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Improvement of the Heat and Sound Insulation of a Bus for Compliance with American Regulations

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Abstract

In this study, heat, noise and vibrations of 3-axle bus which was produced according to the American regulations were determined. Insulation designs were made according to heat levels, intensity of noise and vibration and frequency. Comfort conditions inside the bus and the American regulations outside the bus were provided. Heat sources of the bus were detected. Insulations which are able to prevent the heat generated by those sources to reach passenger cabin and other badly affected areas. Maps of noise and vibration of bus is determined, according to the intensity, wavelength and frequency of the noise, using these data more insulation designs were made to reach more comfortable and quieter bus.

Keywords: Noise, Vibration; Harshness; Insulation; Frequency; Resonance

Introduction

Vehicle noise and vibration performance is an important vehicle design validation criterion, since it significantly affects the overall image of a vehicle. Noise and vibration degrade the driver's and passengers' comfort and induce stress, fatigue and feelings of insecurity. Modern vehicle development requires noise and vibration refinement to deliver the proper level of customer satisfaction and acceptance. It is common for a customer's perception of vehicle quality to relate closely to the noise and vibration characteristics of the vehicle [1].

Globalization combined with increased competition in the marketplace requires a vehicle's noise and vibration characteristics to be well optimized. The sound present in the interior of a vehicle consists mainly of power train noise, road noise and wind noise. Given the increased market demand for lighter and more powerful vehicles, it becomes evident that power train induced noise is a key component of the vehicle's interior noise. Automotive manufacturers are increasing the number of power trains available on vehicle programs because of the potential for improved fuel economy. For example, diesel-powered vehicles are one of the popular alternatives in the global automotive market. This presents and further complicates a unique set of noise and vibration challenges that need to be solved during the vehicle development process. This means not only eliminating squeaks and rattles and suppressing overall noise levels, but also tuning the sound of the automobile to reflect the high quality and distinction of the brand.

Noise, vibration and harshness (NVH) have become increasingly important as a result of the demand for increasing refinement. Vibration has always been an important issue closely related to reliability and quality. Noise is of increasing importance to vehicle users and environments. Harshness is related to the quality and transient nature of vibration and noise. Noise and vibration problems may originate from systems such as the engine, pumps, drive train, wheels and tires, or may be related to system integration issues, for example matching between power train and body and between chassis and body. Controlling vibration and noise in vehicles poses a severe challenge to designers because motor vehicles have several sources of vibration and noise which, being interrelated and speed dependent, are different from many machine systems. Vehicle noise and vibration refinement has been considered essential for vehicle designated development because of legislation, marketing needs and customer expectations. In order to minimize the impact of the automobile on the environment, legislation has become increasingly demanding on vehicle noise emission and vibration controls. Noise and vibration refinement distinguishes a vehicle from its competitors, thereby attracting new customers [1].

Vehicle refinement encompasses noise and vibration refinement, ride and drive ability. Vehicle refinement affects the customer's buying decision and the business of selling passenger cars, as it directly affects the driving experience.

A refined vehicle should have the following characteristics:

- High ride quality
- Good drive ability
- Low wind noise
- Low road noise
- Low engine noise
- Idle refinement (low noise and vibration)
- Cruising refinement (low noise and vibration, good ride quality)
- Low transmission noise
- Low levels of shake and vibration
- Low levels of rattles, squeaks and sizzles
- Low level of exterior noise of good quality
- Low level of interior noise of good quality
- Noise that is welcome as a 'feature'.

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Customers have come to expect continuous improvement in new vehicles. They expect their new purchase to be better equipped and more comfortable, and to perform better than the vehicle they have just traded in. If the new vehicle is better in all respects than the old one, but lacks refinement, the customer will not be fully satisfied. Vehicle refinement aims to enhance vehicle performance, styling and acoustics. The motivations for vehicle refinement are therefore:

- Brand image
- Drive comfort
- Quality enhancement
- Cost and weight reduction
- Customer satisfaction

Noise and vibration refinement is an important aspect of vehicle refinement. It deals with noise and vibration suppression, noise and vibration design, rattle and squeak suppression [1]. The vehicle noise and vibration refinement process covers the following tasks:

- Benchmarking
- Target setting
- Noise and vibration design and development
- Prototype NVH testing and design validation
- Noise and vibration diagnostics and problem solving
- NVH design solutions for production
- NVH audits on production vehicles.

In this study, heat, noise and vibrations of 3-axle bus which was produced according to the American regulations were determined. Insulation designs were made according to heat levels, intensity of noise and vibration and frequency. Comfort conditions inside the bus and the American regulations outside the bus were provided. Heat sources of the bus were detected. Insulations which are able to prevent the heat generated by those sources to reach passenger cabin and other badly affected areas. Maps of noise and vibration of bus is determined, according to the intensity, wavelength and frequency of the noise, using these data more insulation designs were made to reach more comfortable and quieter bus.

Thermal and Acoustic Insulation Materials

General properties of thermal and acoustic insulation materials used for Temsa Turkish brand buses manufactured in Adana, Turkey for American market are given below. Typical acoustic kits used for buses are given in Figure 1.

