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Full-scale Unsteady RANSE CFD Seakeeping Simulations of a High-Speed Craft

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1 Introduction

This paper presents a series of RANSE-based seakeeping simulations on a 17m high-speed monohull. The study is performed on the Severn Class all-weather search and rescue lifeboat, designed and operated by the Royal National Lifeboat Institution (RNLI). The Severn is a planing craft with a maximum operational speed of 25 knots, although it often operates at semi-planing and displacement speeds in different situations and weather conditions.

The work in this paper is an independent follow-up study from the EDSARC project (Enhanced Design of Search and Rescue Craft), a collaboration between Newcastle University, the Royal National Lifeboat Institution (RNLI) and Lloyd's Register (LR). The EDSARC project aims to develop improved methods to predict the structural loads on lifeboats including wave bending moments, pressure and slamming loads. The EDSARC project has assessed the structural response of the Severn in different operating conditions from full-scale trial data, segmented model tests in a towing tank and finite element analysis (FEA). Comparative data from EDSARC is presented in this paper.

Table 1: Severn Class main particulars.

Length overall	Loa	17.00	m
Length waterline	Lwl	15.50	m
Beam max	Boa	5.62	m
Draught	T	1.37	m
Displacement (full load)	Δ	42.0	t
Speed max	V	25	kn

Seakeeping measurements of the Severn were also completed in the EDSARC project to verify the structural response results. In particular, wave pressures were predicted using several frequency domain potential flow codes and mapped directly onto a global finite element model of the vessel (Fig.1). Three different linear codes were used: a panel method, a 2D strip theory and a 2.5D strip theory (Prini et al. 2015). In comparison to the model test results for heave and pitch over a range of wave encounter frequencies, better results were achieved with the 2D strip theory at low speed (up to 10 knots or Fn = 0.4) and a 2.5D strip theory at high speeds (from above 10 knots). The latter code includes a forward speed correction term, which makes it suitable for running cases at Froude numbers above 0.4.

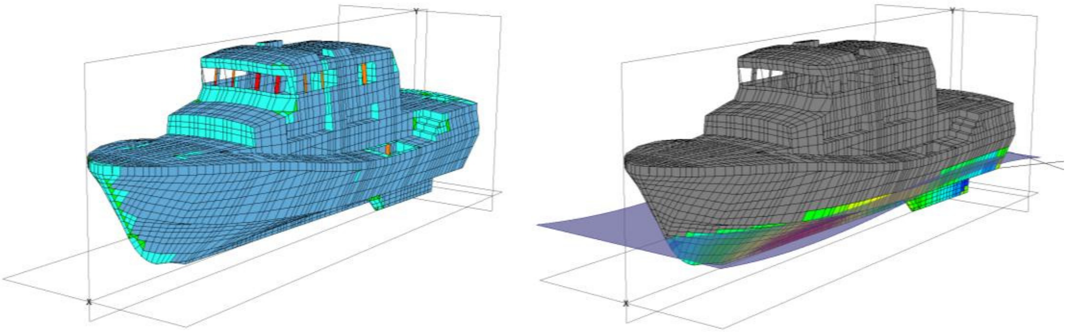

Fig. 1: Global structural finite element (FE) model.

A series of small-scale seakeeping experiments were conducted to validate the CFD results. Two scaled models of the Severn Class were built and tested at Newcastle University's towing tank (Fig. 2). Motions and hull girder loads were measured during tests conducted at varying speeds and in a range of regular waves. Details of the models, the test apparatus and preliminary motion results are detailed in Prini et al., (2016).

The seakeeping analyses presented an opportunity for us to make a further comparative study using a non-linear RANSE-based CFD model. We also discuss the potential use of the CFD model for the prediction of motions and pressure loads of a high-speed craft in waves.

