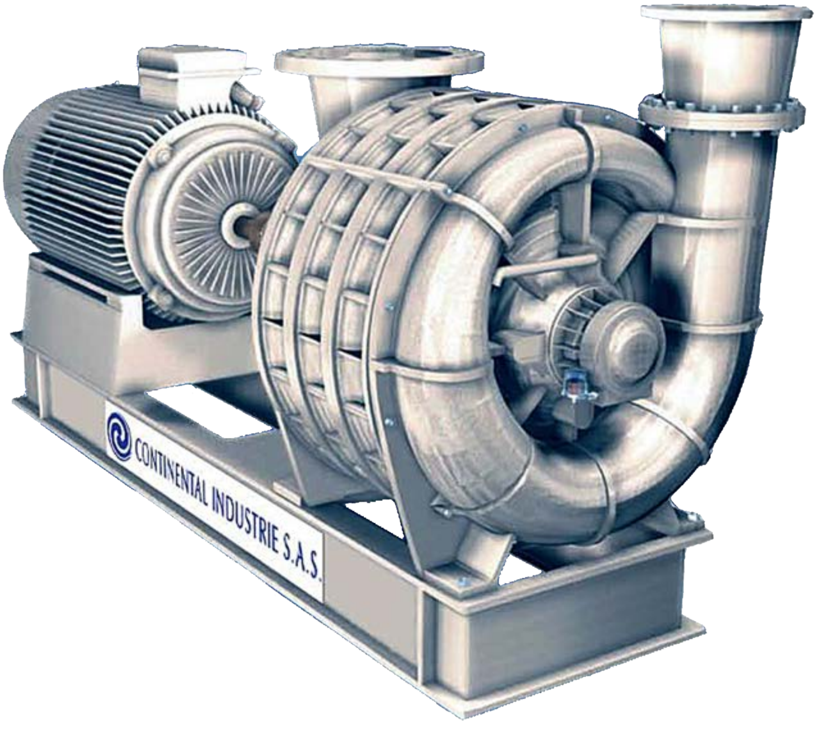


BLOWN AWAY

The ANSYS integrated turbomachinery design platform enabled a rotating machinery company to design a centrifugal compressor with a potential for 2 to 5 percent energy savings during wastewater treatment operations. In addition, the company was able to reduce costs and design time in developing a next-generation product.

By Brice Caussanel and **Renaud Signoret**, Turbomachinery Engineers, Continental Industrie, Saint-Trivier-sur-Moignans France

Most wastewater treatment plants use naturally occurring microorganisms in wastewater to quickly break down organic matter to form carbon dioxide and water. Aeration plays an integral role in these plants by adding air to the wastewater to promote aerobic biodegradation of the organic pollutants. The compressors that inject this air consume substantial amounts of electrical power to overcome the backpressure of the water height and losses in the air injection system. The amount of power is significant. For example, the approximately 20,000 municipal wastewater treatment plants in the United States consume about 4 percent of all the electrical energy generated in the U.S. [1], and the compression of air for the aeration process is estimated to account for about 60 percent of this power [2].

Aeration is a huge expense for municipal treatment plants, and improving the aeration compressor's efficiency provides an enormous opportunity for cost and energy savings. Continental Industrie has 40 years of experience in research, development and manufacturing of centrifugal blowers and exhaust products. The company's engineers utilized the ANSYS integrated design system for turbomachinery applications to design a next-generation centrifugal compressor for wastewater aeration applications that provides a 2 to 5 percent improvement in efficiency compared to the previous-generation compressor. This should provide savings of 15 kW to 50 kW for the average wastewater plant. Based on operating 2,000 hours per year and a cost of $0.20 per kWh, this would yield an annual savings of $6,000 to $20,000 per year per compressor. Engineers used optimization algorithms

