HEARING GAIN

Hearing aid directional filters are normally designed to provide optimal performance on an average head. However, directional performance actually depends on the individual's head and torso shape. Oticon uses multiphysics simulation to advance the personalization of hearing aid performance.

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To suppress sounds coming from any direction other than in front of the wearer, hearing aids typically use a software-based digital filter. Because the wearer normally looks in the direction of the person who is speaking, or toward some other sound they want to hear, designers engineer the devices to target sound originating from the front. Designed only once for each model type, engineers develop these digital filters by fitting a physical model of a head and torso with a specially instrumented hearing aid and taking measurements from a surrounding array of speakers. However, research has shown that the directional performance of a hearing aid depends on the specific geometry of each human head and torso, and that people whose head size and shape is different from the norm often obtain less benefit from a directional microphone.

It would be ideal to design a custom digital filter for each hearing aid wearer. However, the physical approach described above is much too expensive and cumbersome to be used in a clinical practice. Oticon has developed a new approach in which an accurate 3-D model of the individual's head and torso is used to perform simulations of this clinical setup to optimize the directional filter for the wearer's head and torso geometry. Simulation makes it possible to quickly determine personalized settings for the hearing aid to reduce background noise and allow the hearing aid wearer to focus on more relevant sounds.

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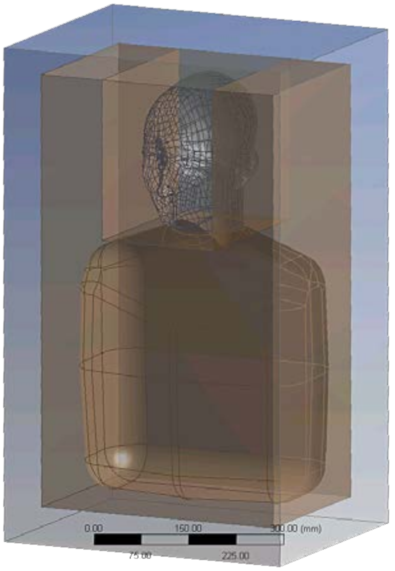
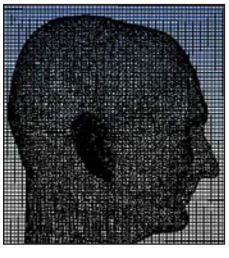


▲ Empty space surrounding head and torso used for acoustic simulation



▲ Mesh for the air surrounding the head

Optimizing the directional filter for the individual user provides an improvement that can make the difference between understanding and not understanding a sentence.

MEASURING DIRECTIONAL PERFORMANCE

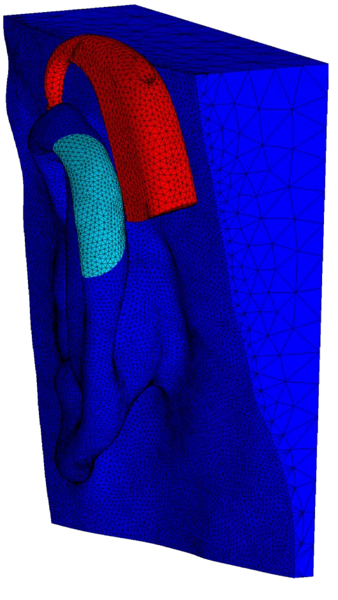
Typical hearing aids contain a front and a rear microphone; the digital filter subtracts a time-delayed version of the rear microphone's output from the front microphone sound. The directional microphone performance of a hearing aid is measured by the directivity index (DI), which describes the sensitivity to sounds arriving from the front relative to sounds arriving from all directions. The directional filter performance is usually evaluated using head-related transfer functions (HRTFs) measured on a physical model of a head and torso. An HRTF describes how a sound from a specific point will be affected as it travels through the air to the outer end of the auditory canal. Research has shown a large range of benefits provided by directional microphones, and has proven that many people could benefit from a directional filter that is optimized specifically for their head and torso.

