DOI: 10.61782/fa.2025.0894

FORUM ACUSTICUM EURONOISE 2025

THE USE OF VIRTUAL REALITY FOR THE SUBJECTIVE EVALUATION OF VEHICLE CABIN INTERIOR REFINEMENT LEVELS

E.Harry[1*] **R.Morris-Kirby**[1]

[1] Adler Pelzer Group, Corso Savona 45, Villastellone, 10029 Torino, Italy

ABSTRACT

A common challenge faced by NVH engineers in the automotive industry is demonstrating complex acoustic phenomena to stakeholders who lack extensive objective or subjective experience. Whilst technologies such as psychoacoustics, driving simulators, or KPIs exist to assist with this, effectively conveying the sensitivity of NVH trim changes remains problematic. Ride and Drive assessments are prone to repeatability variations and simulated spectral response charts can be misinterpreted.

This paper considers the use of virtual reality in an interactive environment, as an effective way to interpret subjective NVH phenomena. Whilst still a proof-of-concept, it describes the necessary fundamental acoustic measurements, panel sensitivity calculations and the importation into advanced visualisation software. This combination allows the user to experience the refinement of the vehicle in any operating condition. It also allows for complete movement within the cabin during vehicle operation and the subjective effect of modifying the noise source contributions from individual cabin sub-systems and / or noise generators.

The final section describes how this concept can be further extended into a complete engineering tool for simulation and the technological steps needed to enable this.

Keywords: *acoustic dna, virtual reality, digital twin*

1. INTRODUCTION

Within the space of virtual development, there already exist several applications and tools that can provide users with a full-virtual driving experience. However, due to the complexity of a vehicle's behavior, these are often limited to large driving simulators. The scope of this project was firstly to develop a tool that would allow us to share complex acoustic results with non-technical team members, and secondly to be able to provide accurate NVH appraisals throughout our global network. By utilizing market-available hardware, we can very easily distribute VR masks and simulation models with limited specialist intervention.

The advent of VR entering the mainstream has provided a flexible platform that will be efficiently augmented to tackle a wide range of NVH phenomena including squeak- and- rattle and the structural transmission paths.

The project, called the Virtual Proving Ground (VPG) was kicked off in 2023. It progressed through 5 stages progressively increasing sound space fidelity and computational efficacy.

The latest iteration of VPG uses the resolved cabin interior spatial sound contribution 3rd octave matrix and associated time domain recordings exported from Spatial Power Evolution Analysis (SPEA) [1]. This technique involves the fitment of surface mounted microphones to each internal body panel of the vehicles cabin. A process of source substitution, superposition and cross transfer determination together with a bespoke algorithm quantifies and spatially isolates the sound energy during vehicle operation. Whilst introducing convoluted cross talk elimination between each microphone would be the academic solution, a simpler and subjectively effective method uses an equalized dataset based on the SPEA solver algorithm.

2. METHOD OVERVIEW

As previously mentioned, the project utilized many resources readily available on the market, either through open-source software or via low-investment technology.

The main driver behind the model is the Unity software and associated game engine [2]. This software offers a capable

*Corresponding author: evan.harry@adlerpelzer.com.

toolbox for VR development and by considering the simulation akin to a game, many shortcuts with regards to visualization and audio playback can be taken.
As can be seen in Figure 1; 7 core groups of tools were utilized in the development of the model, requiring expertise in vehicle measurement, data analysis, 3D modelling, scripting, and game engine usage.

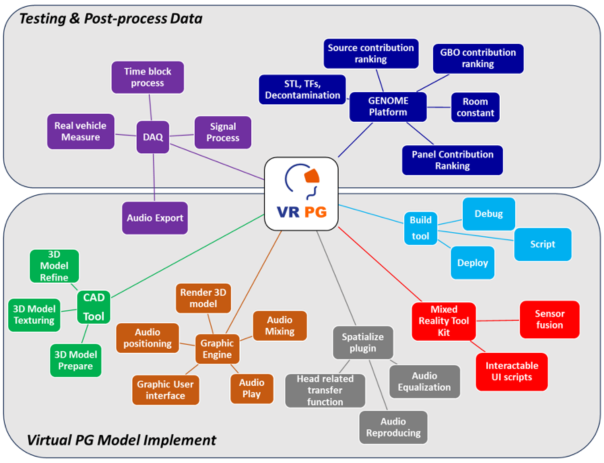

Figure 1. Technologies used in the implementation.

3. MODEL CREATION

The VR model is created from either customer presented CAD of the full vehicle and its interior trim or from internet-based CAD services. Figure 2 shows an example of a high-class saloon modelled into a semi-anechoic chamber.

Figure 2. Example of VR Model in semi-anechoic chamber.

For purely aesthetical reasons, the interior trim is modified, and material properties are applied to increase the familiarity of the vehicle. Ambient factors such as lighting are also included. Figure 3 shows an example of such an interior.

