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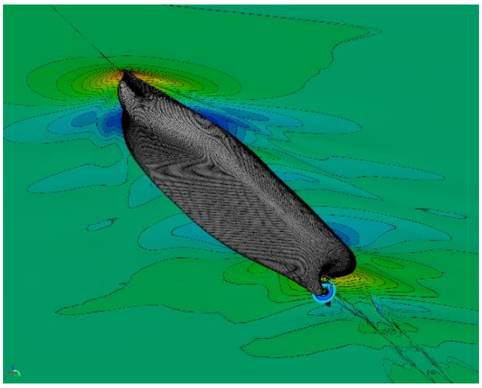
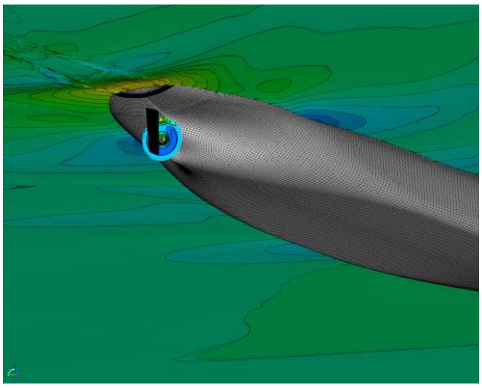
Ship power prediction with CFD in full scale





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Ship power predictions with CFD in full scale

This report demonstrates the qualifications of RISE to carry out CFD for ship self-propulsion, thus predicting the delivered power. The procedures were fully developed at SSPA which became fully integrated into the Maritime Department of RISE by 2023-01-01. An outline is given of the best-practice guidelines used at SSPA/RISE and how they comply with the relevant ITTC recommendations for verification and analysis. In addition, an overview is given of previous validation studies performed for a wide range of ships, including comparison with both model-scale and full-scale data. Complete references are provided to reports and publications in which these SSPA studies and methods are described in detail.

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Summary and recommendations

The report summarizes the qualifications of SSPA to carry out CFD for ship self-propulsion. The methodology was fully developed at SSPA which became fully integrated into the Maritime Department of RISE by 2023-01-01. An overview is given of the employed procedures, as formulated in the internal best-practice guidelines, and it is explained that they comply with the relevant ITTC and IACS guidelines. It is recommended that this methodology be applied to power predictions for full scale. In addition, they are fully applicable for EEXI evaluation with CFD.

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1 Introduction

The CFD[1]-procedure, using the software Shipflow[2], in use at RISE/SSPA for speed-power predictions in full scale is described in this report. An overview is given of the computational methods and the best-practice guidelines in use at SSPA, with references to complete descriptions. The simulations can either be carried out in model scale and translated to full scale according to ITTC-guidelines, or they can be carried out directly in full scale. Also included in the report is a summary of the most relevant verification and validation (V&V) studies which have been done with the proposed methodology.

The procedures follow the ITTC quality assurance guidelines for CFD (ITTC-7.5-03-01-02, 2021). In addition to the SSPA best-practise guidelines, a demonstration of the CFD capability of the organization is required. This demonstration is summarized in section 3.1 of the report.

A special motivation for writing this report is to demonstrate that the procedure in use at RISE/SSPA fully complies with the recent IACS[3] guidelines for the evaluation of EEXI[4] with CFD (IACS, 2022). This demonstration is presented in chapter 4 of the report.

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[1] CFD = Computational Fluid Dynamics.

[2] Shipflow 6.3 Users Manual, Flowtech International AB, www.flowtech.se.

[3] IACS = International Association of Classification Societies.

[4] EEXI = Energy Efficiency Existing Ship Index.

2 Methods

Detailed best-practice guidelines for ship hydrodynamics computations have been developed at SSPA, and are described in an internal report (Kim, 2011 & 2023a). The guidelines cover both simulations in model- and full-scale. In the present section, an overview is given of these methods.

2.1 Software

The CFD software employed is the commercial software Shipflow, which has been in use at SSPA since its initial development, see Larsson et al. (1990) for an overview of the capabilities of an early version of Shipflow. As the name suggests, the software has been specifically developed with ship applications in mind, and it core solver is based on a finite-volume discretization of the flow equations. The numerical and turbulence modelling methods are described in Section 2.3 below. Tools for mesh generation and post-processing are included in Shipflow and are described in the corresponding sections below.

