AURALIZATION OF AIRCRAFT CABIN NOISE PREDICTIONS IN EARLY DEVELOPMENT STAGES

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Abstract

Early prediction and optimization capabilities of aircraft cabin noise are a vital tool in preliminary design stages for increasing product acceptance and customer comfort. Having access to audio samples of early development results can be immensely helpful in the design process by allowing listening tests, further psychoacoustic considerations or presentation purposes. While prototype measurements might be too costly or otherwise not available, auralization techniques based on digital signal processing can serve as an alternative. This contribution's auralization methodology turns a system's frequency response function into a stationary stochastic broadband signal by convolving the system's response with white noise. This way, an output signal of any desired length with the spectral shape of the predicted cabin noise can be generated and used for assessment. The methodology is applied to measured car cabin noise. The resulting auralization shares the main audible characteristics with the reference and is therefore deemed appropriate for further investigations. Additional steps to improve the auralization's realism, i.e. supplementing the signal's high frequency range with corresponding recordings and applying a recording's phase content to the auralized signal, are considered.

Keywords

Cabin noise; Auralization; FEM

NOMENCLATURE

Symbols

$a(t)$	auralization	Pa
df	frequency step	Hz
f	frequency	Hz
p	pressure	Pa
$s(t)$	system's response function	Pa
t, τ	time	s
t_{max}	length of time signal	s
$w(t)$	white noise	Pa

Abbreviations

CPACS	Common Parametric Aircraft Configuration Schema	
elPaSo	elementary Parallel Solver	
FEM	Finite Element Method	
PSD	Power Spectral Density	Pa^2/Hz
SPL	Sound Pressure Level	dB
STFT	Short-Time Fourier Transform	
TBL	Turbulent Boundary Layer	

1. INTRODUCTION

Travelling by aircraft is an established mode of transportation, being especially advantageous for large distances, but also an important consideration for mid- and short-range distances when it comes to time, comfort or accessibility. While aviation has seen a steep decline due to the COVID19-pandemic at the start of 2020, the global passenger numbers have almost recovered in 2022 and continue to grow in the foreseeable future. EUROCONTROL predicts an increase in aircraft travel by at least 19 % until 2050 in a conservative scenario, while another scenario estimates the increase at 76 % [1].

Connected to growing passenger numbers are increasingly worrying climate events all around the world. Calls for immediate action to reduce the emission of green-house gases are ever present and concern aviation as well. Commercial aircraft operations accounted for 2.4 % of global CO_2 emissions in 2019 with approx. 80% of those emissions being due to passenger aircraft operations [2].
The Cluster of Excellence "Sustainable and Energy-Efficient Aviation" (SE^{2}A) at the TU Braunschweig is working towards carbon neutral air travel and brought forth three novel aircraft designs for short-, mid- and long-range requirements which include state of the art developments towards efficient aviation and

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ideally net zero emissions [3]. An early design of the short-range configuration, which has been chosen as the use case of this contribution, can be viewed in Fig. 1.

FIG 1. Early design schematic of the short-range aircraft [3].

While carbon-neutral mobility is gaining significance in society throughout research, manufacturers and travelers, future aircraft are ultimately a product. Numerous other elements play a role in the product's technology acceptance with consumer well-being and comfort being an important one. As technology advanced in the last years and decades, passengers have grown accustomed to a high level of comfort. In addition to seating layout and available space, the impact of noise is the foremost factor when assessing comfort. According to research outlined in [4], the sound pressure levels inside the aircraft cabin are directly linked with passenger satisfaction with an increase from 55 dB to 65 dB dropping passenger satisfaction substantially from slightly over 80 % to just around 60 %.
To effectively reduce CO_2 emissions with novel aircraft concepts and bring them to operation as soon as possible, ensuring a certain level of passenger comfort cannot be omitted. Consequently, it becomes crucial to integrate acoustic noise evaluation into the design process of novel aircraft as early as possible, enabling estimations and optimizations of cabin sound pressure levels to be made.

It is important to note that other early design considerations such as operating costs and energy efficiency undoubtedly hold more weight. Nevertheless, cabin acoustics should not be neglected during the initial design stages and its evaluation tools need to be developed to be as efficient as possible in order to be able to be included in the early development process without taking up large amounts of resources. Given the expense associated with building prototypes for actual cabin noise experiments, the primary focus is set on simulative cabin noise assessment. This approach allows for early estimations and the incorporation of design adaptations into the computational model.

