MICROFLOWN MAGAZINE

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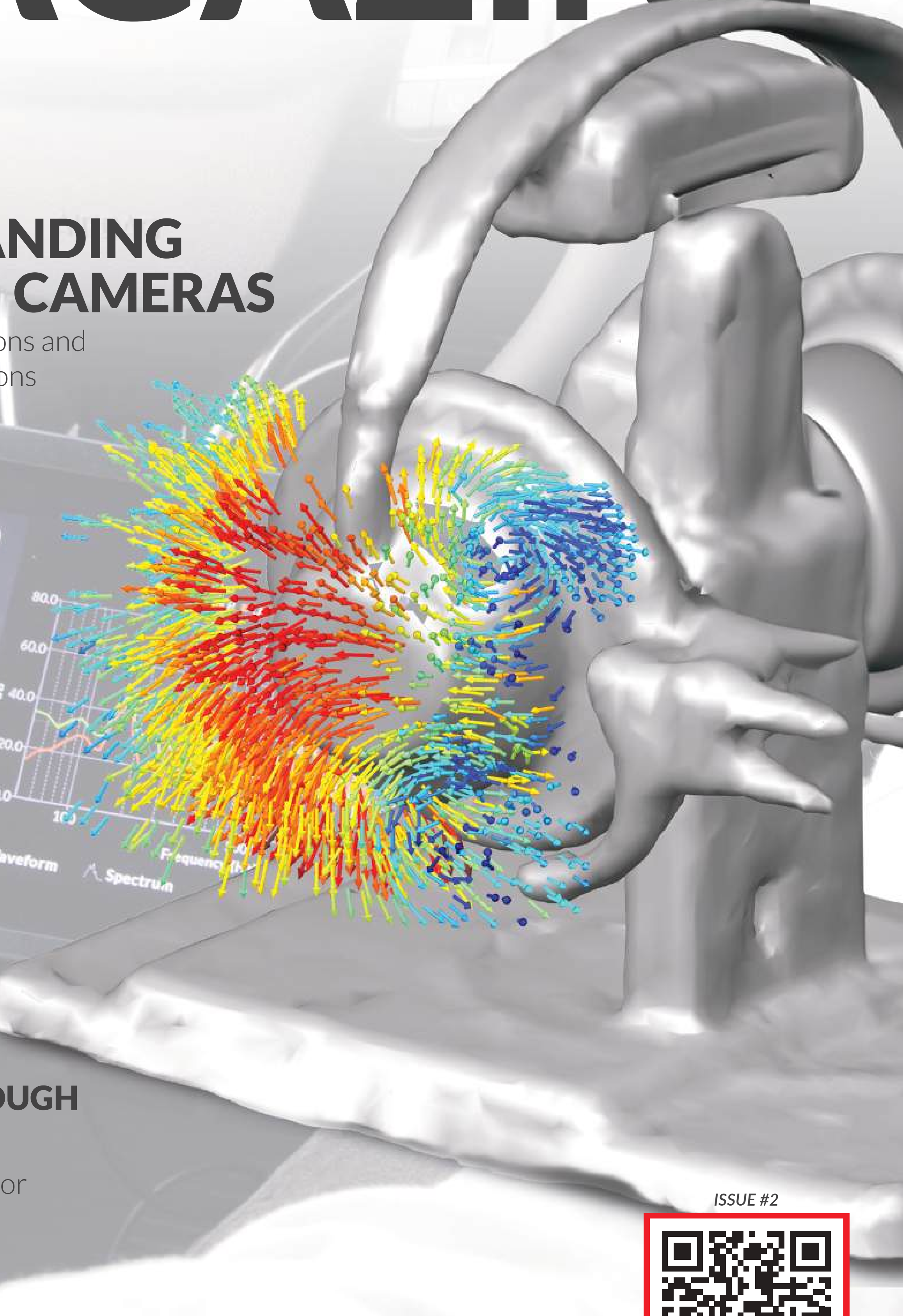
ARTICLE

UNDERSTANDING ACOUSTIC CAMERAS

Effective Use, Limitations and Common Misconceptions

P. 10



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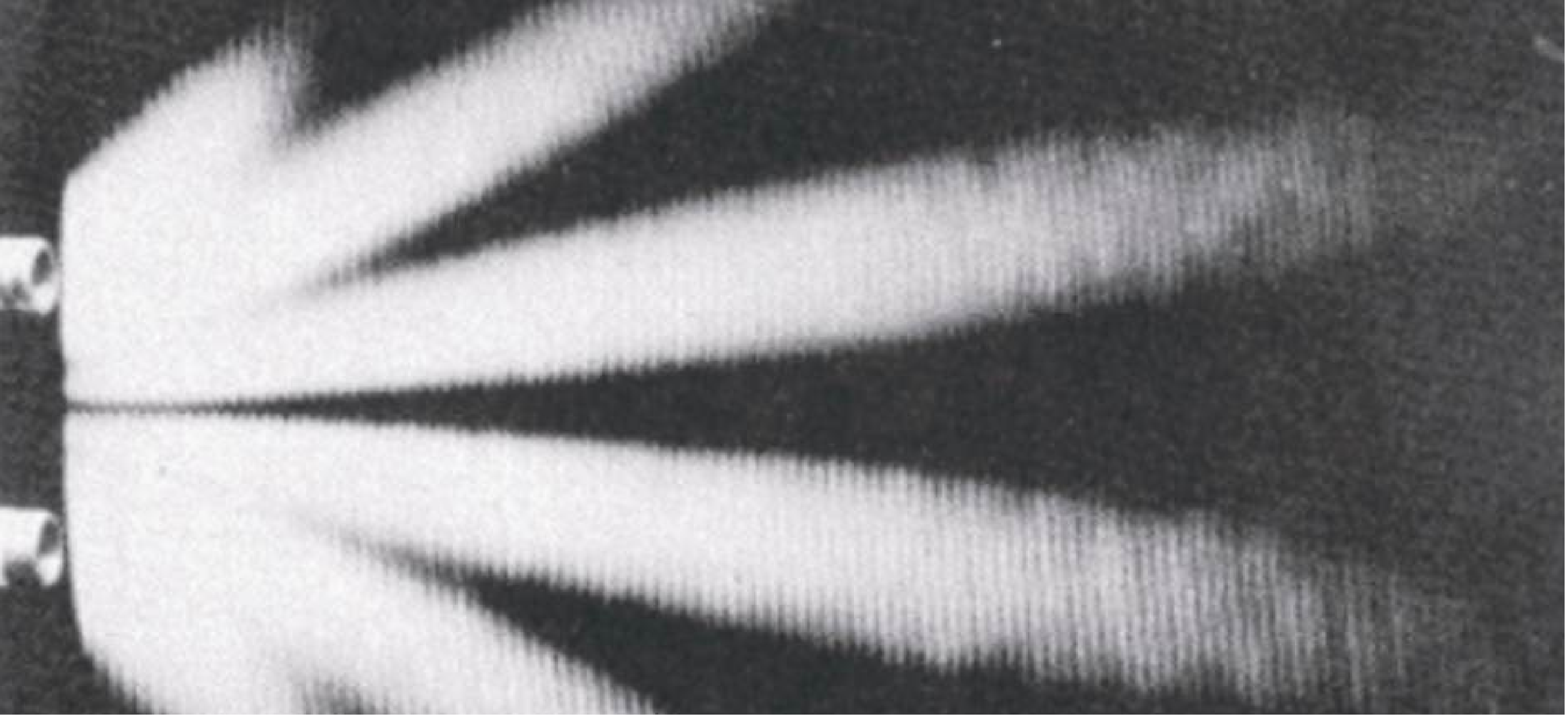


HISTORY OF SOUND VISUALIZATION

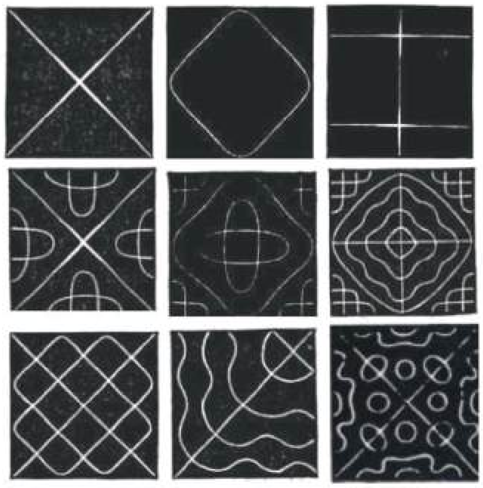
Historical Perspective

The necessity to represent sound and vibration information visually triggered many investigations with a common goal: to create tools to build intuition and understanding of specific problems. To understand the current state of the art of acoustic imaging systems, it is worth highlighting the importance of developing devices for displaying sound phenomena, and how it has evolved thus far. This will allow us to understand the value of the proposed method within the current state of the art and previous techniques.

In this article, we embark on a journey through the annals of history, charting the evolution of innovative acoustic methods and apparatus. We delve into pioneering experiments on sound and vibration imaging from the 18th and 19th centuries. Following this, we assess the advancements made in visualizing sound propagation phenomena. Concluding this historical overview, we outline the principal acoustic measurement techniques that have been unveiled over the past century.

> *"**Napoleon Bonaparte** was so fascinated by **Ernst Chladni's** visualizations of sound patterns that he offered a reward to anyone who could **explain them mathematically.**"*

Early sound and vibration imaging, before acoustic cameras



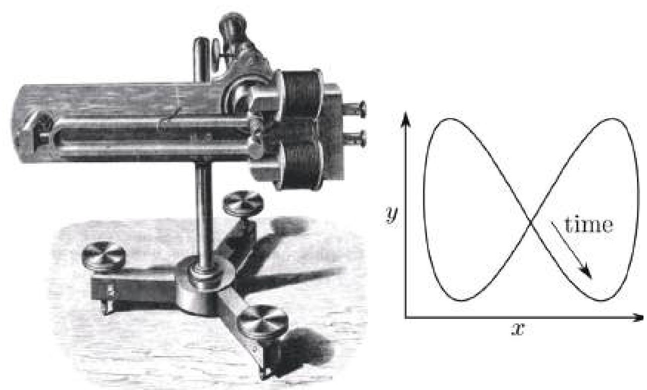
Although the interest in acoustics is considered to have its origins in ancient Greece with studies concerning vibrating strings and musical sounds were undertaken by Pythagoras, it was not until 1787 when the first technique for visualizing vibration in plates was introduced. Ernst Chladni, based on the previous work of Robert Hooke and Simeon Poisson, introduced his method of using sand sprinkled on vibrating plates to show modal lines. He generated the so called by strewing sand on a vibrating plate excited with a violin bow, causing the sand to collect along the nodal lines.

