Fluid Loads and Motions of Damaged Ships

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Sponsored by MoD/Lloyd's Register Centre of Excellence for Marine Structures

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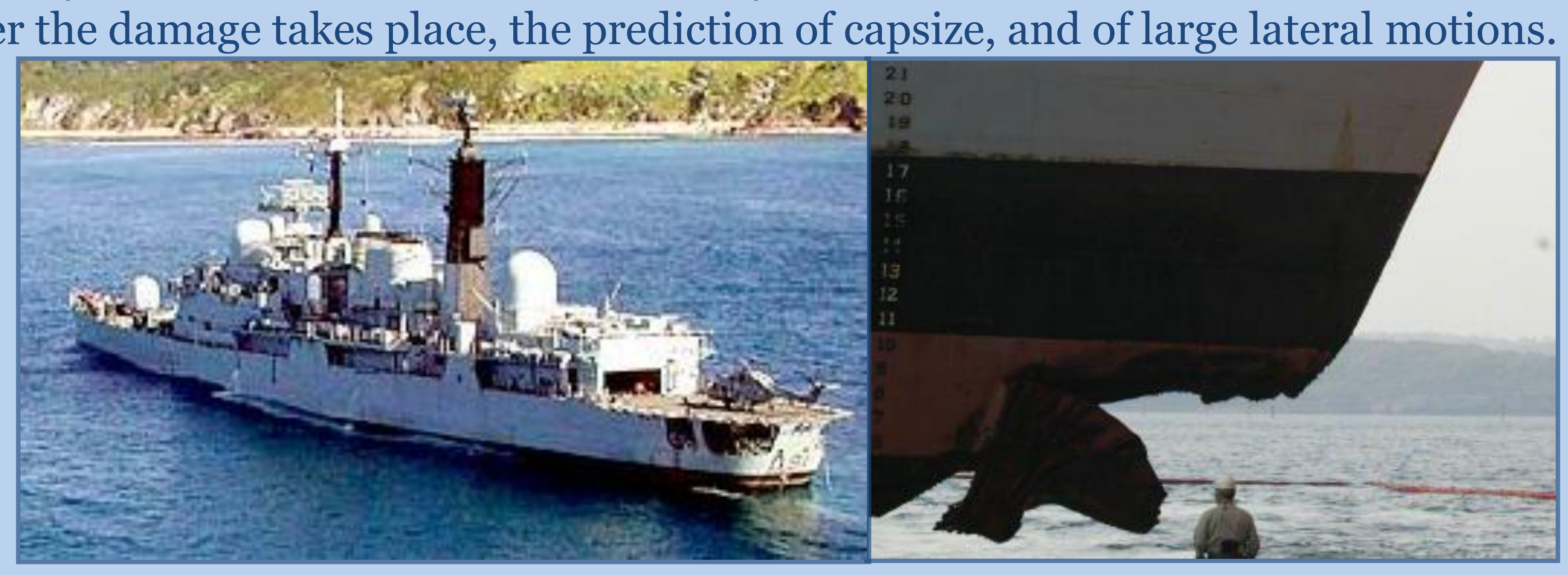
Background

An area of research that is gaining popularity within the marine industry is that of the effect of damage on ships. Early research was aimed directly at improving ship design against damage as a result to incidents such as the Titanic. The mid nineties saw another surge of damaged ship research due to Ro-Ro disasters (e.g. Estonia in 1994); because of the way the Estonia sank, research mainly focused on transient behaviour immediately after the damage takes place, the prediction of capsize, and of large lateral motions.