This contribution presents an approach for perceptual assessment of simulative predictions. It aims to evaluate cabin noise as closely related to the eventual passenger experience as possible by auralizing simulation results, which enables a subsequent psychoacoustic assessment. The outline of the paper is as follows: First, the use case – a Finite-Element-Method (FEM) simulation of a large-scale vibroacoustic model of the SE^{2}A-cluster's short range configuration – is summarized in Section 2. Section 3 details the auralization methodology and adds ideas for enhancing the realism of the resulting signals. A first attempt at validation of the methodology is performed for a related reference case – a car cabin – and the method is consequently applied to the use case in Section 4. Finally, a conclusion and future ideas are presented in Section 5.

2. AIRCRAFT CABIN NOISE PREDICTION

As mentioned in the introduction, the overall goal of this contribution is auralization for psychoacoustic assessment in an early design process. Since no real prototypes have been built at that stage, it is necessary to work with numerical methods that yield the sound pressure level inside the aircraft cabin. In this contribution the FEM is used for these simulations. The wave-resolving nature of the FEM allows us to obtain the sound pressure level at any given point in the cabin. Furthermore, the FEM is conducted in the frequency domain to yield information about eigenfrequencies and frequency response functions of the system. However, in order to compute any results, a vibroacoustic model has to be built beforehand. As stated in the introduction, three novel aircraft technologies have been developed within the scope of the SE^{2}A-Cluster of Excellence [3], with the short range configuration being used as the subject of this contribution in order to establish and test our workflows (see Fig. 1).

This configuration is based on the ATR-72. The early design schematic and the CPACS data serve as input for the vibroacoustic model [5]. However, since aircraft models usually entail a substantial amount of computational effort, a few aspects have to be adjusted. For a first sound pressure assessment chain, only a cabin segment of 5 seating rows is chosen and since the examined frequency domain directly influences the numerical system's size, the model is evaluated for frequencies up to 1000 Hz. The vibroacoustic model entails four major domains that are vital for the sound transmission from the excited outer skin to the cabin volume. Those domains are the airframe, which includes the stiffener structures and the cabin floor, the insulation, the interior trim, as well as the cabin volume itself. Details of the model can be found in [6] and [7]. Fig. 2 shows the meshed model where the different domains are indicated by different colors.

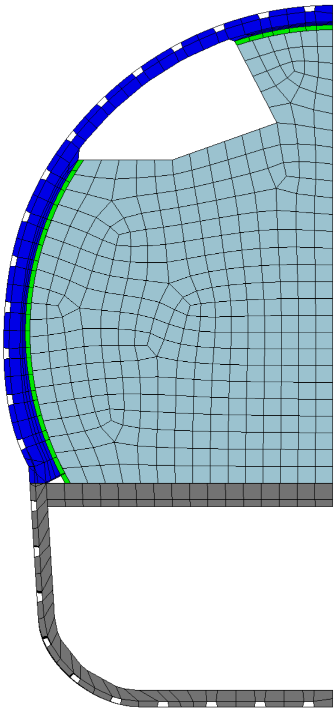

FIG 2. Meshed cross section of the vibroacoustic model.

It should be mentioned here that the displayed model already leads to matrices with a size of approx. one million by one million, meaning that efficient solving strategies become inevitable. Our institute's in-house FEM code 'elPaSo' (elementary Parallel Solver) was created for efficient large-scale vibroacoustic computations [8], [9]. With elpPaSo it is possible to evaluate the model in the given frequency range with a computational time of about three hours, which is feasible for an early design stage where parameter and design changes can still happen.

Furthermore, to complete the model, an excitation is needed that is transmitted into the interior of the aircraft. In previous publications, the aeroacoustic to vibroacoustic simulation chain has been established [10] and the authors have shown how to include several realistic loads in the cabin noise simulation [11]. The excitations examined here are the pressure fluctuations on the aircraft's outer skin due to a turbulent boundary layer excitation as well as the propeller excitation. These noise sources are dominant in the low frequency range up to 1000 Hz which supports the fact that the computations are only conducted up to 1000 Hz.
Still, computations up to 1000 Hz improve the standard, since FEM aircraft segment computations are only conducted in a lower frequency regime. Up until recently, only single parts of an aircraft wall and tubes have been simulated ([12], [13]), rarely a whole segment with the four domains identified here. In recent years the German Aerospace Center DLR has made advances in automated modeling and evaluation of aircraft cabin noise with a fuselage geometry assembler based on engineering knowledge [14]. This means that the model used in this contribution can compete with today's simulation standards.