Aluminum foil coated polyester

The material is made from a white pes non-woven that fulfills the highest requirements of diverse flammability tests - optionally laminated with an embossed foil of highest-grade aluminum, thickness: 0.1 mm, corrosion-proof. Figure 2 shows the section view of aluminum foil coated polyester.

Typical applications are rail vehicles, utility vehicles, buses, buildings or shipbuilding, sound insulation enclosures, casings, cabins, hoods, construction machinery [2].

Material benefits are;

- Excellent sound absorption values
- High temperature resistance
- Fulfills high requirements regarding fire performance
- In vibration tests, the fiber composite shows no tendency to break up
- High shape stability
- Aluminum foil for fulfillment of the highest hygienically requirements
- The aluminum foil prevents the penetration of liquids.

Glass fibre mats

Glass material is a white glass fiber mat laminated with a high-temperature resistant aluminum foil. It is an ideal two-layer combination material for heat insulation and sound proofing. The upper layer is a top quality aluminum foil for reflection of heat radiation. The lower layer consists in a quilted glass fiber mat, which is responsible for the heat insulation effect as well as for the sound insulation properties [2]. Figure 3 illustrates section view of glass fiber mats.

Typical applications in high-temperature areas are machines and industrial plants, compressors, construction machinery, utility vehicles, buses, rail vehicles.

Temperature resistances of material are;

With mechanical fixation: - 40°C to + 450°C

Without mechanical fixation: - 40°C to + 120°C

Key benefits;

- High temperature resistance
- Very high heat insulation effect
- The aluminum foil completely prevents the penetration of dust, water, oil or other pollutants
- Its low weight makes handling and processing easy.

AcSorb noise insulation material

Flexible acoustic foam is generally used in exterior environments. Acoustic insulation interlayer is a noise insulation material optional to address low/mid frequency noise sources. Figure 4 shows the section view of AcSorb insulation materials.

Design Considerations are;

Thickness: Various available. Increasing thickness improves mid frequency noise control.

Weight: 2-5 kg/m^2 (7-10 kg/m^2 with insulation)

Use of closed cell or open cell with impermeable layer only in exterior applications

Foam is compressible. Parts can be 3 mm oversized [2].

Quiet floor material

Constrained layer damping acoustic flooring is offering leading sound insulation in conjunction with improved low frequency damping control. Damping measures ability of floor to dissipate vibration energy.

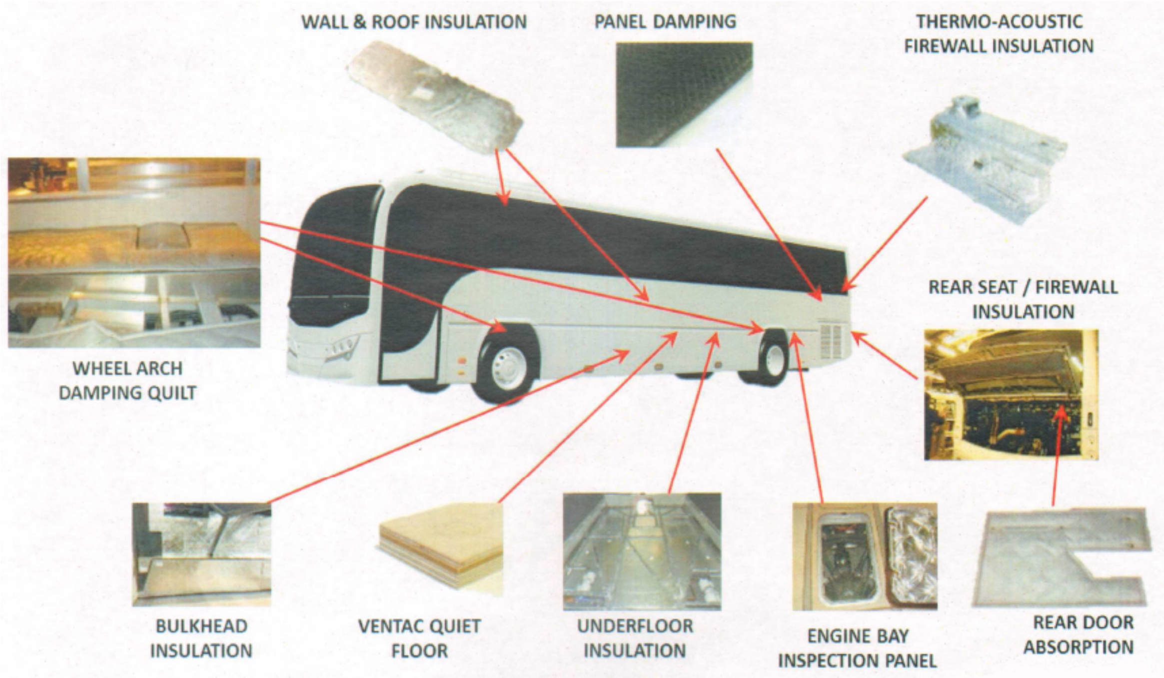

Figure 1: Typical acoustic kits for buses.

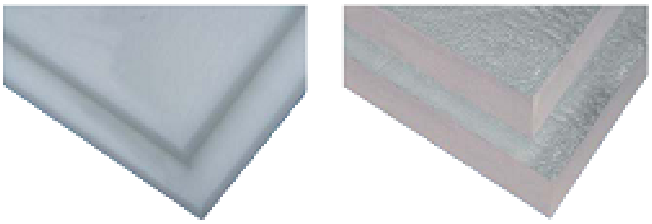

Figure 2: Section view of aluminum foil coated polyester.