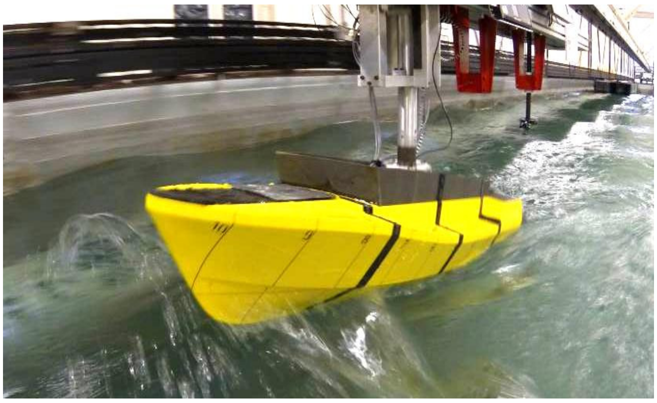

Fig. 2: Small-scale seakeeping experiment.

2 RANSE CFD model

The dynamics of the fluid flow around the RNLI's Severn Class lifeboat was simulated by using a numerical approach. The CFD package STAR-CCM+ finite volume stress solver was used to solve the governing continuity and momentum equations. The setup of the RANS simulations necessitated the determination of a number of crucial settings. Within this framework, the turbulence model selected was a standard "k–ε model" and "Volume of Fluid" (VOF) method was used to model and position the free surface. Dynamic Fluid Body Interaction (DFBI) model was utilized to simulate realistic ship behaviour. The vessel was set free to move in pitch and heave modes. The DFBI module simulates the motions of a rigid body based on the pressure and shear forces exerted by the fluid as calculated by the RANSE solver.

Only half of the vessel hull is modelled within the numerical domain by using a symmetry plane to provide savings from computational time. The computational domain used for the simulations is presented in Fig. 3. Thus, inlet boundary was placed $1L_{BP}$ forward, outlet was placed $3L_{BP}$ backward, side was placed $2L_{BP}$ port and the symmetry plane was located at the centreline of the hull.

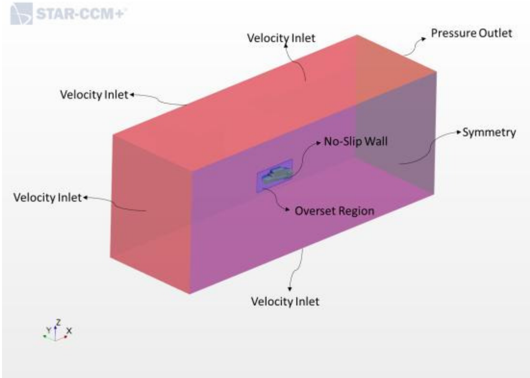

Fig. 3: Numerical domain and boundary conditions.

The Severn surface mesh is shown in Fig. 4. The model incorporates all the underwater hull appendages and details of the deckhouse. Overset meshes, also known as “Chimera” or overlapping meshes, were used to facilitate the motions of the full-scale lifeboat model. The overset region contains the hull body and moves with the hull over a static background mesh of the whole domain. The overset mesh method ensures accurate mesh density in the free surface region both in areas near the hull as well as in the far field regions such as inlet, outlet and ship wake regions.

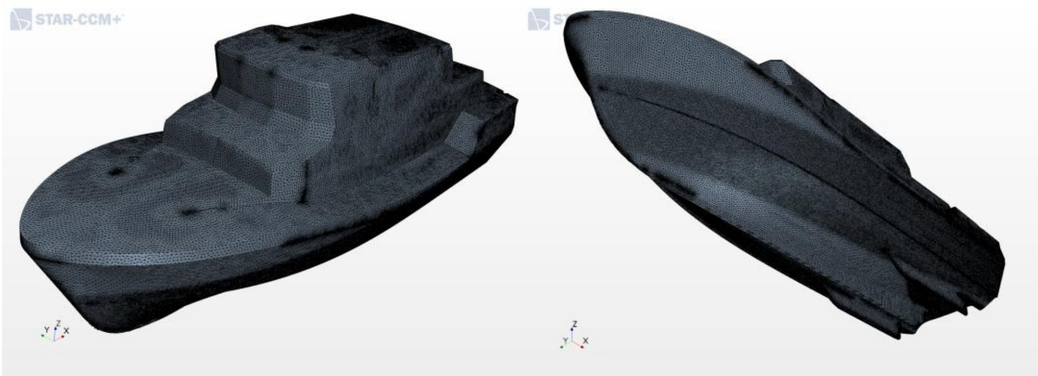

Fig. 4: RNLI’s Severn Class Lifeboat surface mesh.