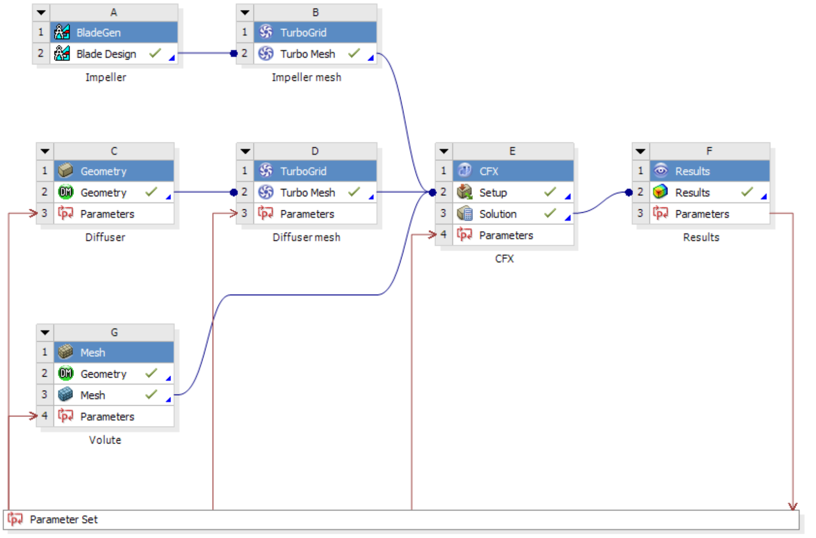
Improving the efficiency of the compressors used for aeration provides an enormous opportunity for cost and energy savings.

to explore 1-D, 2-D and 3-D designs to get the design right the first time while minimizing modeling and computational effort.

PREVIOUS DESIGN METHODS

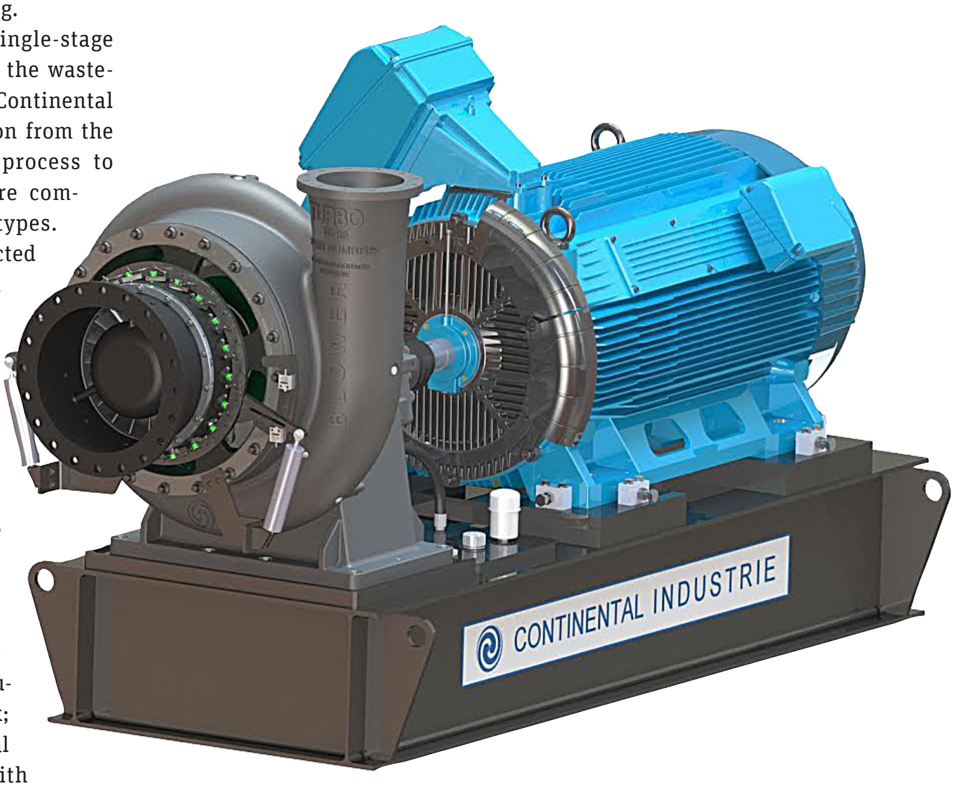
There are many design variables involved in centrifugal compressors, each of which has complex and often interacting effects on the finished product's performance. To design the previous generation of these compressors, experienced designers used empirical methods. The process began with the use of one-dimensional analysis and engineering intuition to obtain an initial design with a reasonable efficiency level. A bench model was then built so that rough performance measurements could be taken. Experienced turbomachinery designers reviewed the test results and made educated guesses on which design changes might be able to deliver significant performance improvements. These designers were able to achieve significant improvements but were not able to fully optimize the design. The full scale prototype did not always meet the design specifications, and this required costly additional cycles of prototype building and physical testing.

