4.5% for the rear seat when a fiber wheel liner was used. For vehicle A, the AI showed no improvement and actually decreased 0.9% for the rear seat and 1.3% for the rear seat when a fiber wheel liner was installed. This variation is within the measuring accuracy of the tests and can be considered no improvement as reflected in Figure 10 and Figure 12.

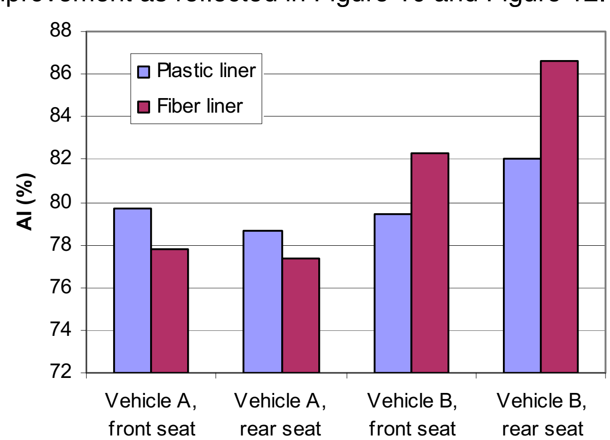

Figure 14 – AI for multiple wheel liner configurations

DISCUSSION

In closing, it would be very significant to use fiber wheel liners and realize the same 5 to 8 dB noise reduction in the interior that was measured at the tire. This is only possible if the residual noise sources (engine, intake, exhaust, powertrain, and wind) that contribute to the interior SPL are brought to a level 5 to 10 dB below the tire noise. This would require a Pareto chart highlighting the contribution from each noise source to the interior. With all noise sources effectively managed to a level below tire noise, then every dB reduction in tire noise would translate directly into a corresponding decrease in interior noise. While this may seem a challenge for traditional internal combustion (IC) engines, this may be a reality on the next generation of electric and hybrid vehicles. With alternate power sources that are quieter than IC engines, the tire noise that always existed will need to be addressed more aggressively. Fiber wheel liners will provide this NVH solution as well as a weight reduction to increase the efficiency of these light weight vehicles.

Unpublished studies have shown that a wide range of different fiber wheel liners are being used in the market today. These fiber liners have different weights, different constructions, and different acoustical properties. For this reason, it would not be incorrect to assume that all fiber wheel liners would produce similar results as documented here. Individual vehicle studies are recommended to assess the value of these products in each application and the measurement procedures reported here have proven to be useful for these comparisons.

CONCLUSION

The conclusions from this study are:

1. A simple, fast, and accurate test procedure has been developed and validated to measure the in-place performance of fiber wheel liners.
2. Fiber wheel liners are lower weight alternatives to plastic wheel liners with weight savings from 600g to 800g per wheel.
3. A fiber acoustical wheel liner will reduce the tire (source) noise from 1 dB to 8 dB, depending on frequency.
4. When a fiber acoustical wheel liner is used, a reduction of the interior noise can be achieved when tire noise source levels are excessive or when engine, wind and other noise sources are managed (reduced) to the same level as tire noise.
5. For vehicle B, a SPL reduction of 2 to 3 dB was measured across a mid frequency range at front and rear seats with fiber wheel liners.
6. For vehicle A, no SPL reduction was measured with fiber wheel liners due to either low tire noise and/or high extraneous noise sources.
7. For vehicle B, improvements in AI ranged from 3% to 5% when fiber wheel liners replaced plastic wheel liners.

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