The recommended procedure for power prediction consists of two simulation steps. In the first step, Shipflow's potential flow solver XPAN is used to obtain the trim and sinkage of the ship. In the second step, Shipflow's main flow solver, XCHAP, is used to compute the flow, forces and power. The necessary pre-processing and the simulation steps are described further in the sections below.

2.2 Pre-processing

A CAD-file of the ship hull in IGES-format is the recommended starting point. If the hull is provided in other formats, a separate CAD-software is used to convert it to IGES-format. Appendages, such as rudders and energy-saving devices are specified in a separate parametrized manner.

The mesh generation for the first step (XPAN simulation) is done using Shipflow's XMESH which generates a panelization (2D-mesh) of the hull surface and the water surface. The best-practice guidelines include recommendations for domain size as well as grid distribution and resolution.

The mesh generation for the second step (XCHAP simulation) is done using Shipflow's XGRID which generates a block-structured grid around the hull with H-O topology. The best-practice guidelines include recommendations for domain size as well as grid distribution and resolution. In particular, for mesh resolution around the water surface and in the stern region. The grid is generated aiming for, $y^+ \approx 1$, at the hull, thus alleviating the use of wall-functions for the turbulent boundary layer. This overall procedure typically results in a grid consisting of $\sim 30 \cdot 10^6$ cells in total.

The propeller effect is modelled by the lifting line (LL) technique. The LL model parameters are derived from the geometrical shape of the blades, i.e., the radial distribution of pitch, camber, thickness and chord length. In addition, the number of blades and the blade-area ratio needs to be specified. No propeller open-water simulation is performed.

The best-practice guidelines contain a complete specification of remaining parameters, such as turbulent inlet quantities etcetera.

2.3 Simulation

Shipflow's XPAN potential flow solver is based on surface singularity panel method (Larsson et al., 1990). It very efficiently provides a prediction of the trim and sinkage which is used in the next step. It also predicts the wave pattern and wave resistance of the hull. According to the best-practice guidelines, however, the definite prediction these quantities is obtained in the next step.

The main flow simulation is done with Shipflow's XCHAP which is a RANS-solver which also implements the volume-of-fluid (VoF) method to capture the water surface, hence computing both the water and air flow. For most ship hull types, it is recommended that turbulence is modelled using an Explicit Algebraic Stress Model (EASM) which has been shown to provide excellent flow predictions (Korkmaz et al., 2021; Hino et al. 2021), including for the wake flow. However, for slender ships, such as container vessels, the use of the $k - \omega$ SST model has been shown to provide slightly better prediction in our experience and is hence recommended for these applications.

As mentioned in the previous section, the propeller is represented using a lifting line model. Shipflow simulations with LL were submitted to the workshops in ship hydrodynamics in Gothenburg (Larsson et al., 2014) and Tokyo (Hino et al., 2021) and its power-prediction accuracy was found to be comparable to that of flow simulations including a complete propeller geometry.

Finally, it is remarked that it is possible to compute trim and sinkage also with XCHAP, thereby eliminating the first step (using XPAN). Currently, however, it is recommended to use the two-step procedure because the XPAN-simulation is very stable and computationally cheap, while providing an accurate prediction of trim and sinkage. Furthermore, the XCHAP simulation is significantly faster if iterations to determine trim and sinkage are excluded.

2.4 Post-processing

The main integral quantities computed, such as trim, sinkage, resistance, propulsive power, etc., are directly written by the solvers (XPAN and XCHAP). For further post-processing and visualization, there are several alternatives. First, the Shipflow-GUI has post-processing capabilities. Second, in particular if hull optimization is of interest, Shipflow has been linked with CAESES[5] and post-processing can be done within the CAESES-GUI. Finally, it is possible to export the full 3D-simulation results in CGNS-format for post-processing in a separate dedicated software, such as Paraview (open source) or Tecplot (commercial).