In order to capture the severe free surface flows incidents, a minimum of 150 grid points per wavelength was used near the hull free surface in both the downstream and upstream directions. For the free surface region, a minimum of 20 cells was used in the vertical direction to ensure accurate representation of the wave steepness (Tezdogan et al., 2015). These cell sizes corresponding to above guidelines are calculated for the worst case scenario (i.e. for the shortest wave) and used for all the cases. Overall, with the wake mesh refinement and volumetric mesh enhancements, the domain and the vessel were meshed with 12.5 Million cells as in Fig. 5. While the overset region is meshed with 6 million cells, the background region comprises 6.5 million cells.

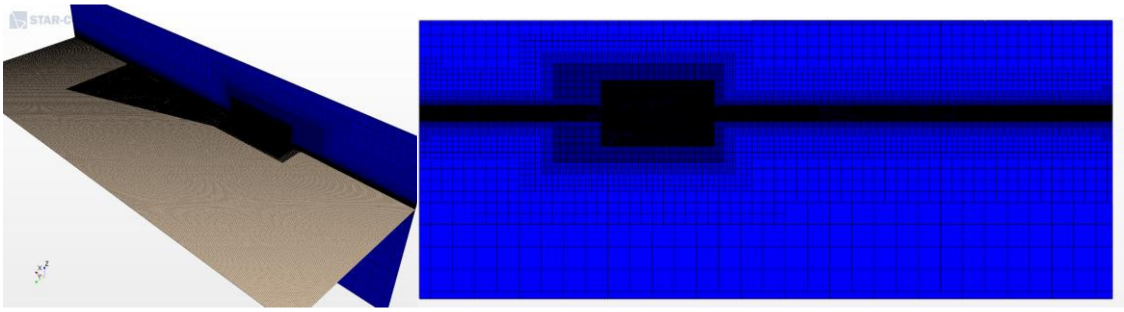

Fig. 5: Volume mesh overview.

The simulations were performed for 32 different conditions incorporating two different wave heights (1m and 2m), two speeds (15kn and 20kn) and eight different wavelengths as outlined in **Error! Reference source not found.**. A standard simulation took 48 hours to converge using 16 processors of the N8 High Performance Computing (HPC) facility. The free surface wave profile for a 2m wave height condition when the simulation is initialized is presented together with the wave profile produced by the numerical solver by Fig. 6

Table 2: Test matrix.

HEADING		SPEED		WAVE HEIGHT	λ/LOA
	[deg]	[kn]	[m/s]	[m]	
head waves	**180**	**15 & 20**	**7.72 & 10.29**	**1 & 2**	**1.4, 1.8, 2.2, 2.6, 3.0, 3.4, 3.8, 4.2**

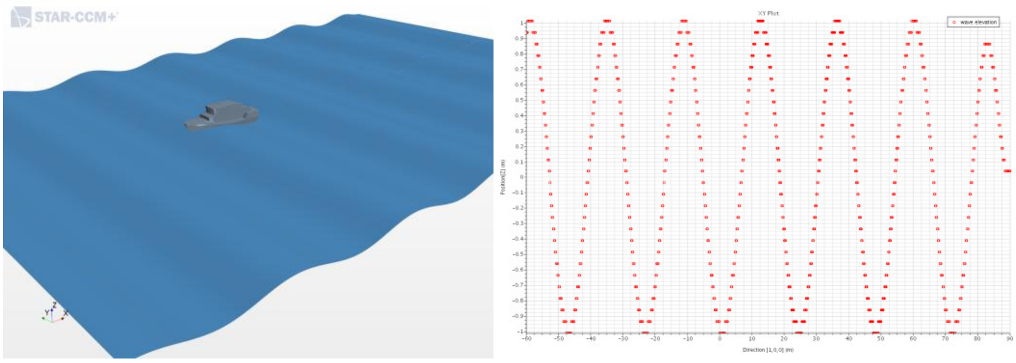

Fig. 6: Free surface wave profile (Left) and wave elevation plot (Right).

