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Application of Aerodynamic Surrogate Models in Actual Development

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Reducing CO_2 emissions is critical as aerodynamic drag accounts for 30% of EV energy loss. While shorter development cycles (1–1.5 years) demand rapid design decisions, high-fidelity CFD remains a bottleneck due to its long computation time. Existing 1D surrogate models only predict scalar values like C_D, failing to provide specific geometric guidance. This study developed an aerodynamic surrogate model for early-stage design that simultaneously predicts C_D values and 3D flow fields (pressure/velocity). By utilizing "Local Drag", the model enables concrete design directions and bridges the gap between rapid AI prediction and practical engineering workflows.

The proposed surrogate model employs a CNN-based Encoder-Decoder architecture. To ensure physical consistency, a Multi-Layer Perceptron (MLP) is integrated at the bottleneck to share geometric features between C_D and flow field predictions. A U-Net structure with skip connections was adopted to capture detailed geometries and complex flow structures, utilizing the Gaussian Error Linear Unit (GELU) activation function for smoother output. For enhanced geometry representation, input data includes normal vectors, curvature, and coordinates aside the Signed Distance Function (SDF). The 292-case dataset was split into 220 for training, 40 for validation, and 32 for testing. Model accuracy was evaluated via "Local drag" analysis, which decomposes drag into total pressure loss, recirculation, and crossflow to validate flow structures.

The proposed and conventional models were compared by calculating the C_D equivalent values of "Local drag" at a cross-section 650 mm behind the vehicle rear end. Compared to the CFD results, the proposed model predicted the total pressure loss and velocity deficit terms within approximately $\pm 5\%$ accuracy, achieving a coefficient of determination $R^2 > 0.90$. Specifically, for the total pressure loss term, the Mean Absolute Error (MAE) was significantly improved from 6.8% in the conventional model to 1.0% in the proposed model.Visualization confirmed that the proposed model provides better alignment with CFD results regarding recirculation and vortex drag components in the wake. Furthermore, the C_D values for most vehicle shapes were predicted within $\pm 5\%$ of the CFD results. The proposed model simultaneously predicts C_D values and flow fields with the accuracy required for early-stage vehicle development. This capability allows for the clear identification of necessary geometric modifications and improvement points, enabling more efficient aerodynamic optimization.

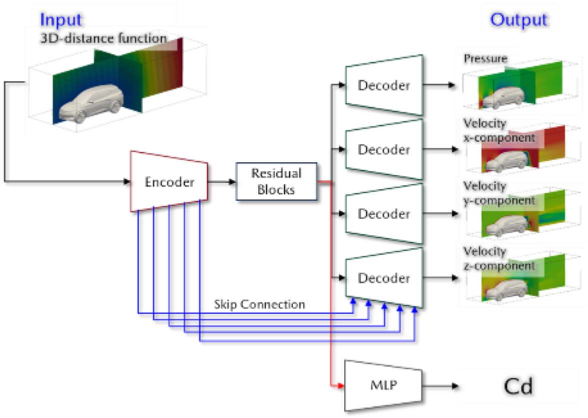

Fig.1 Proposed model structure

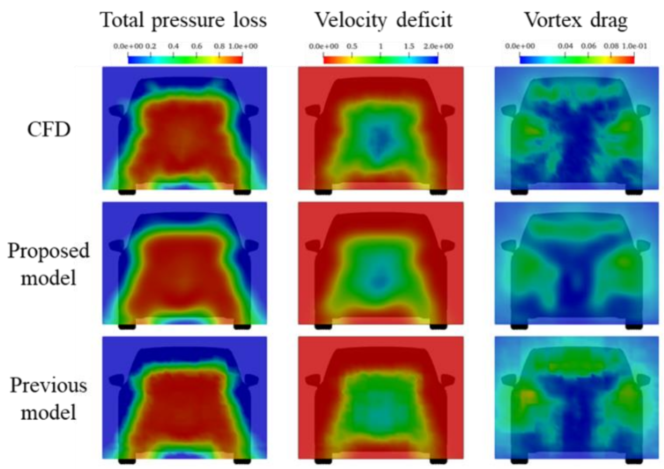

Fig.2 Local drag prediction