CASE STUDY

Nissan Technical Centre Europe
Cranfield Technology Park
Bedfordshire

UK

Automotive

Desktop and On-road NVH Simulators

The latest enhancement to the NVH Simulator suite, the On-road Vehicle NVH Simulator, was developed for a project with Nissan Technical Centre Europe and enables the sounds of virtual vehicles to be evaluated while driving on an actual road and on a variety of surfaces. Recently the "On-road" and "Desktop" simulators were used at the concept stage to deliver an exciting sound to enhance and compliment a new B-segment vehicle. At a recent company sound event, the sound was universally accepted as natural and resulted in senior project management agreeing that the concept proposal sound was the right sound for the vehicle and that they would consider any request for investment or technology to help deliver the sound.

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The Company

Nissan Motor Company, Ltd. is a global automotive company with vehicle sales of 3,411,000 in 2008. Nissan was founded in Yokohama City, Kanagawa Prefecture in 1933 and today has sixteen production sites in Japan and abroad, and offers products and services in more than 160 countries worldwide. In 1999, Nissan entered into an alliance with Renault S.A. of France, which now owns 44.4% of Nissan. Nissan is among the top three Asian (also known as the Japanese "Big Three") automotive manufacturers rivals of the "Big Three" in the US and is present in all major automarkets worldwide, selling a comprehensive range of cars, pick-up trucks, SUVs, and light commercial vehicles.

Nissan Technical Centre Europe

Fig. 1
Nissan Technical Centre Europe Headquarters at Cranfield, England

The Nissan Technical Centre Europe Ltd. (NTCE) was established in 1989 in temporary premises on the manufacturing site of Nissan Motor Manufacturing (UK) Ltd. as part of Nissan's strategy to establish design and development capability in the major overseas markets. Today, with Headquarters at Cranfield Technology Park, Bedfordshire, UK, the NTCE has five subsidiaries in Spain, Belgium, France, Germany and Russia and over 1000 employees. NTCE's European R&D delivers brand identity and customer-oriented engineering through new products and enhancing vehicle quality and attractiveness.

David Quinn is the Manager of NVH Development at Nissan Europe and has been with the company for eight years. Educated in Mechanical Engineering in Liverpool, his career has taken him from Ford to Lotus Engineering and AVL, the Austrian-based automotive consulting firm and independent research institute.

Paul Speed-Andrews is an Engineer in NVH Development, and is NTCE's sound quality expert. He has worked under David Quinn at Nissan for the past four years. After graduating in Mechanical Engineering from the University of Birmingham, he spent six years working in the NVH Department at Jaguar Cars.

Advances in On-road Simulator Technology Enable Firm Targets for Delivery at Concept Phase

One of the great challenges of the NVH development process is to ensure that customers and stakeholders in the vehicle team are involved in sound quality decision making. Interactive NVH simulators have enabled a cost-effective, customer-focused method for capturing the opinions and decision-making processes of non NVH experts. The latest enhancement to the NVH Simulator approach allows the sounds of virtual vehicles to be evaluated while driving on-road. The sounds are created and presented to the driver in such a way that they appear totally natural and the assessor is not aware that they are synthesized. Since the subjective evaluations are performed on normal roads, key decision makers can understand, sign up with confidence to, and appreciate the value of the proposed sounds.

David Quinn says, "The Nissan Technical Centre at Cranfield is the R&D centre of excellence for Nissan. The On-road Simulator was developed here and has contributed to the UK centre taking the lead in Sound Quality Engineering, influencing not only Nissan Japan but also Nissan worldwide". He continues, "With the On-road Simulator as a core development tool, the US and Europe are already sharing road noise models for global benchmarking and target setting. By sharing and comparing data, we can change the global development process and get more accurate results with fewer prototypes".

Recently, the NTCE used the "On-road" and "Desktop" simulators at the concept stage to deliver an exciting sound to enhance and compliment a new B-segment vehicle. The tools were used to:

- Set vehicle level sound quality targets to enhance the appeal of the vehicle, including customer surveys and the use of the On-road Simulator for final sign off at target confirmation drive events

- Understand the path and source contributions of a donor vehicle and key competitor
- Create and demonstrate a strategy for practical realisation of the vehicle level target

The Importance of Sound Quality

Paul Speed-Andrews explains, “Getting the sound of a vehicle just right is becoming increasingly important as a method of enhancing customer opinion about a new vehicle and differentiating it from the competition. The sound of the engine can heavily influence the driver’s perception of both the acceleration and dynamic driving performance and hence their overall satisfaction. The challenge for the vehicle manufacturer is to understand the requirements for the vehicle sound, and to create a design strategy that will deliver this sound in a new product.”

