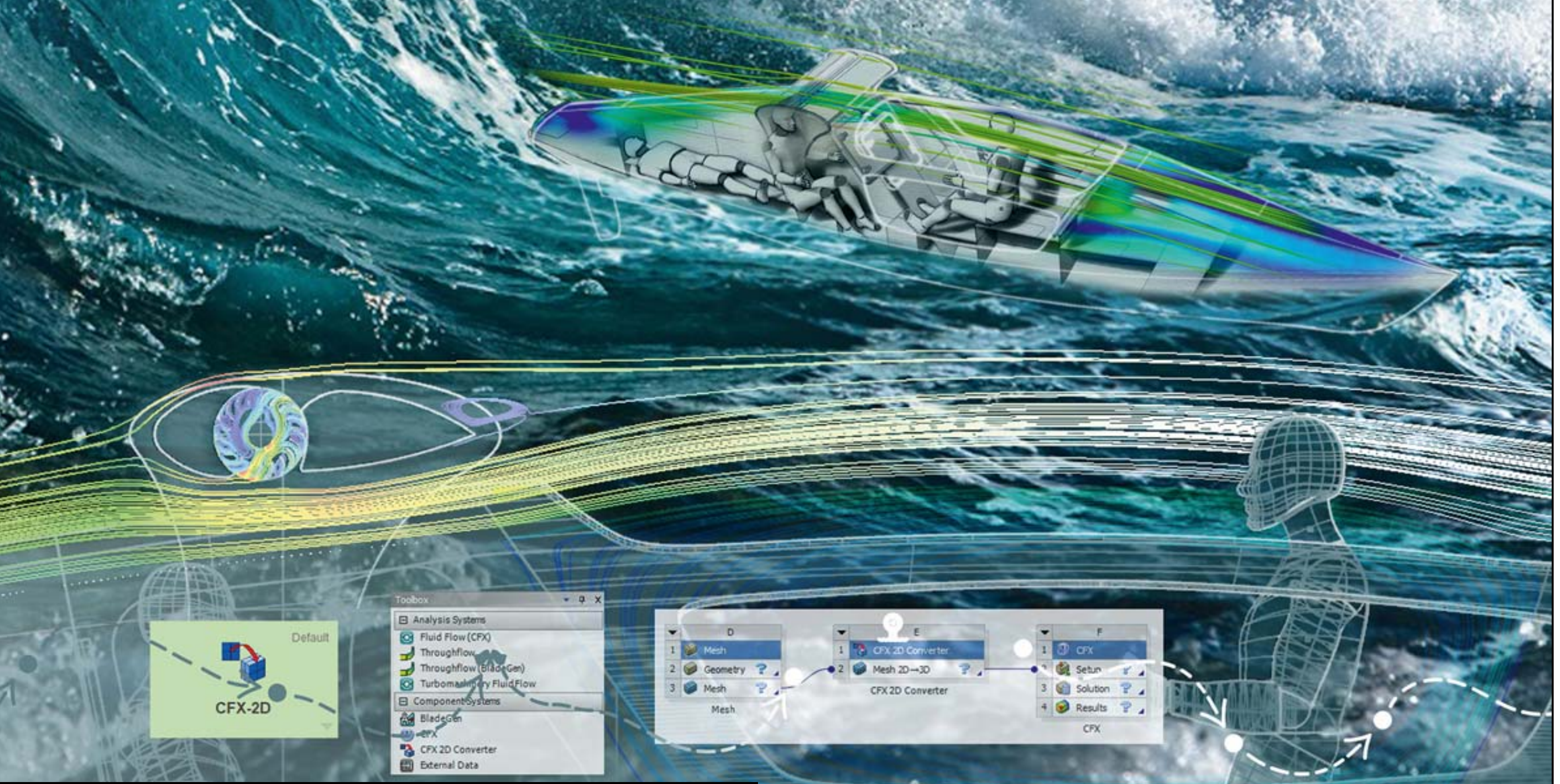

CUSTOMER STORY // MECHANICAL ENGINEERING

DESIGN OPTIMIZATION OF A WIND TURBINE FOR THE ROWING BOAT "AKROS"

The ANSYS optiSLang optimization toolbox was used together with ANSYS CFX fluid dynamics software package in order to find an optimal wing and rotor geometry.

Motivation

At the end of 2018, the famous Russian adventurer Fedor Konyukhov is going to set his solo round-the-world sailing on the rowing boat AKROS from Australia to Cape Horn. The journey will start from the Australian island of Tasmania. Konyukhov will sail south of New Zealand to the Pacific Ocean to meet the largest stretch of the Southern Ocean. The entire route is 9,000 km.