Oticon recently engaged in a joint research project with the Technical University of Denmark to determine whether it was possible to simulate the physical test setup described above to accurately simulate HRTFs based on an individual's head and torso shape. The goal was to develop a personal digital filter optimized for the wearer. The advantage of this approach is that a 3-D model can be obtained in much less time and at a lower cost than would be required to perform physical testing. Oticon selected ANSYS simulation tools because of their multiphysics capabilities, which made it possible to perform the mechanical and acoustical simulations in the same environment with minimal data handling.

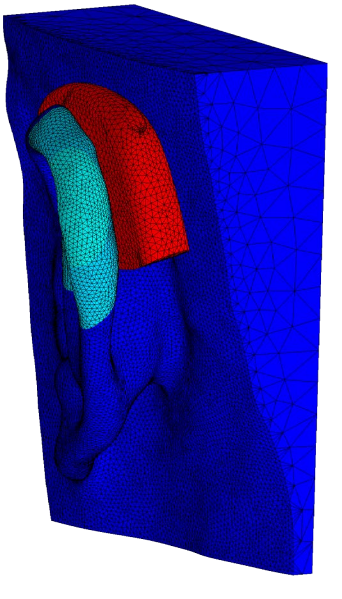
The Technical University of Denmark researcher used ANSYS Mechanical to simulate ear deflection when the hearing aid is worn, and to calculate the HRTFs generated in the ear from a speaker array based on a common test setup. The personalized model of the human head and torso used in the simulation was obtained via 3-D scanning of the individual undergoing HRTF testing. This made it possible for the simulation results to be adjusted to the participant's physical measurements.

MULTIPHYSICS SIMULATION

The researcher generated a mesh for the ear deflection simulation with 25,580 nodes for the ear and 4,754 nodes for the hearing aid, and then simulated the event by applying a displacement to the hearing aid. The displacement was then released and the hearing aid moved to its final position. The deformed mesh of the ear and hearing aid was substituted for the natural ear geometry to create a full system model of the hearing aid in position. The new simulated head model was then placed inside a box with dimensions of 420 mm by 700 mm by 250 mm. The model was subtracted from the box,



▲ Initial position of ear deflection simulation



▲ Final position of ear deflection simulation

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leaving empty air space surrounding the model.

Sound reaches the ear through pressure changes in the air-filled space. The air surrounding the simulated head was meshed with first-order acoustic elements. To reduce computational times, one mesh was created for frequencies below 7.5 kHz and another for frequencies below 10 kHz. Considerably larger elements can be used in the lower frequency mesh, which greatly reduces computational times. The low-frequency mesh was used for rapid evaluation of alternative cases, while the higher-frequency mesh was used for validation purposes.

Acoustic measurements are performed in a semi-anechoic room with special internal surfaces that eliminate reflections off the walls, ceiling and floor that would otherwise interfere with sound measurements. In the simulation, a similar effect was achieved by adding a 40 mm perfectly matched layer (PML) to the outside of the simulation model. The non-reflective PML absorbs all sound waves traveling outward from the bounded domain, and is also used to calculate sound pressure in the far field outside the box. The key advantage of using a PML is that it requires only a fraction of the computational resources that would otherwise be required to model the far field. Engineers took advantage of the acoustical principle of reciprocity, which states that the speaker and microphone positions can be swapped with each other without affecting HRTFs, to reduce the number of simulations needed. Placing the speakers in the subject's ear in the simulation and positioning several microphones around the subject made it possible to measure the HRTFs for all speakers used in the physical tests in a single simulation run.