The strength of the built model is that uncertainties as well as design and parameter changes can be examined in early development with regard to changing sound pressure levels (SPL) inside the aircraft cabin – all the while keeping the computational cost feasible. From this point on, the goal of this contribution is to extend the cabin noise assessment by auralizing the computed system responses and conducting a psychoacoustic analysis. This way, a holistic acoustic design approach is achieved.

3. AURALIZATION METHODOLOGY

Being able to conduct psychoacoustic assessments of aircraft cabin scenarios with listening tests requires audible data. Auralization is an overarching term used for numerous techniques that enable creating audio files for different scenarios. To name a few examples, applications can be found in room acoustics or binaural rendering [15], where convolving a source signal with impulse responses imparts the system behaviour on the source signal, therefore making it appear to be reverberant or binaural respectively. Regarding auralization in the context of transportation and its environmental noise impact, pass-by noise of cars with a special focus on tyre-road and engine noise is a subject in [16] or [17], while important aspects of flyover noise of aircraft such as weather-dependant effects have been auralized in [18] or [19]. Publications focusing on interior noise are e.g. comparisons of different car audio systems in [20] or auralizations of vehicle interior tire-road noise in [21].
Most auralization techniques share the approach of convolving a source signal – recorded or synthesized – with impulse responses describing the acoustic propagation path – atmospheric or inside a cabin – to a receiver point. A similar auralization approach has been presented by the authors in [22], using convolution of plates' impulse responses with different excitation signals to create basic vibroacoustic scenarios.

This contribution's auralization concept aims to auralize an aircraft's interior noise based on wave-resolving cabin noise simulations that already include realistic excitation and acoustic propagation to a receiver point. Therefore, the auralization should preserve the simulation's spectral properties as closely as possible while creating an authentic listening experience appropriate for listening tests.
This section details the main auralization approach which has been implemented using Python code. An aircraft cabin's frequency response function at a receiver point, which is computed with the simulation

setup described in the previous section – or any comparable system's frequency response function for that matter – is considered as the main input.

3.1. Signal processing

The first step of auralizing the given data is transforming the system's response into the time domain. This can be achieved by simply performing an inverse Fourier transform. Before doing so, however, the input has to be prepared accordingly: Assuming the input data is a single-sided amplitude spectrum, as is the case here, it needs to be multiplied by the number of samples and halved, so that half of the energy can be appended as a complex conjugate to restore the negative-frequency side. After these steps, the inverse Fourier transform yields the time signal representing the system's response. Because the inverse Fourier transform can be considered to be equivalent with a simple superposition of the included harmonic signals, one could alternatively do just that. In that case, however, the frequency components added to the final signal should have an equidistant frequency step df and the signal length t_{max} should be exactly equal to the reciprocal value of that frequency step. Otherwise, the resulting signal will not represent a meaningful transformation but rather a looping assortment of incoherent frequency components.

Since the transformed signal response is now a time signal, it could technically be listened to, though it will typically be too short to create a reasonable listening experience. As mentioned above, the signal length t_{max} depends on the frequency resolution which in turn is directly linked to the computational effort of the preceding simulation. In this contribution's example case, a frequency step of 2 Hz – already resulting in a considerable computational effort – only yields 0.5 s of signal.
One way to extend the signal is to simply loop the system response or equivalently not cap the signal length when adding harmonic signals. The resulting signal, however, is audibly periodic and sounds quite artificial which is an issue when trying to create an authentic or even immersive auralization. This issue is clearly visible in Fig. 3, in which case an exemplary system response of 0.5 s length has been looped ten times for a total signal length of 5 s.
Therefore, an auralization approach using convolution with white noise is utilized. For this, a white noise signal $w(t)$ is generated and consequently used to calculate a discrete convolution with the system response signal $s(t)$ resulting in an auralized signal $a(t)$ of any desired length, since the white noise length can be chosen freely:

