The global magazine for pump users and suppliers

PUMP engineer

COVER STORY:

CFTURBO:

Hydraulic Design and Optimization of Multistage Pumps

Page 8

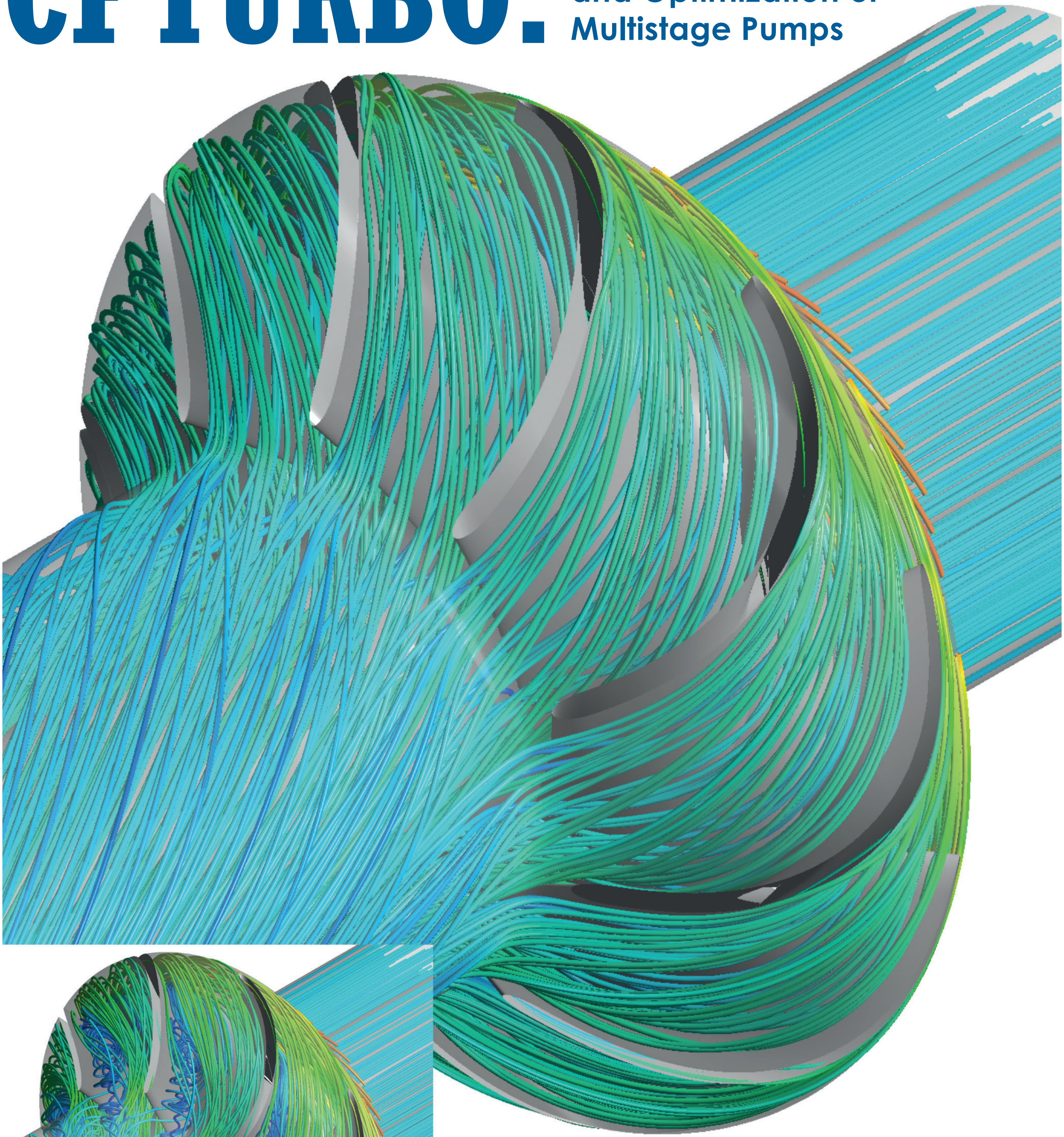
Special Topic: Systems and Software

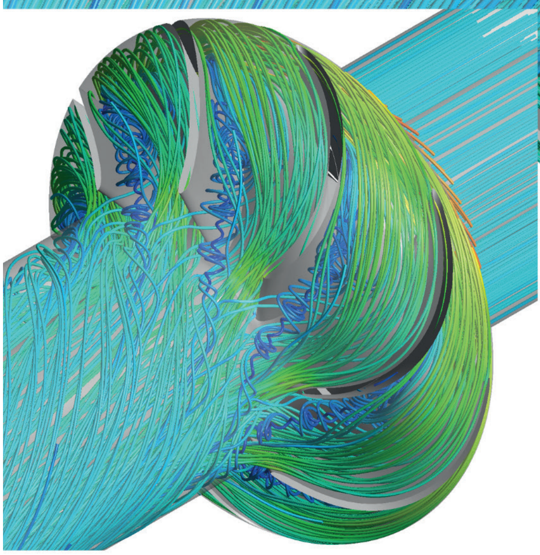
In this issue of Pump Engineer magazine:

Volume 34, February 2022

www.pumpengineer.net

CFTURBO: Hydraulic Design and Optimization of Multistage Pumps





CFturbo's innovative, reliable, and high-quality software has earned its reputation as a leading design- oriented engineering company. Following the path of legendary German engineering, the company's outstanding user-friendly software makes CFturbo continually sought after in the pump industry worldwide. Combined with commercial high-fidelity CFD codes and optimization software, CFturbo represents a truly cutting-edge technology.

By Sarah Do Couto, Ralph Peter Mueller, President CFturbo, Inc., and Sascha Henoch, Senior CFD Engineer, CFturbo GmbH.

The Company

In 2008, Mr. Ralph-Peter Mueller and Dr. Gero Kreuzfeld co-founded CFturbo with the vision in mind to make the turbomachinery design and optimization process affordable, easy to use, fast, and robust. It did so while providing excellent designs and accurate simulation results.