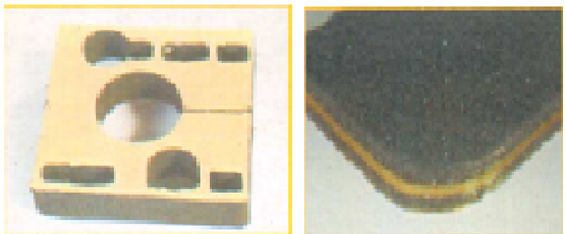

Figure 4: Section view of AcSorb insulation material.

Figure 3: Section view of glass fiber mats.

Higher number is better as structural vibration in the structure is dissipated before being radiated. Noise transfer measures amount of noise radiated from surface of board for every for every 1 N dynamic force input. Lower number is better meaning less noise radiated. Figure 5 illustrates the section view of quiet floor material.

Fixing Methodologies are;

Ideal: Bond in position using structural adhesive. Supports decoupling of top layer.

Screws: Screw down at outer periphery with minimum number of screws. Some vibration transfer to top layer through screw.

Typical application areas;

Bus: Flooring in rear portion of vehicle until rear axle bulkhead.

Bus: Sensitive rear 5-way flooring and rear aisle as required. Improve floor vibration [2].

Heavy Foil

Heavy foil has excellent noise insulation and solid-borne noise attenuation values, easy to adapt and install. This heavy foil consists of a blend of synthetic materials on the basis of epdm/Eva-polymers, with an admixture of special flame-retardant minerals. Figure 6 shows the section view of heavy foil.

Typical applications of material are machine and plant construction, construction machinery, utility vehicles, buses, rail vehicles, air-conditioning technology, solid borne noise damping of metal sheets [2].

Figure 5: Section view of quiet floor material.

Figure 6: Section view of heavy foil.

Key benefits of material are;

- Excellent sound insulation values
- Very good flammability characteristics
- Higher temperature resistance as bitumen layer
- Odorless even when warmed (in contrast to bitumen layers)
- Effortless to cut with a cardboard cutter or similar
- Easy and clean installation
- The material is flexible, not sensitive to pressure and does not emit particles or cause smudges.

Measurement Equipments

Measurement equipment's used for acoustics and vibration measurements in this study are explained below.

Conductor

The Conductor is a high-performance Laptop based analyzer (Figure 7). The Conductor provides a rugged platform for acoustics and vibration measurements. Mainly used for the I-Track sound intensity mapping system, it is also suitable for any other task encountered by a noise and vibration specialist [3].

The Conductor combines:

- A high-power TI 6000 Series DSP that takes charge of critical computation to ensure real-time signal processing,
- A rugged laptop allowing extensive use in the harshest environments,
- The perfect field platform for I-Track sound intensity mapping system,
- A highly versatile software suite (OPUS) allowing a wide range measurement

The I-Track system is a powerful tool for fast, easy and accurate sound mapping. The maps are created by combining in real-time the acoustic data from a sound intensity probe with its position data from a position tracking device. The result is a high definition sound mapping performed in a few minutes and an automatic sound power calculation [3].

The I-Track system offers a complete solution to create sound mapping both in the field and in the laboratory (Figure 8). Its compact construction makes it easy to carry and fast to setup a measurement.

The Opus software suite is a collection of measurement modules that are installed on the Conductor to perform numerous sound and vibration measurements. Advanced yet intuitive, the Opus software suite along with the Conductor platform can improve efficiency and quality of noise and vibration analysis.

The Soft dB OBSI Software is the first turn-key solution for the measurement of On-Board Sound Intensity (OBSI) Method. This software is used both for real-time acquisition and processing, and post-processing of recorded files. Primarily intended for the Conductor platform, the OBSI software can be used with the Alto-6i USB analyzer connected to a PC [3].

Sound Level Meter

An advanced, single-channel, hand-held analyzer and sound level meter that has everything needed to perform high-precision, Class 1

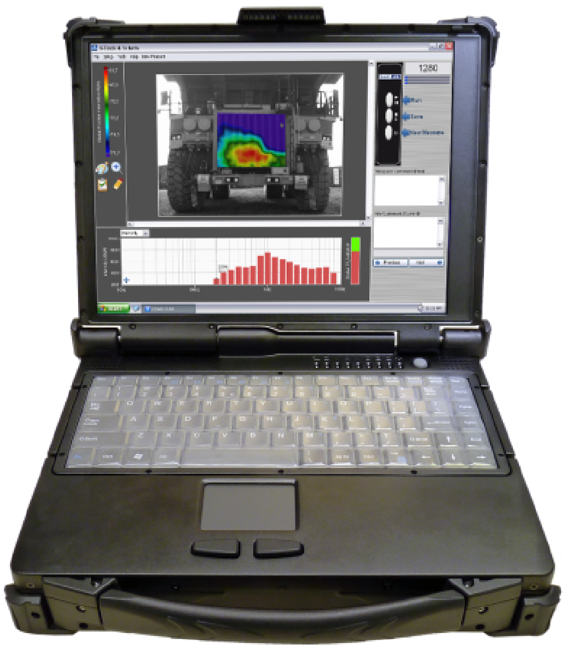

Figure 7: 6-Channel multi-function laptop based DSP analyzer.