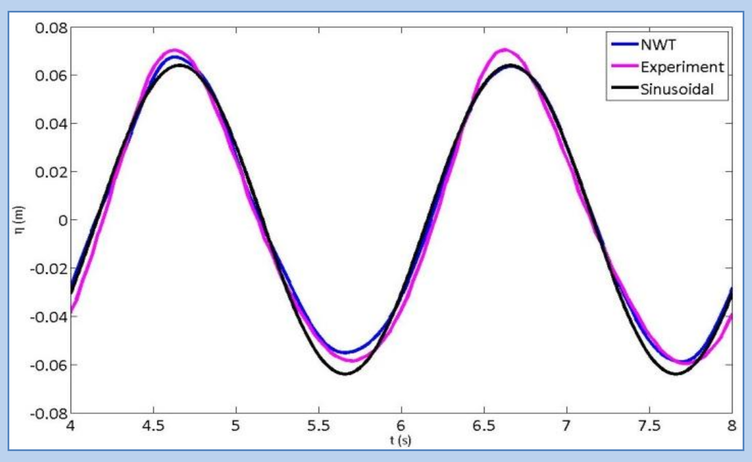


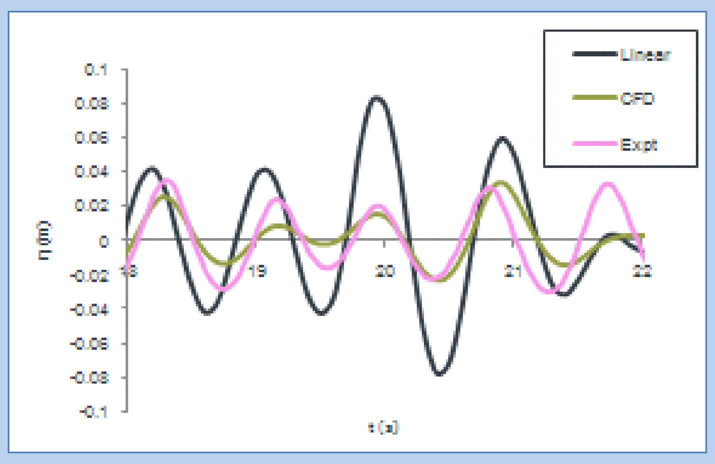
Further research efforts, headed by the UK MoD, were sparked when HMS Nottingham ran aground tearing a 50m hole from bow to bridge, flooding five compartments and almost causing the ship to sink just off Lord Howe Island in 2002. The figure above shows the stricken HMS Nottingham stuck on rocks (left), Close up of damage once lifted from the water (right) from the BBC news website. Whilst the ship remained intact on the rock, it was unknown what would happen to the structure upon release. A collaboration between MoD, Lloyd's Register, UCL and the University of Southampton has been formed to bring together research efforts in this area, the MoD/Lloyd's Register Centre of Excellence for Marine Structures.

A computational damaged ship modelling method is being developed using RANS coupled with rigid body motions. In order to gain confidence in the ability of CFD to predict ship motions and pressure fields for use in a structural solver, the problem is being validated in a number of smaller cases.

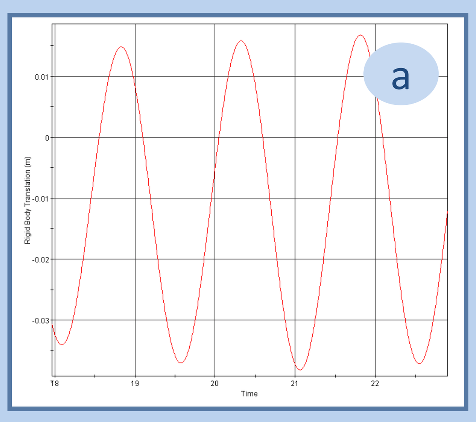
Environment and Ship Motions

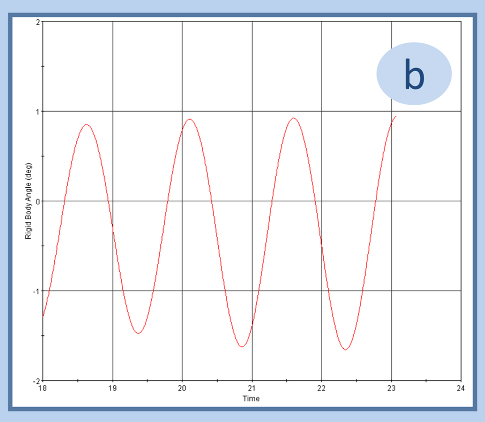
Wave heights are recorded and compared to experimental results for both regular and irregular wave trains. This is to validate CFD capability of creating a section of seaway. Current work includes the superposition of wave components to create freak waves using finite depth first order waves described in the equations. A sample of regular (left) and Irregular (right) wave results are shown below.

