Geometry treatment and Shape optimization for Fluid-Structure Interaction Wind engineering problems

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In this contribution a modular framework for gradient based shape optimization in partitioned fluid-structure interaction analysis is presented. The software environment is designed for the Nested Analysis and Design (NAND) concept and a partitioned FSI scheme using a three field analysis including structure, fluid mesh and fluid. This guarantees the modularity and provides a better flexibility in dealing with different applications. Realization of such an environment is very challenging because on the one hand the coupled sensitivity and optimization have to be consistent with the treatment of the geometry and on the other hand the multi-code software development of such a type of analysis is very complex. Within this framework, the interaction of the optimizer, the coupled analysis and the coupled sensitivity analysis is going to be discussed.

This shape optimization algorithm has been particularly applied for design of light-weight structures subject to the atmospheric boundary layer (fig.1). This class of FSI problems usually deals with strong coupling between the fields. Moreover, specific care for the design and analysis of the structure, as well as the wind engineering aspects is required.

Figure 1: Computational modeling of light weight structure subject to the atmospheric boundary layer.

The fluid structure interaction problem itself is considered to be steady and therefore, in the structure side a static geometrical nonlinear problem is solved and on the fluid side a steady turbulent model is used. Furthermore, since the nature of wind is highly turbulent, wind simulations require a sufficiently
accurate turbulence model which is also efficient with respect to the computational effort, as desired in all design and optimization problems. Besides, the approaching wind flow should represent different properties of the real atmospheric wind such as the velocity profile and turbulence intensities. The coupling of the two field is explicit and in convergence a static solution is archived. The two fields exchange displacements and forces through the interface where a neighbor search algorithm is applied for the mapping of data.

The structural shape definition for such an optimization problem is very important, since it can significantly affect the computational time and the overall solution strategy. Generally, the methods describing the shape can be distinguished to parametric and non-parametric ones. Comparing to the non-parametric FE based shape representation, parametric models have a smaller number of design variables, since in those models a relation between different degrees of freedom is established. Here, both models are combined: The structural edge beams are parametrized using NURBS while the shape of the membrane surface is defined by “Form Finding”. “Form Finding” determines the shape of membrane structures by solving an inverse problem for a given boundary. The resulting geometry represents the state of equilibrium for a given stress state.

Additionally, an important issue from which many shape optimization algorithms suffer, is the distortion of the initial mesh during several optimization update steps. To overcome this problem, a mesh regularization procedure based on applying artificial prestresses on the discretization elements is introduced. The mesh regularization algorithm improves the quality of the mesh by changing the geometry of elements toward a predefined ideal shape. At the fluid side, a numerical wind tunnel around the structure is built.

The shape optimization algorithm is the driving process of the overall procedure and contains three main stages: optimization, evaluation of the objective function, and sensitivity analysis. Here, the computation of the objective function involves an FSI analysis. Within this work, this loop is driven by a gradient based optimization algorithm and a direct partitioned coupled sensitivity analysis is performed in order to obtain the gradient information.

References