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Geometric awareness in high-order numerical modelling of hydrofoils

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ABSTRACT

The aim of this contribution is to present a flexible and efficient software library developed for hydrodynamic performance prediction of hydrofoils and other boat and ship appendages. The simulations of the three dimensional flow past these streamlined bodies are based on the quasi-potential flow model, as in Gennaretti et al. (1996). In the framework of such potential flow model, the presence of a thin vortical wake detaching from the trailing edge is accounted for as a surface of discontinuity of the velocity potential. The entity of the local potential jump is here computed by means of a nonlinear Kutta condition, imposing continuous pressure at the trailing edge and across the wake. The resulting Laplace boundary value problem is discretized via a collocation Boundary Element Method (BEM) coupled, at the trailing edge, with a variational formulation of the nonlinear Kutta condition discretized via the Finite Element Method (FEM). Both the collocation BEM and FEM formulations are based on arbitrary order continuous Lagrangian shape functions. The resulting nonlinear system of algebraic equations is solved by means of Newton iterations. A distinctive feature of the solver is its geometric awareness. Unlike traditional methods that rely on fixed meshes, this approach interfaces directly with CAD data structures, in the form of IGES and STEP files. This capability allows for the solver to have access to the effective geometry of the streamlined body considered, and use it for tasks such as initial mesh refinement, addition of points as needed by high-order Lagrangian elements, or adaptive refinement. In the framework of quasi-potential flow, the position of the wake is an unknown of the mathematical problem. We make use of the Hypersingular Boundary Intergral Equation (HBIE) to calculate the fluid velocities at the support points of the system degrees of freedom, and align the wake with the local flow. The hypersingular integrals in the HBIE are discretized using Guiggiani quadrature formulae, Guiggiani et al. (1992). The influence of the water free surface on the hydrodynamic forces generated by the submerged hydrofoils and appendages is also investigated. Different modelling strategies are considered, so as to capture the interaction between the lifting surfaces and the free surface. This allows the solver to deal with the main physical phenomena and offer reliable results under realistic conditions. Preliminary results on canonical test cases, such as isolated rectangular and swept wing with NACA0012 airfoil section, show good agreement with experimental results, Cattarossi et al. (2024). Numerical calculations on more realistic T-shaped hydrofoil geometries will also be presented and discussed.

References

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