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Hydrodynamic ship design for service conditions

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ABSTRACT

An innovative design methodology considering the simulation of the operational life of a ship is presented, including weather factors and off-design floating conditions. Different methods and data are integrated within a simulation software to achieve this. Advanced numerical methods, mainly Computational Fluid Dynamics (CFD), are used for the analysis of the hydrodynamic performance of the ship in calm water and waves. An application example is shown and results are discussed.

1. Introduction

Currently, the evaluation of hydrodynamic ship performance plays a decisive role in design optimisation. The application of CFD (*computational fluid dynamics*) techniques has become a standard tool for this purpose in industry, which is also the case in hydrodynamic ship design. Often, CFD results are a valuable input for design improvement but, in some cases, this improvement becomes only possible by the integration of these "local" results into a more contextualized analysis of the operational life of a ship, recalling additional sources of data and/or additional tools. This approach will be presented here as a holistic simulation-based ship design, integrating weather and other relevant operational information into the design process, especially for early design stages, where intensive use of simulation techniques is required.

The main objective of the methodology is to provide to the designer, within a preliminary design stage, detailed information about the transport efficiency of the design, in order to be able to identify the parameters leading to design improvement. At the present time, this improvement is achieved by the application of formal optimisation methods, involving modern computational techniques, as shown e.g. by Harries et al. (2006), Campana et al. (2006), Hollenbach and Friesch (2007) or Papanikolaou (2010). Due to the high complexity of the task and the large amount of computational time required for optimisation, only a few optimisation applications consider weather conditions (e.g. Boulougouris et al., 2006) and most of them are focused on a single operational speed (design speed) and a single floating condition (design condition). In contrast, some authors have presented operational simulations, usually for operational – and not design – purposes, making use of linear or slender body seakeeping methods to assess seakeeping performance (e.g. Dallinga et al., 2004; Naito, 2008).

Reynolds-averaged Navier–Stokes (RANS) CFD simulations are finding more and more applications as a design tool at early design stages, and several authors have demonstrated their suitability for accurate calculation of motions and added resistance in waves (e.g. Cura Hochbaum and Vogt, 2002; Carrica et al., 2007). In the present paper, the introduction of viscous CFD methods into an operational simulation platform for design improvement will be presented and results will be discussed.

2. Operational simulations for ships

An operational simulation will be defined as a computational simulation attempting to model the operation of a system, in this case a merchant ship. These simulations should be as realistic as possible within the limited amount of available resources. For this purpose, realistic input data and appropriate methods must be used. For the achievement of these purposes, the operational simulation program `SimOship` was implemented, being applied successfully in previous investigations) (Tampier et al., 2008). For modelling purposes, two main components are defined: an environment model and a ship model.

2.1. Environment model

For the purpose of the presented methodology, all aspects which are not inherently part of the ship are considered as part of the environment, i.e.: routes, cargo, weather and time scheduling.

Routes and cargo are known and defined, within the present approach, along the complete simulation. For this purpose, an

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automatic route generation approach has been included, creating oceanic routes (orthodromic curves) between two or more points and seeking automatically for optimum alternative routes in case of unfeasible routes over land. An example is shown in Fig. 1. For the cargo, manual input of the mass and position of cargo are required. Different scenarios can be studied in this manner, and factors such as ballast and fuel can be considered here.

The complexity of accurate weather modelling makes the use of statistical methods necessary, especially if the complete operational life of the ship is to be represented. In the present case, weather is modelled with local statistical information (short term statistics), making use of existing weather data (behind-cast re-analysis) from the European Centre of Medium Range Weather Forecasts (ECMWF) 40 year re-analysis (ERA-40) data archive (Ecmwf era-40 data portal, 2010). This database provides multiple weather information, in a data period from 1956 to 2002 in 6-h steps for each 1.5° of latitude and longitude. For the purpose of this investigation, wave data (significant wave height $H_{1/3}$, mean wave period T_1 and mean wave direction ξ_m) and wind data (wind velocity VWT and wind direction α_{WT}) are recalled from the database. An example of this data is shown in Fig. 2. From the wave information ($H_{1/3}$ and T_1), a 1D-spectrum for the sea is calculated using the JONSWAP spectrum according to the recommendations of the ITTC (1978). The remaining weather information (ξ_m, VWT, α_{WT}) is considered constant along the 6-h period. From the described weather information, defined in world coordinates (WCS), encounter weather information in ship coordinates are defined.