Sailors call the areas between the latitudes of 40 and 60 degrees south the "Roaring Forties". The average wind speed in these latitudes is 10-15 m/s (6-7 on the Beaufort scale), reaching 30-40 m/s during violent storms which are regular in this area. Icebergs can be seen all year round across the Southern Ocean. Some of them may reach several hundred meters in height.

The new AKROS boat was designed on the basis of the TURGOYAK rowing boat sailed by Konyukhov in 2016, during his world-first circumnavigation. The design has to be adjusted to extreme sailing conditions. To build a new rowing boat, British designer Phil Morrison was invited. He designed the two boats for Konyukhov: URALAZ and TURGOYAK. The size of the new boat will be 9 meters. The forebody will be divided into two watertight compartments with an additional "crash box". The structural design of the boat is shown in Fig. 1.

The preliminary design shows that crossing the ocean at low temperatures will require an additional source of electric power to heat the stern compartment with a navigation room, a cook galley and a recreation compartment. The main source of electric power of the TURGOYAK is solar panels. SimuLabs engineers suggested that the additional source of power for the AKROS boat should be a small wind turbine. The engineers developed and patented a revolutionary configuration and design of the wind turbine which deals with the ship's stability and slightly increases the specific resistance of the boat.

Rowing-boat wind turbine

The main component of the wind turbine is a wing airfoil containing a contoured duct connecting the opposite wing surfaces. The inducted air drives the turbine and the associated generator. The basic design of the wing ensures that all of its components are fixed to increase the reliability of the wind turbine. To find the optimal wing and rotor geometry, the ANSYS optiSLang optimization toolbox was used together with the ANSYS CFX fluid dynamics software package. The designed turbine capacity at a wind speed of 15 m/s and a specific speed of 0.3 is 100 W. The weight of the turbine including the generator is not more than 10 kg. A similar horizontal-axis wind turbine due to dimensional constraints produces no more than 35-40 W at a higher specific speed.

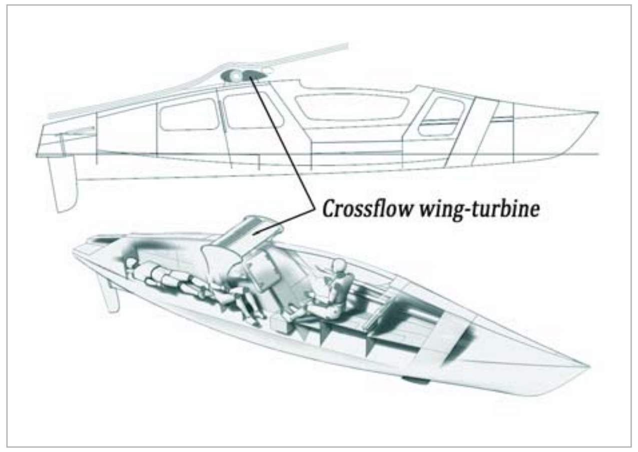

Fig. 1: Structural design of the AKROS rowing boat

Simulation and mathematical models

Optimization was based on varying the geometries of the rotor blades, the composite wing, and the gap between the rotor and the contoured duct inside the wing.

Due to the fact that optimization is resource-intensive, the priority was selecting the right approach to the blading nomenclature to define the blade profile shape with the minimum number of optimization variables. This significantly speeded up the optimization.

Geometry parameterization of the turbine rotor blade with six dimensional parameters is shown in Fig. 2. The geometry of the blade profile was updated by modifying the leading blade angle LeadingAngle, the blade chord Length, the maximum profile width Width, the leading edge radius and the trailing edge radius EdgeR. The two additional dimensional parameters were used for the number of blades count and the gap between the rotating rotor as well as the fixed duct inside the wing Clearance.

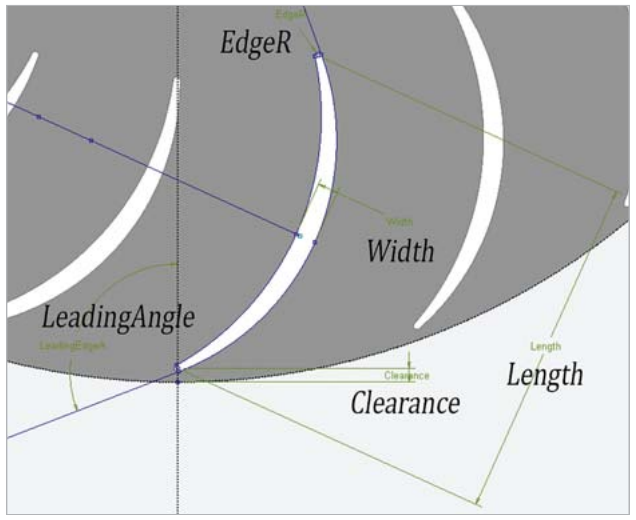

Fig. 2: Simulation model of a wind turbine

The aim of rotor geometry optimization was to maximize the wind turbine efficiency and power with regard to the rotor speed constraint and geometries of the turbine.

