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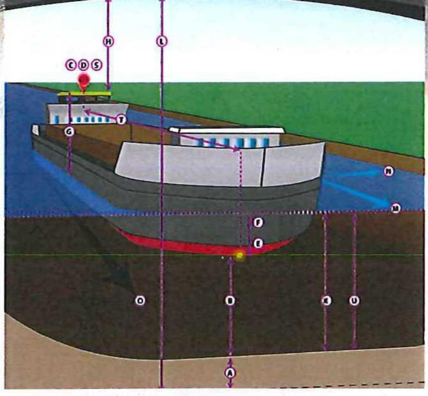
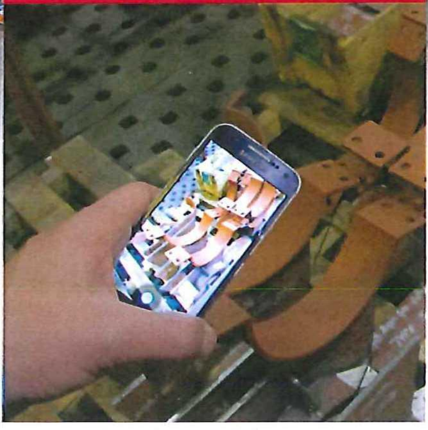
Terminal Automation

Real Time Water Depth Measurements



RFID in de scheepsbouw



Wind-assisted Propulsion

Voortstuwing

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Wind-assisted Propulsion for Commercial Ships

Towards a Reliable Assessment of Wind Energy Potential

The Enercon E-Ship1 equipped with four Flettner rotors (picture by Alan Jamieson).

The Sail Assist project, which started at the Delft University of Technology at the end of 2013, aims to facilitate the assessment of wind-assisted propulsion. A goal that is to be met by introducing a quick and reliable design tool, the Performance Prediction Program.

Wind energy as an auxiliary form of propulsion for commercial ships has again become of great interest as a possible response to volatile fuel prices and increasingly stringent environmental regulations as supported by a study published by Lloyd's Register [1] in February 2015. The same study, however, underlines how a well-founded performance prediction is a key prerequisite for the further development and the uptake of this promising technology. Within the framework of the European Joules project and with the support of Damen Shipyards, Marin and Dykstra Naval Architects, a group of researchers at Delft University of Technology is developing a performance prediction program for these hybrid ships.

Balancing Forces

The Performance Prediction Program (PPP) can be used throughout the entire design process. In the early-design phase, when the user wants to explore several different designs, use can be made of the in-built aero- and hydro-force model. At the moment, most of the resources are dedicated to the development of such an in-built force model. In a more advanced design phase, the user can input his own external data in the program, obtained perhaps by means of dedicated CFD calculations and experiments. In this case, very detailed results can be obtained for the specific design under consideration.

The fundamental task of the PPP solver is to balance the aerodynamic and hydrodynamic forces acting on a wind-assisted ship to

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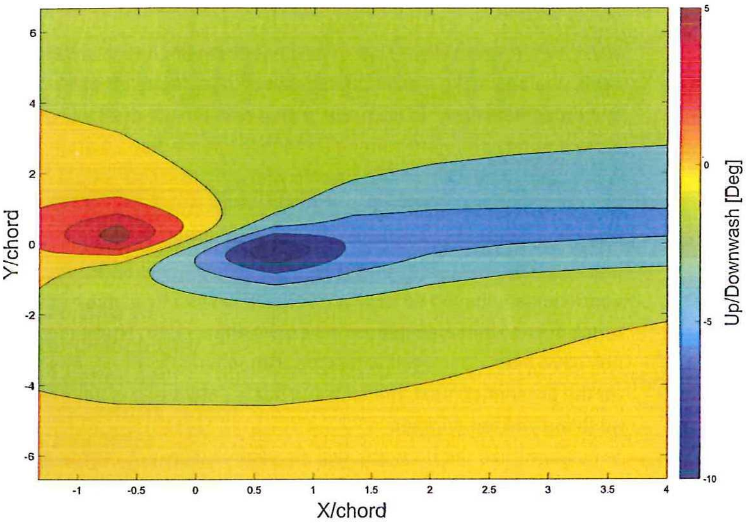


Typical change of flow angle of incidence around a Dynari calculated with the horseshoe vortex method.

arrive at a sailing equilibrium. This is done within an optimisation routine that maximises the per cent total thrust provided by the sail plan (thrust benefit) while maintaining a prescribed vessel speed. Alternative optimisation routines may include pure sailing, delivering nominal engine power and maximising speed, or maintaining a minimum speed. A vessel's performance is determined for a range of true wind angles and true wind speeds. The output of the PPP can be fed to a weather routing program, where the environmental and economic evaluation of the wind-assisted ship can be determined for a specific application.