$$a(t) = w(t) * s(t) = \sum_{\tau=0}^{t_{\text{max}}} w(\tau)s(t-\tau).$$

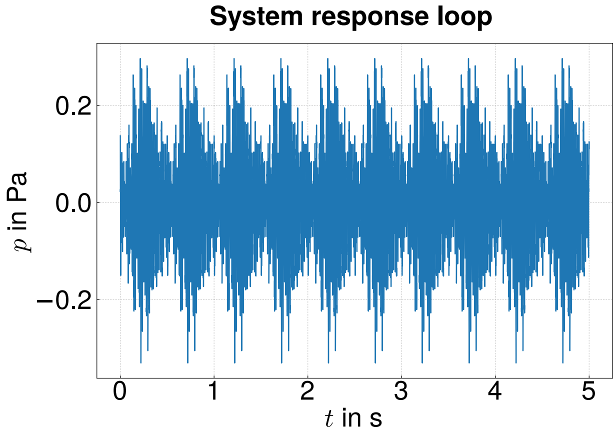

FIG 3. Extending the signal length of an exemplary system's response by looping it ten times results in a visibly and audibly periodic signal.

The main advantage of white noise is that it has constant frequency components. Considering the equivalent of convolving time signals is a multiplication of their frequency spectra, the spectral shape of the system response is thus preserved in the auralization. An example of this displayed in power spectral densities (PSD) can be seen in Fig. 4. Due to the higher signal length, the convolution exhibits a higher frequency resolution than the system response, yet the spectral shape is still preserved. On a side note, the convolution's SPL can also be chosen freely by scaling the white noise accordingly. This makes either matching the simulation's SPL or changing it to other specifications possible.
When convolving source signals with a system's impulse response, which can represent acoustic propagation behaviour for example, the impulse response imparts the system's behaviour on the source signal, e.g. making it appear to be reverberant. The corresponding interpretation for the present case, which contains complex excitation by pressure fluctuations along the fuselage, changes due to it not being an actual impulse response. A possible interpretation would be that the auralization exhibits a stochastic (due to white noise) excitation by one specific pressure distribution – which is not the same as the stochastic behaviour of e.g. a turbulent boundary layer and therefore not necessarily a physically correct representation of realistic cabin noise. However, as a working hypothesis, a white noise auralization of cabin noise should yield a perceptually and potentially even physically representative listening experience compared to the realistic scenario due to having the same spectral shape and exhibiting the same sound quality of incoherent broadband noise. A first validation case is shown in Section 4, in which this procedure was applied to recorded car cabin noise.

3.2. Enhancing realism

With performing listening tests in mind, in which assessing passenger comfort is ultimately the goal, two approaches might be considered. The first approach

