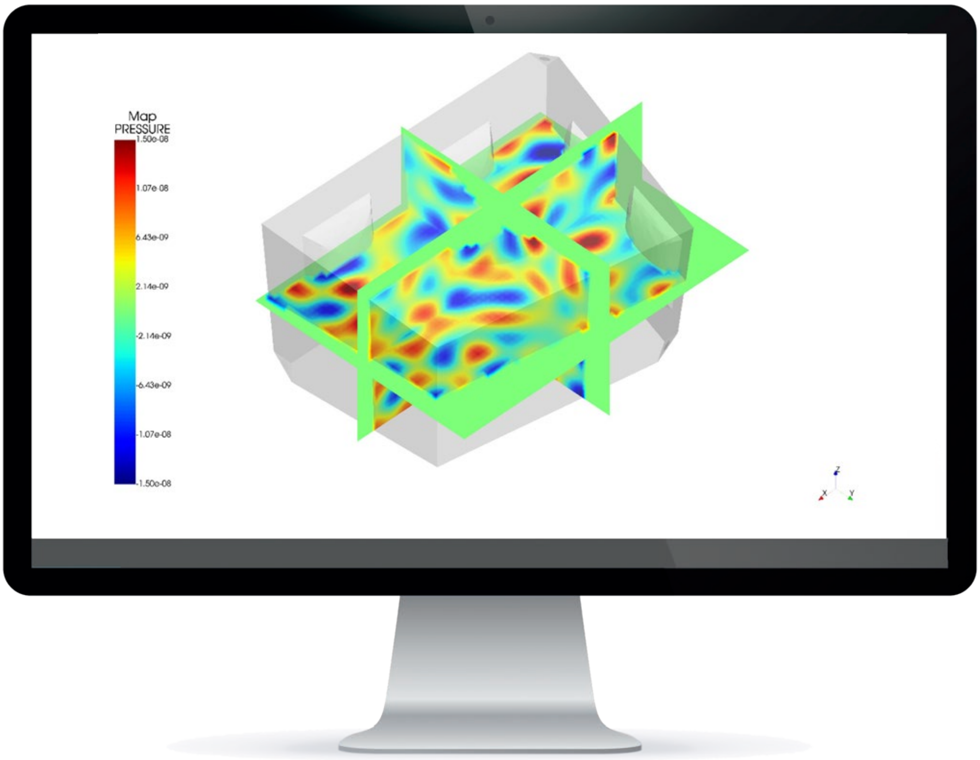
Evaluating acoustic properties of porous material with virtual alpha cabin simulation

An affordable simulation procedure for estimating the absorption coefficient of porous materials up to 10 kilohertz.

Alpha cabins are used by material suppliers across the world to measure the sound absorption that a material provides. These cabins can be very expensive to use for measurements but simulation can help reduce costs while still accurately predicting the sound absorption coefficient of a given material.

To select trims for given applications, original equipment manufacturers require material suppliers to provide them with acoustic performance information such as the absorption coefficient under a diffuse sound field condition. This absorption coefficient can readily be measured in small reverberant test chambers called alpha cabins.

Reproducing the alpha cabin experimental setup with a finite element simulation leads to computationally expensive models due to the large volume of the cabin, the necessary mesh refinement and frequency resolution. A three-step procedure has been developed to overcome those computational challenges. This procedure relies on an energetical approach with scaling to simulate an alpha cabin in the complete frequency range.



Challenge

The absorption coefficient is evaluated from measurements of the reverberation time in the cabin. This reverberation time is determined by the time domain decay of the sound pressure level, as measured by microphones placed inside the alpha cabin. To capture this quantity in a frequency domain simulation, a Fourier transform is performed on time domain results. To ensure sufficient data is captured, the length of the time domain response depends on the frequency step used in the analysis. To capture 2.5 s (reverberation time in a bare alpha cabin) a frequency resolution with 0.4 Hz steps is needed.

