Battery Electric Vehicles
What is the Future for the NVH Package?

In this article, Autoneum compares the current NVH performance in the interior passenger compartment of BEVs with their ICE counterparts and reviews the main global trends that are currently steering electric vehicle development to derive a forecast about the future trends for the NVH package of BEVs.

AUTHORS

Dr. Davide Caprioli
is Head of Product Acoustics & Thermal Performance at Autoneum Management Ltd in Winterthur (Switzerland).

Leonardo Ferrali
is Head of Vehicle Benchmarking at Autoneum Management Ltd. in Winterthur (Switzerland).

Marco Cardillo
is Vehicle Benchmarking Engineer at Autoneum Management Ltd. in Winterthur (Switzerland).

MARKET GROWTH

The increasingly demanding legislation limiting exhaust emissions and fuel consumption has led passenger car makers towards the development and production of Battery Electric Vehicles (BEVs), while at the same time a considerable number of brand new vehicle manufacturers exclusively linked to electric mobility have emerged in the automotive industry. Electric vehicle sales have been slowly but steadily growing worldwide and market analysts mostly agree that BEVs are going to become dominant in the automotive market some time in the future [1]. Electric powertrains can potentially bring some remarkable changes for vehicle Noise, Vibration and Harshness (NVH) due to noise from battery cooling and powertrain whine among others, in addition to tire and aerodynamic noise becoming more prominent in the absence of a standard Internal Combustion Engine (ICE). Under these conditions, it is of great relevance for automotive NVH package suppliers to identify possible future trends for the NVH package of electric cars and understand how those products are going to adapt to this rather unique market change.

The NVH performance investigation is performed by experimental tests in two different configurations: besides interior Sound Pressure Level (SPL) measurements in operational conditions on the road under Wide Open Throttle (WOT) acceleration and constant speeds of 50, 80 and 120 km/h, reciprocal transfer function measurements in a semi-anechoic room have also been carried out.

RECIPROCAL TRANSFER FUNCTION TEST

The reciprocal transfer function test is a good complement to direct road measurements, since it quantifies the noise filtering performance of the car interior for different structure-borne and airborne noise paths in a robust and repeatable way independently from the different source excitation levels [2]. In this test, the vehicle simply stands on the floor of a semi-anechoic room and an omnidirectional acoustic volume acceleration source mounted at the driver's head blows a white noise signal. For airborne noise transfer functions, the output noise is recorded at many different microphone positions, either mounted all around the powertrain or at the tire contact patches, depending on the noise path. For structure-borne noise transfer functions, the output vibration at the powertrain and suspension mounts on the body is recorded by tri-axial accelerometers. The output signals belonging to a given source (e.g. tires) are then averaged and the ratio to the source signal is calculated as a function of frequency. For all test results, lower values correspond to better NVH performance.

