DES Prediction of Cavitation Erosion and Its Validation for a Ship Scale Propeller

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Abstract. Lloyd's Register Technical Investigation Department (LR TID) have developed numerical functions for the prediction of cavitation erosion aggressiveness within Computational Fluid Dynamics (CFD) simulations. These functions were previously validated for a model scale hydrofoil and ship scale rudder [1]. For the current study the functions were applied to a cargo ship's full scale propeller, on which the severe cavitation erosion was reported. The performed Detach Eddy Simulation (DES) required a fine computational mesh (approximately 22 million cells), together with a very small time step (2.0E-4 s). As the cavitation for this type of vessel is primarily caused by a highly non-uniform wake, the hull was also included in the simulation. The applied method under predicted the cavitation extent and did not fully resolve the tip vortex; however, the areas of cavitation collapse were captured successfully. Consequently, the developed functions showed a very good prediction of erosion areas, as confirmed by comparison with underwater propeller inspection results.

1. Introduction

Undoubtedly, the identification of cavitation aggressiveness at the design stage has significant value to ship-owners, as the list of potential solutions at this point is much wider, compared to a limited list of actions when the ship has already been built. The treatment of the problem at the design stage is considerably cheaper, compared to "when built" troubleshooting.

Apart from traditional model experiments [2], it has now become practical to use Computational Fluid Dynamic (CFD) methods to predict cavitation and erosion due to the development in computational power. As summarised in [1], two main approaches can be used for the numerical prediction of cavitation aggressiveness.

One of these can be regarded as complete numerical resolution of the cavitation problem [3], [4], [5] and [6]. As the simulation of shock waves induced by cavity collapses requires very fine mesh, together with a time step in the order of 1 micro second, this approach is initially applicable for model scale objects. When the simulation of marine hydrodynamics is required, such as ship propellers and marine structures, this approach would be impractical, as very fine meshes around these objects would be required, resulting in cell counts in the order of hundreds of millions.

As a practical solution to address these problems, numerical erosion functions have recently been introduced by various researchers. One of the first studies was the development of erosive indexes in [7] and [8]. The validation of these indexes showed good results for a propeller in model scale. Further investigations in the development of erosive functions were completed in [9], [10] and [11], where analysis of existing functions was also performed.

Erosion functions have also been developed by LR TID in [12] and validated for a ship rudder in model scale. As cavitation simulations require a fine mesh, some simplifications had to be introduced in [12]; the real hull and propeller geometry were not included in the calculation and were taken into account by modifying the flow upstream of the rudder.

Results presented by LR TID in [1] were shown to be more accurate, as the realistic geometry of the hull and rotating propeller in ship scale was directly taken into account. A Detach Eddy Simulation (DES) was used, which required a fine mesh consisting of 22 million cells.

LR TID is aware of many cases where ship rudders suffered from cavitation erosion, however, the main concern of designers and ship-owners is aggressive cavitation on propellers, inducing extensive vibration and erosion problems, which cannot be treated easily. This concern has motivated the further study of developed erosion functions for a ship scale propeller completed in the current paper. A cargo vessel was selected for the subject of the study. After approximately 6 months of service, extensive erosion damage on all propeller blades was reported, as shown in **Figures 3** and **6**. LR TID performed borescopic cavitation observations on this vessel and recorded the development of cavitation extent on the propeller. Some results of the observations are presented in **Figure 2**.

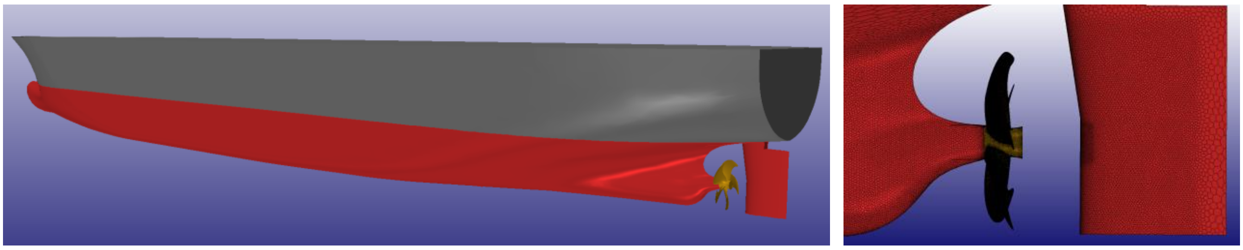

Figure 1. Full scale vessel simulated by DES and the surface mesh on propeller, rudder and hull.

2. Case set up

As the cavitation on the propeller depends on the wake induced by the hull, it was decided to include the hull in the propeller calculations. The hull and propeller geometries were obtained in a high quality IGES file format. The rudder was built separately in STAR-CCM+ using drawings. **Figure 1** shows the full scale geometry simulated in this study.

