Increasing the performance of industrial blowers

with NUMECA optimization solutions

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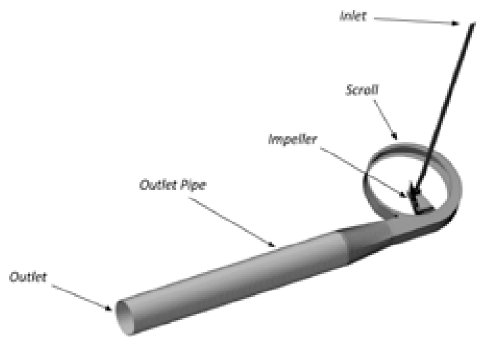
Petrochemical and other industrial applications rely on fans for a series of gas handling processes - which can range anywhere from ambient air ventilation to harmful chloride gases above 500C. The maximum operation speed of these fans is governed and often limited by industry standards. This speed limitation forces fan manufacturers to size the diameter of the impeller up or down in order to obtain the desired pressure output. The challenge for engineers is that the resulting design can become oversized, heavy and expensive to fabricate, test and transport.

Illinois Blower, based in Cary, Illinois, has been working with NUMECA on a design approach that solves this dilemma by achieving higher pressures and increased fan efficiency, yet maintaining impeller speed and diameter. For more than 40 years, Illinois Blower has successfully developed and built custom centrifugal fans and blowers for a variety of worldwide industrial process industries, including refinery and petrochemical power generation, pollution control, pharmaceutical, food processing, and many others.

The goal of this particular case was to increase the pressure ratio of a complete fan stage (wheel and volute) over its entire performance line. Due to manufacturing constraints the solid body thickness around the impeller had to be maintained, and the blade shape needed to be easy to manufacture. In addition to this impeller optimization, the engineers wanted to get a better understanding of the flow physics to help reduce pressure losses in the outlet pipe.

FIGURE 1 : Test case: Impeller and volute of the centrifugal industrial fan to optimize with the surface mesh from Hexpress™.



" I have worked with NUMECA on several projects through the last eight years, and always appreciated the collaboration and the experience of the NUMECA-USA team, in particular in turbomachinery design optimization of torque converters and industrial fans. Such a project always involves objectives and constraints, which are quite intricate, and it is usually quite impossible to know from the project start how things will go. But what we have always done with the NUMECA team is work together, analyze situations, and decide on next steps. And I could count on them to find a way to deliver."

Edward De Jesús Rivera, Engineering Manager, Illinois Blowers.

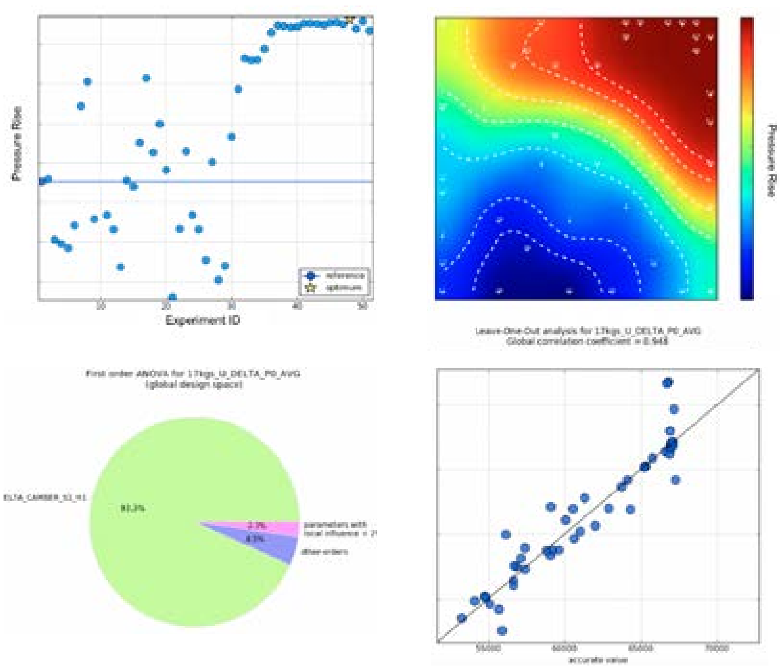
Methodology

A first series of simulations were run from choke to stall in FINE™/Open, NUMECA's unstructured multi-purpose CFD solver package, and the results were compared with experimental data to assure that the CFD settings were reliable.

High speed meshing

A 7.5M-point mesh with smooth boundary layers in the volute and around the impeller blade details was generated in Hexpress™. Only one passage of the impeller had to be meshed in order to run the performance line steady calculations, and each computation took less than 1 hour on 96 cores to achieve full convergence.