With offices in Dresden, Germany, and Brooklyn, New York, the company now has 25 full-time employees that operate out of the two locations. In addition to the core staff, CFturbo works with distributors around the globe. Its commitment to maintaining an international presence in many countries is essential to ensure global success. Today, CFturbo agents are in Brazil, China, India, Japan, South Korea, France, Italy, Spain, South Africa, Switzerland, Russia, Turkey, the UK, and the United States.

Interoperability

CFturbo offers its proprietary turbomachinery design software, *CFturbo*.

The advanced technology used to design the software allows *CFturbo* users to create axial, mixed-flow, and centrifugal pumps, blowers, fans, compressors, and turbines. While each module offers quality calculations, the *CFturbo* pump design module is the most popular product family. The pump module enables the design of all rotodynamic pump types. It supports axial, mixed-flow, and centrifugal pumps, including special components like inducers and sewage water impellers.

CFturbo can operate with computer-aided engineering (CAE) software from other vendors, unlike any other turbomachinery design software. There are several computational flow dynamics (CFD) codes which work seamlessly with CFturbo: Ansys CFX, cadence FINE/Turbo, Simerics MP, or STAR CCM+ of SIEMENS PLM -- just to name a few. For optimization, one can use DAKOTA, SIEMENS PLM HEEDS, or ANSYS optiSLang.