Since the vessel stern wave had a significant height, which will influence the hydrodynamic pressure on the propeller blades, it was necessary to capture the shape of the stern wave in the modelling. In order to reduce the number of cells, the whole analysis was split into two stages. In the first stage of the analysis, the vessel flow was calculated with the free surface, in order to determine the shape of the waves. The cavitation model in this stage was not active. Once the calculation was converged, the deformed free surface was exported as a geometrical entity. This free surface geometry was used in the second stage of the calculation and set to an upper symmetry boundary. In this stage, the cavitation model was active.

The overall mesh for cavitation simulation was approximately 22 million cells; 18 million of which were in the rotating mesh region. Local volume refinements behind the blade tips and propeller hub were carried out, in order to capture the cavitation extent with high resolution.

A DES was employed to capture the dynamics of the highly turbulent flow. Propeller rotation was modelled using rigid body rotation of a cylindrical mesh region around the propeller, with sliding interfaces between the static and rotating mesh regions. For the propeller rotation, a second-order temporal differencing scheme was employed for the unsteady term.

Since the vessel speed, shaft speed and vessel draughts were recorded during the cavitation observations carried out on the vessel, the cavitation analysis was performed in identical conditions.

An indication of the stability of the solution was confirmed by the evolution of thrust, torque and vapor volume; these quantities were stable over the period of 10 sec and a periodic solution was achieved for all parameters.

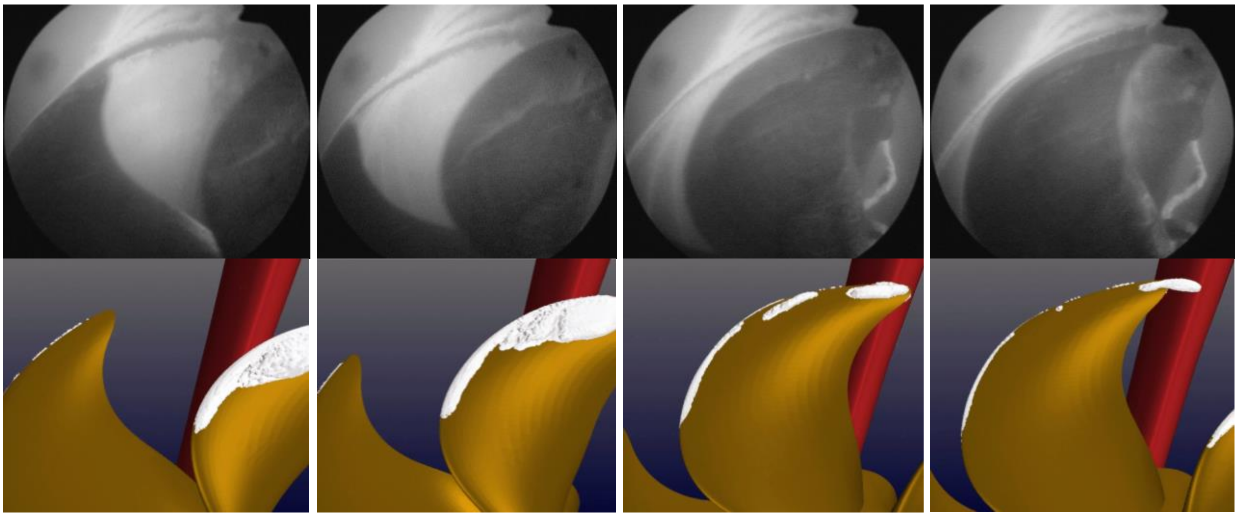

Figure 2. Observed and simulated cavitation on the full scale propeller.

DES was able to correctly resolve the sheet cavity and its rapid collapse, as shown in **Figure 2**. However, the development of tip and hub vortexes was significantly under predicted despite the fact that a fine mesh was built behind the blade tip and in the hub region. This could be due to modelling parameters such as the mesh not being fine enough in these regions or limitations of the cavitation model which is based on the simplified Rayleigh–Plesset equation implemented in STAR-CCM+.

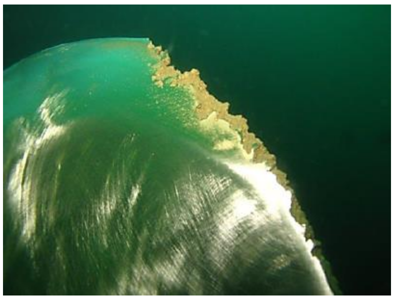

Figure 3. Erosion damage on the propeller.

Figure 4. Erosion damage predicted by Function 5.

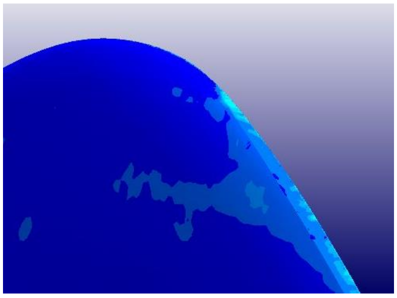

Figure 5. Erosion damage predicted by Function 8.

Figure 6. Erosion damage on the propeller.