Napoleon sponsoring sound and vibration research

Interest in Chladni's success went beyond the scientific community of his time, amusing even Napoleon Bonaparte, who ordered a translation of his major work "Die Akustik" into French and offered a reward to whomever would be able to explain the "Chladni patterns" mathematically. With Fourier's wave theory in its infancy, the necessary theoretical framework to address the challenge was still under development. Esteemed scholars like Lagrange and Laplace believed the mystery was too complex to unravel at the time. Sophie Germain was awarded the prize offered by the French emperor Napoleon for writing a fourth-order equation to describe plate vibrations. Despite this achievement, she couldn't attend the Academy's sessions as a woman. It took another two years and the intervention of her friend, Joseph Fourier, to secure her a seat in the Academy.

Acoustic apparatus of the 19th century

During the 19th century, several acoustic apparatus were designed to measure and visualize sound phenomena. In 1827, Sir Charles Wheatstone coined the term microphone which was initially associated with a purely acoustical device, similar to a stethoscope; nonetheless, his most successful invention was the kaleidophone. Although his apparatus helped him to understand that the modal behavior of a structure is linked to the superposition of transversal waves, the kaleidophone only provided a visual demonstration of the complex motion of a vibrating body.

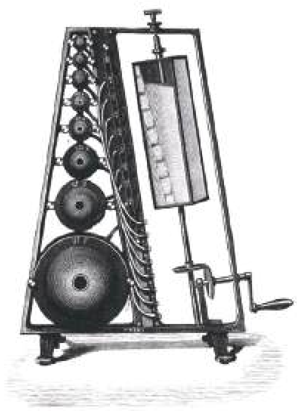


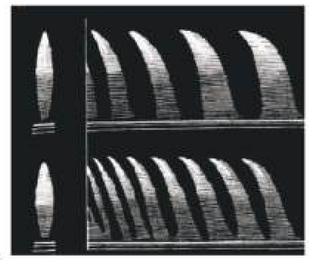
Around forty years later, Hermann von Helmholtz invented a vibration microscope for sound and vibration visualisation of violin strings and human speech. The device reveals the frequency of a tuning fork or other vibrating object with respect to a fork of known frequency by way of Lissajous figure analysis. By viewing the patterns for a bowed violin string, von Helmholtz was able to determine the actual motion of the string, which is still referred to nowadays as the Helmholtz motion. A picture of the device is shown along with some examples of Lissajous patterns.

In 1866, closely related to von Helmholtz' work, the German scientist August Kundt first proposed a way of visualizing standing acoustic waves, ultimately allowing him to measure the speed of sound in different gasses. He used seeds of lycopodium and corkdust to show periodic patterns when standing waves were created in the tube. Similar work was developed in England by John Tyndall, who created several apparatus to illustrate sound phenomena; for instance, he made use of ripples for the demonstration of wave phenomena in connection with the propagation of light. As we shall see, his experiments established a starting point for novel sound visualization techniques based in wave propagation on water developed during the next century.

The use of burning gases for sound visualization purposes was explored in detail by the Russian scientist Rudolph Koenig, who devoted more than 40 years to creating a large collection of innovative acoustical equipment. His most famous contribution, the manometric flame, allowed him to study the nature of all kind of acoustic signals in a visual way. The manometric capsule is divided into two parts by a thin flexible membrane.

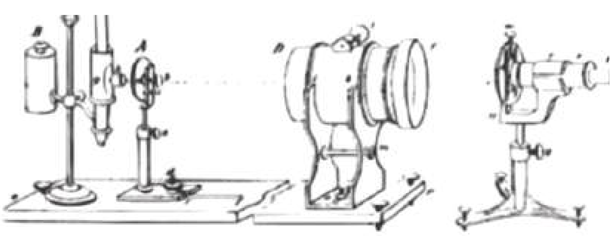
Sound waves are collected by a funnel and cause the membrane to vibrate. The oscillations cause a periodic change in the supply of gas to a burner, so the flame moves up and down at the frequency of the sound. A rotating mirror allows one to view the flame variations caused by the sound. By incorporating Helmholtz resonators it was even possible to use this apparatus as a Fourier analyser, expanding its capabilities for a wide range of applications.

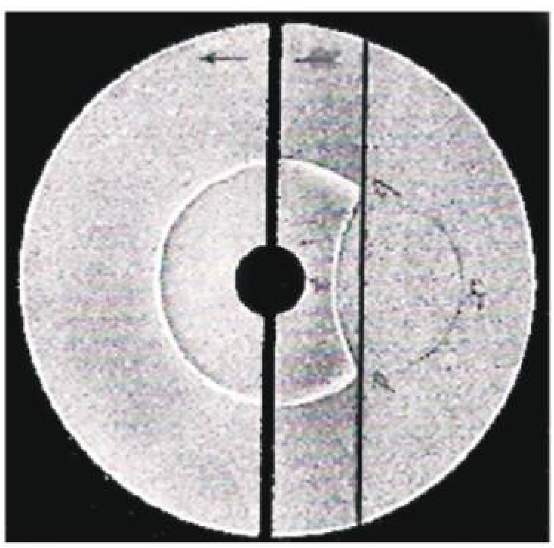




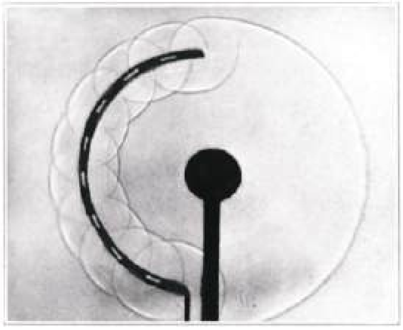
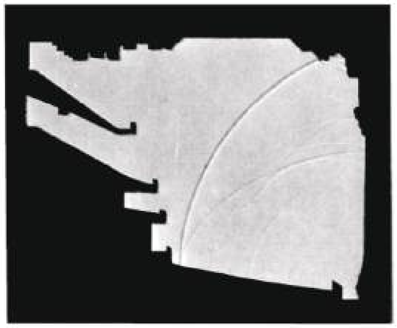
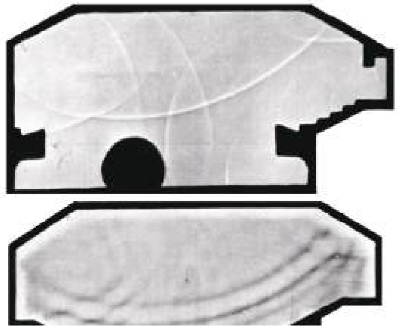
Visualisation of wave propagation

At the beginning of the 19th century, in optics literature, it was pointed out that it was impossible to accomplish a stroboscopic observation of an expanding spherical wave. Nevertheless, August Toepler between 1859 and 1964 realized that a probing wave of pulsed light is able to freeze an expanding spherical sound wave, since the velocity ratios are about one million to one. Thus, he invented a technique to see traveling waves: the Schlieren method. The Schlieren method entails “amplifying” small differences in the optical refraction index of the medium through which the sound wave travels. This amplification therefore increases the contrast between transparent objects having extraordinarily small index differences.





The impressive results obtained by Toepler encouraged other scientists to research this area and also expand upon the method for other fields of science. The Dutch scientist Friest Zernike presented a new perspective of the Schlieren method which won him a Nobel Prize in 1953. The conventional Schlieren methods were applied from a geometrical-optics point of view and, in contrast, he analyzed the method with a wave-optics point of view. He improved the method but constrained to microscopy, introducing the phase contrast microscope. A remarkable example of a prolific career linked to Schlieren imaging is that of Ernst Mach. During his early life, Mach enhanced the initial device of Toepler to achieve a synchronized delay circuit for visualizing “sound” waves from sparks. The combination of his developments with the latest technology of photographic film enabled precise wave-speed measurements. His findings ultimately led him to discover that the waves from sparks were not mere sound waves, they were “supersonic”. Unfortunately for Toepler, he did not live long enough to become aware of Mach’s discoveries and on his epitaph still remains the misleading sentence “He was the first to see sound,” referring to his Schlieren images of weak shock waves.

Another remarkable optic-based sound visualization method was created by one of Mach's assistants, Vincenz Dvorak, who published the first traditionally-recognized account of the simplest sound observation method in 1880, the so-called shadowgraph technique. Dvorak used sunlight focused on a 1 mm aperture to project a diverging light beam across his darkened lab onto a white wall. As a result, refractive phenomena in the middle of the beam appeared as shadows on the wall. There are remarkable similarities between previous research done by Robert Hooke throughout the 17th century and Marat's forgotten ``helioscope'' shadowgraph apparatus introduced in 1780. The lack of popularity of both works left only recognition for Dvorak's ``novel'' device.

Some decades later, in 1912, Foley and Souder reinvented the Dvorak's shadow method as a new alternative to Schlieren devices. Surprisingly, Foley and Souder referenced the previous devices of Toepler and Mach, but did not mention anything about Dvorak's work. They created a device that generates a shock wave from an electric spark followed by a light flash.

Shadowgraph techniques were extensively used by many scientists throughout history such as W. C. Sabine (1868 -1919). He built models of concert halls, fired sparks, and sent weak shock waves reverberating around them. These weak shocks, almost sound waves, revealed themselves in direct shadowgraphs, allowing for the study of the emitted waves at different stages in their propagation through the room.

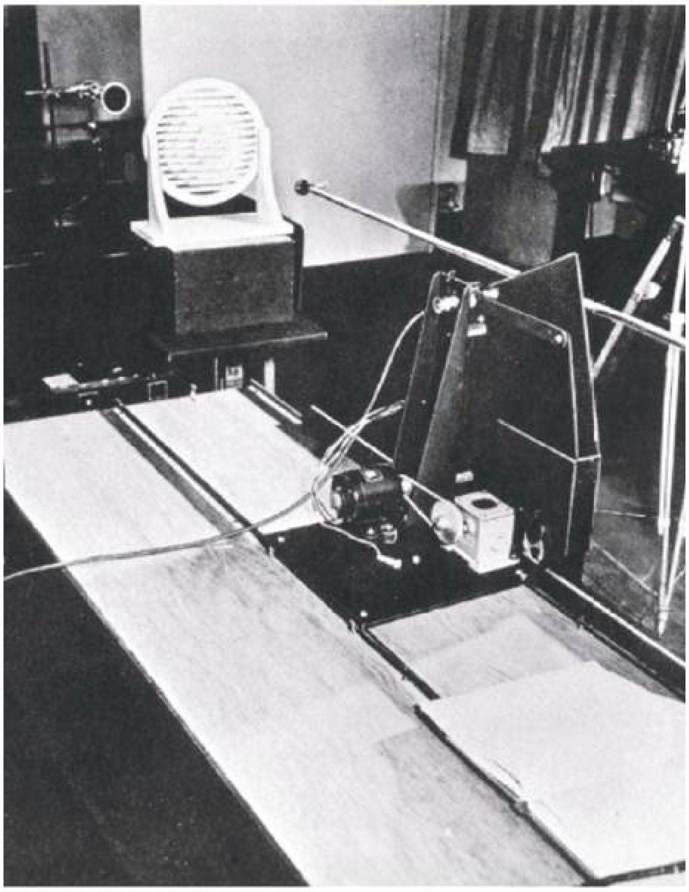
Sabine brought forth the first real understanding of sound in auditoriums at the beginning of the 20th century, for which he is nowadays considered the father of modern architectural acoustics.