Three different passenger car segments have been investigated: A segment

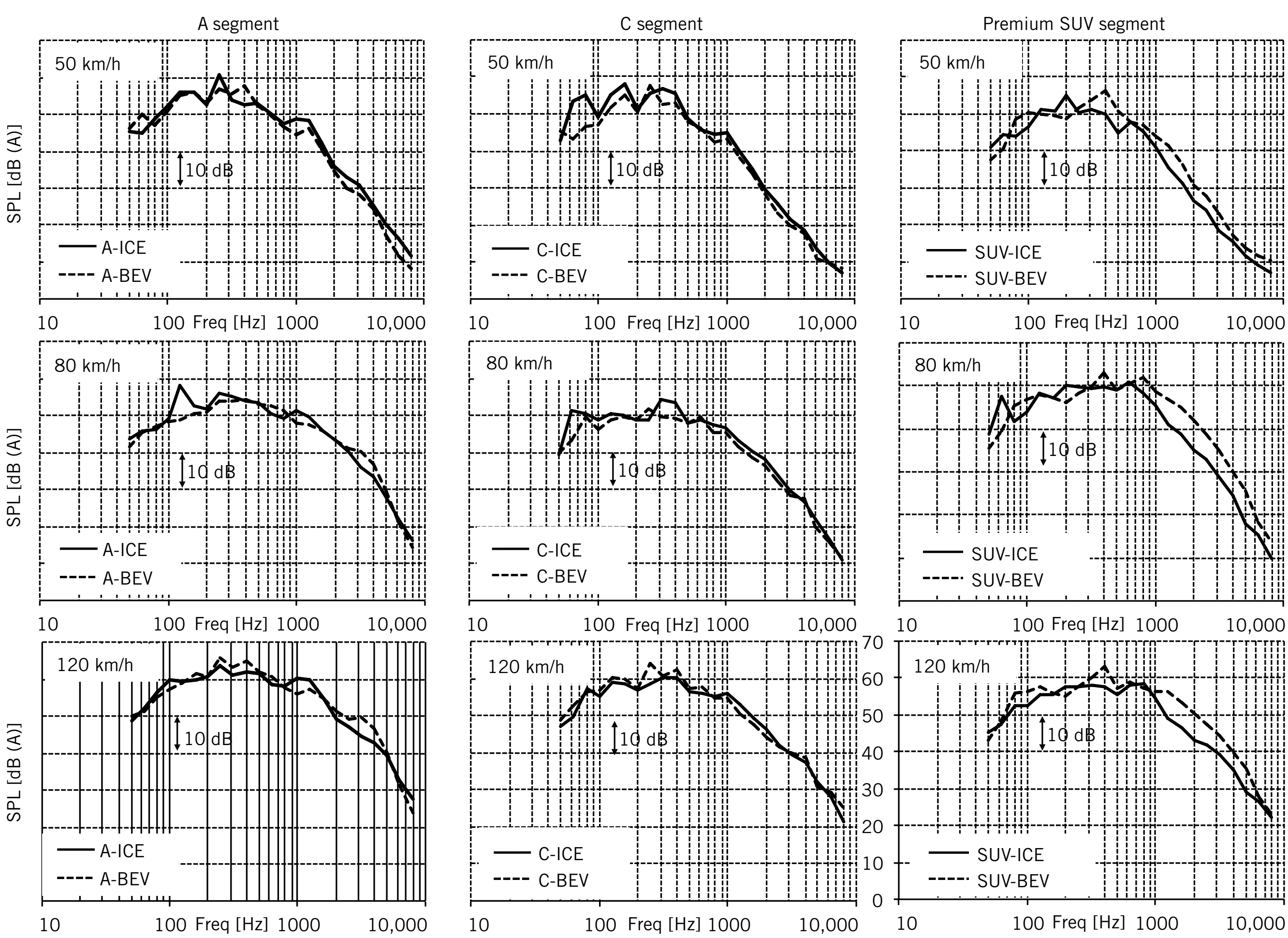

FIGURE 1 Constant speed test results (© Autoneum)

(city car), C segment (compact car), and premium SUV segment. Figures 1 to 4 show the results of the vehicle testing campaign. In each chart, a BEV in a given segment is compared to its corresponding ICE counterpart in the same segment. The charts are ordered by segment from left to right. The A-segment BEV steel body is derived from the ICE (gasoline) version of the same car belonging to the same manufacturer. In addition, the BEV has wider absorption treatment in the engine bay while keeping the same interior NVH package. The C-segment BEV has an adapted steel body from the ICE (gasoline) version by the same manufacturer and carries an identical interior and engine bay NVH package. Concerning the premium SUVs under test, the BEV features an aluminum body with full e-motor encapsulation (for both front and rear e-powertrain), while the ICE car has a conventional diesel engine, steel body (25 % heavier than the BEV), heavier interior NVH treatment and richer acoustic treatment in the engine bay and underbody.

