Putting a new spin on propeller design

With regard to propeller design MARIN focuses on the best possible compromise between the propulsive efficiency and cavitation nuisance, and how further improvements can be made.

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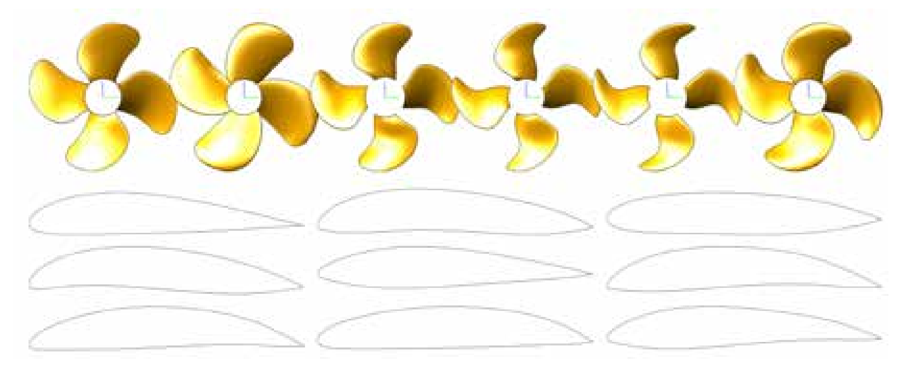

Figure 2: Propellers and hydrofoil shape within the first stage of an optimisation

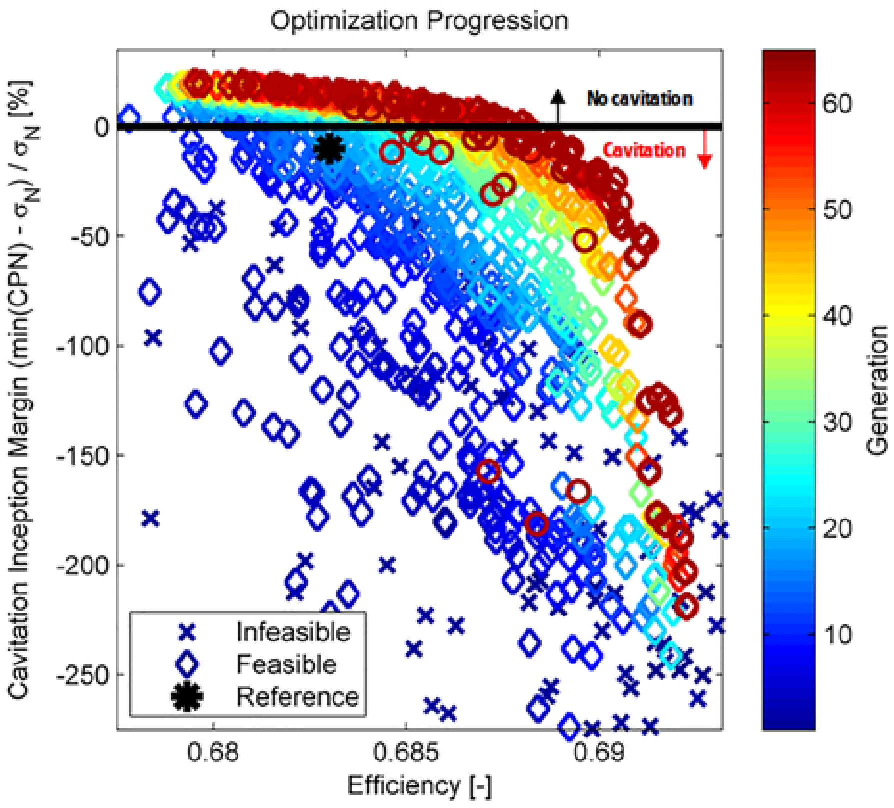

Figure 1: Example of an optimisation case with the Pareto front in red. The margin against cavitation inception and efficiency are maximised. CPN is the pressure coefficient and σ_N the cavitation number.