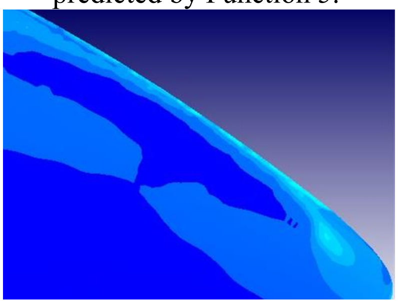

Figure 7. Erosion damage predicted by Function 5.

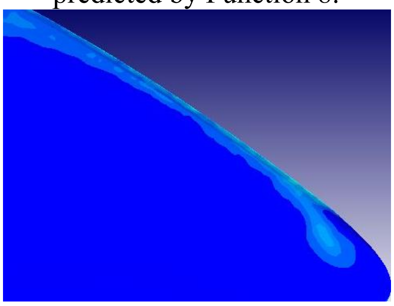

Figure 8. Erosion damage predicted by Function 8.

As discussed in [1] twelve functions have been developed in order to numerically predict cavitation erosion. The functions defined as Function 5 and 8 showed the best results for model scale hydrofoil and ship scale rudder [1]. For the current study these functions again showed promising results, mainly due to the correct prediction of sheet cavity collapse. The figures present the erosion damage on the propeller blade in the tip region closer to the leading edge (**Figures 4** and **5**) and trailing edge (**Figures 7** and **8**).

The presented figures were obtained from one propeller revolution and the predicted areas were similar for all blades. Further calculations for three propeller revolutions showed the same areas of potential erosion, which confirms high stability of cavitation prediction.

3. Conclusions

The erosive functions developed in LR TID and previously reported in [1] were applied for the ship scale propeller behind the hull. The borescopic observations and underwater propeller inspection revealed significant erosion damage on the blade tip, due to a rapid transformation of sheet cavity in the tip vortex. The DES calculation was performed for this vessel in the same conditions as recorded during the borescopic observations. CFD under predicted development of the tip vortex, possibly due to the mesh not being fine enough or due to a simplified formulation of the Rayleigh–Plesset equation; however, the sheet cavity collapse was captured accurately. As a consequence, the developed functions showed very good prediction of erosion areas, as confirmed by comparison with underwater propeller inspection results.

4. Acknowledgement

The current research project was funded under the internal LR R&D program. The author would like to thank his colleagues C. Craddock, A. Caldas and C. Fetherstonhaugh for their significant support.

5. References

[1] Ponkratov D and Caldas A 2015 Numerical Prediction of Cavitation Erosion and its Validation against Model and Ship Scale Results *Proc. of the 4th Int. Symp. on Marine Propulsors, SMP'15*, Austin, USA.
[2] ITTC recommended procedure 7.5-02-03-03.
[3] Schmidt S, Sezal I, Schnerr G and Thalhamer M 2007 Shock Waves as Driving Mechanism for Cavitation Erosion, *Proc. of the 8th Int. Symp. on Experimental and Computational Aerothermodynamics of Internal Flows*, Lyon.
[4] Schmidt S, Sezal I, Schnerr G and Thalhamer M 2008 Numerical Analysis of Shock Dynamics for Detection of Erosion Sensitive Areas in Complex 3-D Flows *Cavitation: Turbo-machinery & Medical Applications, WIMRC FORUM 2008*, Warwick University, UK.
[5] Schmidt S, Schnerr G and Thalhamer M 2009 Inertia Controlled Instability and Small Scale Structures of Sheet and Cloud Cavitation *Proc. of the 7th Int. Symp. on Cavitation CAV2009* – Paper No. 17, Ann Arbor, Michigan, USA.
[6] Mihatsch M, Schmidt S and Adams N 2013 Estimation of incubation times through numerical simulation of 3-D unsteady Cavitating flows *SHF Conf. Hydraulic Machines and Cavitation /Air in Water Pipes*, Grenoble, France.
[7] Nohmi M, Ikohagi T and Iga Y 2008 Numerical Prediction Method of Cavitation Erosion, *Proc. of FEDSM2008*, ASME Fluids Engineering Conference, Jacksonville, Florida USA.
[8] Hasuike N, Yamasaki S and Ando J 2009 Numerical Study on Cavitation Erosion Risk of Marine Propellers Operation in Wake Flow, *Proc. of the 7th Int. Symp. on Cavitation CAV2009* – Paper No. 30, Michigan, USA.
[9] Li Z 2012 Assessment of Cavitation Erosion with a Multiphase Reynolds-Averaged Navier-Stokes Method *PhD thesis*, Delft University of Technology.
[10] Li Z and Terwisga T 2012 On the capability of a RANS method to assess the cavitation erosion risk on a hydrofoil *Proc. of the 8th Int. Symp. on Cavitation CAV2012*, Singapore.
[11] Eskilsson C and Bensow R 2015 Estimation of Cavitation Erosion Intensity Using CFD: Numerical Comparison of Three Different Methods Results *Proc. of the 4th Int. Symp. on Marine Propulsors, SMP'15*, Austin, USA.
[12] Boorsma A and Whitworth S 2011 Understanding Details of Cavitation, *Proc. of the 2nd Int. Symp. on Marine Propulsors, SMP'11*, Hamburg, Germany.