The convective CFL number introduced in STAR-CCM+ v11.06 helped significantly to satisfy keeping the CFL number at an average of 1 for the overall domain and increasing the time step when possible. While the minimum time-step was initially set to 256 time steps per wave encounter period, for certain λ/L_{OA} regions shorter time steps ($T_e/1024$) showed better agreement when compared with experimental findings, as discussed in detail within the Results section.

3 Results

Qualitative visual comparisons were made between towing tank video captures and RANSE CFD simulations. While video comparisons are rather more insightful for this purpose, Fig. 7 shows a sequence of snapshots taken during a typical wave encounter from CFD simulations and towing tank tests.

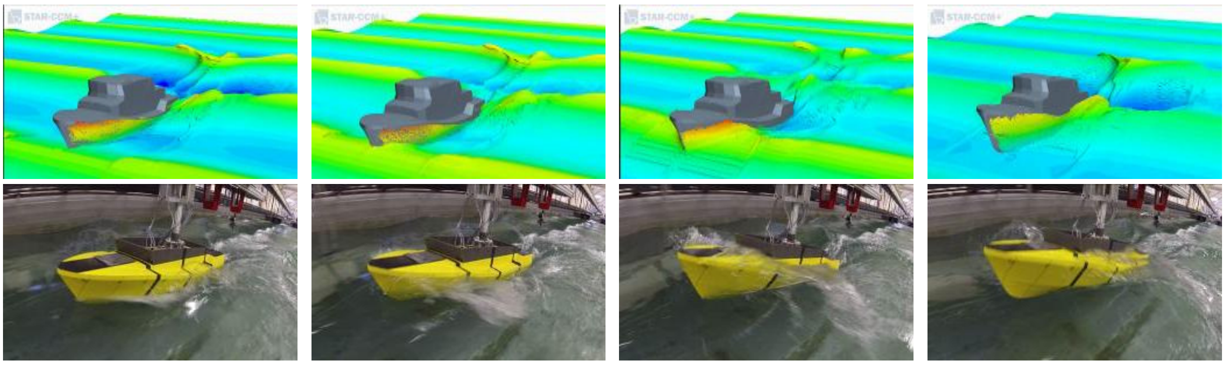

Fig. 7: Image sequence comparison of CFD simulation predictions and experimental observations.

All the motion results are presented in terms of response amplitude operators (RAOs) with the mean motion amplitudes normalised per mean wave amplitude. Both the experimental tests and the STAR-CCM+ simulations produced results in the time domain. A peak-to-peak analysis was conducted to compute the mean values for motion and wave amplitudes.

With the minimum time-step set at $T_e/256$ it was found that the simulations were over-predicting the heave and pitch responses at wavelengths λ/L_{OA}=2.4 to 3.6. Further simulations were completed with refined time-step settings to enable smaller time-steps with feasible the simulation time. An initial simulation stage was run at $T_e/256$ for seven wave encounters to balance the model. A second stage with a reduced time-step of $T_e/1024$ was then completed. The results were extracted from the second stage. Fig. 8 shows heave and pitch RAOs in regular head waves at 15 and 20 knots for the standard ($T_e/256$) and the refined ($T_e/1024$) time-steps.