SIMILAR PERFORMANCE AT HIGH FREQUENCY

By looking at the interior SPL at the front passenger position of the vehicles under investigation respectively at constant speeds of 50, 80 and 120 km/h [3], it can be seen that electric powertrains do not bring any clear acoustic advantage. While conventional ICE cars have a general disadvantage at low to medium frequency in these driving conditions, they perform globally similar or better than BEVs at high frequency. The WOT acceleration results are shown in **FIGURE 2**. For practical reasons related to the test track morphology, the acceleration run up of ICE cars is done in 2nd gear, with additional 3rd gear acceleration possible just for the A segment. It looks clear that, no matter the body, the overall acoustic advantage, **FIGURE 2** (top charts), of purely electric cars over conventional ones appears rather remarkable when powertrain noise dominates. However, by looking at the frequency spectra, **FIGURE 2** (lower charts), it can be remarked that the actual difference between BEV and ICE performance lies mainly in the low and medium frequency range, while the high frequency performance is rather similar. The considerable high frequency content of BEV noise, together with the clear NVH performance worsening as a result of the increasing speed when driving at constant speed, **FIGURE 1**, hints at high excitation coming from tires and aerodynamic noise sources, possibly coupled with some weakness in the vehicle noise filtering performance in that specific frequency range. This would need to be masked or absorbed by some specifically designed acoustic treatment.

The structure-borne transfer function test results from the powertrain and suspension mounts to the driver position are displayed in **FIGURE 3**. It is possible to see the rather clear advantage that smaller segment BEV models have in comparison with their ICE counterparts. It looks physically reasonable to consider this dynamic behavior driven by the BEV battery pack mounted under the vehicle floor, which seems to bring some noticeable advantage in terms of stiffness especially at low frequency. Depending on the particular car, that advantage can slightly level down in some frequency range with the ICE SUV performing partly better than the BEV in spite of having no battery pack under the floor possibly thanks to steel frame versus aluminum of the BEV.

The air-borne noise transfer function results from powertrain to driver of the tested cars, **FIGURE 4** (upper row) show that the A and C-segment BEV models have better overall air-borne noise filtering performance than their respective ICE counterparts. That definitely is a positive contribution to their better