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[5] Computer-Aided Engineering Software Empowering Simulation (CAESES). A commercial software, see: www.caeses.com

3 Quality assurance

As already mentioned, there is an extensive experience at SSPA applying continually developed Shipflow versions to ship hydrodynamics. Here we summarize, and provide reference too, the most relevant studies pertaining to verification and validation. These investigations have been carried out at SSPA, or in collaboration with Flowtech International AB (developers of Shipflow) or Chalmers University of Technology.

3.1 Demonstration of CFD capability

According to the ITTC quality assurance guidelines (ITTC-7.5-03-02-01, 2021) it is required by the organization to demonstrate the CFD capability in the way specified in that document. Here we demonstrate the RISE/SSPA CFD capability for full-scale power predictions. This section is based on the extensive investigation reported by Kim (2023b), in which 29 full-scale speed trial test cases was included for 15 ships (tankers, bulk carriers, PCTC and LPG carriers) in different draft conditions (scantling, design and ballast). The measured power is proprietary data, but the statistical results required by ITTC-7.5-03-02-01 can be included in this open report.

The case type range includes the following parameter ranges. Displacement between 26 000 tonnes and 441 000 tonnes, block coefficients in the interval $0.53 < c_B < 0.87$, (From Ro-Ro to Bulk carrier), and Froude numbers in the interval $0.09 < \mathrm{Fr} < 0.26$. All ships have a single propeller and some of them are equipped with some form of energy-saving device. In figure 3.1, statistics are illustrated for the ratio between the delivered power from the sea trials, $P_{D,ST}$, and that predicted by CFD, $P_{D,CFD}$.

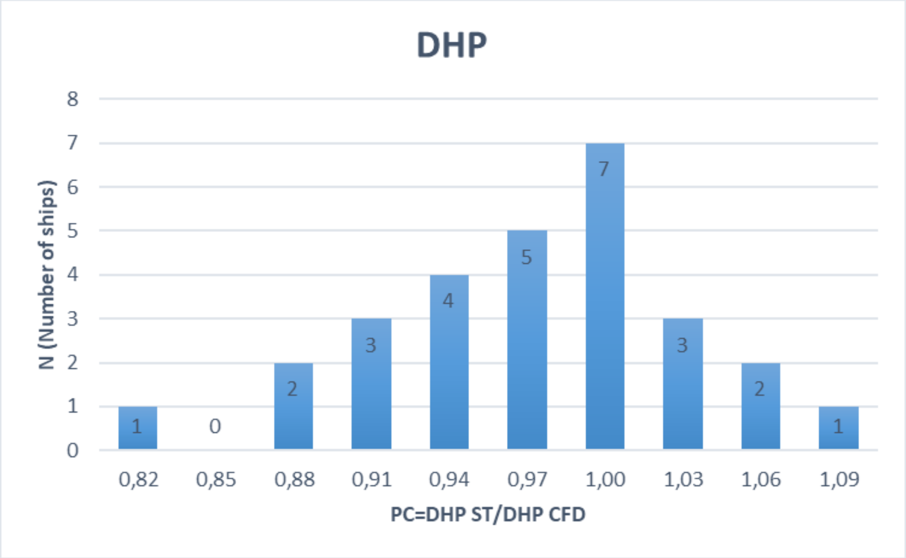

Figure 3.1: Distribution of, $P_{D,ST}/P_{D,CFD}$, *for 29 speed trial test cases (Kim, 2023).*

The probability density of figure 3.1 is nicely centered around 1.0 even though the CFD-prediction is directly taken without any correction factors, or similar experience-based adjustments. Furthermore, the Shipflow best-practice guidelines were applied in exactly the same manner, regardless of the specifics and parameters of the ship test case. Most vessels lie in the limited range between 0.91 and 1.03, but there is a number of outliers with a larger comparison error.

3.2 Uncertainty assessment and grid refinement studies

Systematic grid refinement is one part of the general uncertainty assessment of any CFD prediction. According to the ITTC guidelines for uncertainty analysis in CFD (ITTC-7.5-03-01-

01, 2008) it is recommended to employ multiple grids for the same simulation case. However, it is not practical to carry out a full grid convergence study for every power prediction case, as is emphasized in the recent ITTC guidelines for quality assurance in ship CFD applications (ITTC-7.5-03-01-02, 2021). Instead, it is necessary that the organization has demonstrated a quality assessment of the computational procedure of the best-practice guidelines on a ship which is sufficiently similar to the case in question. This is also the approach which is taken at RISE/SSPA. The resulting best-practice guidelines were outlined in the previous chapter, and in the remaining sections of the present chapter an overview is given of the relevant and necessary quality assurance investigations which have been carried out at SSPA.