The term “Sound Quality” is generally used to describe those features of a sound that generate a positive emotional response from the driver or passenger. In fact, Sound Quality has an effect on the way the customer reacts to the car, and the car’s overall character can be reinforced by its Sound Quality.

By studying independent vehicle quality survey data, the customer’s perception of sound quality can be correlated with other aspects of the vehicle’s performance. Customers were asked to ‘Rate the performance of the car during rapid acceleration from a stop’ and to ‘Rate the Sound of the engine/exhaust during rapid acceleration’ on a scale from 1 – 10 with 1 being “Unacceptable” and 10 being “Outstanding”. Results showed a clear correlation between a customer’s opinion of the engine sound and their perceptions of both acceleration performance and, more surprisingly, overall dynamic performance. Furthermore, by looking at the way customers describe their vehicles, there is a clear link between the performance of the vehicle and its sound.

Interactive Sound Quality Evaluation

Fig. 2
Paul Speed-Andrews, Engineer, NVH Development, Nissan Technical Centre Europe using the Desktop NVH Simulator

David says, “Traditional methods of creating and evaluating sound quality targets have been restricted to playing back and assessing sounds of fixed driving events. Recently, the target setting process has been significantly enhanced by the development of the Desktop NVH Simulator, which has introduced interactivity and context into the evaluation process”. The Desktop Simulator uses driver controls (throttle, gear, steering and brake) as inputs to a real-time sound model that accurately recreates the sound of a car over its full driving envelope. It also includes a sufficiently realistic visual scenario so that experts and non-experts are able to assess the sound quality of existing or virtual (for example, potential target) vehicles with confidence while driving them in their own style.

The On-road NVH Simulator

Paul says, “The Desktop NVH Simulator has now been adapted so that we can use it in a real vehicle on the road to modify the order content of the vehicle sounds perceived by the occupants”. In the On-road Simulator, the actual instantaneous measured performance of the vehicle (rpm, speed, load, gear) replaces the real-time empirical performance modeller used in the Desktop Simulator. These quantities can be measured directly using transducers such as tachometers and displacement sensors or via the CANbus if the codes are known. The On-road Simulator plays the difference between the measured harmonic sounds and the target, which combines with the sound of the real vehicle to result in the target. This means that it is very straightforward to prepare the sound model for the On-road Simulator because it is simply the binaural difference between the target sound model and the original mule car sound model. Using this approach, the On-road Simulator can:

- Add complex order spectra over a wide range of frequencies
- Cancel the fundamental engine orders
- Add (but not cancel) masking sounds

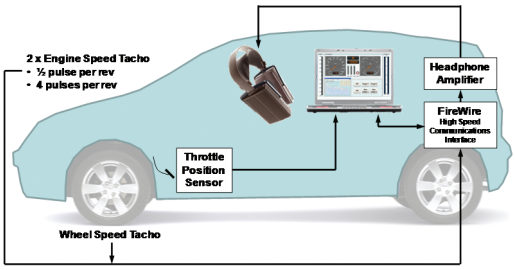


Fig. 3
Schematic of On-road Simulator setup

The sounds are replayed through aurally transparent, open-backed headphones. In addition, all the mixing and filtering capabilities of the Desktop version are active in the On-road Simulator so target harmonics can be modified or switched on/off in real-time while driving on the road.

The main purpose of the On-road Simulator is to present the engine harmonic targets developed in the Desktop NVH Simulator for final validation, fine tuning or sign-off and can be included in evaluation drive events where it can be driven against the competition. Because it is operated while driving on the road, it adds further context in the form of longitudinal and lateral whole body acceleration, vibration and correct steering feel.

Case Study – B-segment Vehicle Concept

"The addition of the On-road Simulator to the NVH simulator suite has greatly extended the benefits of the system, while maintaining a very simple workflow. A concept study was undertaken for a new B-Segment vehicle, which was to have a sporty character, but was not a dedicated sports car," says David. The brief was to create a drivable mule car, based on an existing B-segment Nissan vehicle, that could demonstrate the Ride and Handling and NVH performance of the concept and that could be presented to senior management and key decision makers within the company in order to communicate the concept to them. As engine sound quality can greatly enhance the perception of acceleration and handling performance, it was deemed essential to investigate what sound would be appropriate for such a concept and how to deliver it. It was this desire to present the target sounds in the mule car that led to the development of the On-road Simulator.