In all simulations, the airspeed was assumed equal to 15 m/s, which corresponds to the average annual wind speed in the "forties". The turbulence level was 5%. The curvature-corrected SST k-ω turbulence model was used.

Most of the simulations were carried out by a 2D frozen-rotor approximation. When using the Frozen Rotor approach, all steady-state simulations were performed simultaneously for all blade channels without a circumferential averaging. The obtained quasi-unsteady flow field determined the interaction between the rotor and the stator quite accurately and did not require many computational resources, which was critical to optimization.

At the design completion stage, a number of 2D and 3D steady-state simulations were performed for the optimized turbine geometry.

In order to obtain convergence to a two-dimensional steady-state solution in ANSYS CFX 18.2 with a residual of 10e-5, nearly 130 iterations were required.

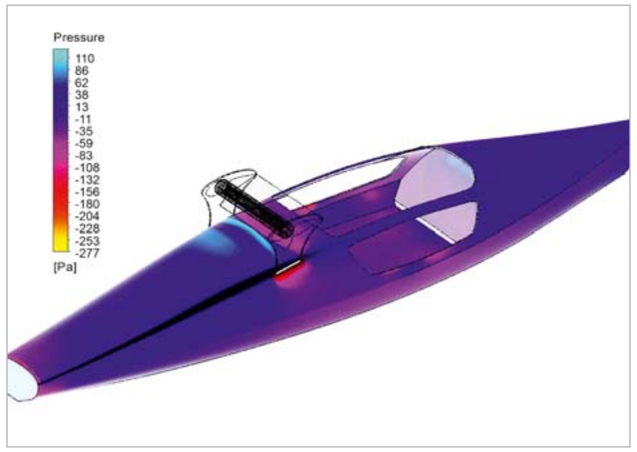

Fig. 3: Unsteady-flow simulation of a wind-turbine boat hull

Geometry optimization process

Geometry optimization of the rotor was performed with the ANSYS optiSlang toolbox and involved the following steps:

1. Sensitivity analysis
2. Parametric response surface modeling
3. Response surface optimization
4. Validation of the Pareto optimal solutions

According to the sensitivity analysis, there is no linear relationship between the pairs of input parameters (no correlations close to 1 or -1). The correlation values mostly

Fig. 4: Parameter correlation matrix

Parameter	Minimum value	Nominal value	Maximum value
Length	30 mm	50 mm	60 mm
EdgeR	0.25 mm	0.5 mm	1 mm
Clearance	0.5 mm	1.5 mm	2 mm
LeadingAngle	100°	110°	130°
Width	1 mm	3 mm	6 mm
Count	15	17	19
TSR	0.3	0.3	0.65

Table 1: Response range of dimensional parameters

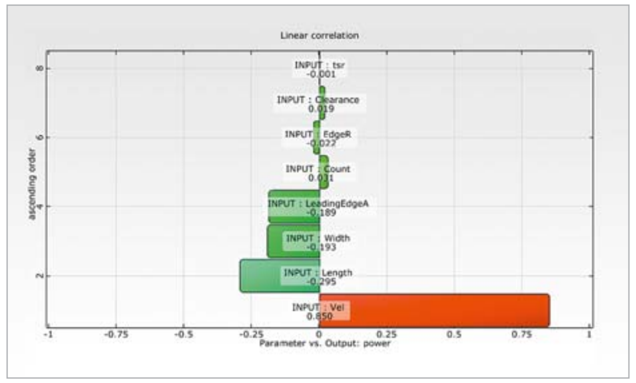

Fig. 5.: Effect of parameters on the wind turbine power

range between -0.5 ... + 0.5 making it clear that there is either no mathematical correlation between the parameters or the correlation is highly nonlinear. There is a nominal non-zero correlation between quite obvious pairs of parameters, for example, the turbine power and the airspeed.

Correlation calculation and response surface modeling required 155 solver calls, i.e., 155 design simulations of the turbine rotor. From the set of simulation points, a response surface was modeled (surrogate/substructure response models) and a Coefficient of Prognosis was estimated.

A Coefficient of Prognosis (CoP) of 95% indicates that the response surface matches well with the design response and may result in successful optimization.

The geometry optimization of the rotor was based on response surface methodology and required no solver calls. Alternatively, the so-called Metamodel of Optimal Prognosis (MOP) solver was used. This metamodel solver estimates the values of output parameters based on the values of input parameters.

The objective was to maximize the turbine power. The two geometric constraints for the selected parameters are critical keys for an accurate geometry and mesh modeling.