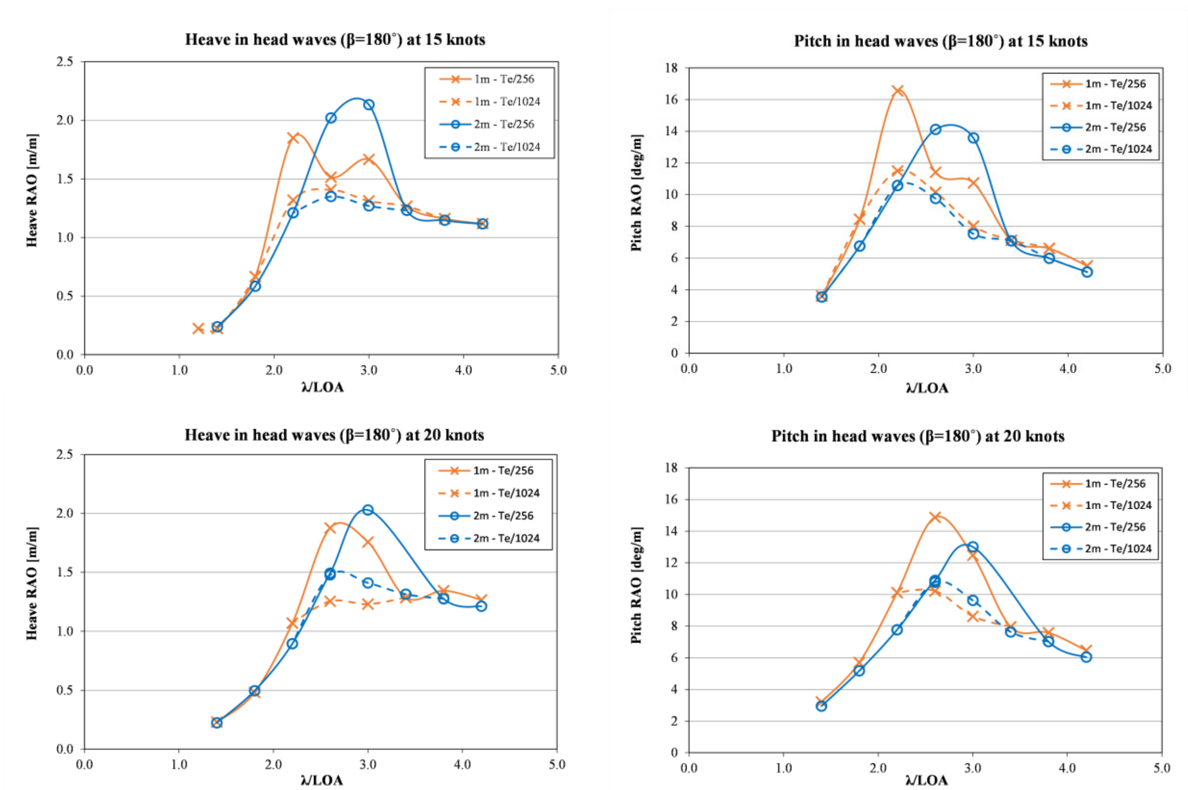

Fig. 8: Heave and Pitch RAOs for the standard and the refined time-steps.

The results obtained with the finer time-step were compared against those predicted by the potential flow solver MAESTRO-Wave and from the towing tank tests. Fig. 9 shows the heave and pitch RAOs in head waves at 15 and 20 knots from the three different methods.