This applies to a wide range of designs such as high-end, 'low-noise' propellers for yachts, naval, research and cruise ships with delayed cavitation inception, high performance propellers for merchant ships, or propellers for special purpose vessels such as dredgers, tugs and fishing vessels.

Currently, we are redesigning our propeller design process. For example, we used to set the diameter applying best-practice guidelines for propeller-hull clearance. Now we specify the maximum force allowed on the hull and ask ourselves: what is the best propeller design within those limits? By setting important propeller parameters at the end of the design process, and not at the beginning, we can obtain a better design. The latest design techniques are used, such as multi-objective optimisation techniques that can:

- Thoroughly explore the many design opportunities within the design space
- Analyse the propeller in all the relevant conditions simultaneously
- Visualise trade-offs between conflicting objectives
- Quantify the influence of design choices, constraints and limitations on the objectives
- Show the physical limitations on improvements
- Provide insight in the relevant design parameters for a certain optimisation goal

It is up to the designer to tune the optimisation to meet the expectations of the clients as efficiently as possible. A design is always a compromise and by using optimisation techniques this can be demonstrated using Pareto Front plots (shown in Figure 1). All designs on this Pareto Front cannot improve on one goal (e.g. efficiency) without compromising another (e.g. inception speed). Using these Pareto Fronts the customer has insight into the consequences of demanding a certain minimum efficiency. In addition, each candidate propeller within this Pareto Front can be chosen as an excellent starting point for a final tweaking towards the final propeller design.

PropArt framework To this end, we developed a framework called PropArt, coupling a parametric geometry description, optimisation algorithms and analysis codes with PROCAL as the basis. Propeller computations are performed on our computational cluster, which computes hundreds of propellers simultaneously. The main parameters, such as the diameter, blade area ratio or rate of revolutions can be selected by the optimiser. The radial distribution curves for skew, pitch, or chord, are parameterised functions which have been developed using our database of thousands of unique propeller designs. The hydrofoil shape can be varied as well, using a range of conceptual section design functions over the radius allowing for very local design choices, such as optimising the leading edge radius for improved cavitation inception performance, or for offering sufficient strength when operating in ice. Typically, the parameterisation results in between 20 and 50 design parameters. Figure 2 shows an example of some designs in the early stage of optimisation.

PropArt is capable of satisfying the constraints automatically, while converging to the best possible values within the given design space. During the first step a propeller geometry is created in line with the main design condition. Typically this is the thrust required at trial conditions at the design rate of revolutions. Next, multiple off-design conditions can be evaluated. The objectives and constraints can be a combination of efficiency, the risk of cavitation erosion, tip vortex noise, hull pressure levels, radiated noise, weight and so on.

Multi-fidelity approach In the future our goal is to use a combination of accurate, but more time-consuming ReFRESCO CFD computations and faster, but less accurate methods in one single optimisation. This multi-fidelity approach combines all our tools to obtain the best results in the shortest amount of time.

Furthermore, we need to divert from the traditional calm water situation. A ship has to face non-optimal weather conditions, multiple modes of operation and requirements concerning manoeuvring capabilities. In the near future the effects of manoeuvring and seakeeping will be taken into account as well.

It will become even more important to optimise the propeller and ship hull together. By using ReFRESCO during the design phase we can predict the effect of the propeller design on the hull. We already know that a ship designed for the lowest resistance is not necessarily the ship that requires the least amount of engine power or allows for a propeller with the lowest cavitation hindrance. Our future objective is to optimise the hull and propeller together to minimise both power and cavitation hindrance.

Foeth, E.J. (2015). Systematic propeller optimization using an unsteady boundary-element method. SMP'15, Austin, Texas, USA.

Huisman, J. & Foeth, E.J. (2017). Automated multi-objective optimization of ship propellers. SMP'17, Espoo, Finland.

Scholcz, T.P. & Veldhuis, C.H.J. (2017). Multi-objective surrogate based hull-form optimization using high-fidelity RANS computations. MARINE 2017, Nantes, France.