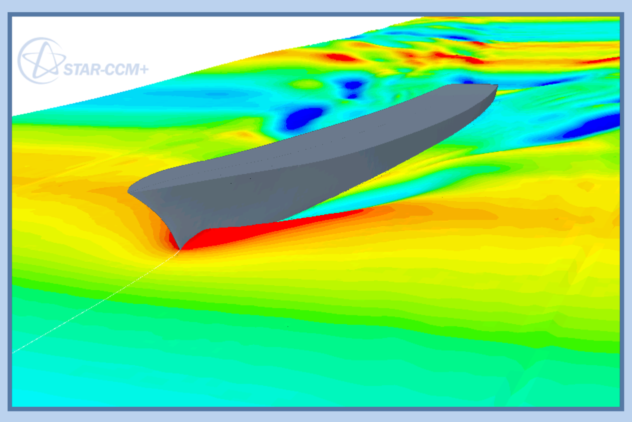




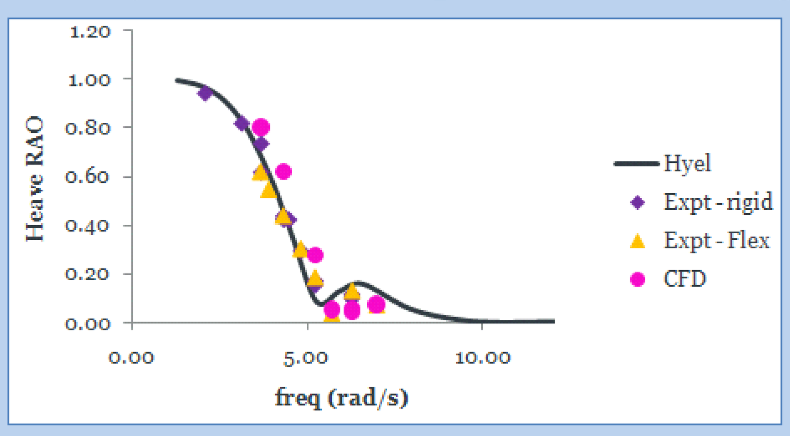
Rigid body motions is the final component of the validation exercises. The motions are induced by pressures on the hull and the loading and moments of inertia of the ship. Above diagrams show heave (a) and pitch (b) motions recorded from the simulation of a 5m frigate model geometry in waves with forward speed with a Froude number of 0.28.