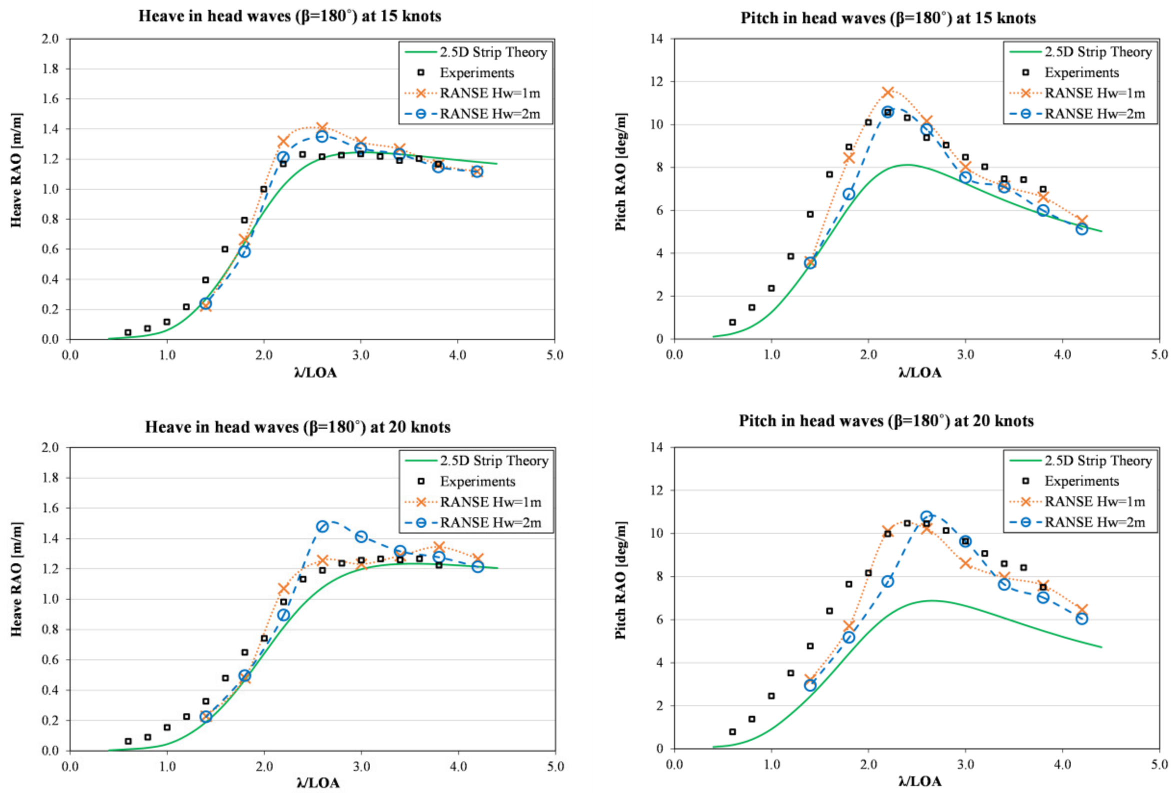

Fig. 9: Heave and Pitch RAOs from experiments, 2.5D Strip theory and RANSE CFD simulations.

4 Conclusions

Fully nonlinear unsteady RANS simulations are conducted at full scale to investigate the seakeeping performance of the RNLI's Severn Class lifeboat. For the majority of the simulations, a standard time-step, given by the ITTC as a guideline, has shown good correlation against the experimental results. However, in the range of wavelengths λ/L_{OA} =2.4 to 3.6, a finer time step has shown to improve the results. Further simulations in different wave heights are being conducted. The results will inform on the effect of the wave height on the seakeeping performance of the Severn. They will also help investigating the effect of the wave steepness on the time-step required to accurately capture the vessel's response in waves.

Acknowledgements

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References

Prini, F., Benson, S., Birmingham, R., Dow, R. S., Phillips, H. J., Sheppard, P. J., & Mediavilla Varas, J. (2015). Seakeeping Analysis of a High-Speed Search and Rescue Craft by Linear Potential Theory. In International Conference on Lightweight Design of Marine Structures. Glasgow, UK.

Prini, F., Birmingham, R. W., Benson, S., Phillips, H. J., Sheppard, P. J., Mediavilla Varas, J., … Dow, R. S. (2016). Motions and Loads of a High-Speed Craft in Regular Waves: Prediction and Analysis. In 24th International HISWA Symposium on Yacht Design and Yacht Construction. Amsterdam, NL.

Tezdogan, T., Demirel, Y. K., Kellett, P., Khorasanchi, M., Incecik, A., & Turan, O. (2015). Full-scale unsteady RANS CFD simulations of ship behaviour and performance in head seas due to slow steaming. Ocean Engineering, **97**, 186–206.