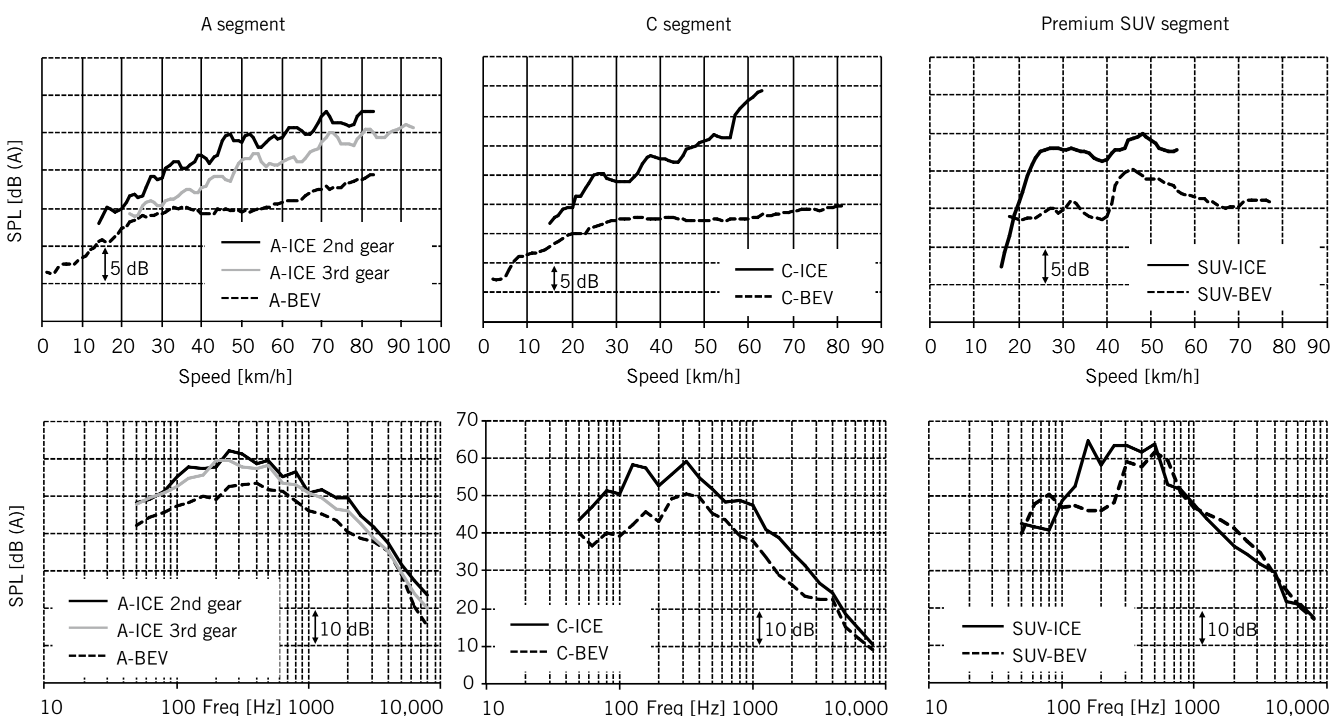

FIGURE 2 Acceleration test results (© Autoneum)

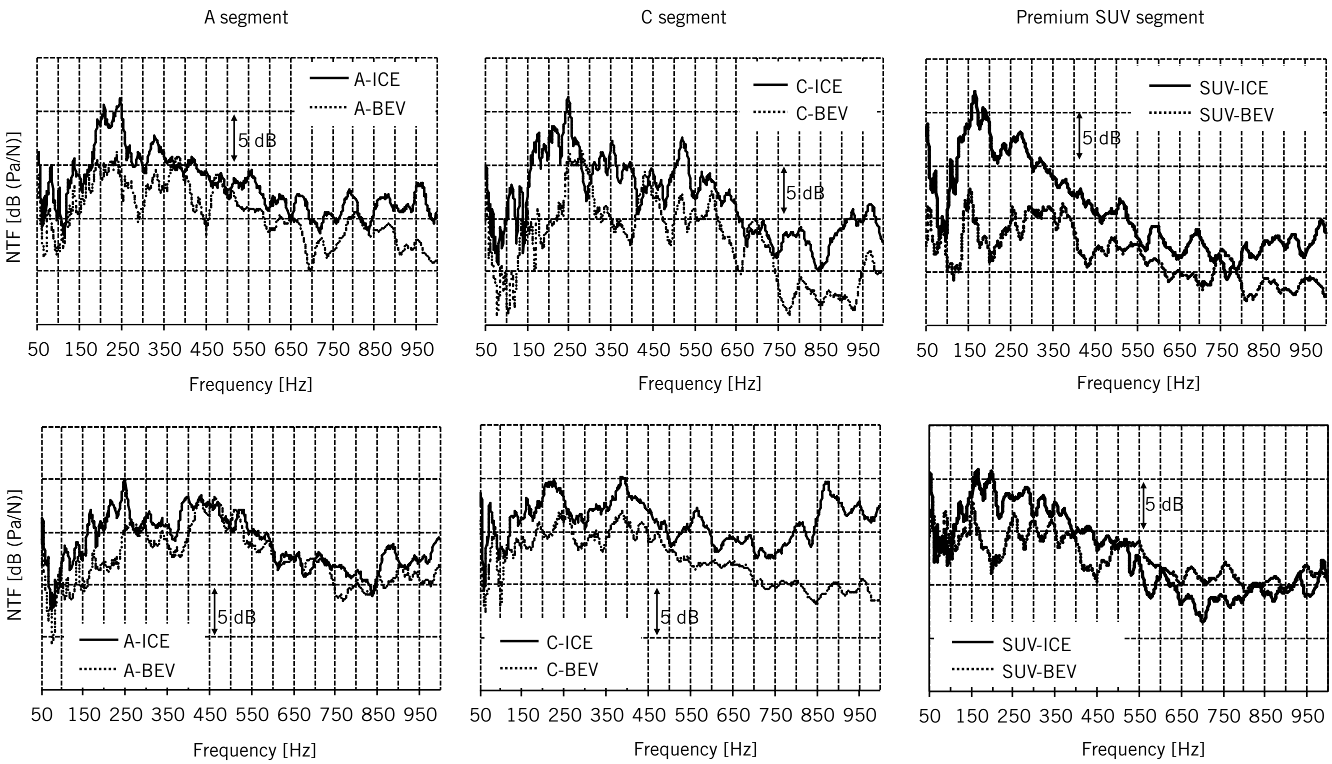

FIGURE 3 Structure-borne transfer functions (© Autoneum)