Combining *CFturbo* with state-of-the-art CFD codes and optimization software leads to unrivaled productivity in the development process of efficient pumps. With roughly 20 new customers each year, the company's global clientele is comprised of small, mid-size, and large corporations. *CFturbo* is proud to serve a variety of companies offering

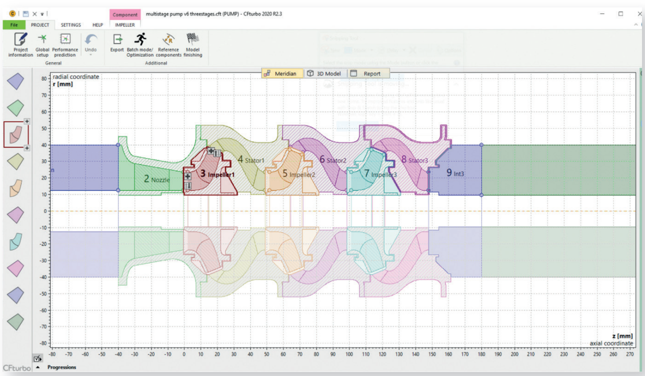


Figure 1: Multistage pump model made in CFturbo, meridional view.

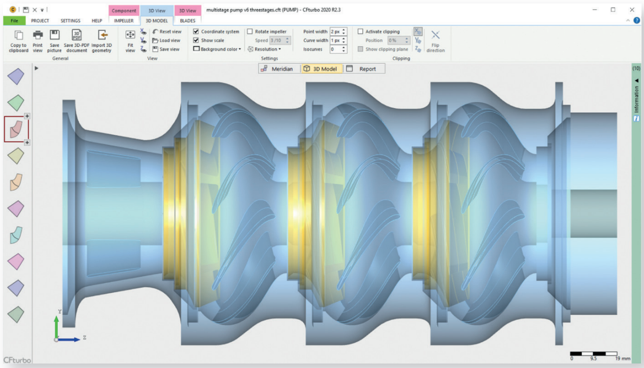


Figure 2: Multistage pump model made in CFturbo, 3D view.

pump solutions for different sectors, such as Franklin Electric, Gorman-Rupp, Griswold PSG Dover, Hayward Tyler, ITT Goulds Pumps, Pentair, ProFlow Pumping Solutions, Shippensburg Pump Co., Toyo, and Xylem, among others.

Baseline Hydraulic Design

The *CFturbo* software guides the user, step-by-step, through the complete design process of a turbomachine. Here, it is explained how a three-stage multistage bowl-diffuser pump is made in *CFturbo*.

STAGE 1: The user must specify the pump's duty point, which is often the Best Efficiency Point (BEP). Like any other turbomachine, a pump has only one BEP called peak efficiency. To describe the duty point, the user must define flow rate, head and rotational speed, and the fluid properties and inlet conditions. For example, the user has selected water, a volume flow rate of 10 m^3/hour, the head of 21 m at 3600 rpm. An initial design can be generated automatically, with the following design details controlled entirely by the user.

The calculations in *CFturbo* rely on fundamental equations describing the conservation of mass, momentum, and energy. The Bernoulli equation and the Euler equation of turbomachinery are two typical applications of those relations for rotating and non-rotating components. Moreover, *CFturbo* uses numerous empirical correlations to create excellent initial designs, and those correlations were collected from textbooks and research papers. However, to a certain extent, the user can integrate proprietary knowledge into *CFturbo*.

STAGE 2: In subsequent steps, the user designs main dimensions, meridional contour, blade angles, mean lines, blade profiles, and blade edges. One entire pump stage comprising impeller, bowl diffuser, and leakages should be finished before copying the initial model three times to create the multistage pump in *CFturbo*, as shown in Figure 1.

STAGE 3: Final steps may include designing an inlet nozzle located upstream of the first impeller or an outlet region downstream of the third bowl diffuser. At the end of the design process, the user receives a parametric 3D CAD model ready for export and simulation (see Figure 2).