3.3 Model-scale studies

Self-propulsion of the KRISO container ship (KCS) was investigated in a contribution to the Gothenburg 2010 workshop on CFD in ship hydrodynamics (Kim & Li, 2010). The study included verification (systematic grid refinement) and validation with publicly available measurement data. Self-propulsion and local flow prediction for the Japan bulk carrier (JBC), with and without ESD, was investigated in a contribution to the follow-up workshop in Tokyo (Korkmaz et al., 2015). Again, the study included V&V with systematic grid refinement and publicly available measurement data. In both these studies, the wave resistance, trim and sinkage was computed using XPAN, while the viscous flow was computed using XCHAP+LL for a double-body configuration, as the VoF functionality had not been developed at that time.

In a recent publication, Korkmaz et al. (2021), a verification study with systematic grid refinement was carried out to obtain the hull form factor. The resistance for hulls with wetted transom was investigated (Korkmaz et al., 2022), again with systematic grid refinement. In both these papers, XCHAP was used, and the hull was simulated in a double-body configuration.

The recent report by Kim (2023b) includes a significant number of model scale cases, in which the best-practice guidelines (Kim, 2023a) are applied with good results. V&V, including systematic grid refinement, has been carried out for self-propulsion also including the VoF functionality, hence not in double-body configuration (Also, V&V for self-propulsion and VoF (Orych & Regnström, 2023).

3.4 Full-scale studies

As is well-known, there are very few high quality full-scale data available for self-propulsion. In one of the few available publications on CFD validation for full-scale power predictions, Orych et al. (2021), applied Shipflow (XPAN and XCHAP in double-body configuration), including systematic grid refinement. A large number of validation cases were investigated by Kim (2023b), with the current best-practice guidelines. The performance data for most cases are not public and, hence, the study was documented as an internal SSPA report. The statistics shown in figure 3.1 is based on this study by Kim (2023b).

4 Compliance with IACS guidelines

The recent IMO[6] resolution MEPC[7] 351(78) considers simulations to be acceptable to provide the necessary data (power prediction in particular) for a ship relative to the EEXI regulation framework. As an immediate response to this, IACS developed guidelines (IACS, 2022) for how such computations should be carried out. The present chapter explains and demonstrates that RISE/SSPA fulfills the requirements of these guidelines and can apply the methodology described in chapter 2 to calculate the EEXI of the relevant classes of ships.

4.1 Demonstration of qualifications

According to the IACS guidelines (Step 1), it is necessary to demonstrate qualifications for carrying out the required type of CFD predictions. As is clear from chapters 2 and 3 of this report, and the references therein, the Shipflow best-practice guidelines at RISE/SSPA fulfills all these requirements with a large margin.

The remaining two steps of the guidelines for a particular case are: (ii) Validation/Calibration; and (iii) Calculation. There are three options for how this can be carried out, and SSPA has the capability to carry out all three options. The choice of option depends partly on the case to be studied and the available data for it. Each of the next three sections describe one of these options, how the guidelines are fulfilled and how the study would be performed at SSPA.

4.2 Validated sea trials or model tests of parent hull

This is option 1 according to the IACS guidelines: When either model tests or sea trial data is available for the parent hull. The application of this option is straightforward, and it is the preferred one which is to be applied if the required data is available. Shipflow simulations are carried out, following the best-practice guidelines, first for the parent hull and then for the specific new vessel configuration for which EEXI is to be determined.

4.3 Validated CFD model tests of similar ship

This is option 2 according to the IACS guidelines: When the validation step is carried out for a similar ship. A definition of “similar ship” is provided in the IACS guidelines. Among other criteria, the length, block coefficient and displacement should be within 5% from the vessel for which EEXI is to be determined. If model test data for such a similar ship exists, then it is straightforward to apply the Shipflow best-practice guidelines for validation and evaluation of EEXI. The key is thus the availability of such data. Either this is provided by the customer, or it is to be found in the very extensive SSPA database of self-propulsion tests for all large classes of cargo ships.