Figure 8: I-Track system.

measurement tasks in environmental, occupational and industrial application areas (Figure 9). Type 2250 is a versatile, modular measurement platform with many optional application modules such as frequency analysis, FFT, advanced logging (profiling), sound recording and building acoustics [4].

Uses;

- General-purpose Class 1 sound measurements to the latest international standards
- Occupational noise assessment
- Environmental noise assessment and logging
- Product development and quality control
- FFT analysis of sound and vibration
- Sound power determination
- Single-channel building acoustics measurements Features;
- Single-channel input (microphone, accelerometer or direct signal)
- 4.2 Hz-22.4 kHz broadband linear frequency range with supplied microphone Type 4189
- 16.6-140 dB A-weighted dynamic range with supplied microphone Type 4189
- Inputs: AC or CCLD, External Trigger
- Outputs: Generator and Headphone
- Communication via USB, LAN, or GPRS/3G modems
- USB 2.0 host for connection to printer, GPS, weather station, modem
- Plug-in rechargeable Li-ion battery (> 8h operation) [4].

Regulations Needed for Engine Bay Insulation Material

1. According to 95/28/EC or ECE R118 regulations, insulation material must have non flammability certification.

Figure 9: Sound level meter.

2. Material kind, thickness or mounting location and type should not be changed after vehicle with insulation material used in engine region tested and confirmed by homologation team according to 70/157/EE or ECE R51 regulations.

According to selection of material used, vehicle exterior noise measurement values required to provide maximum dB values are as follows (Table 1).

3. The materials used in the engine room should include the following features according to 2001/85/EC or ECE R107.

- In the engine region, flammable sound insulation material or material which capable of absorbing fuel, oil or other flammable material should not be used unless coated with oil and fuel impermeable layer.
- Anywhere in the engine region; necessary precautions should be taken in order to prevent accumulation of fuel, oil or any other flammable material by opening the liquid discharge ports or engine region make suitable this situation.

	Vehicle Categories	dB(A)
1	Vehicles which is designed to transport passengers and not more than nine seats including driver's seat	
1.a	Vehicles which is designed to transport passengers and more than nine seats including driver's seat and vehicle which the maximum permissible mass is more than 3,5 tons.	74
1.b	Vehicle which the engine power is less than 150 kW	78
1.c	Vehicle which the engine power is more than 150 kW	80
2	Vehicles which is designed to transport passengers and more than nine seats including driver's; vehicle for transport load	
2.a	Vehicle which the permissible load is not more than 2 tons	76
2.b	Vehicle which the permissible load is between 2 tons to 3,5 tons	77
3	Vehicle which is designed to transport passengers and max permissible load is more than 3,5 tons	
3.a	Vehicle which the engine power is less than 75 kW	77
3.b	Vehicle which the engine power is between 75 kW to 150 kW	78
3.c	Vehicle which the engine power is more than 150 kW	80

Table 1: Maximum dB values according to vehicle categories.

- Partition which made of heat resistant material should be placed at the engine region or between another heat source and the remaining part of the vehicle. All fixing clips or gasket in order to connection to partition region.
- Heaters which excluding working according to circulation of hot water can be located into passenger compartment if placed in a heat resistant housing or not spread toxic gas or the passengers will not touch the hot surface is inserted.

Method

Vehicle noise assessment of bus

It was concluded that both the noise levels in the bus and the weight of the acoustic treatment can be reduced.

This step represents the initial assessment of the TS 45 bus. It found that there was heavy insulation across the rear seat and floor up to the rear axle with the exception of certain locations. These exceptions are acoustic weak points which allow high levels of noise to pass through. It is recommended to treat these weak points and reduce the mass of the acoustic insulation across the remaining areas of the floor to optimize the effectiveness of the treatment. These weak points are the floor in front of the back seat on the left side of the bus, the engine bay access hatches, the seat back of the rear seat and services running up the rear left corner.

There was found to be structure borne noise radiating from the floor itself which may be treated by the New Insulation product which is a flooring material with a damping element incorporated within it.

The evaporator units for the air conditioning it the bus are a very important noise source in the passenger compartment. The ideal solution is to distribute the air more efficiently to each passenger location which would allow for the reduction of the fan speed. It is also possible to apply noise control measures to the evaporators. Measurements taken on the unit suggest a 4-5 decibel reduction can be achieved this way.

The vehicle was assessed in a number of operating conditions but the partially open throttle acceleration (slow acceleration) was identified as the most relevant. The windowing exercise, where the entire rear of the bus was lined with acoustic treatment, produced a reduction of 4 decibels in front of the back seats (in the slow acceleration condition) but on a real installation of noise materials a reduction of 2-3 decibels would be expected. It is noted though there can be variation between the noise measurements on vehicles which can make predictions difficult.

The noise and vibration measurements were carried out as an assessment of the TS 45 Bus. The objective of this step is to identify opportunities for improvement in the sound insulation package for the vehicle. The noise measurements were carried on the public roads around the Temsa Bus Factory. All measurements are repeated 3 times and mean values of these three measurements are used for comparison (Figure 10).