Vehicle Level Target Setting

The first stage was to set high-level vehicle targets. Marketing and Product Planning departments had developed semantic descriptions for the new vehicle, together with a definition of the target customers and their needs and desires. At this stage, competitor cars were also identified with one competitor being of particular interest as the desired direction for engine sound. The aspiration for the target sound of the new vehicle was to be slightly more refined than the existing Nissan mule car, and yet noticeably sportier than the key competitor.

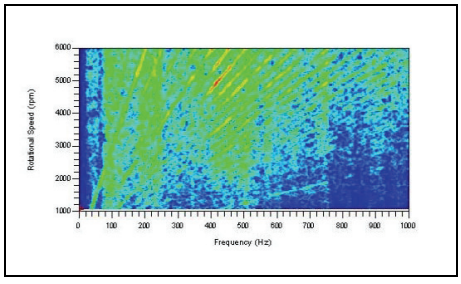
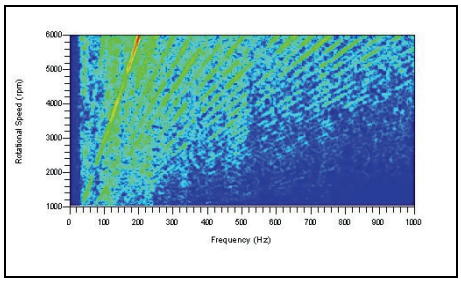


Fig. 4
Key Competitor. 2nd Gear WOT Acceleration

The first task was to benchmark this key competitor and the current production Nissan model on the road, and prepare and validate Desktop NVH Simulator models for each. The Nissan model was selected as the closest B-Segment product to the concept and also the car that would be the donor for the mule car. The sound quality of both vehicles was studied while driving back to back in the NVH Simulator over the full driving envelope. Fig. 4 shows a colour map of the sound at the driver's outer ear for the key competitor during a 2nd Gear Wide Open Throttle (WOT) acceleration. It was found that the main positive, sporty feature of this sound was a strong resonant band from 400 – 500 Hz which excited several half orders, especially above 4500 rpm, giving a rough and sporty character to the sound. This sound also had fairly balanced 2nd and 4th orders giving a smooth, linear acceleration feel.

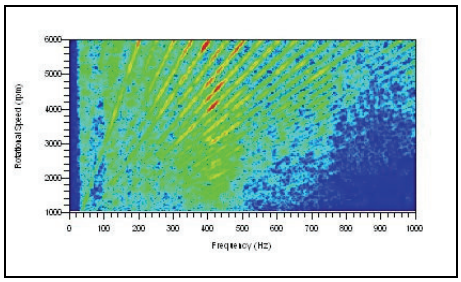
Fig. 5
Nissan donor (standard condition). 2nd Gear WOT Acceleration



A set of possible target sounds was then created for the concept vehicle using the modification tools in the Desktop NVH Simulator to change the sound of the Nissan donor. Fig. 5 shows the colour map of the standard Nissan donor mule car.

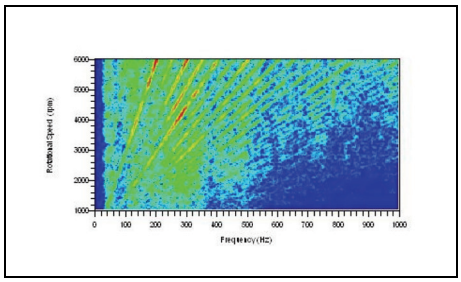
Firstly, negative aspects of the mule car sound were removed to give a clean, 'blank canvas'; 2nd engine order was reduced and smoothed to give a more linear, smooth sound and the high-frequency content was reduced to simulate improved bulkhead isolation. Then the modification tools were applied to this 'blank canvas' sound to create two alternative sound characters.

Fig. 6
Concept Option 1. 2nd Gear WOT Acceleration



Option 1 was a close copy of the character of the key competitor with a strong resonant band introduced from 400 – 500 Hz (Fig. 6). Option 2 used the same idea of a single strong resonant band, but at a lower frequency (250 – 350 Hz) as shown in Fig. 7. This was designed to have a more refined, less harsh character than Option 1 and also this lower resonant band excites 4th order to try and give the smooth character identified in the key competitor.