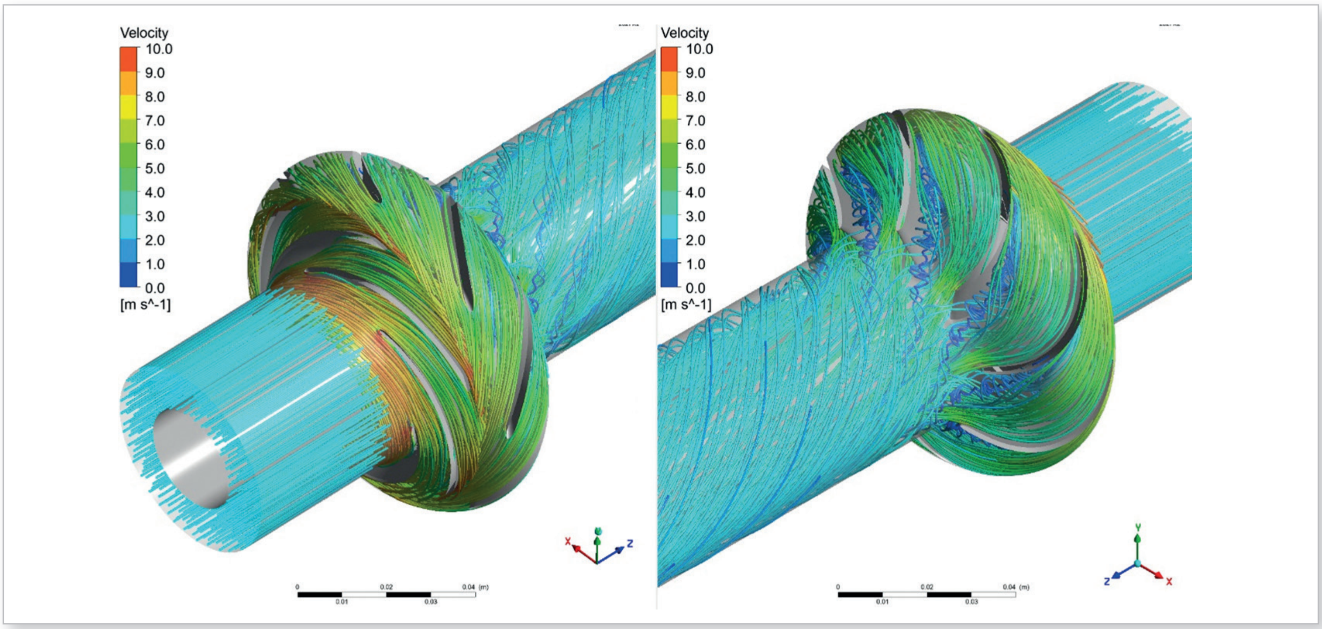


Figure 3: Single pump stage - simulation of the baseline design.

CFD Simulations

Design decisions based on loss models or simplified simulations without considering friction could be misleading. Therefore, *CFturbo*, recommends doing 3D CFD simulations with high-fidelity flow simulation codes to evaluate conceptual designs.

Figure 3 shows two plots of the initial design, one stage, steady-state flow simulation for the duty point, run with the CFD code Ansys CFX. The displayed streamlines represent the velocity magnitude.

Impeller efficiency was 92%, and the hydraulic stage efficiency was 82%, which are excellent numbers for an all-new design. These data points were double-checked and successfully confirmed with steady-state and transient CFD simulations using Simerics MP. For final confirmation, both CFD codes, Ansys CFX, and Simerics MP were used to run the entire pump with all three stages. The user observed only minor differences comparing the pump performance and hydraulic efficiency to the single-stage simulations.

One can observe flow separation in the bowl diffuser. There is even a visible potential to improve stage efficiency, and the bowl diffuser geometry should become the first optimization item.

Design Exploration and Optimization

To establish an automated workflow for turbomachinery design exploration, the following is needed:

- A versatile, parametric free-form modeler for 3D CAD, like *CFturbo*
- Reasonable conceptual designs based on fundamental physics and empirical correlations
- Excellent data export functionality to all significant CAD, CFD, and FEA software tools