acoustic performance on-road under WOT acceleration conditions. In the case of the A-segment BEV, some additional positive contribution is given by the extended absorption treatment on the outer dash area against bare outer dash for the ICE model. The SUV segment BEV is characterized by worse air-borne noise filtering performance than its conventional competitor. This can be physically related to the ICE car double dash wall and fully extended absorption treatment in the engine bay, in addition to the different body weight. The same considerations can be made for the air-borne noise filtering performance from the tires, **FIGURE 4** (lower row). In general, there is a rather clear gap between BEV and ICE models for the powertrain, while the transfer functions from the tires look closer, likely because of exterior acoustic paths. This can also partly justify the similar performance of BEV and ICE models on road at constant speed. The noise masking effect of the large and heavy battery pack seems to be just partly effective in this case. It is also interesting to notice that, besides a heavy battery pack under the floor, the A-segment BEV has an extended underbody treatment (including the wheelhouse outer liners) with integrated acoustic function (over 40 % of the total underbody area is textile), while almost no underbody treatment is present on the ICE version, **FIGURE 5**. In a similar way, the C-segment BEV underbody area is almost totally covered, with about 50 % being textile, while the ICE version, although largely covered, has almost no noise absorption function included. On the other hand, it should be considered that the ICE SUV carries a large underbody treatment with integrated acoustic function (almost 60 % of the total underbody area against only 20 % for the BEV), and performs clearly better than the BEV, which has a largely untreated and acoustically reflecting underbody area, despite its large battery back mounted under the floor. In summary, the test results show that cars with higher underbody coverage rates and larger acoustic surfaces perform better for tire noise filtering performance, no matter the powertrain type.

WEIGHT REDUCTION

In addition to test results, some general considerations about the main current trends in the electric vehicle market can support our analysis about the BEV NVH package envisaged future as well.

In particular, car makers have constantly strived towards body weight reduction in order to decrease fuel consumption and greenhouse gas emissions. When electric vehicles are concerned, this effort is expected to become far less important in direct connection with the reduction of emissions (no exhaust pipe on BEVs) [4]. However, it should still remain an important aspect independently from the powertrain because lower vehicle weight generally improves the handling and crash behavior [5] and in electric cars it helps to extend the mileage range. Moreover, body weight reduction triggers overall vehicle weight reduction in general since lighter bodies require lighter chassis components and sub-systems, like suspensions and brakes for example, and also need a lighter, less powerful powertrain to be displaced (mass decompounding) [6]. On the other hand, body weight decrease is not beneficial for NVH in general. Nowadays, although the majority of electric car bodies are still made of steel, other lightweight materials like aluminum and carbon fiber-reinforced composites have been introduced in production. In conclusion, body weight reduction still remains a priority for electric car makers today, however it is still unclear whether it will remain so in the long term.

EVOLUTION OF BATTERIES

Another important aspect to take into consideration is the evolution of batteries. Although no huge battery technology breakthrough is expected in the near future, a steady and constant battery cost reduction and capacity improvement is forecasted in the near to medium term [7, 8]. Among all the electrified vehicle types, BEVs carry the biggest and heaviest battery packs, which typically need to be located under the car floor mainly due to space and center of gravity reasons. Those batteries are very heavy and stiff components and, as the test results confirm, bring a corresponding remarkable influence on the vehicle NVH behavior, particularly concerning structure-borne noise. Reducing their cost and augmenting their capacity is increasingly going to allow electric car makers to either save on battery weight keeping the same driving range or to increase the driving range keeping the same weight. In general, car makers tend to give priority to battery capacity against possible cost and weight reduction in order to minimize the so-called "range anxiety" of drivers. Under these conditions, battery downsizing should not be expected to take place soon and the large mass and stiffness of battery packs should keep affecting the overall NVH behavior of electric vehicles in a remarkable way in the next years.