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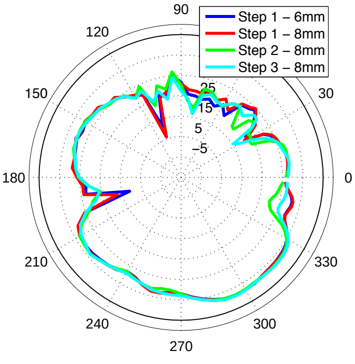
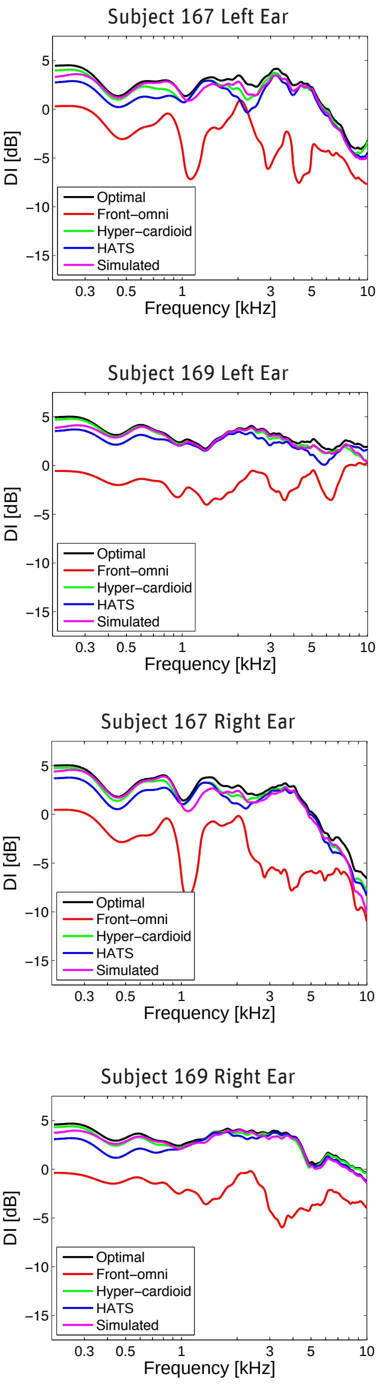


The polar plots show the directionality at a specific frequency. A perfect circle means that sounds coming from all directions are weighted equally. The plots show how the head and torso create a directional pattern, where sounds from some angles are suppressed. Acoustic simulation results are shown for three different cases and two different element sizes. Step 1: Head model only; Step 2: Head and half of torso; Step 3: Head and full torso.

VALIDATION WITH PHYSICAL MEASUREMENTS

The HRTF simulation results were compared with HRTF measurements obtained with an instrumented hearing aid. Engineers concluded that simulations and physical experiments exhibited similar overall trends. Oticon engineers optimized the directional filter based on the simulation results. Additional measurements showed that the resulting directional microphone performs almost as well as a directional microphone optimized using physical testing. Researchers concluded that current simulation accuracy levels are sufficient to optimize hearing aid directional performance for individual users.

Optimizing the directional filter for the individual user provides an improvement in directionality of up to 2 dB to 3 dB, which in many cases can make the difference between understanding and not understanding a sentence. Performing this optimization using physical testing would require the patient to travel to one of only a few suitably equipped facilities in the world for tests that would cost at least $500. The current goal is to gain more insight into individualized hearing directionality using simulation. At some point in the future, it may become possible for a customer to visit a clinic, be scanned and then have a custom directional filter designed through simulation.



Direction filter optimized with simulation (red line) shows 2 dB to 3 dB improvement over standard directional filter (blue line).

Oticon integrates simulation into the product development process

In addition to cutting-edge research, Oticon has also tightly integrated ANSYS simulation tools throughout the product development process. Confronted with increasing product complexity and the need to stay competitive in a fast-paced and highly regulated market, the company made the strategic choice to democratize the use of simulation across its organization. Oticon is taking advantage of ANSYS ACT, a development tool that leverages a common language to configure and customize the simulation user interface, simulation workflow and solver extensions. The company has made advanced simulation technology accessible to designers not traditionally exposed to simulation by integrating the company's product development best practices directly into the ANSYS user interface.

Oticon analysts have developed simulation models of critical hearing aid components, such as the receiver suspensions and microphone inlets, that are used extensively for validating designs prior to the final prototyping/testing phase. As a result, up to 75 percent of the work traditionally done by experts is now delegated to designers, freeing time for engineers to quickly create more innovative and reliable products. The successful deployment of simulation to a broader user base was a significant step forward for Oticon, extending its capabilities to innovate while delivering the highest quality products in the shortest possible time. The company has gained insight into the design of its products, eliminated trial-and-error design loops, and reduced troubleshooting in the later stages of the product development process.

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