

TECHNICAL BRIEF: Engineering Design Optimization

Engineering design optimization is an emerging technology whose application both shortens design-cycle time and finds new designs that are not only feasible, but optimal, based on the design criteria. Traditional engineering design processes begin with formulating design requirements. Then, an initial design is synthesized which must be tested against the requirements. Such testing can involve building a prototype and performing an experiment. It may entail building a computer model using one of many engineering analysis codes. Of course, the design is usually validated experimentally since analysis codes are not infallible. When the design is found to be deficient in some requirement, it is changed. The change process typically involves strategies such as trial & error, use of previous experience, etc. The new design is again subjected to the test phase. The process iterates until the requirements are either met or changed to fit the performance. Often, the process is time consuming and does not produce the best design, just a feasible one.

Engineering design optimization can both reduce the cycle time for the design iteration loop and find the best (optimal) design for the specifications. This process differs from the traditional process in that the iteration loop is computerized. An optimization problem is posed for which the design variables, the design objective and all constraints are specified. An optimizing algorithm, which serves as the design modifier, is coupled with an appropriate engineering analysis code such as a computational fluid dynamics (CFD) code. The analysis code performs the test phase of the iteration loop. The optimizer may function by perturbing each design variable to determine how each affects the performance and then seek a solution that optimizes the objective.

An example is the design of an automobile air-conditioning duct that connects the air conditioner in the engine compartment to the air registers in the dashboard. The objective is to minimize the overall pressure drop while evenly delivering the air. The shape of the duct cross-section and the severity of the duct bends are important factors. However, changes in geometry are limited by the presence of other components behind the dashboard. The optimizer may change the shape of the initial duct design and see if the pressure is increased or reduced. It finds this out by sending a call to the analysis code. By iterating the above process, the optimizer not only finds a feasible design, but an optimal one based on the given constraints. Optionally, the designer may wish to relax constraints or otherwise modify requirements to see how this affects the performance; he may wish then to change the requirements to achieve an improved performance if the new requirements are acceptable.

Shape can be an important factor in the design performance. Shape can be changed by such methods as perturbing the computational grid or employing advanced geometrical functions such as Bezier curves or nonuniform rational B-splines (NURBS). When simulation-based design optimization is specifically applied to find optimal shapes, it is called shape optimization.

We give a simple example to illustrate shape optimization. Consider the steady, laminar, incompressible flow of air in a two-dimensional channel with a 90-degree bend. The objective is to minimize the pressure drop through the channel. A commercial CFD code has been interfaced to optimization software to provide the flow analysis. The optimizer is constrained to maintain the width and locations of the bend inlet and outlet and to avoid violating the space on the inside of the bend. Using arbitrary shape deformation software, the optimizer changes the shape of the bend to meet the objective. Figure 1 illustrates the geometry and pressure contours of the initial and optimized designs.

Initial design

Optimized design

The outer wall of the channel bend has deformed considerably, yielding a 42% reduction in pressure drop. Initial and optimized shapes and pressure contours for a channel with a bend; the objective was to minimize pressure drop. Engineering design optimization is the next major step beyond simply performing computer simulations. It takes existing analysis tools and combines them into a design loop with an optimizer that can not only find multiple feasible designs, but also optimal designs in a timely fashion. This technology can be applied across the entire spectrum of engineering application and will be an important factor in the future in improving industrial efficiency.

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