Figure 3. Example of VR Model Interior.

Unlike many driving simulator applications which simply relay a general diffuse sound field to the user VPG attaches virtual sources to each interior cabin surface and allows the ray tracing processor in Unity to create the spatial interpretation of the received sound field. So that when wearing the VR headset, a user's head movement, either turning or relocation, creates a perceived change in cabin sound location. As seen in Figure 4, this offers the possibility to move within the vehicle cabin in a manner that is not possible in reality due to safety concerns.

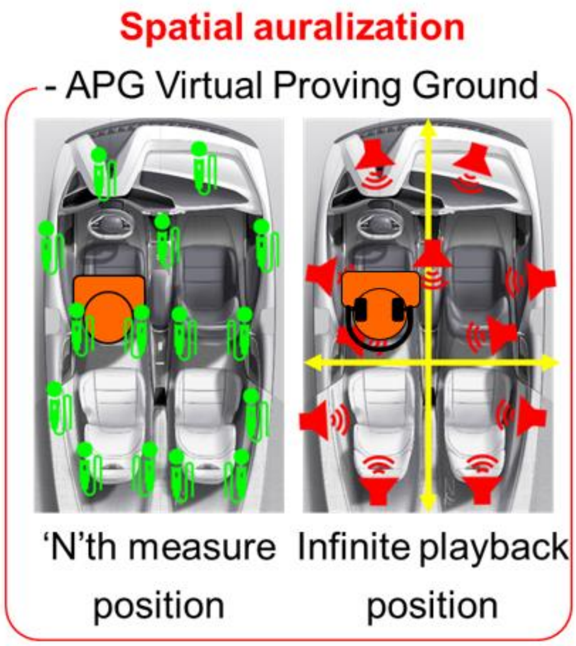

Figure 4. Infinite playback positions inside of the model.

4. EVALUATION OF INTERIOR REFINEMENT

VPG allows the user to evaluate both source location sensitivity and the effect of changes to either global or local NVH characteristics. It has been used in collaboration with simulation tools described in [3] and [4] to provide additional validation evidence prior to final vehicle road testing and ride and drive appraisal. Table 1 compares the VPG simulation of an NVH package weight reduction and sustainability exercise to that measured on the test track. The target being to decrease refinement by no more than 5% Articulation index.

Table 1. Comparison of VPG to Test Track Results

Index	VPG	Test Track
dB(A)	+0.7	+0.6
Articulation Index %	-4.6	-3.1

By utilizing the VR headset as an audio output device, it is possible to connect to a data acquisition frontend and perform simulated real on-the-road measurements. If developed further, this could allow for the tool to perform the role of NVH package validation measurements, enabling engineers to perform normal operating measurements without requiring a prototype pack to be fitted. However, the full realization of this potential requires several other advances in technology that are discussed in the following section.

5. NEXT STEPS

Currently, the system can provide standard acoustic metrics such as Articulation Index and Sound Pressure Level with different weightings. However, the integration of psychoacoustic KPIs is a possibility that the authors are currently evaluating to further enhance the capability and potential of the tool.
The evolution of the VPG application will examine not only cabin interior NVH changes but also how any individual noise generating source such as tyres and power unit effects both the airborne and structure borne distribution of noise inside the cabin. This will involve the introduction of convolved cross talk decontamination, using a technique based on the cross-transfer matrix approach together with convolving the time domain prime number FFT algorithm to isolate each source as a suitable listening file.

6. CONCLUSIONS

This paper has provided a brief overview of the Virtual Proving Ground concept which has been in development since 2023. This project, whilst still a proof-of-concept, has demonstrated the potential of virtual reality technology in understanding the sensitivity of a vehicle's NVH behavior. The next steps of the project, whilst ambitious, will provide a significant step forward for virtual development in a rapidly changing industry.

7. DEFINITIONS / ABBREVIATIONS

NVH = Noise Vibration and Harshness.
CAD = Computer Aided Design
AI% = Open Articulation index

8. ACKNOWLEDGEMENTS

The authors would like to thank Jin-Young Park who previously worked at Adler Pelzer Group and whose contributions to the project were instrumental.

9. REFERENCES

[1] R. Morris-Kirby et al, "The determination and ranking of interior cabin noise sources via advanced matrix manipulation" Forum Acusticum Euronoise 2025.

[2] Unity Technologies 2024. Unity Engine version 2022.3.37f1. Retrieved from https://unity.com

[3] R. Morris-Kirby et al, "Acoustic Diagnostic Network Algorithms, their description and implementation from concept into a comprehensive vehicle optimization program" *SAE Technical Paper 2015-01-2358.*

[4] Morris-Kirby, R. and Harry, E.J., "Use of Sound "Phonons" in the Modelling and Optimization of Automotive Acoustic Systems in 3D," *Internoise (2022).*