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A. Serani (CNR-INM, Italy), T. P.Scholcz (MARIN, Netherlands) and
H. P. Solak (Pîrî Reis University, Turkey)

Robust Parametric Models for Simulation- and Data-driven Design

Stefan Harries [*], Martin Fischer [°] and Heinrich von Zadow [**]

[*] FRIENDSHIP SYSTEMS
Benzstr. 2, 14482 Potsdam, Germany
e-mails: [*] harries@friendship-systems.com (corresponding author),
[**] von.zadow@friendship-systems.com (presenting author),
web page: www.friendship-systems.com

[°] INEOS Britannia
e-mail: martin.fischer@ineosbritannia.com, web page: www.ineosbritannia.com

ABSTRACT

In naval architecture many functional surfaces such as hulls, foils, rudders and propellers feature complex shapes with compound curvature, see figure 1. In simulation-driven design these shapes are subject to variation. Since many variants are investigated during design space exploration and for optimization campaigns robust models are needed that yield very low failure rates, preferably zero failure, meaning 100% robustness. In addition, often quite a few constraints have to be met which calls for nested optimizations and for comprehensive checks before launching any expensive simulation.

The time spent and the workforce bound to create, repair and review shapes interactively are too large, preventing traditional Computer Aided Design systems with a history-based modeling approach to be effective. Rather, a dedicated approach is needed that allows combining a range of modeling techniques and readily incorporating constraints. Using the data that are automatically generated, for instance by means of a Design-of-Experiment (DoE), machine learning (ML) models can be trained.

The presentation will cover techniques of defining robust parametric models for simulation- and data-driven design as implemented in CAESES®, discussing examples from sports, recreation and industry.

Fig. 1: Complex shape of an AC75 class hull as needed for machine learning

From sports, a robust parametric model of the hull for the 37th America's Cup, see figure 1, will be presented, using the effort by INEOS Britannia of identifying a hull shape that differed from the competition and that led to winning the Louis Vuitton Cup in 2024. The fully-parametric approach captured a large number of the many constraints set by the AC rules.

From recreation, a fully-parametric approach of modeling and optimizing a tip-rake propeller for a super-light electric motor boat will be presented, see figure 2. It will be presented how the planing hull could reach a top speed above 32 km/h with a 12 kW propulsion system, a 16.7% increase compared to the baseline.

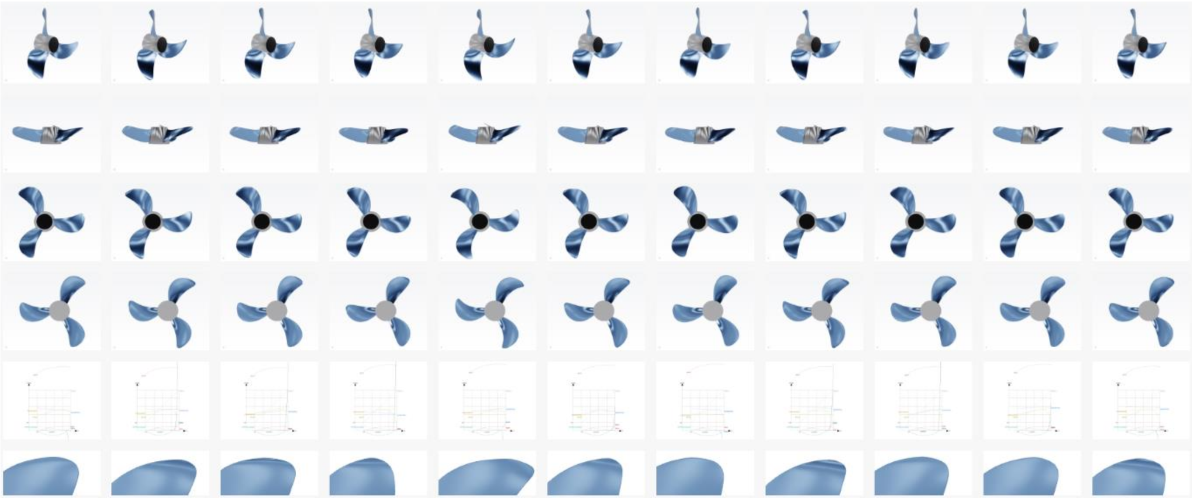

Fig. 2: Variation of a tip-rake propeller within a DoE

From industry, a hybrid model, combining fully- and partially parametric modeling, will be presented as used for the optimization of an electric pilot boat and crew transfer vessel for the port of Singapore, see figure 3. Here, constraints for the storage of batteries needed to automatically captured before launching RANS simulations. Even with tight constraints due to the batteries weight and size, a 10% improvement in power consumption has been achieved.

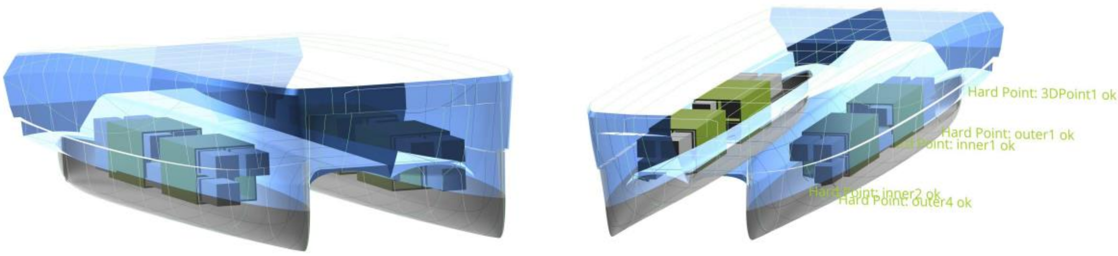

Fig. 3: Hybrid parametric model of an electric boat

Each of the three examples for robust parametric models will be used to showcase important aspects: The AC model is highly-complex and needs to observe a large number of constraints, the propeller model is fully-parametric and incorporates all aspects of the geometry directly while the model for the electric boat is hybrid with fully- and partially-parametric modeling components. Each example will be discussed in the context of its practical application and the results achieved at full-scale.