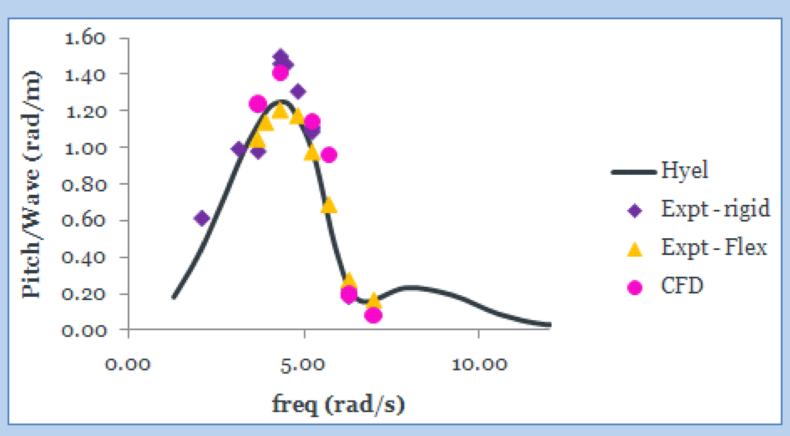






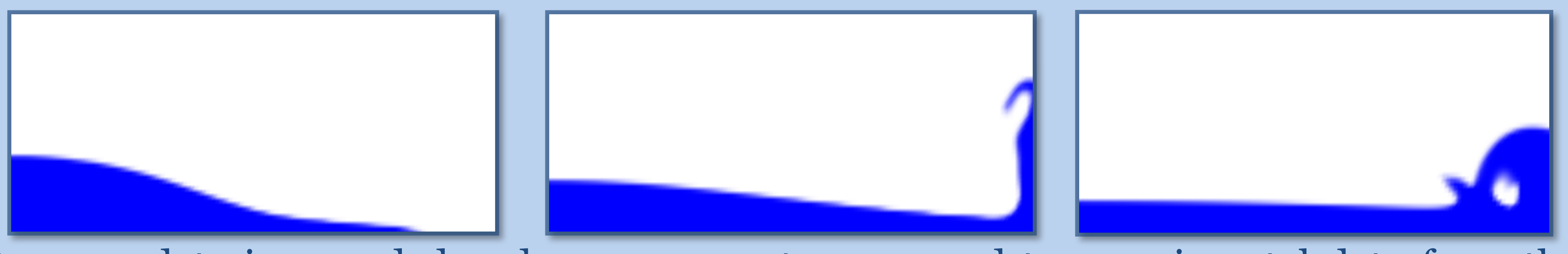
RAO results are shown for the Leander Class Frigate below for regular waves at zero speed. Comparison can be seen between rigid body experiments and rigid body motions and the hydro-elastic response with the segmented model experiments.



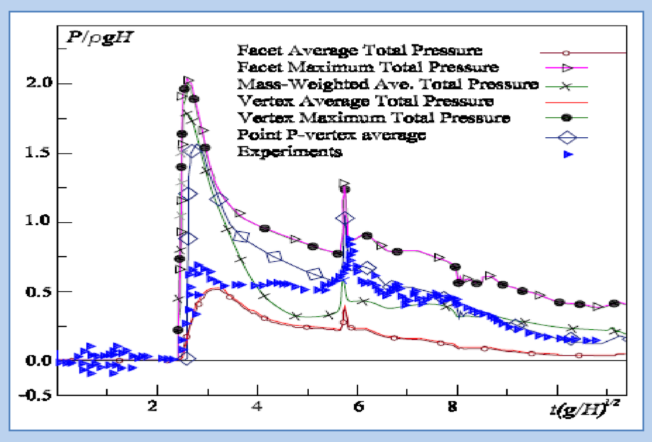


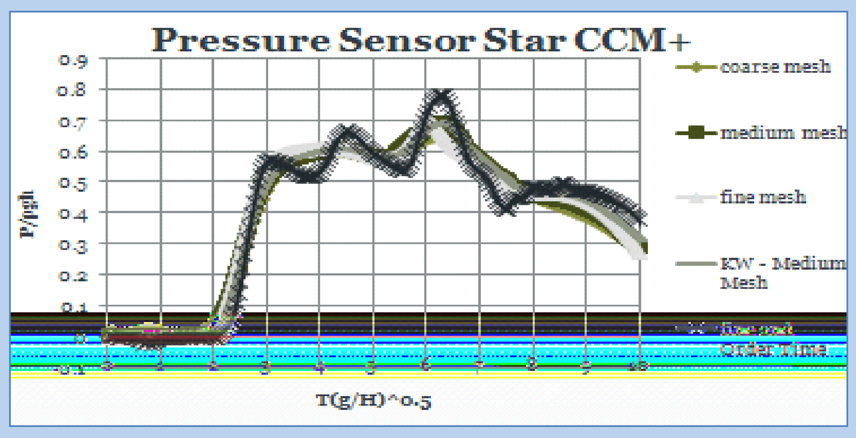
Flooding and Wave Impact

2D Dambreak is a classical free surface problem to simulate, however it also lends itself to the validation of wave impact and pressure peak capture.



Pressure data is recorded and measurements compared to experimental data from the right hand wall 0.16m from the floor. Quantitative comparison is found for pressure everywhere but at the peaks due to the coarse mesh and the 1st order time discretisation scheme that was used in the CFD study.