The measurements were taken with a Type 1 sound level meter that was calibrated before testing and checked afterwards.

Three measurement locations were assessed:

- 1 m over the floor directly in front of the back row of seats, on the center axis of the bus
- 1 m over the floor directly over rear axle, on the center axis of the bus

Figure 10: Bus used in the noise measurements.

- 1 m over the floor on the center axis of the bus in line with the 6th row of seats from the back of the bus (close to the AC units)

The measurements were taken in the following operating conditions for a period of approximately 25 seconds each:

- Acceleration in third gear full throttle
- Acceleration in third gear partial throttle
- 80 kph Steady Speed
- 100 kph Steady Speed
- Stationary, Engine Speed Idle
- Stationary, Engine Speed High Idle

The results are presented as an overall single figure, LAeq dB (continuous equivalent sound pressure level with an integration time of 125 ms).

The results are also broken down into an A-weighted third octave spectrum averaged across the measurement period [5].

Bus masking measurements

To assist in prioritizing noise pathways into the passenger compartment, sections of the bus floor and rear of the bus were masked with sound insulations quilts.

These quilts could be a removed from specific sections and the difference in noise levels was measured (Figure 11).

Results and Discussion

The noise level is reduced for all conditions; the change is 2–5 dB. The targets which we set when first tested are mostly exceeded; cruise at 100 km/h is border line but here last insulation is another 3 dB louder.

Sound quality issues found on R&D vehicle have been resolved. The cabin noise performance is now limited by structure borne noise transfer which new materials will not fix.

Floor vibration levels are significantly reduced with the insulation applied to the bus. The overall level vibration difference is 3 dB for 80 km/h and idle with A/C and 5 dB reduction for 100 km/h. Low frequency peaks of vibration (what is felt most) are reduced by 8 dB for 80 km/h, 9.5 dB for idle with A/C and 13 dB for 100 km/h. Finally, the thermal insulation is now deemed acceptable to prevent cabin hot spots [5].

Figure 11: Floor area masked by sound insulation quilts.

The use of a sound intensity probe with paired microphone arrangement allows for the measurement of the directionality of sound. By taking a series of measurements across a grid, a noise map can be generated that can indicate how the noise is travelling through a space. These noise maps can be used to identify the noise paths into the bus interior (Figure 12). The measurements were taken when the vehicle was stationary with the engine running in the high idle condition.

The overall A-weighted intensity map shows a major hot spot over the left floor section in front of the back seat and over the access hatches. There also a hot spot indicted along the seat back. Areas where high levels of noise are coming through are described as hot spots (Figure 13).

When the intensity measurements are broken into third octave bands it can be seen the hot spot over the floor section on the left side of the vehicle is strong in the mid frequency range particularly at 630 Hz and 500 Hz. The third octave band sound pressure measurements found this to be an important frequency range. The hot spot at the back seat is found to be an important route for low frequency noise 315 Hz–125 Hz. This noise path may be structure borne in nature.

Noise in the high frequency range was measured coming through the access hatch area. This indicates that the access hatches are an acoustic weak point as it should be possible to insulate against this level of high frequency noise.

This study is a baseline assessment of the noise levels in TS 45 bus but its purpose is also to make recommendations that will improve the noise levels experienced in the vehicle. The noise measurements were conducted; firstly to assess how the noise from the vehicle power train was entering the passenger cabin and secondly to assess the evaporator units within the passenger cabin that also were an important source of noise.

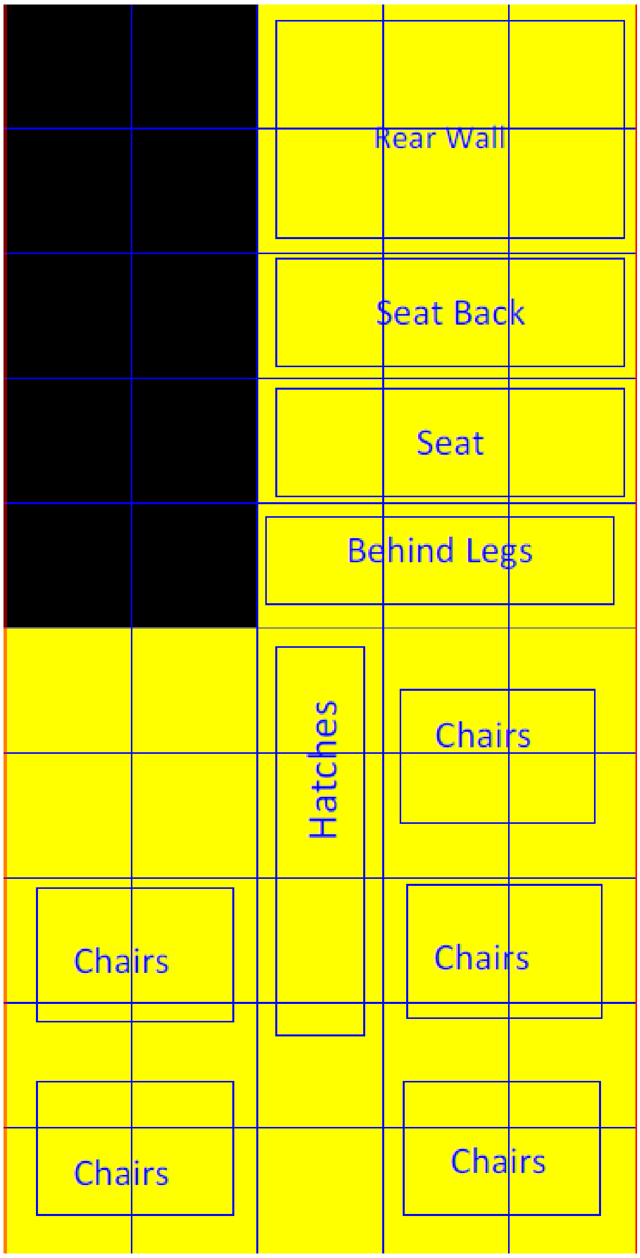

Figure 12: Intensity mesh plot.