In addition, shadowgraphy was also used as a key aid to study the analogy between cylindrical sound waves and waves on the surface of a liquid. Ripples in a small tank are suitable for illustrating acoustical phenomena when the wavelength is comparable to the size of any objects used. Although the potential for using a water tank to study sound propagation inside enclosures was already discussed in 1844, and later demonstrated by Tyndall, it would not be until 1925 when extensive research was undertaken by A. Davis. His work established the limitations of the use of water tanks to study sound propagation phenomena. As can be seen, even though the use of the optic-based technique results in clearer images, the similarities between the two experiments show the possibility of using wave propagation in water as a simple alternative technique to study sound

*"**August Toepler's Schlieren method** in the 19th century revolutionized sound visualization, leading to **Nobel Prize-winning** advancements and the discovery of supersonic waves. This technique paved the way for profound scientific progress in understanding sound waves."*

Visualisation of wave propagation

It was not until the 1960s that new methods for sound visualization were introduced. The first scanning technique to display sound was presented by Winston Kock in 1965. He worked extensively on improving his apparatus which led him to later publish the book "Seeing sound". Kock's method was not directly based upon visual observation like Toepler's technique but rather indirect visual observation. The electrical signal of the microphone can be made visible by causing it to light an electric neon bulb. The brightness of the lamp at a particular spot is then indicative of the loudness of sound at that point. In order to photographically record the brightness pattern, he set a camera with a long time exposure aimed at the area of interest. Consequently, as the microphone-light device scans the area with a fixed speed, the camera records the light intensity variations from point to point. In addition, he also developed a subtraction technique for visualizing the wave patterns across a sound field. The addition of the microphone signal with the excitation signal results in a coherent summation of both waves. This reinforces the light output when the two signals are in phase, whereas the brightness is very low when they have opposite phases.

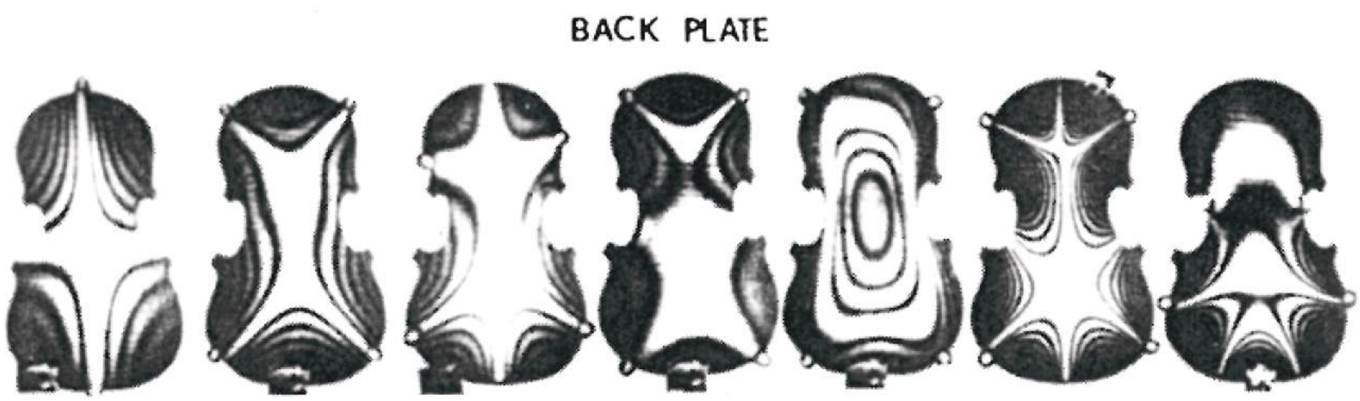


Cymatics

Completely independent of Kock's work, Hans Jenny attempted to redefine the study of visible sound and vibration during the 60s with the term "cymatics". Inspired by the work of Ernst Chladni, he delved deeper into the many types of periodic vibro-acoustic phenomena in a similar fashion to Chladni. He tested the vibrating surface of plates, diaphragms and membranes by applying a thin coating of particles, paste, and liquids. Those materials reorganize depending on the level of vibration across different areas, therefore displaying different patterns. His holistic approach to science, his claims of the ability to "bring matter to life with sound" and his fascination for occultism, divided opinions between those affirming his responsibility for the "history of bad acoustics" and those who believe that his patterns hide something beyond science, something that could lead to the understanding of the healing power of audible sound. The credibility of the second group is undoubtedly questionable, and it is a shame that the supporters of the hidden power of sound can argue that their beliefs are based upon "scientific work".

Holographic interferometry

Another alternative measurement technique which emerged during the same period is holographic interferometry. In the 40s, Dennis Gabor presented a technique that allowed the recording of both amplitude and phase information of a wavefront at any point in space. With this technique, which Gabor named holography (from the Greek holos, or the whole), it was possible to reconstruct, from one hologram measurement plane, the complete field generated. But it was not until the 60s when some independent works revealed that this technique could be very useful for experimental mechanics applications if interferometry between holograms were used to detect phenomena that can be encoded in a wave front. One of the earliest practical studies investigated using holographic interferometry use this technology to produce visualizations of the vibrating behavior of a violin body.



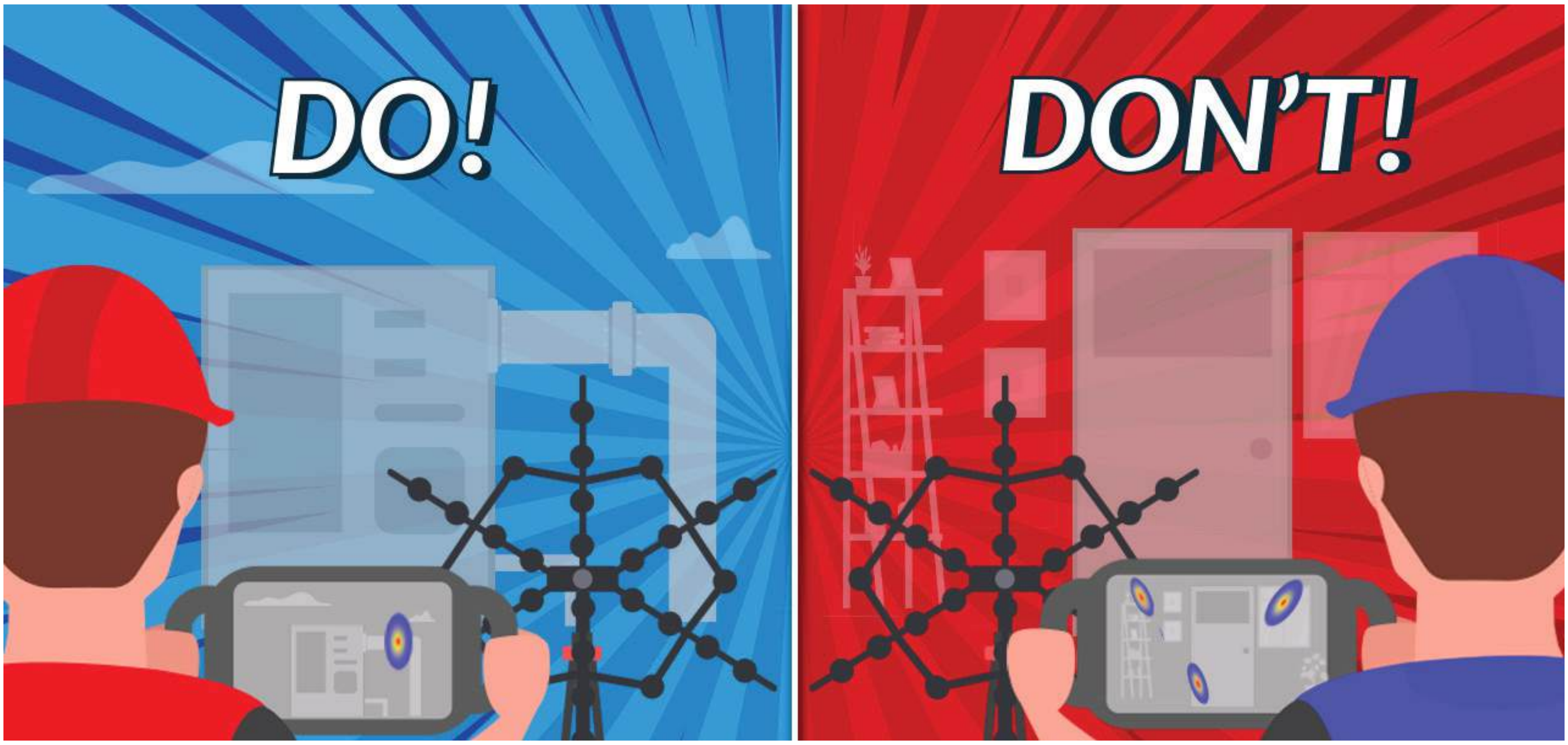
Acoustic Cameras

In the 1970s, multichannel microphone arrays were first applied to sound source localization, although the concept dates back to World War I. The first microphone antenna, or "acoustic telescope," was invented by Billingsley in 1974. Since then, the use of multichannel products has grown substantially with improvements in data acquisition systems, computing hardware, and localization algorithms. Since 1999, devices known as "acoustic cameras" have been marketed as solutions for detecting and localizing noise sources in a sound field.

Concluding remarks

Throughout history, the field of acoustics has seen a persistent drive to better understand sound and vibration. By not just hearing, but visually representing sound, we've opened up new avenues of exploration. Many prolific scientists have harnessed these sound imaging techniques as key tools in their illustrious careers. These pioneers used sound visualization as a catalyst, propelling their research and innovations. Their successes remind us of the importance and potential of this approach, reaffirming the power of visualizing sound in shaping the future of acoustics.

Source: *This article was adapted from an original publication on the Microflown Technologies blog. To read the full article, visit: www.microflown.com/blogs/sound-visualization-tools-history*



UNDERSTANDING ACOUSTIC CAMERAS

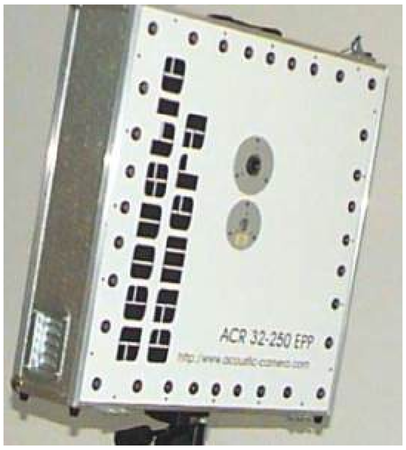
Effective Use, Limitations and Common Misconceptions

Acoustic cameras, widely known for their ability to visualize sound sources using beamforming algorithms, have significantly impacted various fields from environmental noise monitoring to industrial diagnostics. However, despite their capabilities, these devices are often misused or pushed beyond their intended limits, leading to inaccurate results and misconceptions. This article post outlines the main dos and don'ts of using acoustic cameras for solving problems in the audible domain, emphasizes their limitations, as well as introduces viable alternatives for certain applications.