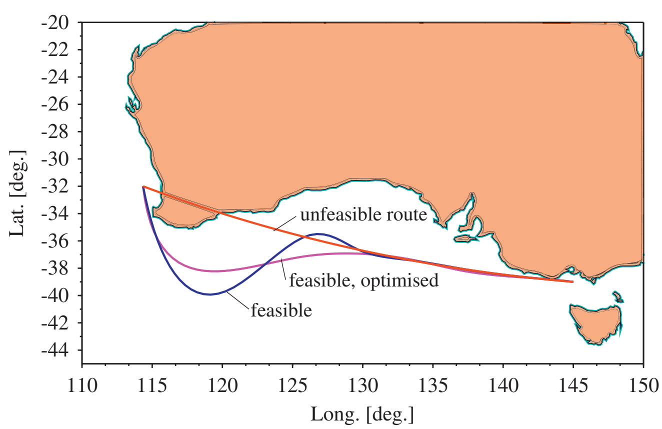

Fig. 1. Example of automatic route creation starting with an unfeasible route.

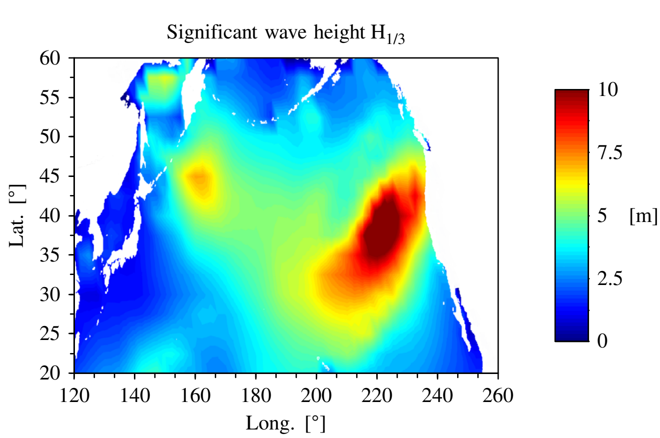

Fig. 2. Example of a ERA-40 dataset: significant wave height in the north Pacific.

2.2. Ship model

The modelling of a ship in operation can be considered as a very complex task, which must be simplified depending on the purpose of the model. An accurate, but simple ship model is probably the most difficult compromise to achieve for a successful operational simulation. The present model includes all tasks which have a direct effect on hydrodynamic and propulsive performance, including hydrostatics, resistance, propulsion, seakeeping and machinery. The simulations to be presented include all the mentioned tasks but, due to the importance of calm water resistance and seakeeping performance for the purpose of the present methodology, only these will be defined in detail here.

2.2.1. Calm water resistance

Calm water ship resistance plays a significant role in preliminary design, being its estimation with simple, but accurate methods an important task to be accomplished. The use of data sheets, systematic series, statistically based calculations and potential CFD methods are among the most typical methodologies used in preliminary design, with viscous CFD gaining importance in recent years. The presented implementation recalls calm water resistance data from any of these sources, being the statistically based method of Holtrop (1984) and the potential flow solver FS-Flow (Futureship GmbH) directly linked. The data is stored in the form of response surfaces for any given floating condition and velocity found within the operational simulation.

2.2.2. Seakeeping performance

Typically established linear, frequency domain seakeeping methods are not sufficiently accurate for a qualitative evaluation of different design variants with slight geometrical differences. Methodologies for the estimation of added resistance in waves, derived from linear methods (e.g. Gerritsma and Beukelmann, 1972) also present this disadvantage and can often be considered only as a first approximation. The present approach makes use of coarse-mesh time-domain CFD simulations, for which OpenFOAM (Open source Field Operation and Manipulation toolbox) (Openfoam user manual, 2010) has been used for the implementation of the `TUBsixDOFFoam` solver. The OpenFOAM toolbox is a collection of open source libraries and solvers for continuum mechanics problems, as described in Jasak (2009).

The implemented `TUBsixDOFFoam` finite volume, multiphase solver permits solid body motions in 6° of freedom (6-DoF) by mesh deformation and the explicit solution of the equations of motion. This solver is based on the open source solver `shipFoam` (Couwenberg, 2008), adding several improvements and corrections. The basic abilities of the solver, besides its rigid body motion feature, are based on the standard OpenFOAM `interFoam` solver, a multiphase Volume of Fluid (VoF) flow solver, which has been described and validated for multiple application cases, as shown by Deshpande et al. (2012). The rigid body motions are obtained from the solution of the equations of motion, which are solved by an explicit Euler or Runge–Kutta method, from which the 6-degree motion vector is obtained. From this vector, an automatic mesh-adaption solver generates a new mesh for the subsequent time step, simulating the rigid body motion. Due to the explicit nature of the solver, an external iteration has been added for each time step, improving the stability of calculations under sudden pressure changes, such as slamming or green water events. In its present form, the implemented solver is not able to represent turbulent flow. Since the main components for the correct prediction of forces and motions in waves are pressure forces, this drawback does not represent a significant problem for seakeeping applications. For calm water resistance applications, standard RANSE OpenFOAM solvers without rigid body motion features can be