During the response-surface optimization, 7,900 points were counted with the MOP Solver and, subsequently, the Pareto front was found.

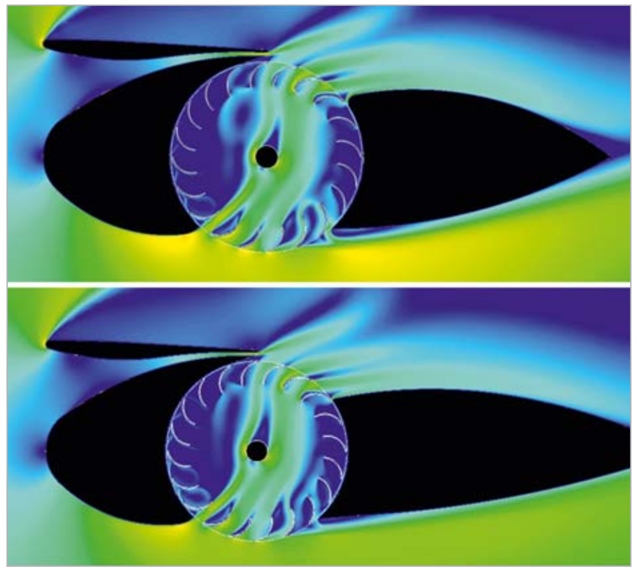

Fig. 6: 2D simulation of various turbine rotor and wing geometries

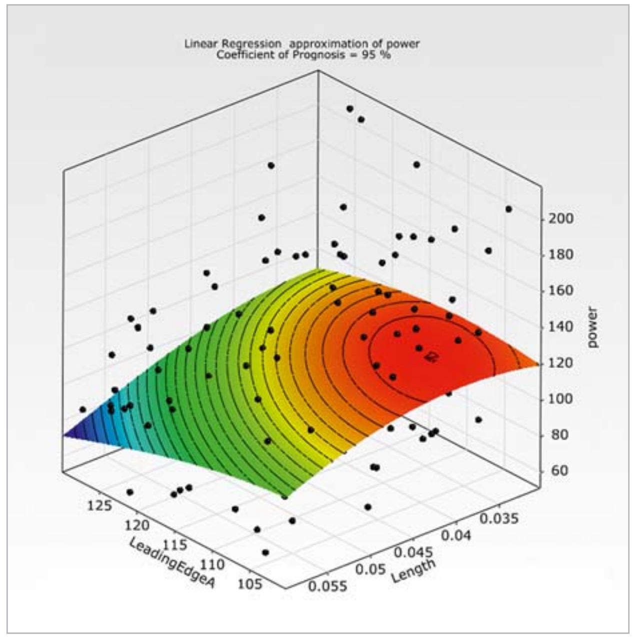

Fig. 7: Response surface

After the response-surface optimization, the optimal solution was validated, i.e., by using a full-scale design solver for the simulation of the design with optimal values of the input parameters.

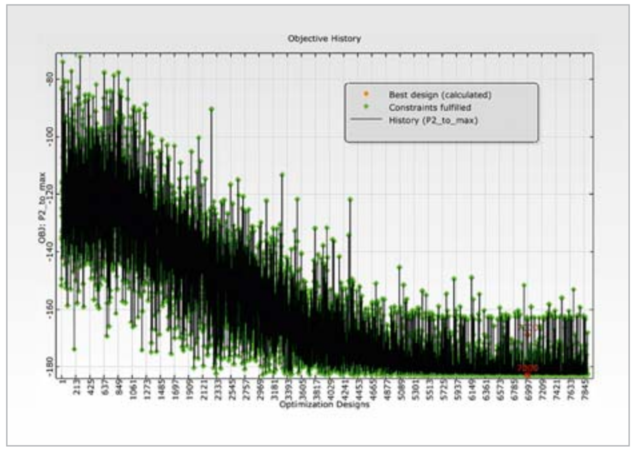

Fig. 8.: Optimization process convergence

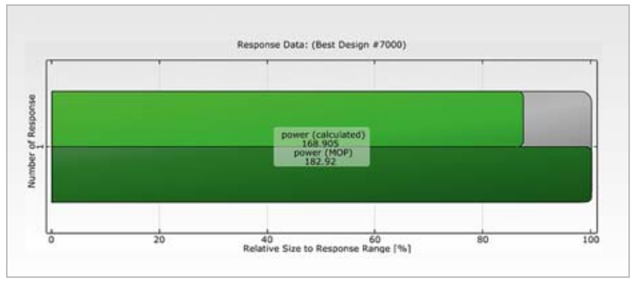

Fig. 9.: Power values: response surface vs. validated solution

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