*"**Acoustic cameras** use beamforming to create real-time noise maps, revolutionizing noise localization. However, they face **limitations** with environmental factors and **low-frequency** sound resolution, necessitating careful application and consideration of alternatives."*

Historical Perspective

In the 1970s, multichannel microphone arrays were first applied to sound source localization, although the concept dates back to World War I. The first microphone antenna, or "acoustic telescope," was invented by Billingsley in 1974. Since then, the use of multichannel products has grown substantially with improvements in data acquisition systems, computing hardware, and localization algorithms. Since 1999, devices known as "acoustic cameras" have been marketed as solutions for detecting and localizing noise sources in a sound field, with Gfai being the first company to introduce such a commercial tool.



How does an acoustic camera work?

Acoustic cameras utilize an array of microphones, known as sensors, to capture acoustic signals from multiple locations. By employing advanced beamforming techniques, these cameras can localize and identify specific sound sources within a given environment. Beamforming allows the system to focus on particular directions, effectively steering a "virtual microphone" to target different areas. This capability enables an acoustic camera to "listen" selectively, amplifying sound from desired directions while filtering out background noise and unwanted sounds.

This process is crucial in creating highly accurate noise maps, which are generated almost in real time. These maps provide a visual representation of the sound intensity and location of noise sources, often overlaid on a video image for enhanced clarity. This visualization helps in pinpointing the exact sources of noise, making it a powerful tool in various applications such as machinery diagnostics, environmental noise Additionally, the near-instantaneous computation of noise maps facilitates quick analysis and decision-making, thereby improving efficiency in troubleshooting and noise issues

Ideal Conditions for Acoustic Cameras

Most acoustic cameras are designed based on a theoretical framework primarily focused on localizing far-field point sources in free-field conditions. This means that ideally the sound sources should be omnidirectional, sufficiently far from the array, and have a wavelength much smaller than the array size. Under these conditions, an acoustic camera can accurately detect and quantify sound sources. The technology works best when measurements are conducted in environments that closely match the free-field assumption, such as outdoor facilities or anechoic test chambers.

DO

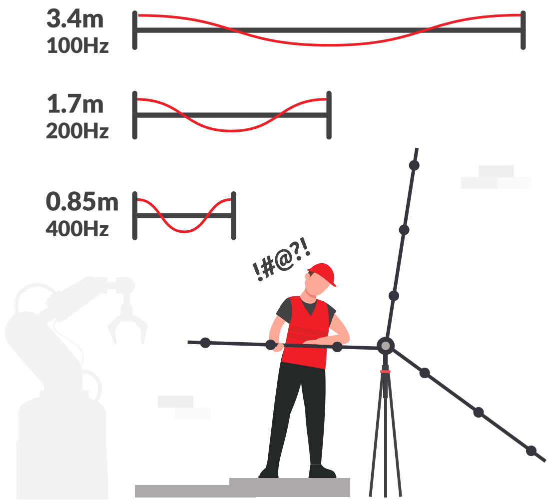
- Use acoustic cameras for outdoor measurements where scattered sound sources are far from the array.
- Focus on mid to high-frequency ranges where the wavelength is much smaller than the array size.
- Utilize the technology to localize stationary or transient noise sources with low directivity.

DON'T

- Use acoustic cameras for near-field measurements or indoor settings without considering significant limitations.
- Expect accurate results for low-frequency sound sources due to the large wavelength relative to the array size.
- Rely on acoustic cameras for quantifying complex sources distributed across a large area and/or with high directivity.

Challenges with Low-Frequency Sound

A critical limitation of acoustic cameras is their difficulty in resolving low-frequency sounds. The ability to focus on different directions is highly dependent on the ratio between the array size and the wavelength. Low-frequency sounds, which have longer wavelengths, do not allow for the strong directivity needed for accurate localization, especially with portable microphone arrays, resulting in poor spatial resolution and very low dynamic range. While large microphone arrays can somewhat mitigate these issues, they remain limited by the physical principles governing their operation.

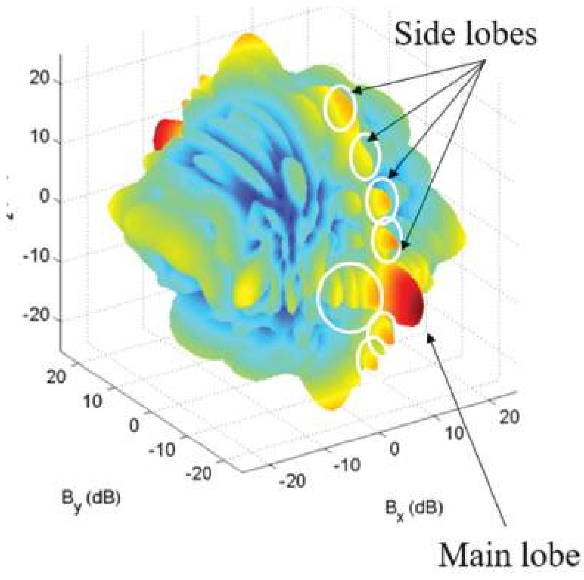


Technological Limitations

- **Aperture Size:** The size of the acoustic camera's aperture affects its angular resolution. Larger apertures provide finer resolution, but this can make the cameras bulky and cumbersome, limiting their mobility.

- **Frequency Range:** The maximum frequency an acoustic camera can detect is limited by the spatial separation between adjacent microphones. To sample higher frequencies, the microphones must be spaced closer together. The lower effective cut-off frequency is defined by the total array size.

- **Miniaturization Challenges:** While there is ongoing research to miniaturize acoustic cameras for better portability, this often involves trade-offs in directivity and noise suppression capabilities, especially at lower frequencies.



Application Limitations and Environmental Factors

Acoustic cameras can more easily resolve multiple sources of equal power than sources with vastly different levels. The directivity pattern of the array introduces leakage when the main lobe is too wide or the side lobes are strong, masking weaker sources near louder ones. Advanced signal processing algorithms such as deconvolution techniques can extend the effective range but often introduce other challenges, such as increased sensitivity to noise and discrepancies between theoretical models and practical conditions.

Indoor Measurements and Acoustic Reflections

The propagation path between the sources and the measurement array can be strongly affected by the testing environment where the acoustic camera is used, which can effectively distort the resulting acoustic images. In environments with complex acoustics, such as architectural spaces, sound behavior is far from the predefined ideal free-field models used in the imaging algorithms, making it challenging to accurately map sound sources.

Acoustic cameras can help verify compliance with noise limits but may not capture all noise emission points or provide a reliable sound pictures in acoustically complex environments.
Indoors, acoustic reflections from floors, walls, and other surfaces can create ghost sources that interfere with the accurate characterization of noise sources. These reflections complicate the analysis and often lead to artifacts in the resulting sound maps, making it difficult to link the maps to physical sources. Advanced signal processing algorithms can extend the effective range but often introduce other challenges.

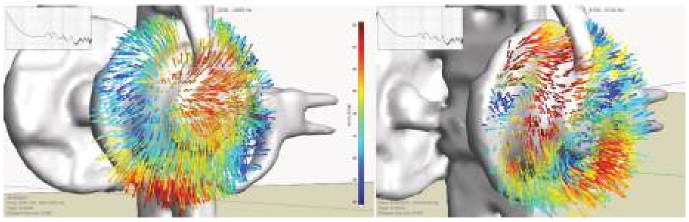
Beamforming and Near-Field Acoustic Holography (NAH)

Far-field beamforming, the underlying algorithm used by most acoustic cameras, is a spatial filtering operation applied to sensor data to extract the localization information of noise sources. An array of transducers captures certain acoustic properties of the sound field at discrete positions. The data is processed using wave propagation models to estimate their direction of arrival, acting as a spatially discriminating filter.

Near-field acoustic holography (NAH), on the other hand, can be applied if the array is placed close to the noise sources, capturing both the evanescent and propagating sound waves, allowing for an accurate sound field reconstruction and quantification. Coherent sources are easily assessed, while incoherent sources require more complex processing methods. Commercial solutions using this technology are commonly referred to near-field acoustic cameras. Both beamforming and NAH are very powerful for multiple applications, especially in assessing non-stationary sources. However, their practical limitations, such as the finite, discrete aperture and sensor calibration errors, should not be disregarded.

Direct Sound Mapping: A Simple Alternative

Direct sound mapping offers a viable alternative to acoustic cameras, particularly for near-field applications under time-stationary conditions. Unlike acoustic cameras, direct sound mapping measures sound directly near the source, obtaining visual representations based on the measured sound that are not constrained by the frequency of interest (i.e. suitable for low-frequency noise problems). Physically measuring at a discrete set of points near the target device allows for accurate quantification of noise emission. This approach avoids the theoretical assumptions used by beamforming algorithms related to propagation path or testing environment that can lead to inaccuracies. Measuring close to the sources provides unparalleled spatial resolution with a very high dynamic range due to the intrinsic spatial variability of the sound field and near-field evanescence energy. Depending on the visualized quantity, the spatial resolution varies, with particle velocity being the superior quantity for sound localization, enabling the resolution of sources as close as the measurement distance. Furthermore, if sound intensity is captured all around the target device/source, accurate sound power characterization can be performed in-situ. This makes direct sound mapping very attractive for both troubleshooting and benchmarking products.