A lot of the focus of this study was on measuring the vehicle under acceleration. It was measured under wide open throttle acceleration where the noise levels were at their worst and it was measured under partial throttle acceleration which was a more typical operating condition.

The figures below compare the baseline noise measurements in the acceleration condition with levels measured when the floor area over the engine, rear axle and rear wall were fully screened. This gives an indication of the optimal noise levels that can be achieved on a vehicle where there are no practical limitations.

The graphs in the Figure 14 indicate that there is a large amount of medium to high frequency noise that could be treated. It also shows

Figure 13: A-weighted broadband level max: 78 dB Min: 52 dB.

that noise reductions can be achieved across the frequency spectrum. The high frequency noise at the current levels results in poor sound quality and the harsh quality experienced when the vehicle is under acceleration.

The large reduction in high frequency noise achieved by screening the vehicle meant that the lower frequency noise (~160 Hz) would dominate the noise. This shift changed the character of the noise experienced in the bus very significantly rather than just reducing the overall noise level. This meant that a better improvement in the interior noise of the bus was achieved than was indicated by the reduction in overall decibel level measured.

Digital recordings taken during the acceleration measurement periods of the bus were post processed and presented as a sonogram. A sonogram is a graph that presents the frequency vs. time high levels are shown by yellow and red, lower levels are shown by green and blue.

The time measured is as the vehicle is accelerating in the third gear both under wide open throttle and also partially open throttle.

The treatment package trialed in the prototype bus replaced the heavy foam and barrier material with a quilt material at the back and a slab material in the floor. Barrier was only used in the floor treatment in front of the rear seat and not in the panels over the rear axle. The floor was fitted with acoustic insulation floor to minimize the structure borne noise radiating from it. Parts were made for weak points in the floor insulation particularly around the hatch area where high frequency noise was found to be coming through strongly in the previous.

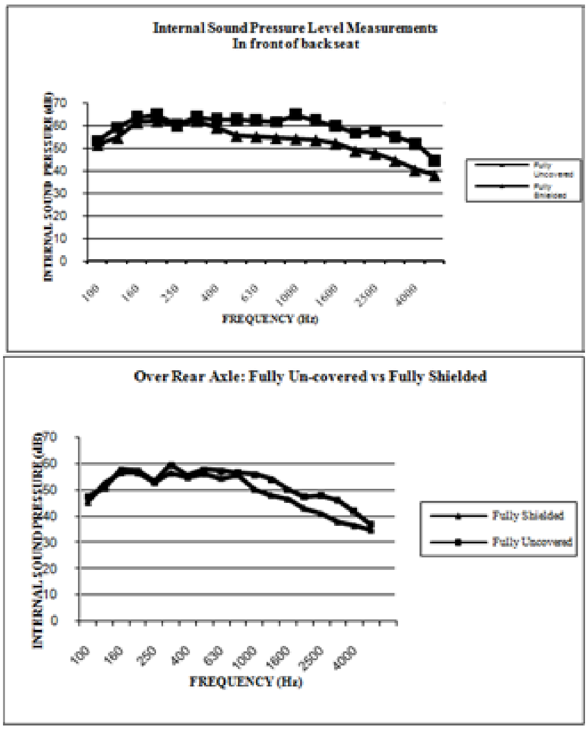

Figure 14: (Up) Fully shielded vs. unshielded measurements accelerating under wide open throttle and (Down) under partially open throttle.

Floor over rear axle

The results over the rear axle were disappointing. It was hoped that mass could be taken out of this area and fiber glass slab alone used to treat the higher frequency noise. It was found that mass is needed in this area to mitigate the noise in the mid frequency range. This effect is clear in the POT sonograms and even more clear in the WOT sonograms (Figure 15).

It was found that the quiet floor removed a resonance in the floor. This improved the sound quality in this area despite the increase in noise levels. The recommendation for this area is to include a barrier layer in the under floor slab treatment.

Rear Seat

The levels measured along the rear seat remained at about the same levels as measured in the previous measured this was despite the fact that the levels coming through the engine bay access hatches was significantly reduced (Figure 16).

One of the reasons for this was acoustic weak points in the rear seat area. One of these weak points is the seat rails in the rear seat itself. Another weak point was found to be where the services enter the rear corner of the bus. It is planned to improve the insulation in this area by treating it with a combination of quilts and treatment within the frame of the bus.