Fig. 7
Concept Option 2. 2nd Gear WOT Acceleration



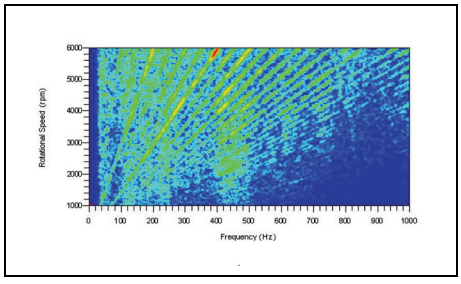
These two options along with the Standard Nissan donor car and the key competitor sound were presented in an interactive jury evaluation on the desktop simulator to a number of local staff made up of NVH experts and experienced vehicle evaluators. The jurors were asked to drive the simulator freely around a visual scenario that matched local roads with which they were familiar and, for each of the four test vehicles, to rate the sound of the engine against two specific questions: "How sporty is the sound?" and "How refined is the sound?".

The purpose of this jury exercise was to identify a clear consensus and to provide direction for the concept target sound. The results were plotted on a 2D semantic space and the scores were normalised relative to the Standard Nissan model.

The results of this study indicated that Option 2 was the closest to the target area. However, the comments from the jurors suggested that Option 1 was a far closer match to their image of the concept vehicle.

Refining the Targets

Fig. 8
Concept Proposal Sound. 2nd Gear WOT Acceleration



Based on this feedback, Option 1 was taken as the base sound and further modifications were made. The resonance at 400 – 500 Hz was retained, but the levels were reduced. The variation with throttle pedal demand was also altered, such that there was a greater difference between 0% and 100% throttle. This gives good cruising comfort when using small throttle openings, but maintains the aggressive, sporty character when driving enthusiastically. In addition to the changes in the resonance, 4th order was also increased to balance with 2nd order. The combination of these two smooth, linear orders gave the sound a smooth refined quality (see Fig. 8).

This modified sound was presented again to the same jury and the results plotted. Although this 2nd iteration sound didn't fully achieve the target area, the comments from the jurors were very positive and it was decided that this sound should be presented as the target sound for the concept vehicle.

FInal Presentation and Sign-off of the Vehicle Level Target

The mule car was presented at a concept decision drive event at the proving ground. At this event, key senior project management plus a number of attribute experts drove the mule car, with On-road Simulator presenting the concept proposal sound, as well as modified suspension to show the proposed direction for ride and handling. This was driven alongside a standard Nissan B-segment vehicle and three other competitors (including the key competitor for engine sound).

David says, “The sound was universally accepted as natural. In fact, many asked whether the equipment was turned on as they could not tell that the sound was being generated at the headphones. The result of this drive event was that the senior project management agreed that the concept proposal sound was the right sound for this vehicle and that they would fully support any request for investment or technology to help deliver the sound. Product planning also accepted that the sound added value to the product, again supporting any investment required to deliver the sound”.

This event and buy in to the target sound by important stakeholders was completed before the project had been formally approved and kicked-off. At this point in the project, there was no final style, the powertrain line up had not yet been finalised, sales volumes, profit and value calculations had still to be completed, and yet a powertrain sound quality target had been developed, and which had been driven and experienced in a real car by all the key decision makers.

The mule car was later presented at a target confirmation drive event held in Germany. Traditionally this event involves driving all the competitors and one or two current Nissan products on normal roads to agree target positioning for all the main dynamic performance attributes. For the first time in Nissan, this event also included the On-road Simulator mule car with the concept proposal sound. Again there was universal acceptance of the technology and all comments were about the sound and not the equipment. After some debate, the sound was accepted as the right target sound for the project and was included in the formal set of targets for the project.

Understanding Sound Sources and Paths

The next step of the process was to decide how to deliver the target sound in the mule vehicle. This required a thorough understanding of sound transfer paths for both the key competitor and the Nissan donor car. The path contributions were all calculated for 2nd and 3rd Gear, 0% and 100% throttle. The result is a time history for each contribution, for each of these driving conditions. These were processed to create simulator sound objects for each contribution. The desktop simulator was then used to interactively drive the contribution models and clearly identify which paths contribute to the various characters. Also, importantly for sound design, individual path contributions could then be modified to conduct ‘what-if’ studies in order to develop a strategy for delivery of the target sound.

