DOI: 10.61782/fa.2025.0693

FORUM ACUSTICUM EURONOISE 2025

PREDICTION OF ENVIRONMENTAL NOISE FROM ROTORCRAFT USING A NOISE HEMISPHERE WITH TIME-DOMAIN DATA

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ABSTRACT

Recently, demand of UAM has been increasing because of the high versatility. However, there are several technical issues that makes the public acceptance about the UAM operation. One of the major issues is the environmental noise problem. The environmental noise should be quantified for the noise regulations issued by FAA or EASA.
Measurements of the noise in the urban areas would be the most reliable way for the quantification. However, it is impossible on the current step that any UAM vehicles have not got certification from FAA or EASA. Alternatively, numerical methods efficient for the environmental noise prediction could be used
In this study, we use an environmental noise prediction method based on noise hemisphere database (NHD). The NHD for a UAM vehicle is generated with using noise measurement data, which were obtained from flight tests conducted in K-UAM Grand Challenge. The noise propagation in an urban area is simulated to predict the noise data in the area. Then, the noise data is analyzed to estimate whether the noise satisfy the public acceptance in the urban area.

Keywords: *environmental noise, rotorcraft, noise hemisphere method, auralization*

1. INTRODUCTION

Environmental noise refers to sounds people hear in everyday environments, such as vehicle noise, mechanical noise, and conversational noise. Aircraft noise can also be classified as environmental noise, especially when sounds from aircraft operations like take-offs and landings impact daily life. Such environmental noise significantly affects public acceptance of aircraft. Indeed, the limited frequency of helicopter flights in urban areas can be attributed to their low public acceptance, resulting in frequent complaints.
This public acceptance issue is expected to become even more critical with the advent of Advanced Air Mobility (AAM). When dozens of small Unmanned Aerial Systems (sUAS) and Urban Air Mobility (UAM) vehicles fly within urban environments, citizens exposed to unfamiliar environmental noises may experience discomfort. This discomfort could ultimately undermine public trust in aviation systems, becoming a barrier to related industrial advancements.
Psychoacoustics quantitatively analyzes the psychological discomfort caused by audible noise. Although still relatively unfamiliar in the aviation field, psychoacoustics is essential for enhancing public acceptance of the upcoming AAM era. This analysis requires the subjective evaluation of listeners after auralizing the aircraft-generated noise. For accurate auralization, time-domain data is required instead of the frequency-domain data typically used in many aircraft noise studies.
Environmental noise can be analyzed through direct measurements from flight tests or predictive methods using

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analytical approaches. The noise hemisphere method is commonly used, storing aircraft noise data on a hemispherical surface to rapidly predict environmental noise by substituting the aircraft noise source with this hemisphere. However, existing noise hemisphere methods typically propagate sound in the frequency domain, complicating accurate auralization (1,2).

Considering these limitations, this study improved the existing environmental noise prediction code, enabling the creation of a noise hemisphere through noise back-propagation and facilitating noise predictions at specific locations in the time domain. The analysis primarily focused on noise back-propagation data.

2. NUMERICAL METHODS

2.1 Noise back-propagation and auralization

Microphones measure acoustic pressure in the time domain. Thus, noise back-propagation from microphone data to the hemisphere surface is performed for each time instance as described by Eqn. (1).

$$p'_{spr} = p'_{mic.} \times \frac{r_0}{r_s} \tag{1}$$

Here, the subscript denotes information on the hemisphere surface, represents information at the microphone, is the distance from the microphone to the hemisphere center, and is the radius of the hemisphere. This back-propagation is conducted for all measured time instances. The back-propagated noise data on the hemisphere surface does not initially account for physical phenomena such as atmospheric absorption and ground effects. To model these phenomena, previously proposed methods operate in the frequency domain. Therefore, back-propagated noise data is converted into narrow-band (NB) frequency-domain data using the Short Time Fourier Transform (STFT). Each modeling method then adjusts the amplitude of NB frequency-domain data for hemisphere construction.