Possible vehicle architecture changes should also be taken into account. Today's BEVs have either a built-on-purpose body (i. e. a specific body just for the electric powertrain) or a modified body on the basis of a previously existing ICE vehicle, however a clear trend still needs to be identified. While some car makers go for adaptation to avoid the risk and cost of brand new body development, others, especially those without any ICE tradition, choose to develop electric car bodies from scratch. With the advent of electric mobility, car makers with conventional ICEs have been increasingly developing their conventional vehicles taking into account electric powertrains right from the beginning to avoid later structural body modifications and additional costly development. Every time automobile manufacturers carry over an existing ICE body for a BEV model or develop a common body for ICE and electric powertrains, they also try as much as possible to convey the associated components, including most of the NVH package (e.g. dash insulator, floor carpet, wheelarch liners). This becomes particularly relevant in light of the predicted hybrid propulsion transition of the world automotive market [1, 5].

SUMMARY AND OUTLOOK

In light of the test results and the main global automotive market trends for electric vehicles, it looks reasonable to foresee that the NVH package of BEVs is certainly not going to become redundant anytime soon. Electric vehicles have to face many of the NVH issues that conventional ICE vehicles have faced until today. Tire and aerodynamic noise is equally present for any kind of powertrain, while ancillaries (e.g. air conditioning compressor, brake booster vacuum pump) and running components (e.g. battery and electrical motor cooling systems) devoted to electric powertrains will make additional noise. In addition, the electric motor, although generally quieter than ICE, can still emit remarkable high frequency noise. In general, vehicles need to become quieter, lighter and more energy-efficient, no matter the type of propulsion. As a consequence, new types of drives such as electric cars do require lightweight NVH components that integrate acoustic and aerodynamic functions. Electric vehicles also open