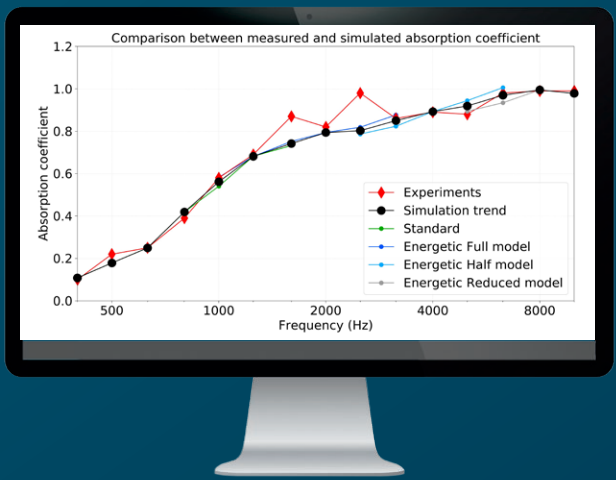
Alpha cabin experimental results are generally given from 400 Hz up to 10 kilohertz (kHz). In simulation, the refinement of the finite element mesh should be chosen according to the target frequencies. Meshing an alpha cabin with a refinement valid up to 10 kHz leads to a model with more than 100,000,000 degrees of freedom.

The need of high frequency resolution and a sufficient mesh refinement leads to the creation of huge models which are not practical to solve in an industrial context.

Solution

Above the Schroeder frequency (1200 Hz for an alpha cabin) the sound field in the cabin can be considered as diffuse. When the sound field is diffuse, the energy contained in the cabin decays exponentially. The reverberation time can then be linked to energetical quantities directly available from a frequency domain simulation. As no Fourier transform is performed with this approach, the frequency step is no longer linked to the reverberation time. Using an energetical approach therefore allows for reducing the model size by getting rid of the high frequency resolution. For example, instead of solving the system at every 0.4 Hz interval, it is now only necessary to identify five frequencies per third-octave band.

Even if we use an energetical approach to get rid of the high frequency resolution, meshing the whole cabin with elements refined to reach 10 kHz still leads to a large model with many degrees of freedom. A solution to reduce the model size is to mesh the 6.5 cubic meter cabin with a coarse mesh targeting 3 kHz. To get results up to 10 kHz this volume mesh is then scaled, reducing the element size without adding degrees of freedom. As a result, higher frequencies can be studied at the same computational cost.



> **"Using this three-step procedure, an alpha cabin simulation can accurately predict the absorption coefficient of a trim sample, up to 10 kHz, in less than a working day"**

The three-step procedure may then be summarised as follows:

- At low frequencies (400 Hz to 1200 Hz), the sound field in the cabin cannot be considered as diffuse and the energetical approach cannot be used. This means that the experimental setup and post processing must be reproduced. As the time domain decay is evaluated using a Fourier transform, a high frequency resolution is needed; however, only low frequencies are studied so the mesh may remain coarse.

- For mid-range-frequencies above the Schroeder frequency (1200 to 3000 Hz), the energetical approach can be used. With this approach a high frequency resolution is not needed as the reverberation time is directly evaluated from frequency domain quantities. The mesh is refined compared to the low frequency procedure, but an affordable model size is kept.

- To reach high frequencies (up to 10 kHz), the mid-range frequency model is scaled. Thus, the scaled mesh is valid for higher frequencies and the size of the model is not increased. As the energetical approach is still used, a high frequency resolution is not needed.

This three-step approach has been used to study a porous sample for which experimental results are available in literature.

Benefits

The computational challenges of alpha cabin simulations can be overcome using this three-step procedure. With this approach, the size of the model stays affordable and results are obtained in less than one working day. Alpha cabin results are reproduced up to 10 kHz and the correlation with experimental data is good. Being able to reproduce alpha cabin results with simulation enables a reduction in the number of iterations for a design.

Modelling alpha cabins can also help to understand the physics. For example, the diffusivity of the sound field can be investigated with simulation.

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