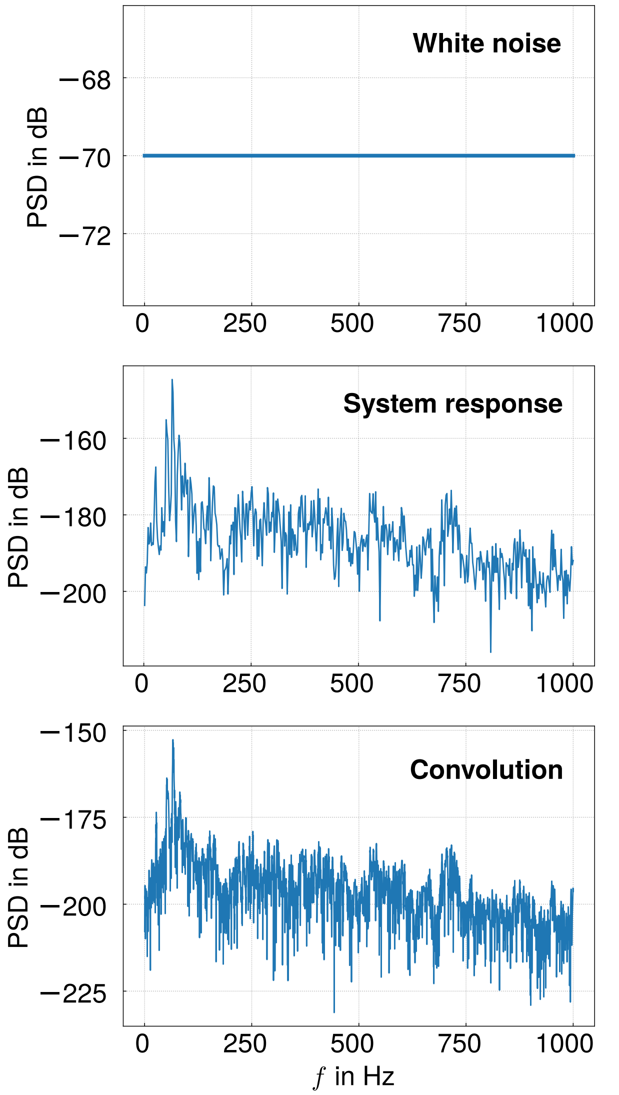

FIG 4. PSDs of ideal white noise at the top, an exemplary system response in the center and their convolution at the bottom.

would be to focus on the sound quality of the limited bandwidth that can be accurately predicted, ideally in a non-reverberant listening facility. This way, utilizing the auralizations of FEM simulations as described above, individual 'components' of a realistic scenario could be evaluated precisely without excess information.

The other approach, which this section focuses on, would be creating a test setting that should be as immersive as possible. Besides including an authentic environment to seat test subjects in, the listening experience itself needs to be believable. In this regard, the current auralizations of FEM simulations as described above lack two key features to be considered truly authentic: high frequency content and familiar sound characteristics of the environment.

To target high frequency content while maintaining the stance to solely rely on numerical predictions, the efficiency of using FEM simulations on large-scale vibroacoustic models can be further developed in order to reduce computational cost and push the feasible maximum frequency to higher ranges – which is actively pursued be the authors but not subject of this contribution. Otherwise, numerical methods other than the FEM that are able to predict high frequency content would have to be applied. In addition to more modelling and computational cost, this would possibly require further auralization methods as well. Taking statistical energy analysis as an example, which is typically used for high frequencies, the method computes energies in frequency bands – those bands would have to be converted to a corresponding assortment of frequency components before used for auralization.

Another way to introduce a higher frequency range into an auralization is to rely on recorded data. Since flying prototypes of novel aircraft typically do not exist in early development stages, cabin noise recordings of similar scenarios regarding aircraft type, propulsion, materials, flight scenario etc. can be added as a high-pass-filtered addition to the spectrum. While this can immensely improve immersion and familiarity with the noise, special care has to be taken that the added content does not overshadow the actual sound variations that need to be assessed in listening tests. Additionally, if psychoacoustic metrics such as sharpness are calculated, which are heavily dominated by high frequency content, they would be impacted by the chosen recording as well.

Targeting sound characteristics of familiar environments, two main ideas come to mind: First, there is a difference between artificial noise, such as white noise, and realistic noise which is based on stochastic physical processes. The auditory impression of noise caused by the convolution with artificial noise could be improved upon. Secondly, elements of the scenario's soundscape such as quiet rustling of neighbouring passengers or background chatter might be added to increase the familiarity with the situation.

For both these ideas, recordings are the way to proceed. Instead of completely adding recorded data as described for higher frequencies, only exchanging the existing phase content of the auralization in the frequency domain with the phase content of a recording is recommended. The phase content of a time signal affects the superposition of its frequency components and therefore entails auditory characteristics or events. Since the phase content of artificial noise is completely random, it doesn't hold any specific information. The phase content of recorded data, however, can include both, the sound characteristics of realistic noise as well as auditory events coming from neighboring passengers. Again, caution is required for the additions to not overshadow the targeted sound variations.

4. RESULTS

After the previous two sections detailed an example of cabin noise predictions as well as the auralization methodology, this section aims to link these two

