Efficient Reduction in Shape Parameter Space Dimension for Ship Propeller Blade Design

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ABSTRACT

In this work, we present the results of a ship propeller design optimization campaign carried out in the framework of the research project PRELICA, funded by the Friuli Venezia Giulia regional government. As the project joins the efforts of both academic and industrial partners, the campaign made use of different methodologies and techniques to explore possible reduction in the propeller noise emissions with no reduction of hydrodynamic performance. Thus, the main idea of this work is to operate on a multidisciplinary level to identify propeller shapes that lead to reduced Tip Vortex-Induced pressure and increased efficiency without altering the thrust. A first component of such a process is represented by a suitable shape parameterization tool. A propeller is in fact a highly engineered shape, which cannot be easily treated with general purpose shape parameterization methodologies (such as Free Form Deformation or Radial Basis Functions) without affecting the shape of the sectional airfoils or other characteristics that have been specifically selected over the years by engineers. A specific tool for the bottom-up construction of parameterized propeller blade geometries has been developed. The algorithm proposed operates with a user defined number of arbitrary shaped or NACA airfoil sections, and employs arbitrary degree NURBS to represent the chord, pitch, skew and rake distribution as a function of the blade radial coordinate. The control points of such curves have been modified to generate, in a fully automated way, a family of blade geometries depending on as many as 20 shape parameters. Such geometries have then been used to carry out potential flow simulations with the Boundary Element Method based software PROCAL. Given the high number of parameters considered, such a preliminary stage allowed for a fast evaluation of the performance of several hundreds of shapes. In addition, the data obtained from the potential flow simulation allowed for the application of a parameters space reduction methodology based on active subspaces (AS) property (see [1] for details on a naval application). AS analysis was able to suggest that the main propeller performance indices are, at a first but rather accurate approximation, only depending on a single parameter which is a linear combination of all the original geometric ones. AS has also been used to carry out a constrained optimization exploiting response surface method in the reduced parameter space, and a sensitivity analysis based on such surrogate model. The few selected shapes were finally used to set up high fidelity RANS simulations and select an optimal shape.

REFERENCES

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