To design its newest single-stage centrifugal compressor for the wastewater treatment industry, Continental Industrie utilized simulation from the beginning of the design process to optimize the design before committing to physical prototypes. Continental Industrie selected the ANSYS integrated approach for turbomachinery design for several reasons: The ease of use of ANSYS solutions makes it possible to define a complete workflow and methodology in a short period of time the ANSYS parametric platform allows the team to explore the complete design space to identify the optimal solution with a high level of accuracy, eliminating guesswork; and both flow and structural engineering teams work with

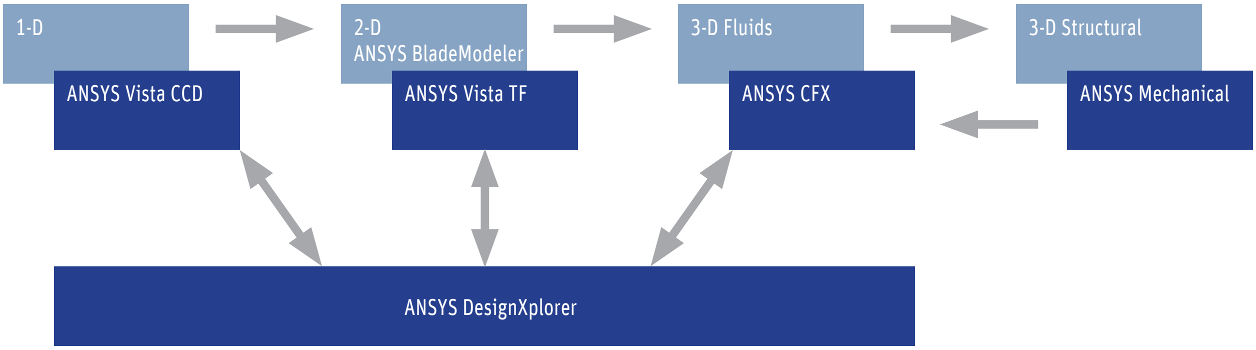


▲ ANSYS Workbench geometry and CFD simulation workflow schematic used in the design of a new compressor

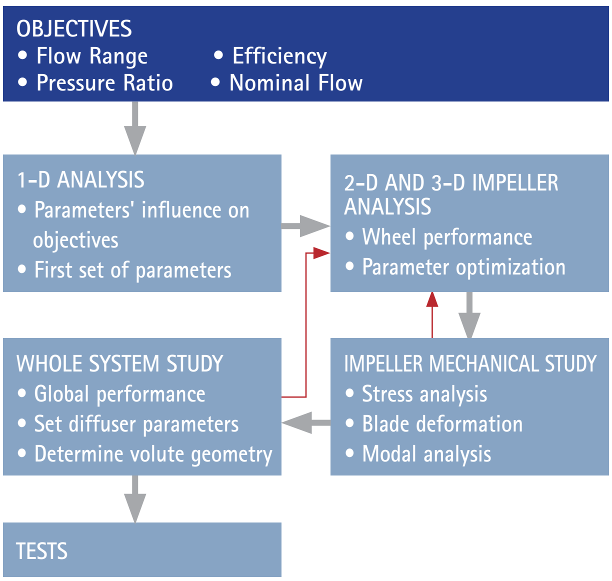
Continental Industrie utilized simulation from the beginning of the design process to optimize the design.



