Shape Optimization techniques for industrial application

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Topic
Computational methods are widely used in industry and bring a considerable advantage to product design. Now it is impossible to imagine the design of new building or airplane without proper tests of the constructions using computational simulations. The primary goal is not only to find a working and safe design, but also to optimize it for a particular scenario. A lot of different optimization techniques are created and implemented in hundreds of applications. Now engineers are trying to optimize complex cases and do optimization for multi-disciplinary problems (MDO). A good example is optimization of an aeroelastic wing of the airplane. In this case, the wing bends under aerodynamic forces, and the forces are depended on the deformed shape of the wing. This problem requires solving Fluid-Structure interaction (FSI) problem (see Fig. 1a) [1, 2].

The key technology is a node-based approach in which the model's shape is controlled using its geometrical discretization. Hence, the coordinates of the nodes on the optimized surface are used as design parameters. That gives strong local control of the shape update and does not require additional parameterization.

Methods
In node-based optimization approach the number of design variables is huge. Hence, it is very expensive to do non-gradient stochastic algorithm. Therefore, we focus on gradient-based algorithms with adjoint sensitivities methods. For mesh control and regularisation, we use the Vertex-Morphing technique.

The main idea of the Vertex-Morphing technique is to move the optimization problem from design space to control (optimization) one. To transfer data fields from design space to control space and vice-versa specific filtering is used. Vertex-Morphing technique is a powerful tool, which gives a high design freedom with great optimization potential [3, 4].

In MDO the coupling of the individual physics (state variables) is required. The objective function is dependent on coupled variables from different...
disciplines, hence to get correct sensitivities (gradients of objective function) one should use coupled sensitivity approach, where adjoint variables from different physics are coupled to each other. The coupled physical problem is modelled with high-fidelity models. A steady-state assumption is usually introduced in these problems. The coupled analysis is done in a partitioned manner, where the core of framework is an optimization and coupling tool with external solvers (co-simulation environment). In the Fig. 1b there is an optimization process with coupled sensitivity method and in the Fig. 1c One can see the result of minimizing drag force of elastic ONERAM6 wing.

The combination of all methods should give us a powerful optimization tool for MDO problems, which could be used for industrial problems. Follow-up work will focus on coupling thermal forces on the structures and doing multi-objective optimization with coupled sensitivity method.

References

[1]: Ruben Sanchez, Rafael Palacios, Thomas Economon, Heather Kline, Juan Alonso, and Francisco Palacios. Towards a fluid-structure interaction solver for problems with large deformations within the open-source SU2 suite. January 2016.


[4]: Reza Najian Asl, Shahrokh Shayegan, Armin Geiser, Majid Hojjat and Kai-Uwe Bletzinger. A consistent formulation for imposing packaging constraints in shape optimization using vertex morphing parametrization. Springer, September 2017

Fig. 1: a) FSI solution of elastic ONERAM6 wing; b) Optimization process with coupled sensitivity approach; c) The optimized elastic ONERAM6 wing with coupled sensitivity approach;