Modelling, simulation and validation of wind-structure interaction for flexible, ultra-light-weight structures

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ABSTRACT

In the case of light-weight structures, the fluctuating wind loads can lead to significant structural vibrations and a more detailed assessment of this possible interaction is mandatory for safety and usability reasons. However, physical wind tunnel approaches (as the state-of-the-art technology to evaluate wind loads on complicated geometries) are nearly impossible for thin-walled light-weight structures, like e.g. membrane roofs, due to the scaling laws. Besides the problem of properly scaling the structural and flow properties to wind tunnel scale for fluid-structure interaction phenomena, the preparation of the flexible small-scale models and the accurate measuring of transient design-relevant quantities is very complicated or even not realizable. Moreover, geometrical complexity prohibits the use of tables and standards. Hence, within this contribution the general layout of a computational simulation framework is shown which enables the in-depth analysis and evaluation of wind-induced effects of free-form civil engineering structures. From a practical perspective, a numerical wind tunnel must be able to treat very different scenarios and also a collaborative work of different expert groups with their respective solution schemes must be supported. As a consequence, a modular coupled simulation environment for analysis and design of light-weight structures subjected to transient wind loads is developed and presented. The actual partitioned realization of the computational FSI is centrally based on the generic coupling tool EMPIRE which conducts the coupled co-simulations. Different coupling strategies (e.g. explicit and implicit with different solution approaches) as well as the correct treatment of non-matching grid situations at the interface (e.g. finite volumes, finite elements, isogeometric elements) enable a versatile combination of different models and solution schemes which are best-suited for the specific target application. Within this work, the simulation of the highly turbulent wind flow is performed with ALE-based flow solvers (OpenFOAM (FVM) and KRATOS (FEM)) as well as an embedded solver (KRATOS) which is especially advantageous in cases of large deformations of the structure. The nonlinear structural dynamics is simulated with the in-house code CARAT++, using standard FE and also isogeometric elements. The created numerical wind tunnel is completed by an independent wind inflow generator module which guarantees for the correct modelling of the atmospheric boundary layer (ABL) flow with its specific statistical properties. Finally, to ensure the physical significance of the wind-structure interaction co-simulations, a systematic validation campaign for ultra-light-weight structures in ABL-flow was developed and conducted mainly within the European research project uLites (FP7-314891). The corresponding models, results and experiences made during these investigations will be demonstrated and proposed as test cases for FSI in the field of Computational Wind Engineering (CWE).