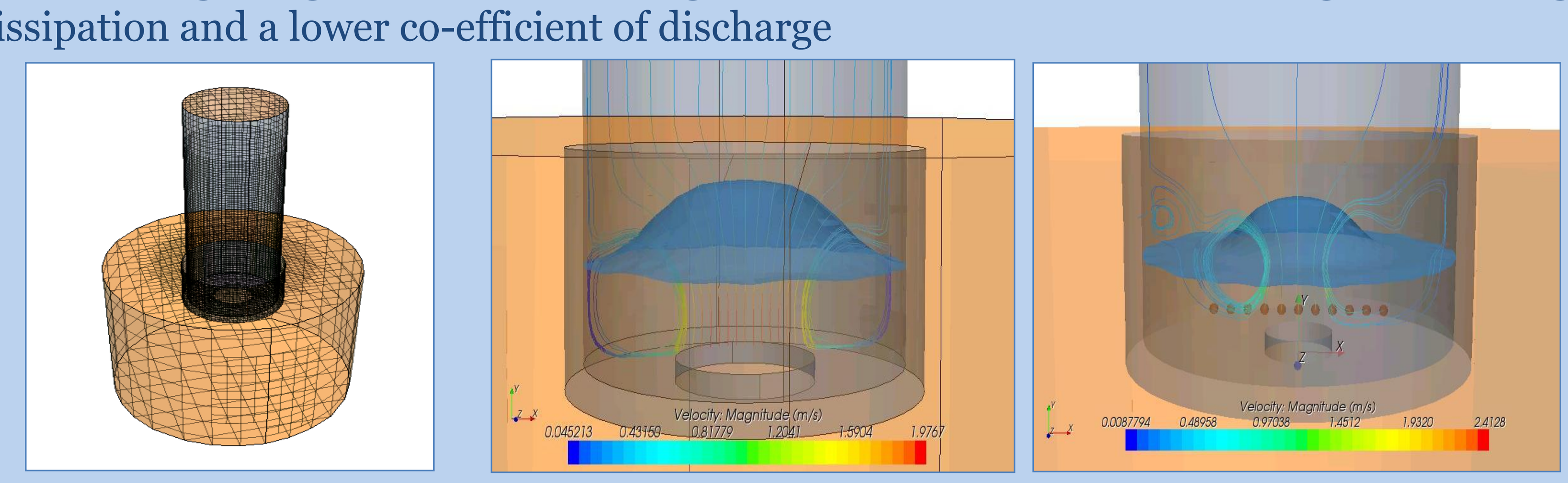




For flooding simulation volume flow rate through an orifice is generally calculated using a simplified formula which includes correction for viscous effects by use of a discharge co-efficient C_D. Typically this value is assumed to be constant, through experiment and CFD this assumption is being tested. Preliminary CFD results are shown below.

Damage Area (m^2)	Shape	Time to flood (s)	Average flow rate ($m^3 s^{-1}$)	Average Discharge Coefficient
5.03E-03	Circle	1.51	0.006740901	0.677
5.03E-03	Square	1.46	0.006971754	0.700
5.03E-03	Rectangle	1.41	0.007218979	0.725
2.83E-03	Circle	3.19	0.003190834	0.570
2.83E-03	Square	3.43	0.002967569	0.530
2.83E-03	Rectangle	3.35	0.003038436	0.543
1.26E-03	Circle	7.25	0.001403967	0.564
1.26E-03	Square	9.04	0.001125969	0.452
1.26E-03	Rectangle	8.14	0.001250462	0.502

The snapshots taken below show the formation of the vena contracta and the vortex ring formation. For the larger damage (centre), the vortex formation is inhibited, however for small damage (right) two vortex rings are formed, which result in greater energy dissipation and a lower co-efficient of discharge



Conclusions

- The component parts require differing levels of grid refinement and modelling approaches, the challenge will be to bring these parts together into a single simulation that gives a stable and accurate solution.
- There are many different ways in which a ship can be damaged which bring about different flooding behaviour. Many cases will therefore be conducted to build a response surface for these variables. Therefore the simulations will need to be as computationally efficient as possible.

Future work

A detailed investigation into orifice flow will be performed and using the components a full damaged ship model will be built up. For benchmarking and direct simulation of ship motions for any given damage scenario.

Papers

Denchfield, Wood et al. (2010) Comparisons between CFD predictions and experiments for rogue wave-ship interactions, PRADS 2010.

Wood et al. (2010) CFD Simulation of Orifice Flow for the Flooding of Damaged Ships, NuTTS 2010.

Wood et al. (2009) Numerical Simulation of Compartment Flooding for Damaged Ships, NuTTS 2009.

Lloyd's Register

FSI Away Day 2011