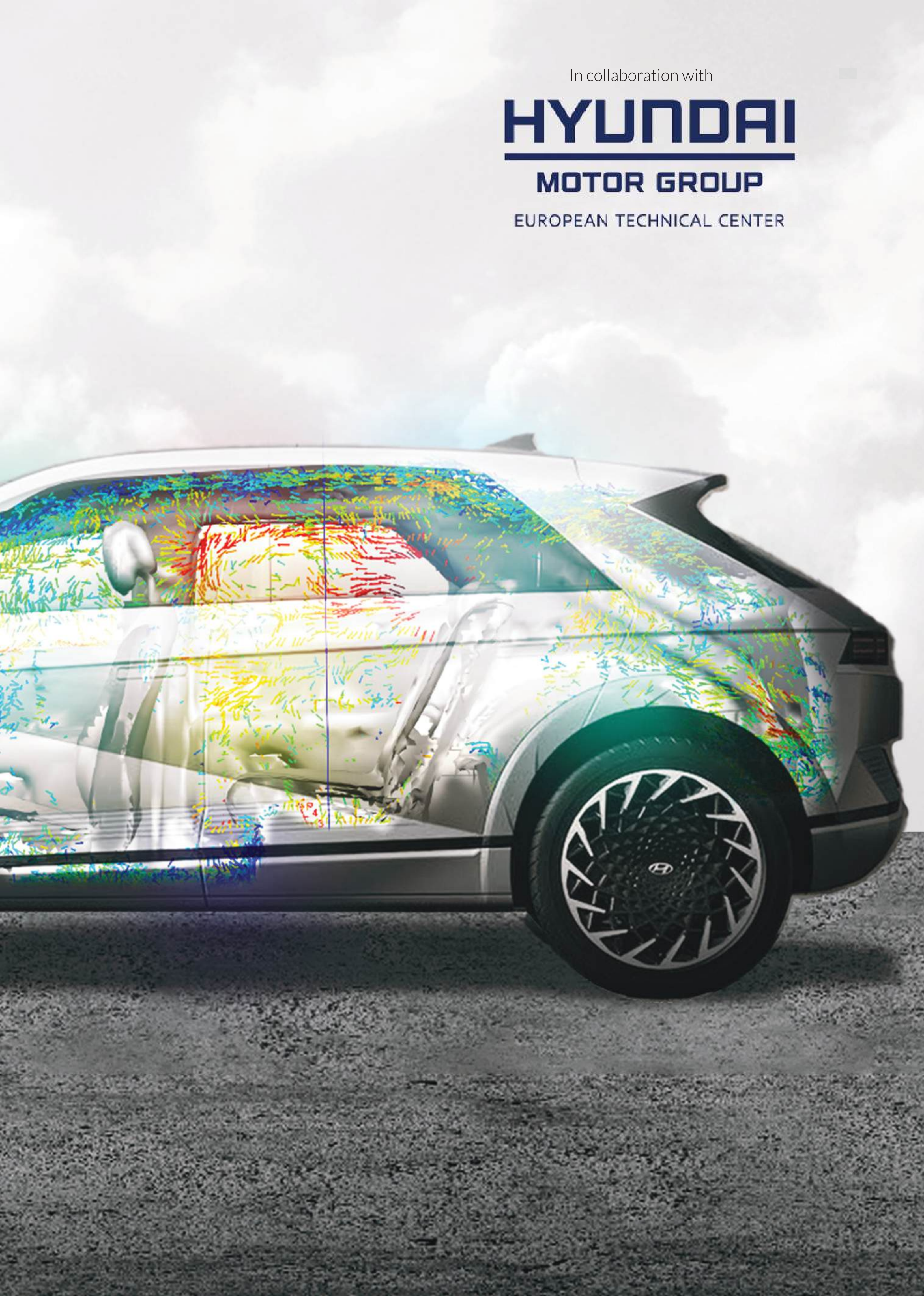


Source: *This article was adapted from an original publication on the Microflown Technologies blog. To read the full article, visit: www.microflown.com/blogs/understanding-acoustic-camera*

ACOUSTIC PERFORMANCE ENHANCEMENT OF A HYUNDAI ELECTRIC VEHICLE INTERIOR

By Engin Güven

The vibro-acoustic properties of a car cabin play a key role in the perception of vehicle quality. One of the main NVH goals of most car manufacturers is to enhance acoustic performance while meeting demanding weight and cost targets. Traditional applied experimental techniques have strong limitations, especially testing a complete vehicle is mostly unfeasible, requiring an independent evaluation of each subsystem.


In collaboration with
HYUNDAI
MOTOR GROUP
EUROPEAN TECHNICAL CENTER

Hyundai

In this case study, a novel methodology has been successfully applied to identify key radiation areas and rank their importance towards the position of front and rear passengers. An extension of the substitution monopole technique has been introduced, combining Microflown 3D sound intensity measurements and acoustic transfer functions. This measurement approach significantly simplifies the refinement process of a vehicle interior, reducing the traditional testing process to just a few days. The experimental results demonstrated that the proposed technique provides an extensive amount of vibro-acoustic data for every vehicle section, including noise ranking and visualization of complex acoustic phenomena in three-dimensional space.

Goal & requirements

Apply a novel methodology to enhance acoustic performance while meeting demanding weight and cost targets.

- Complete vehicle 3D scanning and broadband, high spatial resolution sound field mapping
- Noise ranking of vehicles sections, so called panel contributions
- Design and improve the acoustic package of a commercial electric vehicle

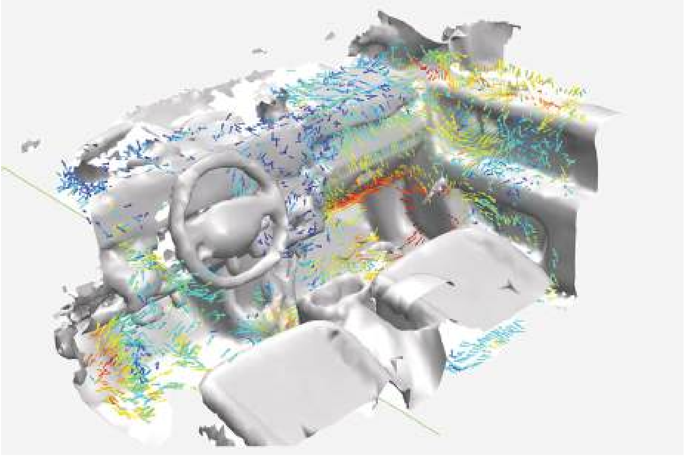
Measurement Methodology

There were two types of measurements performed in this campaign; operational experiments and transfer function measurements. Operational experiments to evaluate the noise produced by an electric car, were carried out while running on a dyno inside a semi-anechoic chamber at 80 KPH and 100 KPH. Scan&Paint 3D enabled to perform a complete 3D scan of a Hyundai electric vehicle interior and measure the acoustic radiation of panels. Secondly, in non-operating conditions, volume velocity sources enabled reciprocal measurements of the acoustic transfer functions.
A 3D model of the vehicle is needed to link the position data with acoustic data and to create a visual representation of the sound field. The required 3D model can be imported from an existing file or obtained by scanning the area(s) of interest with a structural scanner. In this case the structural scanner was used to scan the entire vehicle interior to obtain fast & easy a 3D model.
In order to capture the complete vehicle interior and obtain a high spatial resolution, the engineer performed sound intensity measurements from multiple camera positions. Once the camera is in a position, the acoustic data acquisition process starts by manually moving a 3D sound intensity probe while a stereo camera is used to extract the instantaneous position of the sensor in the 3D space. The recorded data were segmented using a 15 mm spatial resolution grid, yielding more than 16000 data points per measured condition.

Secondly, in non-operating conditions, volume velocity sources allow reciprocal measurements of acoustic transfer functions. Two types of Microflown Volume Velocity Sources, the Low Frequency, and Mid-High Frequency VVS are needed to cover a broadband frequency range. The acoustic transfer functions enable obtaining the source-path-contribution to every discrete point location of each pre-determined panel.

15 mm spatial resolution *grid, yielding more than* ***16000 data points*** *per measured condition.*

Outcome



The visualization of sound intensity in a 3D space enables to get an intuitive and comprehensive understanding of sound radiation mechanisms as well as the interaction between problematic elements. By 3D scanning, it was already possible to identify two critical bands with very different behavior. The trunk has the highest acoustic emission for lower frequencies, whereas the C pillar, B pillar, and rear passenger windows seem to dominate the medium frequency range.

Secondly, a ranking of the main sections of the car interior was presented, showing that the combination of reciprocally measured acoustic transfer functions with 3D sound intensity measurements can reveal the main problematic areas for multiple operational conditions and/or frequency bands. This information was used to apply an effective acoustic treatment in order to reduce the noise perceived by the vehicle's passengers.

Source: *This article was adapted from a case study originally published by Microflown Technologies. To explore the full case study, visit: microflown.com/hyundai-case-study*

REDUCING NOISE EMISSIONS FROM LONTRA'S LP2 COMPRESSOR

By Mikhail Soloviev

Lontra has a culture of innovation, encouraging thorough engineering evaluation to design better products. We wanted a rigorous approach to identify and precisely target key noise sources in our new blower, to efficiently achieve a quiet product. LP2 is the first fully packaged blower manufactured by Lontra using its proven patented Blade Compressor. It operates at up to 1barG, delivering up to 2600m3/h of air at 2500rpm. It is a positive displacement machine, which produces 1 discharge per revolution, resulting in low frequencies of emitted noise. This poses some unique acoustic challenges for various aspects of the design, and led us to use the Microflown equipment. Microflown Scan&Paint 3D utilises sensor technology that directly measures acoustic particle velocity and sound intensity in 3D. A 3D model of the compressor and enclosure is imported into the software where the sound field can be visualised and quantified. The tool allows us to identify sources within the enclosure, prioritise and precisely target them with minimal modifications and cost. The key benefit from Lontra's perspective is the ability to accurately resolve low frequencies, even below 50Hz, which is critical due to the low running speeds of the LP2. Additionally, with the same equipment we could calculate sound power even when used in relatively small test cells, which is important to avoid costly facilities.

In collaboration with

Goal & requirements

Reducing noise emissions, especially the low frequency components, from Lontra's LP2 compressor.

- **Quickly identify dominant noise areas**
- **Measure in-situ, in a normal environment**
- **Measure low frequencies, even below 50Hz**
- **Reducing the overall sound power level**

Measurement Methodology

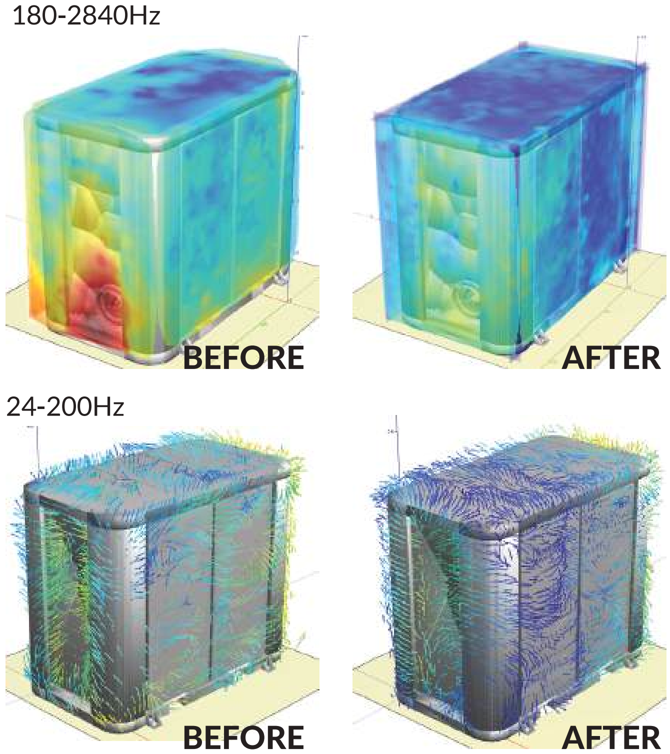
A pre-production LP2 unit was scanned using Microflown Scan&Paint 3D to locate where the sound was emitted from the enclosure (scanning the outside), and to then identify the sources responsible for those emissions inside the enclosure (scanning the interior of the opened enclosure). Due to the size of the LP2 package, the outside of the enclosure required around 16 individual trajectories, by repositioning the 3D camera. All the trajectories were analysed together in the Velo software, giving a single processed dataset. position the 3D tracker into the measuring environment. The acoustic data acquisition process starts by manually moving a 3D sound intensity probe whilst a stereo camera is used to extract the instantaneous position of the sensor in the 3D space. The recorded signals are split into multiple segments and assigned to their corresponding locations using a spatial discretization algorithm. The spatial resolution is defined during the post-processing stage and thus can be adjusted depending on the available data. The maximum feasible resolution is determined by the accuracy of the 3D tracker, in this case, down to 3 millimeters. Sound pressure, particle velocity, or sound intensity across the sound field can then be computed to provide a visual representation of the sound distribution.