▲ New centrifugal compressor



ANSYS Workbench enabled engineers to easily design and optimize the compressor.



Engineers used simulation to meet design objectives for the new product.

the same design geometry, making it possible to easily incorporate both simulation types into the optimization.

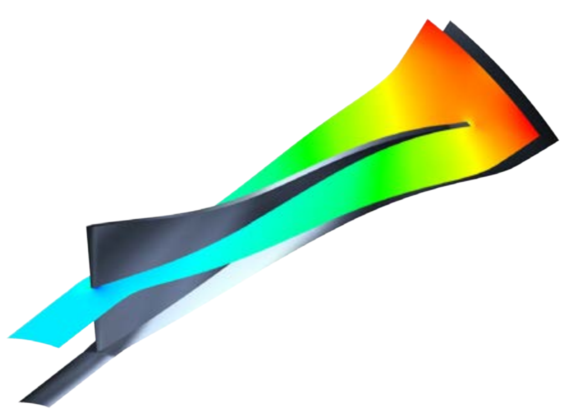
PRELIMINARY DESIGN

Continental Industrie engineers used the ANSYS Vista CCD tool (included with ANSYS BladeModeler software) to perform preliminary design or sizing of the compressor based on input parameters such as the pressure ratio, mass flow rate, rotational velocity and other geometrical constraints. They evaluated about 50 impeller blades manually to gain an informed understanding of the effect of the different parameters, and then used ANSYS DesignXplorer to perform a designed experiment that evaluated about 200 more designs to fully optimize the variations from a 1-D perspective. The very short run times provided by Vista CCD made it possible to evaluate each design in less than a minute.

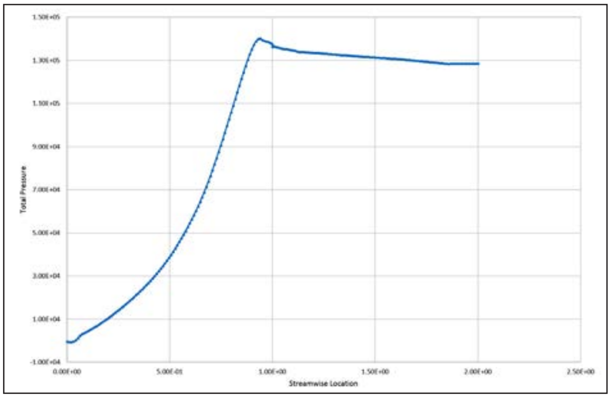
Next, engineers used ANSYS Vista TF to evaluate the 2-D blade row design. The throughflow solution captured many features of a full 3-D flow simulation with much less computational effort. An additional step was performed at this stage to optimize the blade in the context of the impeller. During this stage, Continental Industrie engineers examined 20 different designs and made only very small changes to the parameters, but gained significant improvements in projected efficiency.

COMPLETE 3-D COMPRESSOR DESIGN

The next step involved integrating the impeller into the complete 3-D compressor. Continental Industrie engineers produced the geometry of the complete flow path, including the inlet guide vanes, impeller, diffuser and volute casing in SolidWorks® computer aided design software. After they imported the geometry into ANSYS DesignModeler, the ANSYS Meshing platform generated the mesh in the volute casing fluid volume, and ANSYS TurboGrid automatically produced a hexahedral mesh of all the bladed components — the inlet guide vanes, impeller and diffuser. Using ANSYS CFX computational fluid dynamics (CFD) software to minimize the flow losses through the diffuser and volute, engineers re-optimized the system by employing ANSYS DesignXplorer to perform another experiment, in this case with about 250 designs.