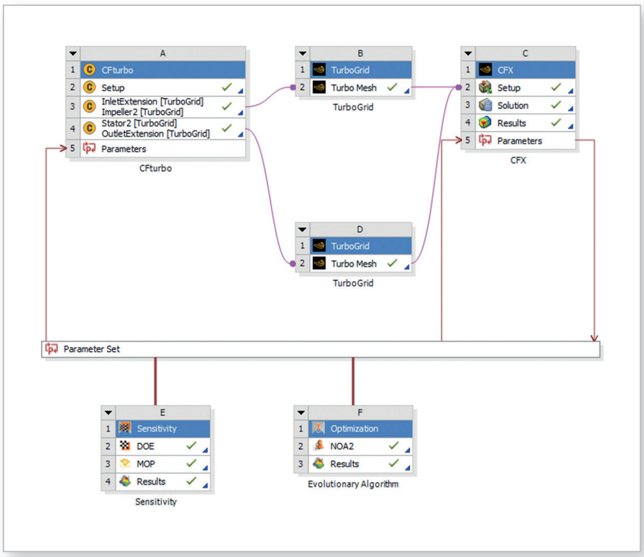


Figure 4: Optimization workflow – CFturbo with Ansys Workbench.

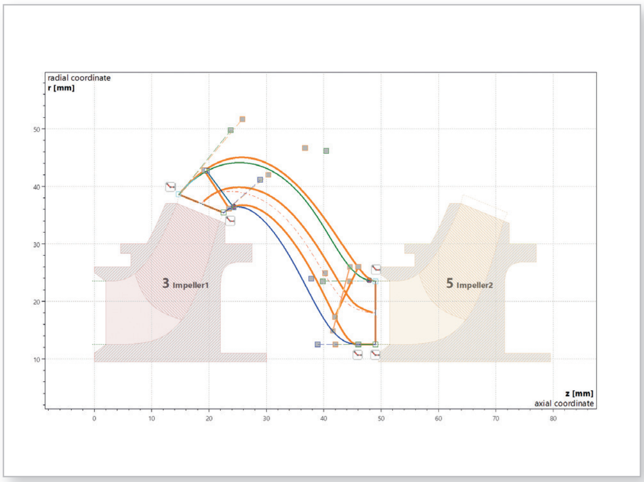


Figure 5: Bowl diffuser – meridional contour design parameters.

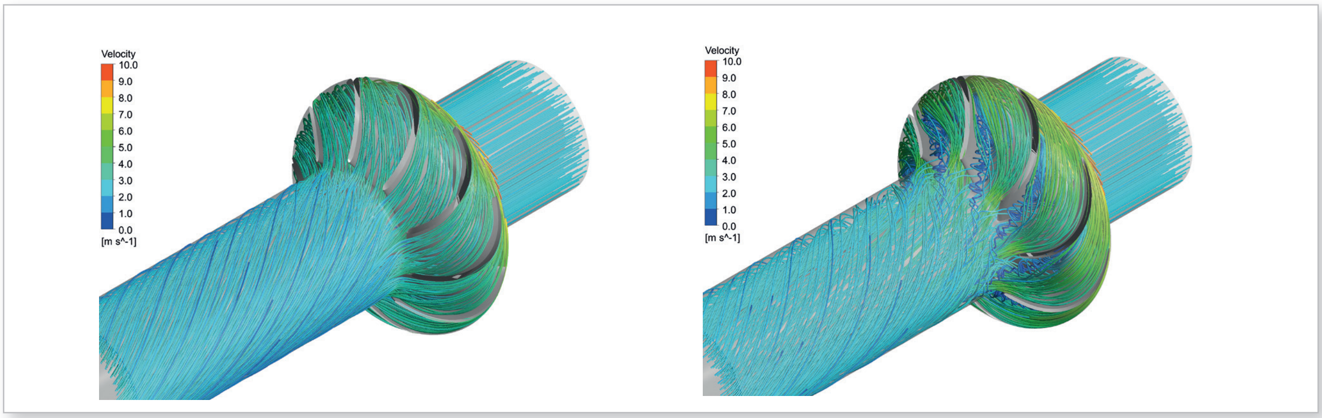


Figure 6: Optimized Bowl Diffuser Design (left) vs. Baseline design (right).

- Interoperability to set up automated simulation workflows and digital twins

To optimize the bowl diffuser the *CFturbo* integration in Ansys Workbench was used. The principle setup of the project schematic is shown in Figure 4. A bi-directional interface between *CFturbo* and Ansys is available and allows the exchange of design parameters. Hence, it is a genuinely integrated workflow that allows CAE process automation.