Outcome

This study focused on reducing noise emissions from a compressor enclosure by redesigning key components. The changes primarily involved modifying the cover of the outlet silencer pipe and implementing anti-vibration mounts for the inlet silencer. These modifications significantly reduced sound power levels, particularly at the rear and front of the enclosure.

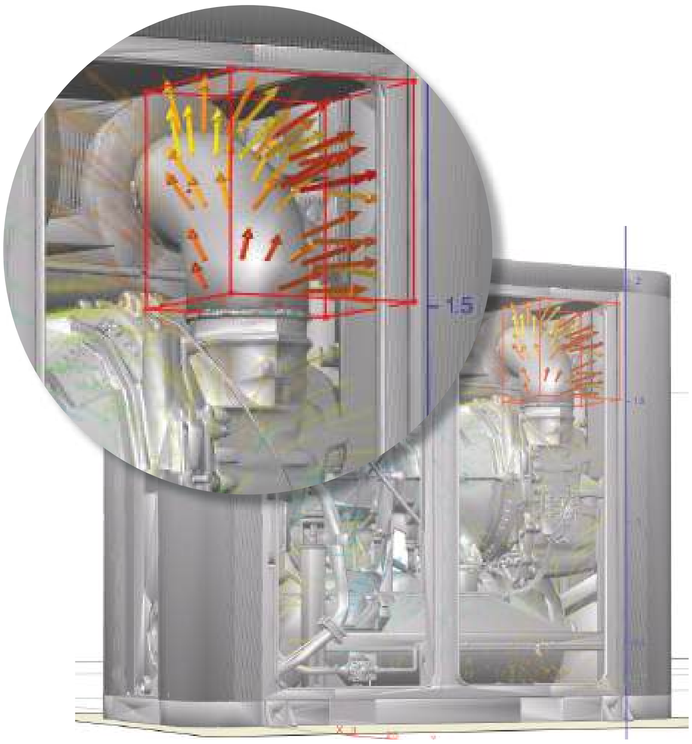
Before and After Comparisons:

- Sound Power Levels: Total sound power was reduced from 119.5 dB (re 1e-12 W) to 116.8 dB, and A-weighted sound power dropped from 96.9 dB to 92.6 dB.
- Greatest Improvements: Significant reductions were noted at the rear of the enclosure, where A-weighted sound power decreased from 93.5 dB to 87.4 dB.



Improvements in Enclosure Design:

- Outlet Silencer Cover: Redesigning this component eliminated rattling and reduced emissions across a wide frequency range.
- Inlet Silencer Mounts: Softer mounts reduced vibration transmission, especially at low frequencies.



Frequency Analysis:

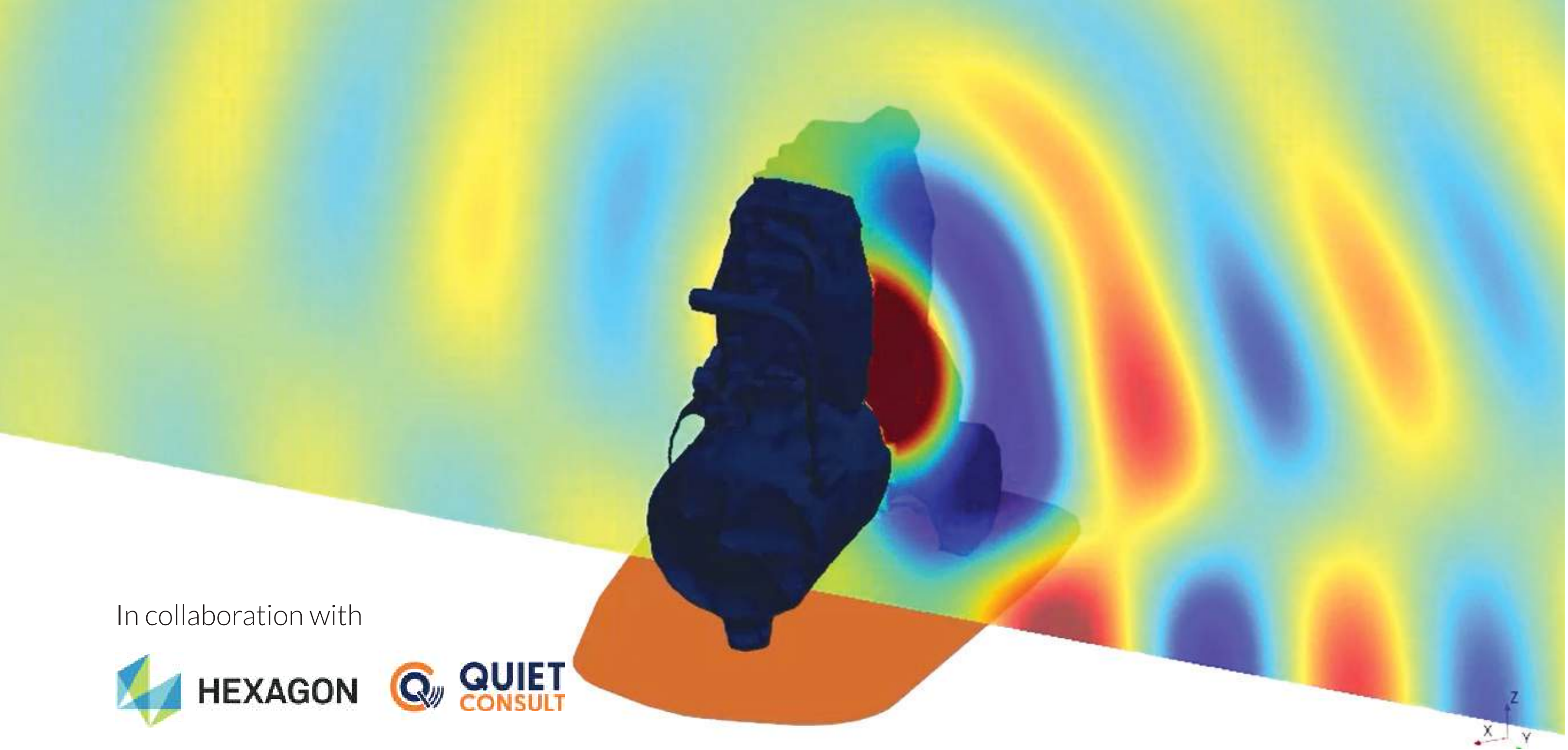
- Low Frequencies (24-200 Hz): Reductions in active intensity vectors showed overall emission improvements, especially from the rear.
- Mid Frequencies (100-140 Hz): Particle velocity analysis indicated that both the atmospheric inlet region and the outlet silencer were major sources of noise.
- High Frequencies (Above 125 Hz): Identified that gaps around doors and improper sealing were contributing to noise leakage.

Strategic Design Decisions

- Attenuation at 125 Hz: Modifications targeted at this frequency resulted in improved noise containment.
- Air Pipe Design: Reinforced, angled pipes reduced vibration transmission, leading to lower noise emissions.

The redesign of the compressor enclosure led to notable reductions in noise emissions. Addressing the specific components that contributed to higher sound levels, particularly the outlet silencer and inlet mounts, resulted in a quieter and more efficient enclosure. Further optimization, especially in sealing gaps and improving internal component mounts, is expected to yield additional reductions in noise emissions.

Source: *This article was adapted from a case study originally published by Microflown Technologies. To read the full case study, visit: microflown.com/Lontra-case-study*



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FROM MEASUREMENTS TO SIMULATIONS

By Joseph Orselli, Xavier Robin, Jonathan Jacqmot, Dani Fernandez Comesaña and Jared Schmal

Measurement Methodology

This study introduces an innovative approach for predicting the far-field acoustic behavior of complex vibro-acoustic sources. Utilizing sound intensity data captured through the Scan&Paint 3D system, combined with computational modeling, we develop a hybrid method to accurately simulate noise generated by intricate acoustic phenomena. This approach accelerates data acquisition and provides detailed insights into near-field behavior, enhancing the accuracy of far-field predictions.

Sound Intensity Measurements

Sound intensity is a critical metric in understanding acoustic emissions and propagation. For this study, we used the Microflown Scan&Paint 3D solution, a portable tool that captures and visualizes acoustic fields in three dimensions. This system allows for rapid and precise data collection, offering a detailed snapshot of the source's acoustic performance.

For this research, we conducted measurements on an air compressor, moving the probe approximately 5 cm from the surface to analyze its near-field behavior. Over 13 separate captures, totaling 18 minutes of scanning, were performed, resulting in a highly detailed acoustic dataset.

Numerical Technique for Acoustic Radiation

The numerical analysis in this study was performed using Actran, a powerful Finite Element (FE) software widely used in both academic and industrial contexts. Actran is particularly effective in solving complex acoustic problems, allowing for detailed simulations of sound radiation from vibrating structures.

The core of Actran's functionality lies in its ability to predict the harmonic response of an acoustic system by solving a system of equations that account for stiffness, mass, and damping factors. This method is well-suited for predicting the free-field or semi-free-field sound radiation of a vibrating structure, making it ideal for our application.

In traditional approaches, engineers typically generate the acoustic excitation data (F) required for the simulation through dynamic structure simulations. However, in our study, we utilize the sound intensity data captured by Scan&Paint 3D as a direct input for the FE model. This integration eliminates the need for meshing or creating a structural FE model to generate vibration data inputs, significantly streamlining the simulation process.

