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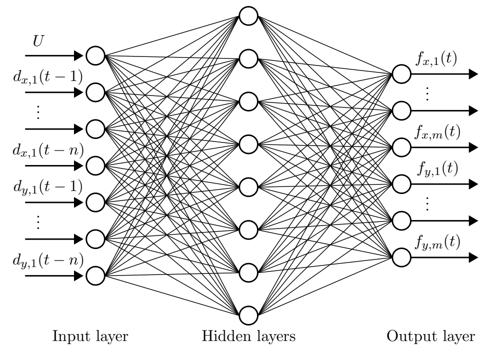
Advanced coupled numerical models for aeroelastic interactions of thin-walled structures

Abstract

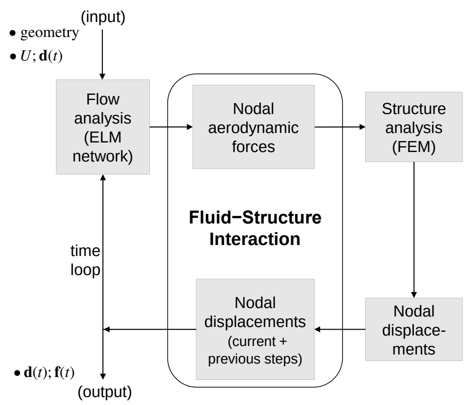
Thin-walled structures such as membrane roofs and umbrellas, tall tubular structures and wind turbine blades are remarkably light and flexible and thus highly susceptible to aeroelastic vibration phenomena such as flutter and vortex-induced vibration (VIV). Models to accurately predict aeroelastic interactions are critical for evaluating structural performance related to various limit states. Wind tunnel models are commonly used, however, they are time-consuming, costly and suffer from scaling issues. Numerical fluid–structure interaction (FSI) models have experienced growing attention in design and research for predicting full-scale aeroelastic behaviour and detailed insight into flow physics, however, they are computationally expensive to perform high-resolution analyses. Flow solvers generally require more time to compute sophisticated fluid dynamics around flexible immersed boundaries.

The aim of the project is the development of advanced coupled numerical models for the analysis of aeroelastic interactions of thin-walled flexible structures with significantly improved computational efficiency and quantifiable prediction quality. Data-driven aerodynamic force prediction models will be formulated using machine learning (ML) algorithms for selected thin-walled systems to couple them with a geometrically nonlinear finite element formulation to develop partitioned FSI models. Without compromising prediction accuracy, this will drastically reduce the computational time of FSI simulations. Training data of aerodynamic forces on thin-walled systems for different inflow conditions must include the effects of motion-induced forces and vortex shedding, which are obtained from high-resolution flow analyses with the help of vortex particle methods (VPM).

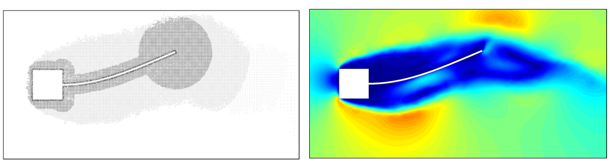
The methodological basis is to substitute the role of classical flow analysis methods in coupled analysis by utilising an ML-based force prediction model. The project also intends to improve the quality of flow modelling for the VPM by developing a novel adaptive surface discretisation technique for boundary elements. This will lead to significant advances in the simulation of flow around complex geometries and flexible structures. The validation and interpretation of analysis results will be supported by wind tunnel experiments and by the investigation of benchmark FSI problems of thin-plate systems in the open literature. The numerical methodology shall be developed based on the generalised formulation to apply the models to different thin-walled systems and for small and large displacement FSI problems.



Extreme learning machine (ELM) for prediction of aerodynamic forces



Schematic FSI model using ELM



FSI simulation of a flexible cantilever in Kármán vortex street

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