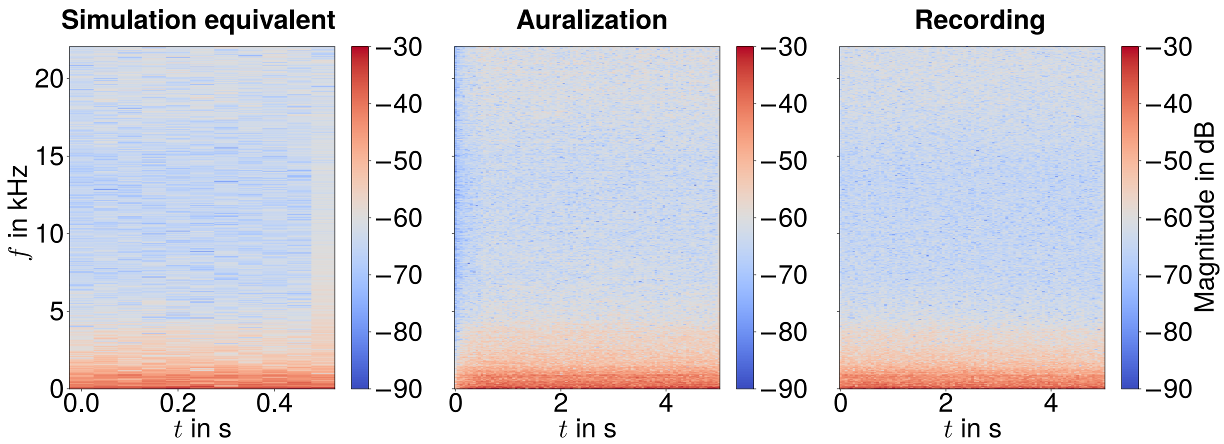

FIG 5. Relevant spectrograms of the car cabin validation case.

aspects together. The following results begin with a first attempt at a validation case of the auralization methodology and conclude with an exemplary application to aircraft cabin noise.

4.1. Validation case: car cabin noise

An ideal validation of the proposed auralization method in connection to aircraft cabin noise would have to entail a flying prototype of an aircraft with an existing numerical model or setting up a numerical model of an already existing aircraft. Since data for both of these cases is difficult to obtain, a more easily accessible validation case has been chosen: as a first approach, the auralization method itself is focused on and validated for a vibroacoustic scenario, that encompasses similar characteristics as aircraft cabin noise. For this, car cabin noise has been chosen because it shares broadband noise properties caused by turbulent pressure fluctuations.

For the reference measurement inside a car cabin, a SEAT Ibiza IV representing a standard compact car with a straight-three engine was equipped with a Norsonic class 1 microphone, which was mounted to the side of the passenger seat's headrest. The measurement of the reference signal used in this validation case was taken while driving 140 km/h on the Autobahn at night with little traffic, no notable weather or road conditions and the car's air-conditioning turned off. At this velocity, aerodynamic noise sources dominate most of the frequency spectrum with engine and tyre noise having some influence around 1–2 kHz and below 100 Hz [23]. To emphasize the cabin noise coming mostly from turbulent pressure fluctuations, the reference signal was measured for a duration of 5 s with the gear in neutral position, so that engine noise was no longer noticeable. During this time, the velocity decreased slightly due to the drive power missing – this is, however, not actually audible in the measurement. The spectrogram of this measurement is visible in Fig. 5 on the right-hand side.

With the reference signal available, an auralization needs to be created with white noise in order to compare the two signals. Instead of modelling the cabin analogously to this contribution's aircraft cabin predictions, which would have introduced numerous modelling approximations, a simulation equivalent is taken directly from the reference signal. Since the aircraft simulation example yields a frequency discretization of 2 Hz, the car simulation equivalent is created by using 0,5 s of the reference signal, which then matches the simulation's frequency resolution and represents a highly accurate cabin simulation. Any major audible deviations the auralization should have compared to the reference signal are now solely due to the auralization procedure, not the input.

The simulation equivalent is treated as the system's response and auralized with white noise as detailed in Section 3. The auralization length is set to 5 s to match the recording length.

The result of this validation case is displayed in Fig. 5 in spectograms with the simulation equivalent on the left-hand side, the auralization in the center and the recording on the right. The spectrograms have been created using the short-time Fourier transform (STFT) and display frequency spectra of short 0.1 s long, half-overlapping time windows with the magnitude color-mapped. The full frequency range is displayed from zero to 22.05 kHz, which is the Nyquist frequency of the recording's sampling rate of 44.1 kHz.

Starting with the recording, the quasi-stationary quality of this cabin noise scenario is quite apparent with individual frequency components fluctuating slightly over time but the overall image remaining in clear horizontal shapes. Also recognizable is the spectral composition of turbulent noise with most of the energy contained in the lower frequencies – though also including tyre noise – and decreasing energy content towards higher frequencies. The same observations can be made for the simulation equivalent on the left-hand side since the 0.5 s of signal are essentially a zoomed-in view of the recording.