Conclusions

The measurements in these results were to assess the effectiveness of the heat and noise control kit on the TS 45 prototype bus. General view of new design insulating material at rear chassis region is shown in

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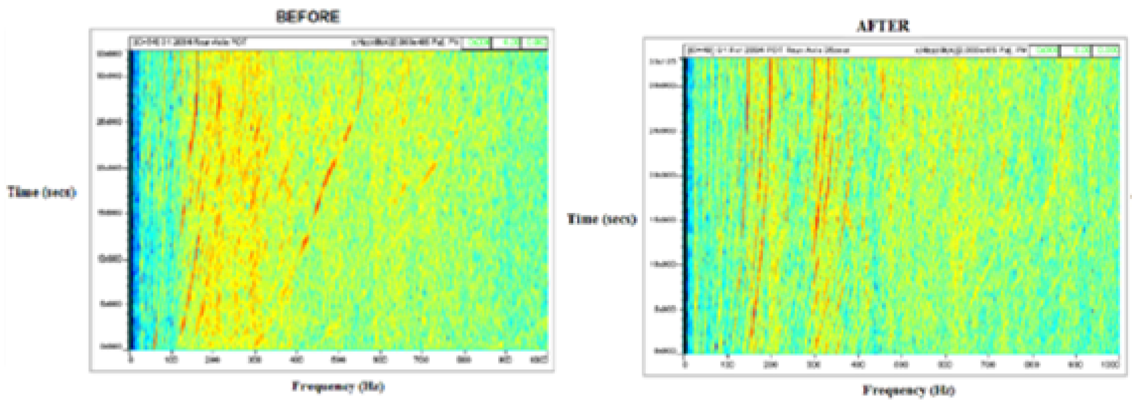

Figure 15: Sonograms of POT over rear axle.

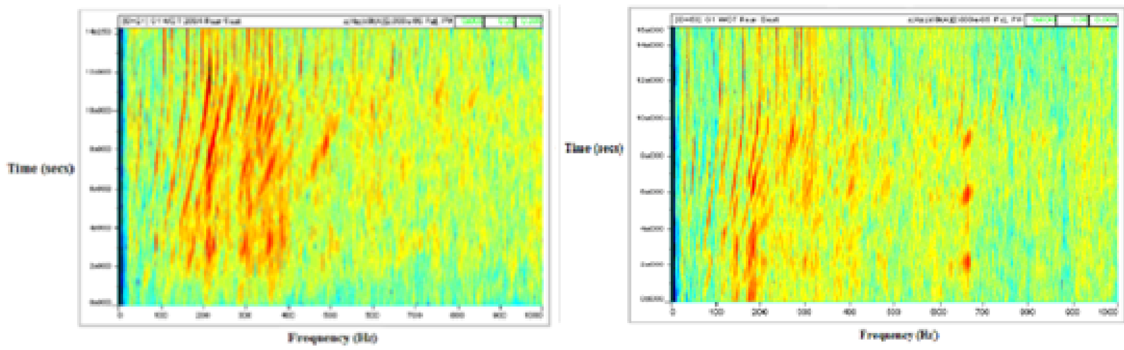

Figure 16: Sonograms of WOT over rear seat.

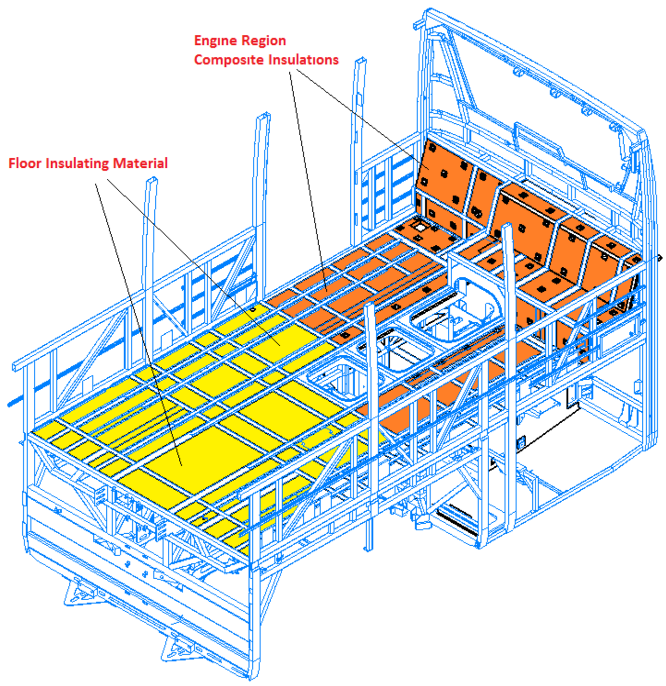

Figure 17: General view of new design insulating materials at rear chassis region.