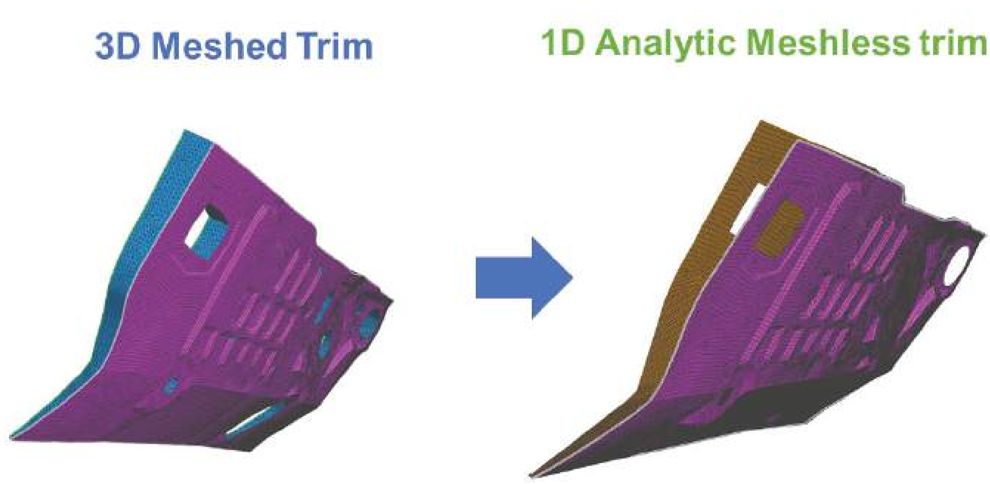
*"Actran's ability to use data from **thousands of virtual measurement points,** captured in a matter of minutes by Scan&Paint 3D, gives it a **significant advantage** over traditional measurement techniques."*

BC Mesh Method

One of the standout features of Actran is its BC Mesh component, which allows engineers to apply previously captured vibration data as an excitation in the simulation model. This component converts structural displacement, velocity, or acceleration data into acoustic pressure and particle velocity boundary conditions, which are then applied to the acoustic mesh.

The main assumption for this approach is that the coupling between the radiating fluid medium and the vibrating structure is weak, meaning the air does not significantly alter the structure's vibration characteristics. This assumption holds true for air in a free-field environment but may not apply in other scenarios, such as heavy fluids or closed acoustic cavities.

Actran's ability to use data from thousands of virtual measurement points, captured in a matter of minutes by Scan&Paint 3D, gives it a significant advantage over traditional measurement techniques. Traditional methods, which rely on structure-mounted accelerometers, are often limited to a few dozen measurement points, restricting the resolution of the simulation. In contrast, our approach enables a much more detailed and accurate representation of the vibrating structure's acoustic behavior.



Application Case

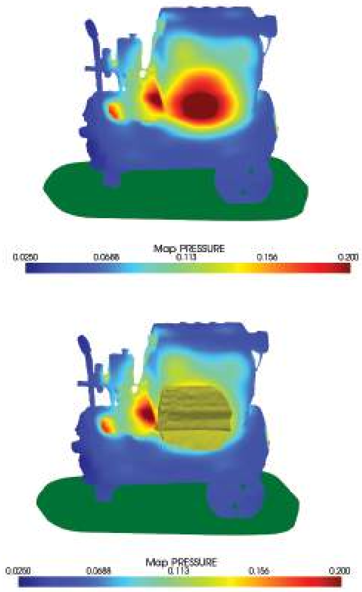
To demonstrate the practical application of this hybrid modeling approach, we conducted a case study on an air compressor. The compressor's acoustic intensity was measured using the Scan&Paint 3D system, capturing over 3000 measurement points with a grid resolution of 10 mm. This dense dataset provided a detailed snapshot of the compressor's acoustic performance, which was then used to generate a finite element "shrinkwrap" mesh in Actran.

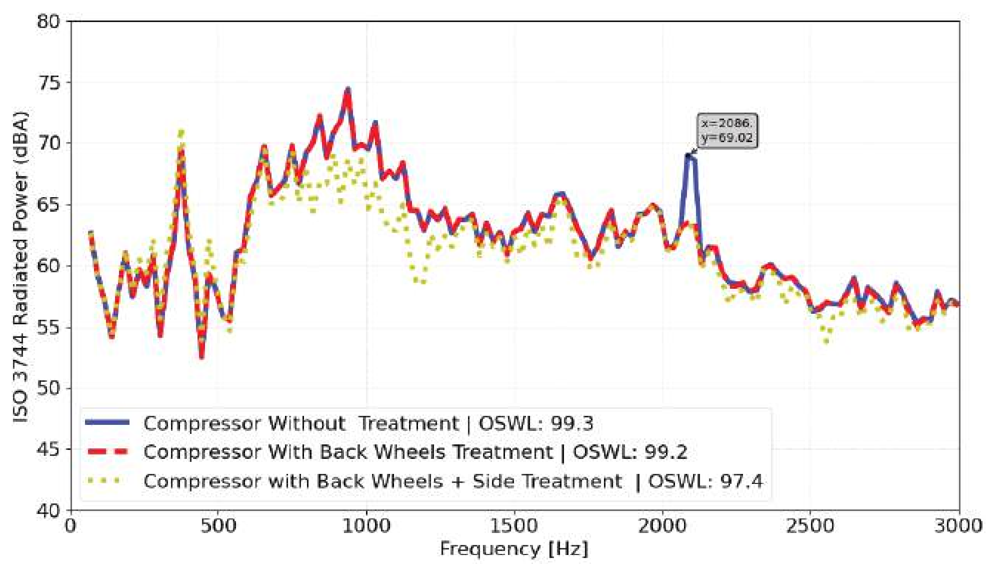
The acoustic radiation model created in Actran included a 100% reflective floor to simulate real-world conditions. The measured particle velocity data was applied as an excitation to the BC Mesh, ensuring an accurate representation of the compressor's acoustic behavior.

Noise Reduction Strategy

After establishing the baseline acoustic model, we explored various noise mitigation strategies by adding acoustic treatments to the compressor. One of the most effective treatments involved applying a 10 mm layer of foam combined with a 4 mm heavy rubber layer over the pressure tank end cap. This treatment significantly reduced a pronounced peak at around 2000 Hz, as identified in the radiated power spectrum.

To further enhance noise reduction, we used frequency-averaged maps to identify additional "hot zones" on the compressor where damping materials could be applied. By adding a 20 mm foam layer combined with 4 mm of heavy rubber to these areas, we achieved a 2 dB reduction in the overall sound power level, particularly in the 700 – 1300 Hz range.





Conclusion

The hybrid approach presented in this paper combines the best aspects of experimental measurements and computational simulations, providing a robust methodology for addressing complex acoustic challenges. By integrating detailed measurement data with advanced simulation tools, engineers can gain a comprehensive understanding of the acoustic behavior of vibro-acoustic sources and develop effective noise mitigation strategies.

This approach is particularly valuable in the late stages of product development when time is critical, and acoustic issues must be resolved quickly. However, it is also applicable earlier in the development process, providing insights that can inform design decisions and improve overall product performance.

Source: *This article was adapted from a conference paper entitled "Hybrid Acoustic Modeling: Far-Field Predictions from Scanning 3D Sound Intensity Data", originally published in Inter-Noise 2024.*

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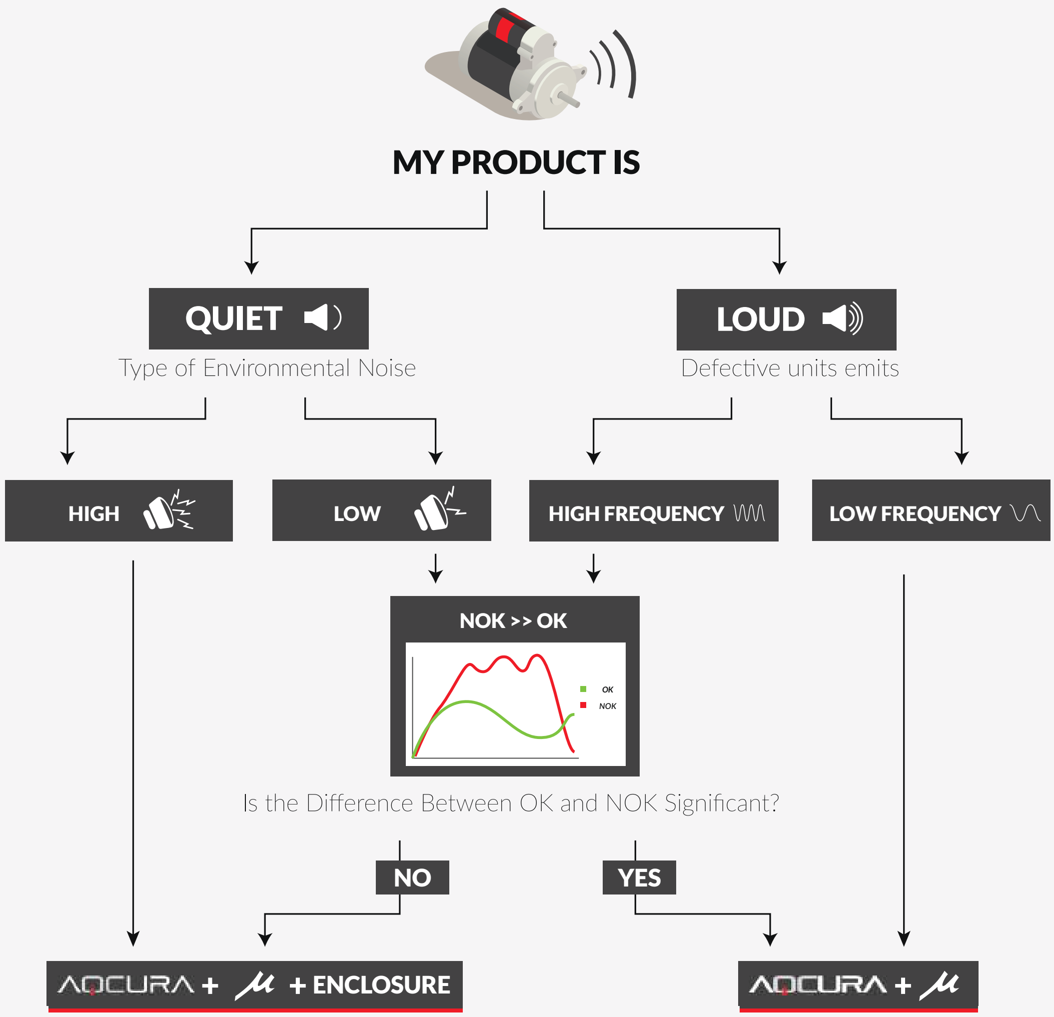

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UNCOVERING THE MEMBRANE EFFECT

By Maro Puljizević, Tadej Poljansek, Andraz Polak, Jared Schmal and Dani Fernandez Comesaña

Understanding the sound absorption characteristics of multi-layered materials is crucial for applications requiring effective noise reduction, such as in architectural design and automotive engineering. This study investigates the acoustic properties of a multi-layered material, focusing on the membrane effect of the upper aluminum layer, which enhances acoustic absorption at lower frequencies. The study compares results from various testing methods, including the reverberation room, impedance tube, and in-situ PU-based measurements, highlighting the complexities of accurately characterizing sound absorption in such materials.