2.2 Auralization through Grifin-Lim algorithm

Noise data converted to NB frequency-domain form via STFT can be returned to time-domain data using the Inverse STFT (ISTFT). However, the phase angle information of this reconstructed data often lacks accuracy. To resolve this, the Griffin-Lim Algorithm (GLA) is employed to reconstruct the phase angle using only the continuous amplitude of NB frequency-domain data. Figure 1 illustrates differences between original sounds restored with and without applying

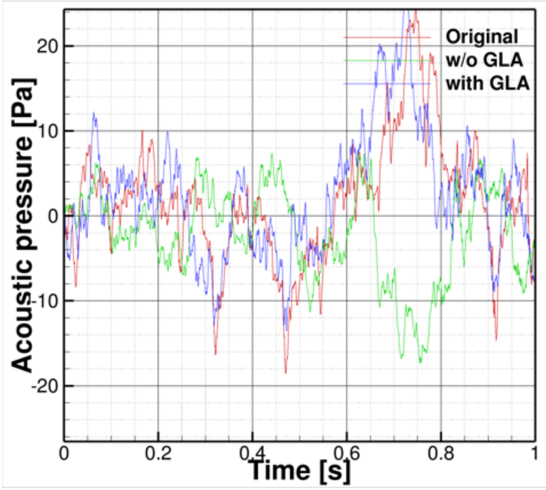


Figure 1. Comparison of restored time-domain data with and without GLA

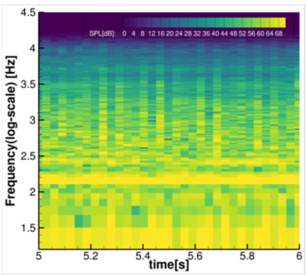
GLA. Although the reconstructed sound slightly differs from the original, GLA prevents critical errors like inverse phase reproduction. Sample points used for noise hemisphere construction are finalized through GLA.

2.3 Noise hemisphere generation using a surrogate model

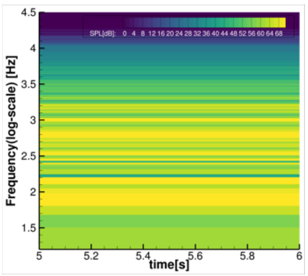
Traditional noise hemisphere methods utilize grid-based data structures, storing noise data at grid centers or points. Interpolation with pre-generated noise samples often leads to unrealistic sound data due to insufficient grid resolution in time-domain noise prediction and auralization. To overcome this, the current study implements Kriging surrogate models for hemisphere generation, deriving noise information at various radiation angles required by the noise propagation algorithm. Figure 2 shows spectrograms comparing grid-based hemispheres and surrogate model-based hemispheres with the original sound. The surrogate model achieves more accurate restoration similar to the original, unlike the grid-based method, even at high grid resolutions

3. CONCLUSION

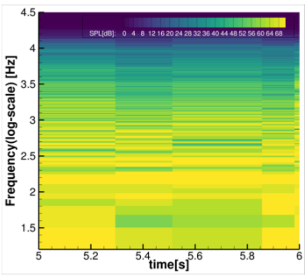
This study proposes a method to enable auralization in environmental noise prediction from rotorcraft by transitioning noise hemisphere techniques from frequency-domain to time-domain data. Implementing the Griffin-Lim Algorithm and surrogate models significantly improves the accuracy of sound reconstruction, closely matching original



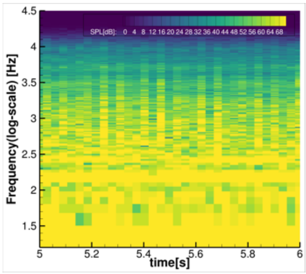
(a) Original data



(b) Data using a noise hemisphere with 5° resolution



(c) Data using a noise hemisphere with 1° resolution



(d) Data using a surrogate model

Figure 2. Comparison of spectrogram for noise source data

sounds. Future research will utilize the developed time-domain noise hemispheres for noise propagation and auralization studies in both open and urban areas.

4. ACKNOWLEDGMENTS

This work is supported by the Korea Agency for Infrastructure Technology Advancement(KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant RS-2024-00444205).

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