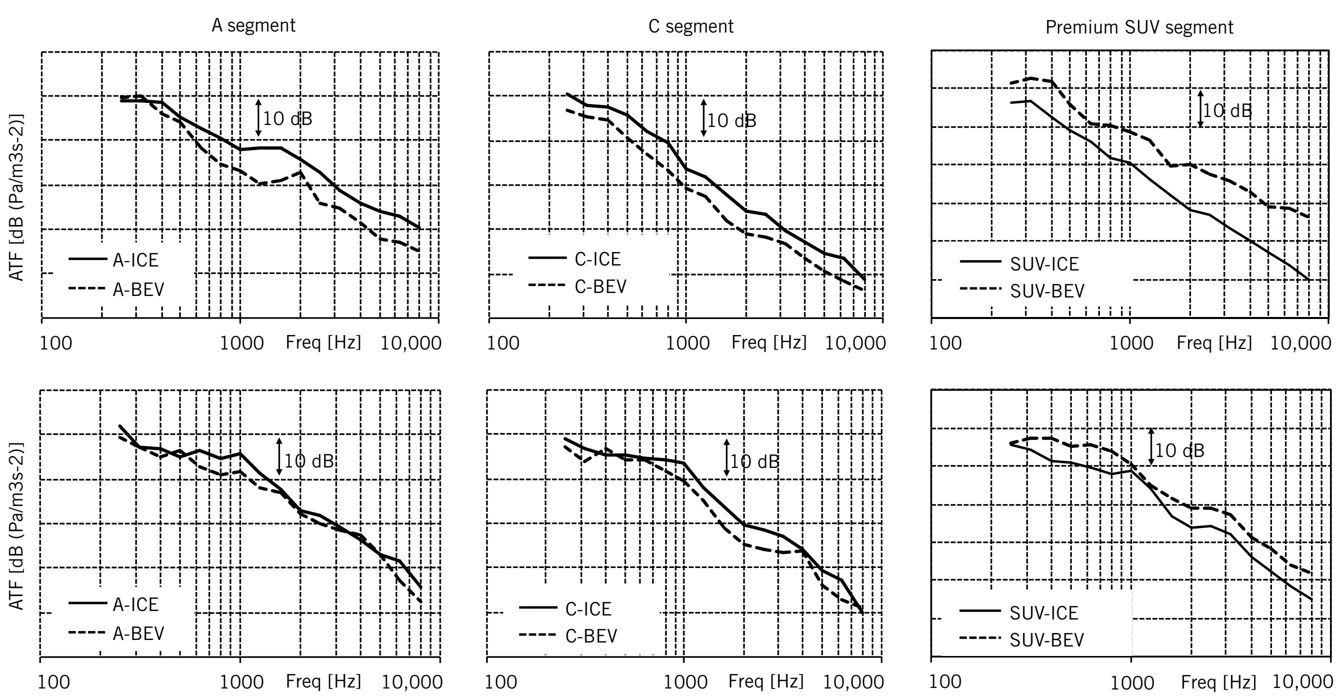

FIGURE 4 Air-borne transfer functions (© Autoneum)

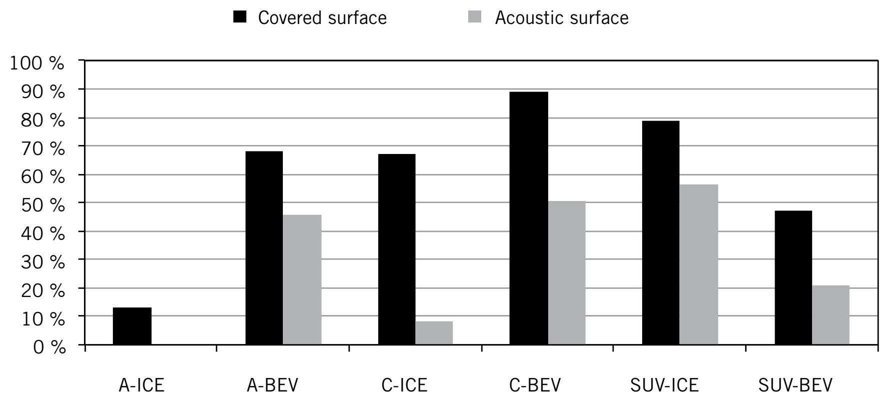

FIGURE 5 Underbody coverage rates as a percentage of the total underbody surface (© Autoneum)

innovative application areas for the treatment and insulation of bothersome high frequency noise from the electric motor, as well as road and wind noise. This is particularly true considering that there is also a growing demand from motorists for a significantly increased driving comfort for future vehicles.

REFERENCES

[1] Subramanian, V.: CO_2 Compliance and Bang-for-Buck Importance to OEMs' Powertrain Trends, IHS Markit New Year's Briefing, Frankfurt, Germany, 2017

[2] Grébert, J.; Mazzarella, L.: Reciprocal Transfer Functions Synthesis Method for Rolling Noise and NVH Floor Treatment Investigations, SAE 2009 Noise & Vibration Conference, USA, 2009

[3] A2Mac1 Acoustic Benchmarking Database. Online: https://www.a2mac1.com, access: 28 June 2018

[4] Bütler, T; Winkler, H.: Energy consumption of battery electric vehicles (BEV). EMPA, Dübendorf, Switzerland, 2013

[5] IHS Automotive: Weight Reduction In Automotive Design. Report, 2014 edition

[6] Malen, D. E.; Reddy, K.: Preliminary Vehicle Mass Estimation Using Empirical Subsystem Influence Coefficients. Ann Arbor, Michigan (USA), University of Michigan, Report, 2007

[7] Electric Vehicles in Europe – 2016, European Federation for Transport and Environment. Online: https://www.transportenvironment.org/publications/electric-vehicles-europe-2016, access: June 28, 2018

[8] U.S. Department of Transportation; National Highway Traffic Safety Administration: Corporate Average Fuel Economy for MY 2017-MY 2025 Passenger Cars and Light Trucks. USA, 2012