FIGURE 2 : From left to right, top to bottom: The scatter plot shows the value of an objective for all the database and optimization samples, with the optimum individual highlighted by a star. The self-organizing map reveals correlation and anti-correlation between parameters. The analysis of variance (ANOVA) decomposes the global variability of an output over a range of input variables. The Leave-One-Out (LOO) plot estimates the model reliability.



Optimization part 1: Identifying the main performance parameters

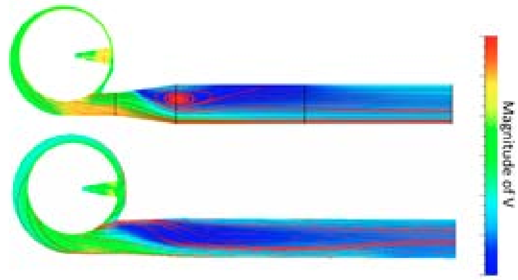
A first step of the optimization was to identify the main factors influencing the centrifugal fan's performance, in order to know exactly where optimization would be most effective. Twenty user-defined parameters of the impeller blade and flow channel were carefully selected, describing the hub and shroud shapes; the blade metal angles; and the blade camber and lean. The choice of these free parameters and associated variation ranges turned out to be key for the success of the project. For each set of the parameters a new geometry was created by FINE™/Design3D, and an unstructured mesh was automatically generated in OMNIS™/Hexpress, using a dedicated python script to save time.

After parameterization, the design of experiments (DOE) database was generated by FINE™/Design3D with the Minamo module. The main optimization algorithm of the Minamo data-mining tool is based on evolutionary algorithms, accelerated by the use of surrogate models to speed up the convergence rate. A database of 70 samples was built, filling the design space with 210 CFD solutions at three operating conditions (at stall, near design point, and at choke). By applying the grid-to-grid interpolation to improve the initialization of each CFD sample, a 25% reduction of iterations (and therefore CPU time) was achieved.

A thorough analysis of the database allowed the engineering team to understand the influence of each of the free parameters and their impact on the performance.

It was found that the volute was the main limiter in the optimization of the fan performance! Ensuing work de-coupled the components to further optimize the impeller separately and to design a new volute that minimizes the pressure losses observed in the sample CFD solutions.

FIGURE 3 : Comparison of the velocity streamlines and contours of velocity magnitude before and after volute redesign for one operating point.



Optimization part 2: Focus on the impeller

The second part of the performance optimization focused on the impeller blade, meridional effects, and corresponding solid walls, decoupled from the volute. Using Autogrid™ and FINE™/Turbo, the large database and optimization can easily be run over a weekend on a desktop machine, and the process is also fully automated by python scripts.

Once a new optimal impeller was obtained, the performance of the entire fan was then computed by coupling the detailed geometry of the optimal impeller with the redesigned volute.

FIGURE 4 : Static pressure difference for the baseline test data and the optimized CFD designs (values are removed for proprietary reasons).

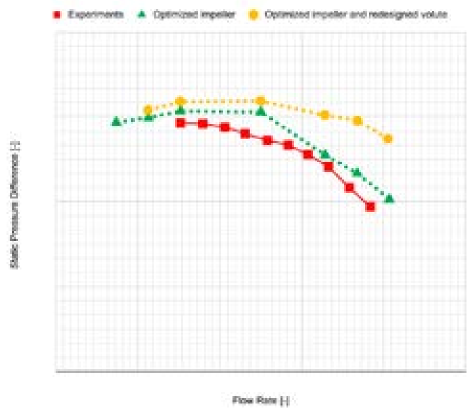
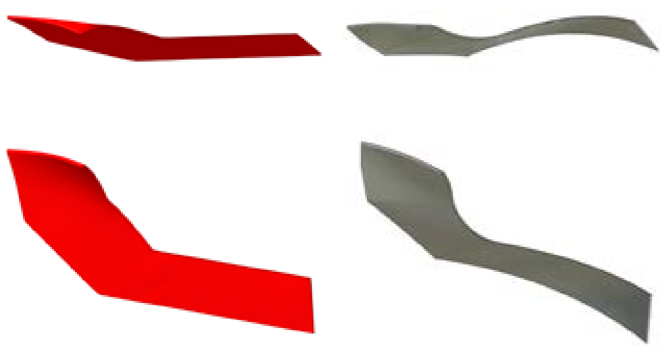


FIGURE 5 : Comparison of the impeller blade shape before optimization (in red) and after optimization (in grey).



Conclusion

Challenge completed. Thanks to this two-part optimization project, Illinois Blower managed to increase fan performance by up to 44% overall, while maintaining their original design constraints. The optimization of the impeller blade shape and flow channel led to an increase of static pressure of up to 20% at some operating points (near choke). Furthermore, thanks to a better understanding of the flow-induced pressure losses downstream of the volute scroll, a smart redesign of the volute led to an additional increase in pressure over the whole performance line, going up to 24% at some operating points (near choke).