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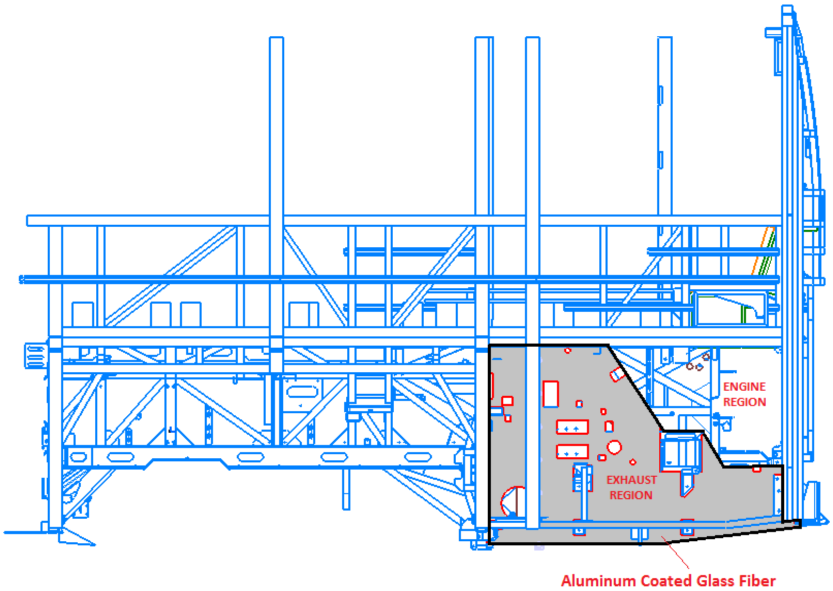

Figure 18: General view of new design insulating material at exhaust after-treatment region.

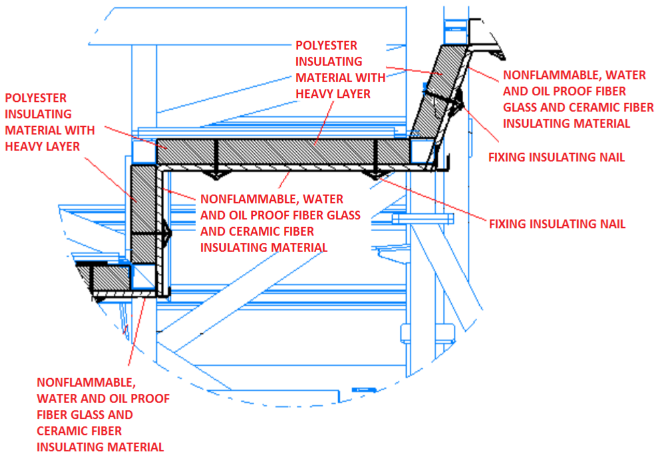

Figure 19: Detail view of new design insulating material.

Figure 21: View of rear chassis bay treatment.

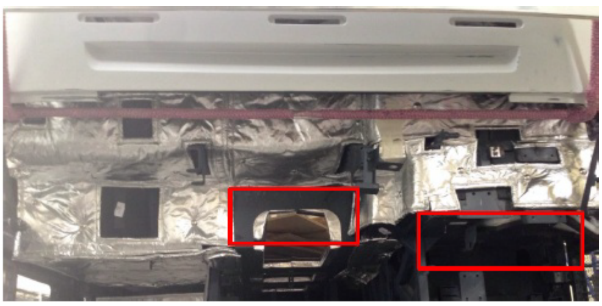

Figure 20: View of engine bay treatment.

Figure 22: View of rear chassis bay treatment.

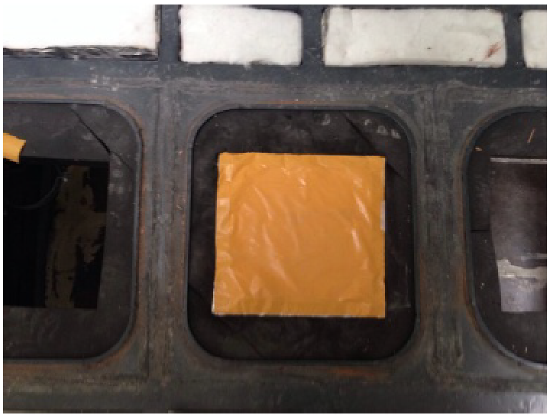

Figure 23: View of rear chassis hatches treatment.

Figure 24: View of rear module treatment.

Figure 17, exhaust after-treatment region in Figure 18 and detail view of new design insulating materials in Figure 19.

After this study, more quitter and comfortable bus has been developed for American market. Noise and vibration insulation developments of TS 45 bus are summarized below:

- Lower noise levels for increased comfort,
- Noise quality – vastly improved, less harsh,
- Rear seats are no longer 'noisy seats',
- Floor vibration is a lot less noticeable,
- Buzz through floor much subdued Quieter Cabin,
- 70 dB Temsa goal achieved
- Reductions of 3 to 5 dB
- Rear half of bus improved Cabin Insulation – Sound Quality;
- Better sealed from engine bay noises
- Tiring low frequency noise reduced

Floor Vibration Reduced;

- 4 dB reduction overall
- Up to 13 dB off tactile buzz

Engine bay treatment

Material in an engine bay is composite quilt; this material's function is thermal and tuned acoustic performance for engine bay (Figure 20).

Under floor treatment

Material is combination composites including acoustic polyester. Its function is thermal and acoustic performance at low weight engine bay noise, road noise, and gear noise (Figures 21and 22).

Material is a well-developed acoustic wood. Function is high performance flooring to reduce low frequency noise and floor vibration.

Hatches

Material is combination foam and barrier composites. The function is preventing noise leakage in through sensitive inspection hatches, engine high frequency noise (Figure 23).

Rear Module

Material is well developed acoustic polyester. Function of this material at this region is reducing rear openness and noise leakage from engine bay (Figure 24).

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