4.4 Validated CFD with sea trials of comparable ships

This is option 3 according to the IACS guidelines: When the validation step is carried out for a set of comparable ships. This is the last options, if it is not possible to determine the EEXI according to options 1 or 2 due to lack of necessary validation data. A definition of “set of comparable ships” is provided in the IACS guidelines. This option is the most complicated. Among other things, it is necessary to perform CFD calculations for at least 10 combinations of vessels and drafts within the set of comparable ships. On the other hand, this option, in combination with the extensive SSPA database, allows for the determination of EEXI for essentially any type of cargo ship in use.

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[6] IMO = International Maritime Organization

[7] MEPC = Marine Environment Protection Committee of IMO

5 Summary

An overview is given of how CFD-based power predictions, using Shipflow, are carried out at SSPA. The methodology is outlined in chapter 2, and the verification and validations studies which have been carried out are found in chapter 3. Both chapters provide a summary, with references to complete descriptions. One special application is to evaluate EEXI, exclusively using CFD. In chapter 4 it is described that the SSPA procedures fulfill the recent IACS guidelines for this type of computation, and it also explains how it would be carried out for any particular case, based on the three options of the IACS guidelines.

6 Bibliography

Hino, T., Stern, F., Larsson, L. & Visonneau, M., *Numerical ship hydrodynamics. An assessment of the Tokyo 2015 workshop*. Lecture notes in applied and computational mechanics, vol. 94, Springer, 2021.

IACS Guidelines on numerical calculations for the purpose of deriving the Vref in the framework of the EEXI regulation, IACS Rec. No. 173, 2022.

ITTC-7.5-03-01-01: Uncertainty analysis in CFD verification and validation. Methodology and procedures. ITTC Recommended procedures and guidelines, 2008.

ITTC-7.5-03-01-02: ITTC Quality system manual. Quality assurance in ship CFD applications. ITTC Recommended procedures and guidelines, 2021.

Kim, K., *Best-practice guidelines for SHIPFLOW application in SSPA CFD consultancy services*, SSPA Report RI90095289-01-00-A, 2011.

Kim, K., *Best-practice guidelines for SHIPFLOW VoF simulation*, RISE/SSPA Report, *in preparation*, 2023a.

Kim, K., *SHIPFLOW sea trial simulation*, RISE/SSPA Report, *in preparation*, 2023b.

Kim, K. & Li, D.-Q., *Estimation of numerical uncertainty of Shipflow in self-propulsion simulation of KCS*. In proceedings of the Gothenburg 2010 workshop – CFD in ship hydrodynamics, 2010.

Korkmaz, K. B., Orych, M. & Larsson, L., *CFD prediction including verification and validation of resistance, propulsion and local flow for the Japan bulk carrier (JBC) with and without an energy-saving device*. In proceedings of the Tokyo 2015 workshop – CFD in ship hydrodynamics, 2015.

Korkmaz, K. B., Werner, S. & Bensow, R., *Verification and validation of CFD-based form factors as a combined CFD/EFD method*, J. Mar. Sci. Eng., vol. 9, p. 1-30, 2021.

Korkmaz, K. B., Werner, S. & Bensow, R., *Scaling of wetted-transom resistance for improved full-scale ship performance predictions*, Ocean Engineering 266 (112590), p. 1-22, 2022.

Larsson, L., Broberg, L., Kim, K. & Zhang, D., *A method for resistance and flow prediction in ship design*. In proceedings of the *Annual meeting of the society of naval architects and marine engineers*, San Francisco, California, November, 1990.

Larsson, L., Stern, F. & Visonneau, M., *Numerical ship hydrodynamics – An assessment of the Gothenburg 2010 workshop*, Springer, 2014.

Orych, M., Werner, S. & Larsson, L., *Validation of full-scale delivered power CFD simulations*, Ocean Engineering, 238 (109654), p. 1-10, 2021.

Orych, M. & Regnström, B., *Verification and validation of volume-of-fluid functionality in Shipflow*. Private communication, 2023.