ANN Wall-Pressure Spectrum Prediction on Iced Airfoils

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Predicting airframe noise in real-world conditions remains a challenging engineering problem, particularly when surface contamination such as ice accretion is present. While wall-pressure fluctuations beneath turbulent boundary layers are the main drivers of broadband trailing-edge noise, existing semi-empirical models are often limited to specific flow conditions and struggle in more complex regimes, especially under adverse pressure gradients or modified geometries. Recently, data-driven approaches have shown strong potential to overcome these limitations.

The present work extends this ANN-based framework toward predicting far-field noise from iced airfoils. The methodology follows a two-step approach. First, a boundary-layer autoencoder compresses the velocity profile into a low-dimensional latent space, capturing the key features of the flow. It has been shown that as few as three latent variables are sufficient to represent the boundary layer across different regimes, including laminar separation bubbles and varying pressure gradients. Second, a separate ANN uses this latent space along with flow conditions as an input to predict the wall-pressure spectra.

The framework is applied to iced airfoil configurations, including both rime and glaze ice cases. The ANN is trained exclusively on clean airfoil data from a database of previous DNS and LES across a wide range of flow conditions. The iced configurations are then evaluated in a predictive capacity, without retraining the model. Compared to the clean case, ice introduces localized flow disturbances such as early separation, shear-layer instabilities, and modified transition behavior. The predicted wall-pressure spectra are then coupled with an analycial model to estimate far-field noise, forming a complete data-driven pipeline from near-wall flow physics to radiated sound.

In summary, this work shows that combining machine learning based WPS prediction with acoustic analogies provides an efficient and robust alternative to high-fidelity simulations for aeroacoustic analysis. The approach shows potential for applications such as aircraft icing, wind turbines, and other configurations where boundary-layer-driven noise plays a key role.

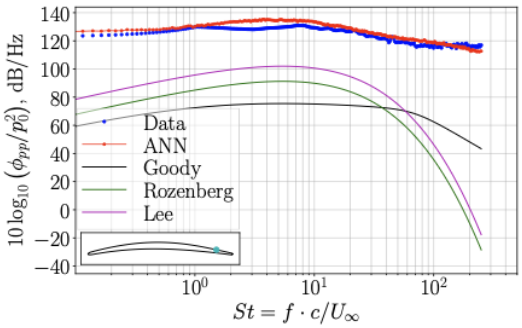

Figure 1: Wall-pressure spectrum prediction and comparisons with empirical models for a probe at $x/c = 0.95$, unseen during training.

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