Mid-span pressure field calculated by ANSYS CFX



Total pressure variation through the compressor

STRUCTURAL DESIGN

Engineers also used ANSYS Workbench to link the pressure and temperature predictions from ANSYS CFD to ANSYS Mechanical to evaluate the stress levels and deformation of the impeller wheel and other mechanical components. The structural simulation revealed that the initial impeller design experienced stress values beyond the impeller material yield strength, so engineers increased the thickness of the blade to ensure reliability. Additional CFD calculations were performed to check the new design at three mass flow rates. The impeller deformation results provided by ANSYS Mechanical were used to avoid contact between impeller blade tips and the shroud. A modal analysis was also performed to investigate the vibrational behavior of the rotating impeller and ensure that it did not have any resonant frequencies that would be excited under normal operating conditions.

3-D flow simulation using ANSYS CFD allowed Continental Industrie to improve the performance of a centrifugal compressor.

MODELING INTERNAL FLOW-INDUCED MOTION WITH ANSYS FLUID–STRUCTURE INTERACTION — WEBINAR
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By using an integrated design process that optimized the compressor at three separate phases, Continental Industrie engineers were able to deliver 2 to 5 percent higher efficiency than the company's previous generation of wastewater aeration centrifugal compressors. The new compressor can vary flow while maintaining constant pressure, which makes it possible to save even more energy by reducing flow rate to the minimum level required by the process. Continental Industrie also generated substantial cost savings in the process because the entire design was completed by a three-person team, and the first prototype met the company's performance requirements.

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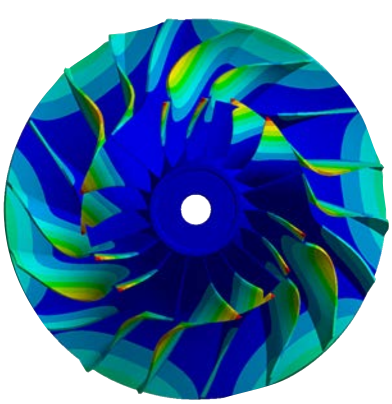
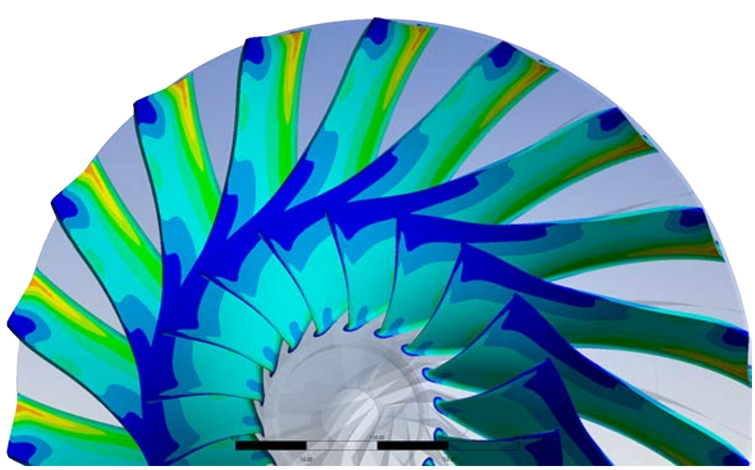
[1] Circle of Blue. EPRI Technical Report: Water & Sustainability (Volume 4). U.S. Electricity Consumption for Water Supply & Treatment — The Next Half Century. circleofblue.org/waternews/wp-content/uploads/2010/08/EPRI-Volume-4.pdf (09/22/2015).

[2] Bolles, S. Process Energy Services, LLC. Modeling Wastewater Aeration Systems to Discover Energy Savings Opportunities. processenergy.com/Aeration%20Paper.pdf (09/22/2015).



Modal analysis of the impeller was performed.



Stress field on the compressor blades was simulated to ensure reliability.