14 different parameters for the meridional design of the bowl diffuser were selected, while the inlet and the outlet cross-sections remained unchanged (see Figure 5). Additionally, five parameters for the blade angles and four for the meanline design were selected.

In total, 23 parameters were modified for an initial design exploration. In a Design of Experiments (DoE) study, 300 pump designs were created automatically using an advanced Latin Hypercube Sampling (LHS). Based on the results of the DoE, the most important geometry parameters related to each objective and constraint were identified. With this analysis, users reduced the number of parameters and selected a suitable algorithm for a subsequent optimization study. By implementing an Evolutionary Algorithm, an additional 300 designs were created to maximize the hydraulic efficiency of the pump stage and get a highly uniform flow field at the bowl diffuser outlet. Using a workstation with a mid-range Intel Xeon processor, the DoE and the optimization took up approximately 120 hours, elapsed real time.

As a result of the optimization, the improved design of the multistage pump achieved +2.0 % in pump performance at the duty point and 2.5 points in hydraulic efficiency. Figure 6, which compares streamline plots of the optimized model (left) with the baseline design (right), indicates no separation regions in the bowl diffuser at all.

Cavitation during the pump operation should be avoided because it could cause additional noise, vibrations, and mechanical damage. It can lead to an early failure of the pump. The required net positive suction head (NPSHr) as a pump characteristic needs to be calculated in order to decide whether the pump is suitable for a given pumping system. Transient, multi-phase CFD analyses were performed to determine NPSHr value of the multistage pump. In these

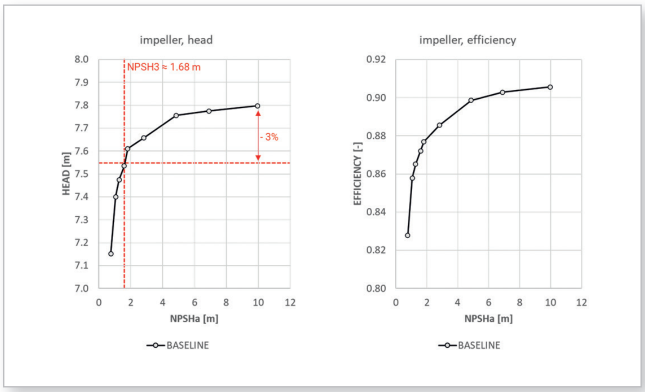


Figure 7: Baseline design suction performance at the design point.

studies the pressure conditions at the pump intake were lowered until the delivery head of the impeller was reduced by 3% due to cavitation (see Figure 7).

As the next step - if necessary - an impeller optimization of the first pump stage should be considered to lower the required NPSHr while maintaining the overall hydraulic efficiency of the pump. A multi-objective optimization analysis may be needed since we have conflicting objectives.

Outlook

There is an ongoing global trend towards highly efficient turbomachinery and systems since they consume less energy and cut costs for businesses. This trend gained traction in recent years due to strengthening regulations, which require companies to reduce CO_2 emissions.

Looking to the future, *CFturbo* sees ample opportunity to streamline the turbomachinery design process further. It strives to continue making design, computational fluid dynamics, and optimization accessible to all engineers with different levels of expertise.

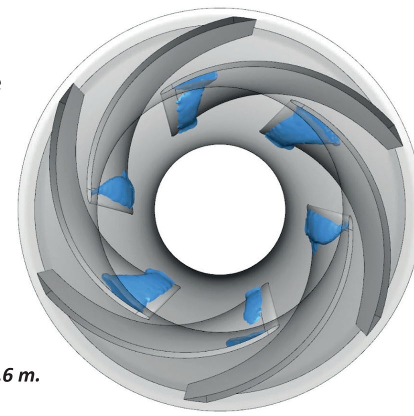


Figure 8: Vapor volume Isosurfaces of the pump impeller (first stage) at a NPSHa = 1.6 m.