More interesting is the step from this simulation equivalent to the auralization in the center, being the only two signals present in an actual application case, in which a reference signal does not exist. A ramping effect can be observed in the first half second of the

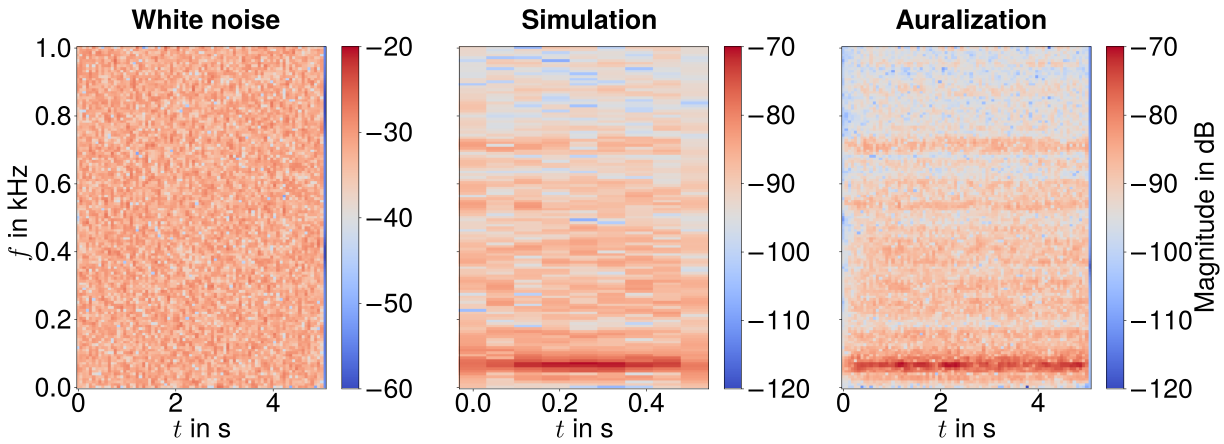

FIG 6. Relevant spectrograms of the aircraft cabin auralization.

auralization's spectrogram, which originates from the convolution procedure, but can be easily cut away and is therefore not an issue. Comparing the two spectrograms now, the quasi-stationary shades of color are preserved in the auralization, which was expected due to the constant frequency values of white noise. Special note should be taken of the fluctuations with slightly darker red tones at the the bottom and the fluctuations with pale orange tones scattered throughout the spectrum but amassing at the top in the high frequency range. Both these fluctuations are found in both spectrograms.

Finally, the validating observations lie in comparing the auralization to the reference signal. At first glance, the spectrograms look very similar qualitatively. Especially the defining two points described in the recording – the horizontal, slightly fluctuating shapes and the turbulent energy distribution – were able to be reproduced in the auralization. However, the noted fluctuations of darker red tones at the bottom and pale orange at the top, that are found in the auralization and originated from the simulation equivalent, are not as prominently found in the recording. This is an important observation for white noise auralization: the convolution with white noise will preserve the spectral shape of the system input and turn it into a quasi-stationary signal, even if the input included an instationary occurrence such as a gust of wind. Considering the actual application case of numerical simulations of stationary systems though, this should not be an issue there.

To conclude the validation case with the subjective assessment of the authors, the listening experience when comparing the auralization to the reference can indeed be described as similar, making this contribution's auralization methodology appear valid for broadband noise applications. The slightly more prominent fluctuations don't take away from the auralization's authenticity.

It should be emphasized once more that the presented validation is obviously a first attempt with only qualitative statements being made. A quantitative validation of the methodology can be expected with listening test evaluations and comparisons to psychoacoustic metrics in the future – see the outlook in Section 5.

4.2. Aircraft cabin noise

Now that the auralization method has been established and its applicability demonstrated for car cabin noise, it is applied to the aircraft cabin noise prediction that was detailed in Section 2. The results are displayed in Fig. 6 with spectrograms of the corresponding time signals, created with STFTs with 0.1 s half-overlapping windows again. The frequencies range from zero to 1 kHz according to the FEM simulation.

Starting on the left side, a spectrogram of white noise is shown in order to display the scale of the random fluctuations being imparted in the convolution and to emphasize the quasi-stationary constant values of white noise across the entire frequency spectrum.