A Strategy for Delivering the Target

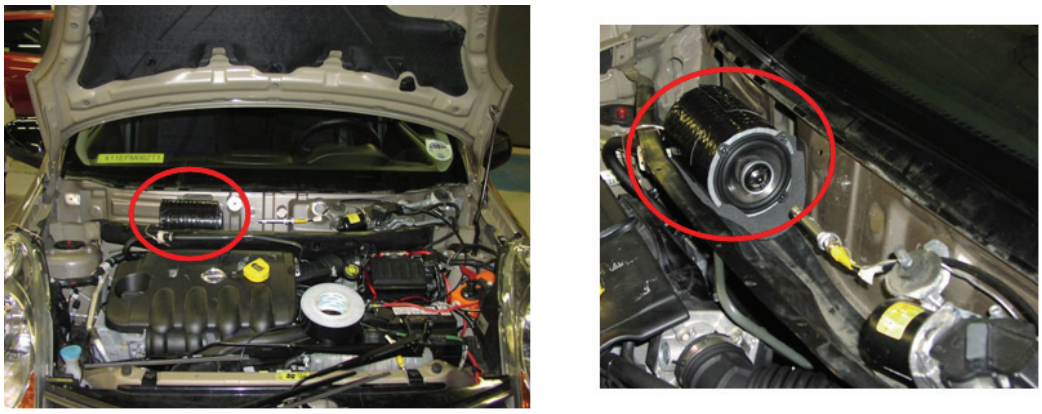
The contribution analysis showed that there was very little scope for tuning any of the existing structural paths on the Nissan donor car to achieve the desired character. However, the target sound that had been developed could be generated by a secondary air intake system. It would also give the load dependency required in the target. To develop the required contribution for the secondary intake orifice, a simple difference calculation was done again. The original donor car “blank canvas” sound (that is, with reduced 2nd order and improved engine isolation) was subtracted from the target sound. The result was a sound that just contained the modifications made to create the positive character and hence, ideally, the contribution required from the secondary intake orifice.

Cascading the Target to System Level

In order to turn this secondary source contribution into a system level target, it was necessary to identify a potential location for the orifice. After a packaging study it was decided to place the secondary intake orifice in the cowl area. Not only was this a location with sufficient space, but this location also had a more sensitive transfer function than any in the engine bay

meaning the source could be quieter for pass-by considerations, and it was still possible to maintain good overall engine isolation.

Fig. 9
Photos of the speaker in-situ in the cowl area



Acoustic transfer functions were measured to this location by placing a speaker in the correct location and measuring the response binaurally at the driver's seat. These transfer functions were then averaged, inverted and applied to the secondary intake source target contribution to create source strength, system level target.

Verification of the System Level Target Using the On-road Simulator

It was important that this strategy and hence system level target was signed off by both the programme management and the design groups responsible for delivering the working system. To achieve this, the On-road Simulator was used to play the target intake system source strength data using a loudspeaker in the target location in the cowl area instead of presenting the binaural target sound at the driver's seat via headphones.

The mule car with this speaker arrangement was presented to the key programme management and the NVH planning group responsible for delivering the target. The car was set up such that the system could be switched quickly between presenting the new source strength sound via the speaker and the original target sound via headphones. The back-to-back evaluation verified that the system level target presented at the chosen location in the cowl accurately matched the vehicle level target and the system level target was universally agreed.

Design Sign-off

The concluding stage of the process will be to monitor the design as it progresses and to finally sign off the design. To do this, close collaboration is required between the NVH group responsible for the target and the intake system supplier.

Benefits of the On-road Simulator Approach

Paul states, "One of the biggest challenges for the NVH engineer is to communicate targets to key programme management and decision makers, so that they can sign off the targets and commit to any hardware required to deliver them. The On-road Simulator provides a tool that enables non-experts to drive and experience the sounds of virtual vehicles on road with no special training. It can be used in drive evaluation events alongside competitor vehicles so that targets can be agreed and signed off with confidence".

For the NVH engineer, the On-road Simulator provides a quick and easy tool that allows desktop NVH simulator models to be evaluated in the correct multi-modal context (that is, on the road). Furthermore, the modification tools allow the targets to be fine tuned in real-time while evaluating on the road. Practically, if the mule car has already been instrumented for the benchmarking measurements, only minimal setup is required to use it as an On-road Simulator.

Finally, it has been shown that the On-road Simulator can also be used to simulate engineering changes by using secondary sources such as loudspeakers or shakers, and to validate source targets for those components directly.

The Future

The NVH simulator technology is already being integrated into Nissan's NVH development process on all programmes where a specific sound quality is required. Specifically, the NVH simulator technology is being enhanced for use with CVT transmission vehicles and planned future projects which include defining the interior and exterior sound requirements of Electric Vehicles. As David Quinn, Manager, NVH Development, Nissan Europe, elaborates, "It is our vision to create a Nissan electric vehicle brand sound that demonstrates character and individuality".

Nissan are set to launch their new electric car by 2010.

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