ASSESSMENT OF MACHINE LEARNING METHODS FOR THE PREDICTION OF AIRCRAFT BUFFET LOADS

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ABSTRACT

The accurate prediction of buffet loads and sound emission generated by unsteady pressure on lifting surfaces remains a major bottleneck in modern aircraft design. Conventional high-fidelity tools such as large-eddy simulation (LES) are computationally prohibitive for early-stage design and optimization, while existing reduced-order models (ROMs), based on empirical correlations and analytical considerations, often fail to preserve the spatial and temporal coherence required for reliable sound and vibration source estimation. In this study we address the question whether a data-driven machine-learning surrogate can reproduce the full spatio-temporal statistics of the unsteady pressure field over a lifting surface.

To answer this question, we implemented a machine learning model (Zahn, Weiner, & Breitsamter, 2023) which was originally applied to the prediction of the pressure field on the surface of a wing in a flow condition dominated by a lambda shock. In this work, the model is applied to a subsonic and fully turbulent test case dominated by vorticity. The reference geometry is the Aeroelastic Wind Tunnel Model (AWTM) developed jointly by the Technical University of Munich and Airbus DS, see (Katzenmeier L. , 2025), which features a delta wing and a horizontal tail plane. A training database of wing wall-pressure snapshots was produced by simulating the flow around the AWTM with the Lattice-Boltzmann Method (LBM) solver ProLB at Mach 0.15, Reynolds 3.6 M and various angles of attack. The quality of the LBM simulation was assessed by comparing the pressure field with the corresponding Pressure-Sensitive Paint (PSP) measurements (Katzenmeier, Hilfer, Stegmuller, & Breitsamter, 2023). The machine-learning model consists of two modules: a convolution-based autoencoder (AE) and a long short-term memory (LSTM) recurrent neural network. The AE is in its turn made up of two modules: an encoder and a decoder. The encoder transforms a snapshot of wall pressure into a latent vector of a given length, the decoder transforms the latent vector back to the pressure field. The LSTM learns the time dependency of the latent vectors: given an input sequence of 128 time steps, it outputs the following 128 time steps, which are processed by the decoder unit to obtain the predicted pressure field. The process is repeated iteratively until reaching a signal length sufficient to calculate wall-pressure single-point and cross power spectral density. The choice of the loss function for the training of the neural network is a critical factor that is discussed in this work.

In summary, we have shown that an autoencoder-recurrent neural network can produce a physically accurate unsteady pressure field over a lifting surface, preserving both point-wise statistics and broadband spectral content at a computational cost that is several orders of magnitude lower than high-fidelity CFD. This capability enables rapid evaluation of buffet loads and acoustic source strength early in the aircraft design process, allowing for multi-fidelity optimization driven by evolutionary algorithms. The methodology is inherently modular: the encoder-decoder pair can be retrained for alternative geometries (e.g., tail planes, nacelle), while the recurrent core can be replaced by more advanced physics-informed

neural operators, graph neural networks or transformers in order to achieve a broader generalization. In fact, the main limitation of this approach is that the surrogate model is limited to the range of flow conditions represented in the training set. However, this study is a step towards building an accurate and robust framework for the fast prediction of buffet loads and acoustic sources.

References

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