The center of the figure shows the spectrogram of the 0.5 s simulated signal. The signal can be characterized by a prominent peak around 100 Hz, a few smaller peaks around 600–700 Hz and overall quasi-stationary behaviour including slight fluctuations in all frequencies.

Finally, turning to the auralization on the right side and comparing it to the simulation, a broadband noise signal has been created while preserving the defining characteristics of the simulation. The aforementioned peaks are clearly visible and the quasi-stationary, noisy behaviour of the white noise is imparted by definition.

Since there is no reference for this case, the realistic accuracy of the created auralization is difficult to assess on its own. Judging by the validation case, major deviations from realistic stationary cabin noise should stem mostly from modelling assumptions, material inaccuracies etc. – in this way, the auralization method might be used to identify such inaccuracies, given an appropriate reference measurement. Furthermore, concerning realism of this scenario, the auralization only includes frequencies up to 1000 Hz and therefore sounds quite dull or muffled, like any low-pass filtered signal would. This was mentioned in

Section 3: This signal might be used for listening tests in non-reverberant listening facilities along with e.g. auralizations of parameter variations to truly focus on this specific frequency range.
When aiming for immersive listening tests, however, the realism of this auralization can be improved. As a first test, the proposed additions to the signal's frequency range and phase content have been performed in an exemplary way. For this, a simple recording taken from a commercial flight including noise from the cabin's ventilation system as well as other passengers rustling in the background. The connection of the auralization and the cabin recording can be seen in the PSD diagram in Fig. 7. The actual added frequency content goes up to 22.05 kHz.

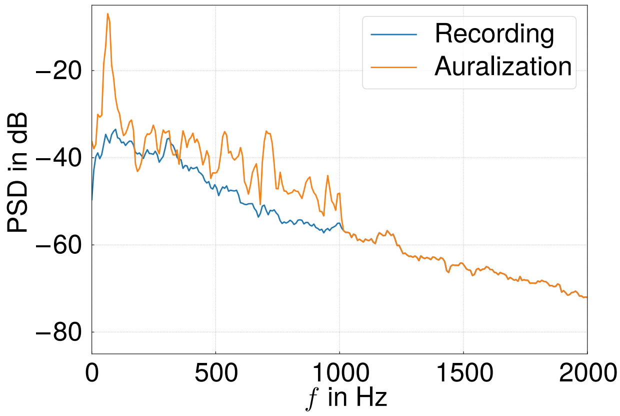

FIG 7. Averaged PSD of an aircraft cabin recording and an aircraft cabin auralization with added high frequency content of the recording.

Based on the subjective assessment of the authors, the listening experience of the enhanced auralization added a significant amount of realism to the scenario while not significantly overshadowing the lower frequencies.

5. CONCLUSION AND OUTLOOK

Aircraft cabin noise is an important issue regarding passenger comfort and product acceptance, which is why early prediction and optimisation capabilities need to be established and applied in preliminary design stages.
In this contribution, an auralization methodology was proposed which enables turning a system's frequency response function into a stationary stochastic broadband signal of any desired length by convolving the system response with white noise. In a first promising validation approach, the methodology was applied to a car cabin measurement and its simulation equivalent. The resulting auralization shared the defining signal characteristics with the reference and the listening experience was subjectively authentic.
After being deemed appropriate for broadband noise signals, the method was applied to an aircraft cabin simulation and was able to produce an auralization which preserved the spectral characteristics of the simulation. Additional steps to improve the auralization's realism were proposed – supplementing the signal's high frequency range with corresponding recordings or applying a recording's phase content to the auralized signal – and applied in an exemplary way.

Having access to audio samples of early development results now calls for listening tests to be conducted. In the future, ensembles of auralizations will be created focusing on the two following aspects:

- Cabin noise predictions in early development come with uncertain parameters that each influence cabin noise in different ways. Therefore, design parameter variations within the scope of their respective uncertainties and whether these variations are audible will be investigated.
- Using the most sensitive parameter variations as a baseline, the question of whether the proposed realism enhancements of auralizations influence the test subjects' evaluations significantly or not needs to be investigated.

Additionally, listening tests will be conducted in a non-reverberant listening facility as well as in an authentic aircraft cabin section in order to investigate the influence of the listening environment.

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