Multi-disciplinary and Multi-point Design Optimization of a Centrifugal Compressor Impeller

Recently Mehrdad Zangeneh, professor of thermofluids in the Department of Mechanical Engineering at University College London (UCL), has been considering aero/mechanical issues arising from design of high-speed turbomachinery, such as centrifugal compressors or radial turbines used in turbochargers. The major design bottleneck in many of these applications is the iteration between the aerodynamic design, where optimum performance is required at multiple operating points, and mechanical design. One way to reduce the aero/mechanical design time is to use multi-disciplinary design optimization (MDO). Conventional approaches for MDO based on parameterization of blade geometry usually require a large number of design parameters.

However, by parameterizing the blade using the blade loading and 3D inverse design code TURBOdesign1 by Advanced Design Technology to generate the blade geometries, the optimization can be performed efficiently and with a very small number of design parameters. Typically, five to 10 loading parameters can cover as much design space as 30 to 100 geometrical parameters, resulting in a significant reduction of computational time and costs. Furthermore, the 3D inverse design code automatically satisfies the specific work at the design flow rate without the need to use any constraints in the optimization.

In an application of this approach, the Eckardt centrifugal compressor impeller was used. First, the compressor was analyzed by means of Computational Fluid Dynamics (CFD) in CD-adapco's STAR-CCM+ and Abaqus Finite Element Analysis (FEA) software. The results compared to the available test data. This provided initial information on the stage performance to be used as reference for improvements and validation of the numerical analysis.

In this study, only four design parameters were used to represent the 3D blade geometry. Isight was then employed to generate a Design of Experiments (DOE) table and the resulting 22 designs were analyzed with both multi-point CFD and FEA. An important aspect of the optimization process is the capability of the different codes to operate in a seamlessly integrated manner. By making use of the existing compatibility between the different blade generation, CFD, FEA, and optimization codes, this process only required minor human intervention.

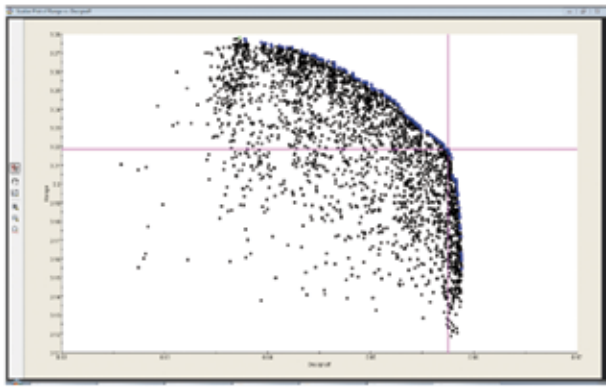

Figure 1. Pareto front showing minor improvements in one performance parameter can significantly affect the contrasting performance parameter.

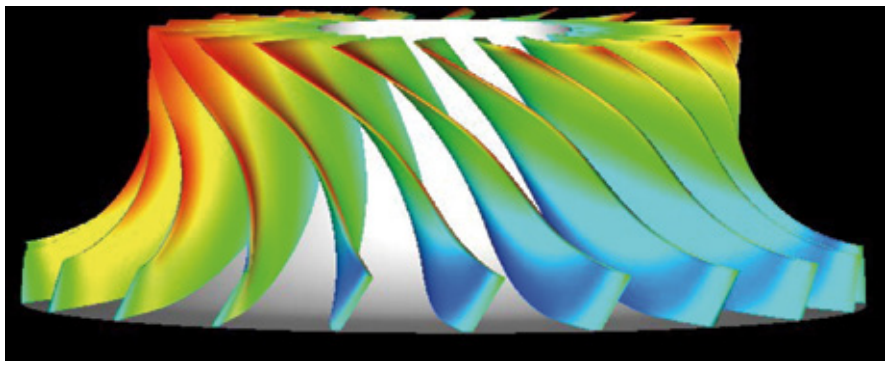

Figure 2. The geometry of the resulting optimized impeller provides the best compromise between design efficiency and flow range and subject to the required stress level.

After the CFD and FEA results were inserted into the resulting DOE table, Isight generated the Response Surface Model (RSM), an efficient mathematical regression method that correlates each performance parameter with different design parameters. Performance parameters can represent any type of data. Then designers can use their own validated methods to evaluate aerodynamic performances, mechanical reliability, production time, and manufacturing costs.

Once the accuracy of the RSM is tested and confirmed, it is possible to run a MDO using the RSM. In this case, a Multi-objective Genetic Algorithm (MOGA) is used to find the Pareto front, which is a trade off between different contrasting objectives subject to certain constraints. MOGA requires a large number of performance parameter evaluations. By running the MOGA on the fast Response Surface approximation, the performance parameters are evaluated very quickly and without the need for expensive CFD or FEA computations. The point selected on the resulting Pareto front (marked with the pointer in Figure 1) represents the best compromise between the operating range and design impeller efficiency. The resulting impeller geometry is shown in Figure 2.

The proposed optimization process is generally applicable to all types of turbomachinery for all design requirements, potentially providing turbomachinery manufacturers with the capability to create initial designs customized to the specific customer requirements very quickly.

For More Information

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