XI International Conference on Computational Methods in Marine Engineering

On the Merits of a Lifting Line Model for Simulating Hydrofoil Hydrodynamics

Lev Chernyshev[1,*], Natalia Kabaliuk[1] and Mark Jermy[1]

[1] Department of Mechanical Engineering, University of Canterbury
Ilam, Christchurch, Canterbury, 8041, New Zealand

[*] lev.chernyshev@pg.canterbury.ac.nz

ABSTRACT

In the last decade, the popularity of hydrofoils on marine craft has increased significantly, particularly in the yachting industry and on recreational products. With a widespread push for more efficient, low-emission transport, commercial applications for fast ferrying of passengers and cargo are also being explored. Hydrofoil design poses a significant challenge to naval architects, due to complex hydrodynamics and operating regimes which are challenging to analyse (Faltinsen, 2005). Marine engineers employ a range of tools to study hydrofoil hydrodynamics, ranging from experimental methods in water tunnels and tow tanks; to simulation-based approaches such as computational fluid dynamics (CFD) and other numerical models. To reduce cost, much of the preliminary design is done using the latter (Newman, 2018). Accurate and validated methods for simulating hydrofoils are therefore crucial for engineers seeking to develop efficient and performant designs.

In this study, we showcase the development, validation, and application of a numerical lifting-line (LL) model for simulating hydrofoil hydrodynamics (Chernyshev et al., 2024). This model was adapted to simulate free surface and wave-making effects by employing a Green's function for a source in steady motion under a free surface, originally derived by Newman (1987). High-fidelity steady Reynolds-Averaged Navier Stokes (RANS) simulations were used as a benchmark to verify the LL model's accuracy. This was done by first validating the RANS model against experimental datasets, and then using it to simulate a rectangular NACA4412 hydrofoil submerged one chord-length beneath the free surface at Reynolds numbers between 2.57×10^5 and 2.06×10^6 (Froude numbers between 0.5 and 4) and comparing the results with the LL model.

Overall reasonable agreement between LL and RANS was seen when comparing the lift, drag and moment coefficients across all simulated Froude numbers. The LL model also simulated the downstream induced velocities behind the hydrofoil with fidelity that was on par with RANS. This increased our confidence that the LL model can be relied upon for dictating design choices and direction at the preliminary stage of design. Its key advantage over RANS was its efficiency with compute resources, permitting extensive parametric design studies (e.g. exploring how different taper/twist combinations affect the resistance) and optimisation. However, great care should be taken when interpreting the LL results as the theoretical models employed, especially for the free surface effects, were difficult to validate and still showed considerable discrepancies with RANS, particularly when simulating regimes with intermediate Froude numbers.

References

Chernyshev, L., Kabaliuk, N., Jermy, M., Corkery, S., & Bernasconi, D. (2024). *Evaluating Hydrofoil Resistance Components from RANS and Lifting-Line Fluid Simulations* SNAME Maritime Convention, https://doi.org/10.5957/SMC-2024-033

Faltinsen, O. M. (2005). *Hydrodynamics of high-speed marine vehicles*. Cambridge university press.

Newman, J. N. (1987). Evaluation of the Wave-Resistance Green Function: Part 1—The Double Integral. *Journal of ship research*, *31*(02), 79-90. https://doi.org/10.5957/jsr.1987.31.2.79

Newman, J. N. (2018). *Marine hydrodynamics*. The MIT Press.