Aerodynamic Aspects

During the initial phase of the project, it appeared that arguably the most challenging aspect to properly estimate the aerodynamic performance of a wind-assisted ship is to take into account all the complex aerodynamic interaction effects that occur on board of the ship. Due to the complexity of these phenomena, and the lack of simple ways to take them into account in the performance prediction, they were often neglected, although their impact on the overall performance of the ship was proven by studies such as [2]. Needless to say, that an inaccurate performance prediction leads to an unreliable evaluation of wind energy potential in shipping.

Another appreciable finding of the initial phase of the project was that the aerodynamic characteristics of several wind propulsion systems (Flettner rotors, Dynarig, Wing sails, et cetera) are more or less known, if taken singularly, meaning that the amount of aerodynamic force (lift and drag) that each system is able to generate in a certain weather condition can be properly estimated.

Following this condition, and having in mind the aim of the PPP to be a generic, quick, yet reliable design tool, it was decided to develop a method that can be applied to a large number of different designs capable of taking into account the aerodynamic interaction effects. For the sake of clarity, the interaction effects are divided into two categories and they are treated separately:

1. the interaction effects occurring between the several wind-propulsion systems mounted on the ship's deck, and
2. the interaction effects occurring between the propulsion systems and the ship itself (hull, superstructure, cargo, and so on).

Regarding the first type, the hypothesis standing behind the methods that will be discussed is that, effectively, the interaction effects between several propulsion systems mainly concern two phenomena: change of the flow angle of incidence, and reduction of the incoming flow velocity. The first effect is mainly caused by lift while the latter is mainly caused by drag. Knowing the lift and drag generated by the propulsion systems installed on board a ship, it is therefore possible to estimate the way they interact with each other. Two different approaches are currently being tested: a modified version of the horseshoe vortex method and the body force method. The first one, although very simple, has proven to give encouraging results while the latter is a CFD method that implies the introduction of an extra force (body force or, in this case the lift and drag of a certain propulsion system) in the Navier-Stokes equations, resulting in a much faster solution than standard CFD simulations. Validation of these methods is going to be carried out in the wind tunnel facility of the Polytechnic University of Milan in March 2016.

On the other hand, the numerical methods mentioned above are not suitable to investigate the interaction effects occurring between the ship and the propulsion systems. The ship's structures are in fact blunt bodies and their main effect on the flow is to generate large areas of turbulence and separation. Even CFD Rans simulations are not likely to be effective for such purpose. Thus, the second type of interaction effect will be directly studied by means of experiments. A systematic series of wind-assisted ship models representative of several different designs will be generated and tested at the Polytechnic University of Milan, most likely in the second half of 2016. Eventually, the data collected during the testing campaigns will be processed and combined into the aerodynamic model of the PPP.

Hydrodynamic Aspects

Sailing with an auxiliary wind propulsion system will have a significant impact on a ship's behaviour, as the ship must provide the necessary reactionary forces to counter the lateral component of the aerodynamic side force, as well as the heeling moment. As a result, at equilibrium, the ship will adopt a steady-state heel and leeway angle: the sailing condition. Any resulting drag penalty incurred will negatively impact the performance of the wind-assisted ship. The "sailing condition" will also influence the conventional propulsor, as the propeller thrust is not directed along the direction of travel, and the propeller is subject to oblique inflow. The sailing condition's influence on resistance, yaw balance, propeller efficiency, stability, manoeuvrability and seakeeping all require careful study.

For brevity's sake, I will introduce side-force generation in this piece. The hull of a commercial ship differs significantly from that of a conventional sailing yacht, and operates at a lower Froude number. A key task is to find hull form features which deliver the needed forces effectively and efficiently. This is a new area for commercial ships. When speaking of side-force generation (in the absence of a keel), one can make a distinction between circulatory lift generation and cross-flow drag. To illustrate, a ship with infinite draft will generate a purely circulatory lifting force in the same way as a wing with infinite span. Alternately, a ship with infinite length would have no leading or trailing edge and thus no circulation, and the side-force is generated by momentum transfer as vorticity is shed from the ship. The cross-flow drag is typically modelled as an empirical approximation based on the transverse flow velocity, though other terms may be included depending on the application. These methods have been developed within the manoeuvring context, whereas for the present context, the leeway (that is drift) angle is not expected to exceed ten degrees.