Sound Absorption Testing Methods

Accurately measuring sound absorption in multi-layered materials can be challenging due to the complex interactions between sound waves and the material layers. The three primary methods used in this study include

Reverberation Room - This method measures the diffuse field absorption coefficient by analyzing the rate of sound decay in a room, offering a more generic approach. However, achieving a perfectly diffuse field in practice is difficult, leading to potential discrepancies in the absorption coefficients.

PU-Based Method - A free-field approach that captures acoustic pressure and particle velocity above the material's surface, offering a robust alternative to traditional methods without the need for specialized facilities.

Impedance Tube - Also known as the Kundt tube method, this approach measures the normal incidence absorption coefficient on small samples. It's highly precise but limited to normal incidence plane waves and can differ significantly from results obtained in diffuse fields.

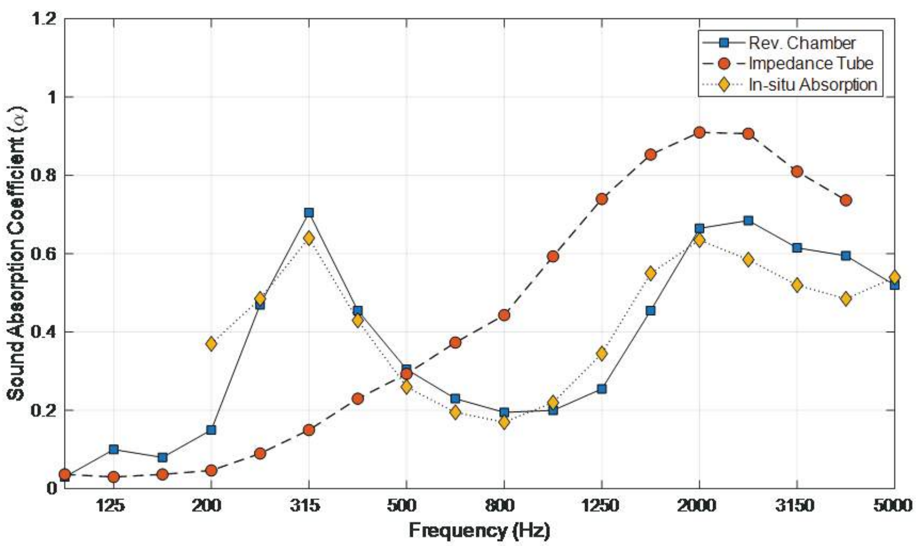
Experimental Investigation

The study focused on a 2-layer material consisting of rock mineral wool with an aluminum layer on top. Various samples were tested using the three methods described, with significant findings regarding the membrane effect of the aluminum layer. This effect, crucial for low-frequency absorption, was particularly evident in the reverberation room and in-situ PU measurements but was less pronounced in impedance tube tests.

Results

The results highlighted large discrepancies between the impedance tube method and the other two methods, especially in the low-frequency range. The in-situ PU method showed strong correlation with the reverberation room results, challenging the assumption that impedance tube measurements are always the most accurate for porous materials. The aluminum layer's role as a resonant membrane was evident, with its removal and reattachment shifting the absorption peak from 315 Hz to 800 Hz, significantly enhancing sound absorption at higher frequencies.

*"the **impedance tube** may not fully capture the complex interactions within **such materials**"*



Conclusions

This study underscores the importance of selecting appropriate testing methods for accurately assessing the acoustic properties of multi-layered materials. The findings reveal that conventional methods like the impedance tube may not fully capture the complex interactions within such materials, particularly those involving non-porous layers like aluminum. The strong agreement between in-situ PU and reverberation room results suggests that these methods may be more reliable for evaluating materials with significant membrane effects.

Source: *This article was adapted from a conference paper entitled "Comparative analysis of acoustic testing methods of a multi-layered material: uncovering the membrane effect", originally published in Inter-Noise 2024.*

A JOURNEY THROUGH SOUND

Interview with Professor Eric Brandão

In the complex world of acoustics and sound technology, few have made as profound an impact as Professor Eric Brandão. As a renowned expert in acoustical engineering and a professor in Southern Brazil, he has spent more than 14 years exploring the intricate realms of room acoustics, signal processing and material characterization.

From PhD to Present Day: A Retrospective

During a recent visit to Europe, Professor Brandão took the time to pay a visit to Microflown. This was an emotional homecoming of sorts, as he reflected on the years spent working in the field of acoustics and working with Microflown's particle velocity sensors and probes since the early days of his career.

Professor Brandão's journey began in University of Santa Catarina, Brazil, where he embarked on his PhD journey in 2008. He recounts how Microflown was much smaller at the time, and many of his then-colleagues are still contributing to the company's growth.

His focus was to understand the technology, especially the PU probe, and to learn to perform measurement of surface impedance in situ. "We had some interesting measurements of perforated panels and we would take very close space measurements and see the color maps of the absorption," he explains.

Material Characterization and Beyond

Ever since his PhD, Professor Brandão has focused on material characterization and room acoustics. From his time at Microflown to the present, he's covered significant ground on this topic, enjoying what he describes as a "long and fun ride." His deep insights into this field have shaped many new ideas and approaches. His passion for continual learning is evident in every word.

For those aspiring to work in this stimulating environment, Professor Brandão emphasizes the importance of mastering signal processing and programming. Understanding these technical aspects, he says, equips one to thrive in the world of acoustics.

Conclusion

Professor Eric Brandão's journey through the world of acoustics offers inspiration and wisdom to engineer students and seasoned professionals in the field. His connection to Microflown and the broader acoustic community underscores the importance of collaboration, continuous learning, and embracing the ever-evolving technological landscape. We're honored to have had this opportunity to sit down with him and learn from his rich experiences. For more visual insights into our conversation, please find the full video footage.

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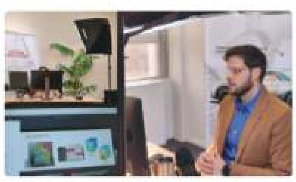

WEBINAR: SCAN&PAINT 2D UPDATES 2023

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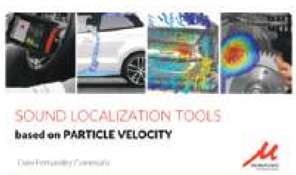

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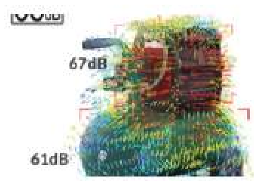

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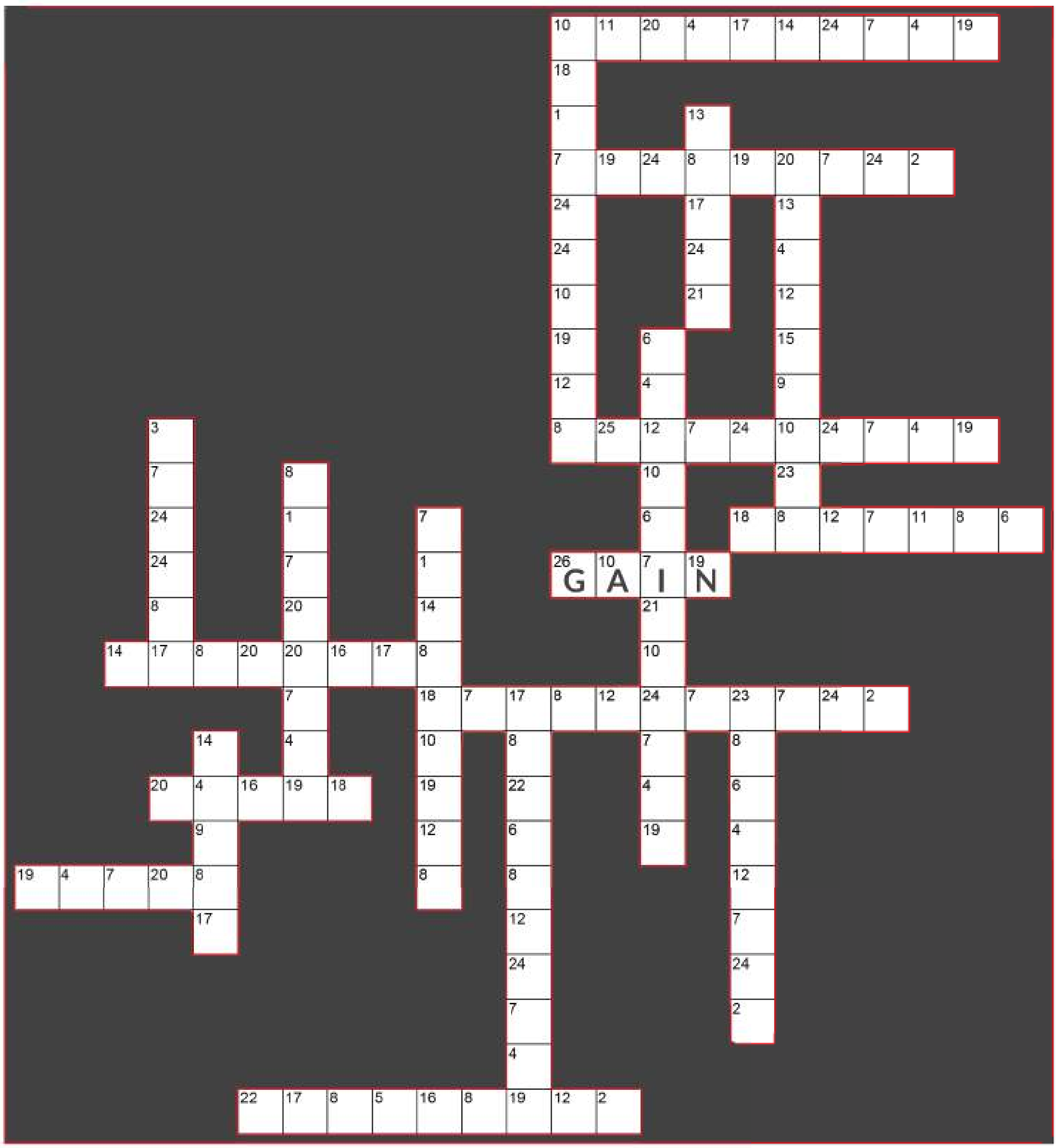
MICROFLOWN'S CODEWORD PUZZLE

Codewords are like crossword puzzles without clues: the letters have all been replaced by code numbers. Using the letters already provided, work out the rest by identifying the missing words!

Hint: all the words can be measured/characterized using Microflown's testing solutions

CODE KEY

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
						I			A									N							G



If you solve this puzzle you will get FREE

20	24	17	4	4	14	9	10	22	8	6	20

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"August Toepler's Schlieren method in the 19th century revolutionized sound visualization, leading to Nobel Prize-winning advancements and the discovery of supersonic waves. This technique paved the way for profound scientific progress in understanding sound waves."

p.7

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