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CN-AeroModels: A C++ implementation of aerodynamic models for wind propulsion systems of cargo ships

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Summary

Wind propulsion systems are technologies that aim to reduce greenhouse gas emissions in the maritime transport sector by partially (or totally) replacing combustion engines. Several methods have been proposed to assess the aerodynamic forces they generate as a function of wind and ship sailing conditions; however, they have not yet been integrated into an efficient open-source numerical tool. `CN-AeroModels` has been developed to fill this gap.

Statement of need

Key aspects to consider in the computation of aerodynamic forces generated by a wind propulsion system are aerodynamic interactions between the possibly numerous wind propulsion units (e.g. wingsails, Flettner rotors, …) making up the wind propulsion system, wind shear and computational time. Therefore, `CN-AeroModels` implements:

- The Nonlinear Lifting Line theory of Phillips & Snyder (2000). This theory was selected because comparisons of its results with experiments or Computational Fluid Dynamics (CFD) for wind propulsion units and wind propulsion systems have shown good agreement (Graf et al., 2014; Kramer & Steen, 2022; Schot & Garenaux, 2023). It is also orders of magnitude faster than CFD,
- The ISILL method of Malmek et al. (2024). This recent method can be considered a simplified version of the Nonlinear Lifting Line theory. Its advantage is that it seems to suffer less from convergence issues than the Nonlinear Lifting Line theory while still providing meaningful results compared to CFD or experiments (Malmek et al., 2024).

For comparison, `CN-AeroModels` also implements the strip theory. However, this method is not recommended as it does not account for interactions between multiple wind propulsion units.

Open-source implementations of the Nonlinear Lifting Line theory already exist, such as `xflr5` (Deperrois, 2023) and `MachUpX` (Moulton et al., 2024). However, these software have been developed to analyze airplanes in flight. Moreover, we wanted a wind propulsion system model that could be easily coupled to the open-source ship simulator `xdyn` (Cady et al., 2021) to investigate the effect of wind propulsion systems on manoeuvering and seakeeping. Therefore, we decided to develop `CN-AeroModels` by building on parts of the `xdyn` code rather than adapting `xflr5` or `MachUpX`.

Other significant differences between `CN-AeroModels` and `xflr5` or `MachUpX` are:

- To date, the ISILL method is available in neither `xflr5` nor `MachUpX`,
- `CN-AeroModels` includes the option to optimize the trim of the wind propulsion system. The optimization method uses a slightly modified version of `openGA` (Mohammadi et al., 2017).

Implementation, Verification and Validation, Future perspectives

`CN-AeroModels` was developed in C++ (like `xdyn`). It includes a comprehensive documentation. It has been verified and validated against experimental and numerical data published in Phillips & Snyder (2000), Graf et al. (2014), Badalamenti & Prince (2008), Malmek (2023), and Malmek et al. (2024). It is already being used at the LHEEA for an experimental project to provide target aerodynamic loads to an actuator that emulates the wind propulsion system during tank testing of ships (software-in-the-loop approach). It will also be used in a PhD project investigating sail-induced resistance effects. By releasing `CN-AeroModels` as open source, we expect it will be widely used in the research and industry of ship wind propulsion systems.

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References

Badalamenti, C., & Prince, S. A. (2008). The Effects of Endplates on a Rotating Cylinder in Crossflow. *Proc. Of the 26th AIAA Applied Aerodynamics Conference*. https://doi.org/10.2514/6.2008-7063

Cady, C. E., Jacquenot, G., Lincker, L., & Charlou, M. (2021). Xdyn. In *GitLab repository*. GitLab. https://gitlab.com/sirehna_naval_group/sirehna/xdyn

Deperrois, A. (2023). xflr5. In *SourceForce repository*. SourceForce. https://sourceforge.net/projects/xflr5/

Graf, K., Hoeve, A. v., & Watin, S. (2014). Comparison of full 3D-RANS simulations with 2D-RANS/lifting line method calculations for the flow analysis of rigid wings for high performance multihulls. *Ocean Engineering*, *90*, 49–61. https://doi.org/10.1016/j.oceaneng.2014.06.044

Kramer, J. V., & Steen, S. (2022). Sail-induced resistance on a wind-powered cargo ship. *Ocean Engineering*, *261*(11688), 49–61. https://doi.org/10.1016/j.oceaneng.2022.111688

Malmek, K. (2023). *Rapid aerodynamic method for interacting sails*. Thesis for the Degree of Licentiate of Engineering, Chalmers University of Technology, Gothenburg, Sweden.

Malmek, K., Larsson, L., Werner, S., Ringsberg, J. W., Bensow, R., & Finnsgard, C. (2024). Rapid Aerodynamic Method for Predicting the Performance of Interacting Wing Sails. *Ocean Engineering*, *293*(116596). https://doi.org/10.1016/j.oceaneng.2023.116596

Mohammadi, A., Asadi, H., Mohamed, S., Nelson, K., & Nahavandi, S. (2017). OpenGA, a c++ genetic algorithm library. *Systems, Man, and Cybernetics (SMC), 2017 IEEE International Conference on*, 2051–2056. https://doi.org/10.1109/SMC.2017.8122921

Moulton, B., Goates, J. K., Goates, C., Hunsaker, D., & Schoenfeld, J. (2024). MachUpX. In *GitHub repository*. GitHub. https://github.com/usuaero/MachUpX

Phillips, W. F., & Snyder, D. O. (2000). Modern Adaptation of Prandtl's Classic Lifting-Line Theory. *Journal of Aircraft*, *37*(4). https://doi.org/10.2514/2.2649

Schot, J. J. A., & Garenaux, M. (2023). Modelling of aerodynamic interaction effects for wind propulsion applied in commercial shipping: Development of a non-linear lifting line method. *Proceedings of the 6th International Conference on Innovation in High Performance Sailing Yachts and Wind-Assisted Ships*, 381–412.