Simulations like the Rans solution displayed below are computationally prohibitive within the context of the PPP. When developing a regression that will allow the interpolation of simulation results, a physical model for the breakdown of the force into components is key as it is difficult otherwise to distinguish between the components. The flow separation seen along the bilge is categorised as cross-flow drag in the manoeuvring context, but may be interpreted as the "tip vortex" of a low-aspect wing. The rudder's tip vortex is clearly distinguishable; however, the conceptualisation of the hull as a low aspect ratio foil is not tenable. It is expected that tip effects will influence the nature of the flow over the entire span. In addition, the ship's wake will manifest as pressure variations at the free surface, the "root" of the wing, further disrupting any resemblance to the two-dimensional flow models.

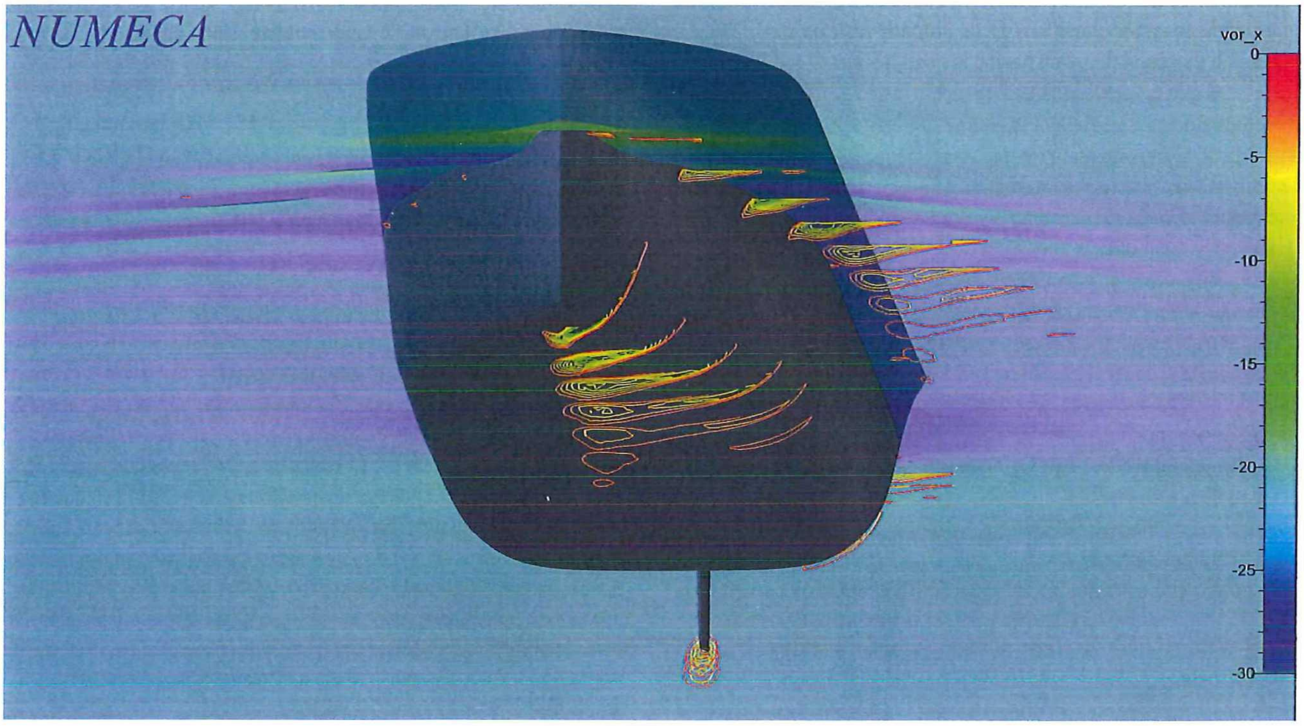
Accurate Modelling Essential

To conclude, a sufficiently accurate modelling of the aero- and hydrodynamic force components described above is essential for the prediction of performance gains by wind-assisted technologies, and a necessary requisite for a sound environmental or economic evaluation. The Wind Assist Project deliverables are due at the end of 2018. Comments and questions are welcome at the author's e-mail addresses.

References

[1] D. Argyros, "Wind-powered shipping: a review of commercial, regulatory and technical factors affecting the uptake of wind-assisted propulsion". Lloyd's Register Marine, Southampton 2015

[2] T. Fujiwara, G.E. Hearn, F. Kitamura and M. Ueno "Sail-sail and sail-hull interaction effects of hybrid-sail assisted bulk carrier", J Mar Sci Technol (2005) 10:82-95



Full model sailing toward the camera, showing iso-contours for the x-component of the vorticity. Leeway and rudder angles equal three degrees. Observe the separation of a bilge vortex near the bow and the strong tip vortex of the rudder.