Deterministic Validation of a Time Domain Panel Code for Parametric Roll

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ABSTRACT

Validation of simulation methods for dynamic stability is hampered by the fact that dynamic stability phenomena can be quite rare. In order to obtain sufficient statistical confidence in both experimental data and simulation results long duration time histories are required for a range of operational conditions. This is at most times not feasible from a practical point of view.

One way of validating time domain simulation methods for dynamic stability phenomena is by deterministic validation. This means that the simulation is run in the same wave sequence as used during the model experiments. Ideally, a one to one comparison between experiments and simulations is then possible. A difficulty in such an approach is, in case of irregular waves, the reconstruction of the experimental wave train in the simulation tool. Even if this were successful, the encountered wave train in the simulations will deviate from the experimental one because it is inevitable that the position in the horizontal plane will differ from the experimental one after some time.

The paper describes the deterministic validation of a non-linear, 6-DoF time domain panel code for parametric roll. The paper explains the method for reconstructing the experimental wave train in the simulation method and how to circumvent the problem of the deviation in horizontal position. Finally, comparisons between experimental and simulated time traces are given for the motions in the vertical plane.

KEYWORDS
Parametric roll, time domain simulation, 6-DoF panel method, determinsitic validation.

INTRODUCTION

The operability and safety of a ship and its cargo depends, amongst others, on its behavior in waves. Under certain conditions in bow and bow quartering seas resonant (parametric) roll may occur which can lead to large roll angles. This can lead to loss of cargo and endangers the ship and its crew. The occurrence of parametric roll can be investigated by means of scale model tests. Provided the tests are properly executed, they offer the most reliable information on dynamic stability.

Issues in the use of model testing are the costs, the limited statistical reliability of the required tests in irregular waves, the limited flexibility and the fact that the test results are not always easy to understand. The limitations in the physical representation relate to viscous effects in the components of the hull resistance with an effect on the propeller loading and speed loss in waves, in some of the smaller components of the roll damping and in components of the manoeuvring reaction forces. The neglect of wind on the roll damping, the wind heel and on the propeller loading and related steerage has an effect in bow quartering seas. Issues that are modeled implicitly correctly are the natural crest-trough a-symmetry in steep waves, the presence of breaking waves, the wave induced forces on the propeller and rudder, rudder and propeller ventilation and down-stream effects of vortices from the bilges and bilge keels on the rudder.

In order to understand the physics of dynamic stability, numerical modeling has been pursued for quite some time. Although the latest CFD techniques have undoubtedly the largest potential, they have not met the expectations yet. This is partly due to the problems of modeling the generation, propagation and absorption of steep waves in a limited computational domain and partly due to the local physical character of issues like spilling wave crests on deck, roll damping from bilge keels and rudder stall and ventilation and the role of the propeller herein. In combination with the required domain size, this yields an extreme computational effort.

In between the above two techniques are hybrid time domain methods, which combine the efficiency of potential flow theory with empirical modules covering the non-linear aspects of manoeuvring and roll damping. After successful validation, these models are particularly useful to investigate dynamic stability.

The present paper deals with deterministic validation of such a hybrid simulation method for a container ship subject to parametric roll. A brief description of the simulation method is given first and the experimental arrangement is outlined. Next, the method to reconstruct and use the experimental wave train in the simulation method is described and finally a comparison between experimental and simulated motion responses is given.

SIMULATION METHOD

The time domain panel method PANSHIP, see De Jong and Van Walree (2009) and Van Walree and Carette (2010), is characterized by:

- A 3D transient Green function to account for linearized free surface effects with the exact forward speed effects for the mean wetted surface, yielding mean, radiated and diffracted wave components along the hull and a Kutta condition at the stern,
- A 3D panel method to account for Froude-Krylov forces on the instantaneous submerged body,
- A cross-flow drag method to include viscosity effects, resistance (in waves) is obtained from panel pressure integration each time step applying an empirical coefficient to the local flow velocity,
- Propulsion and steering using propeller open water characteristics, semi-empirical lifting surface characteristics and propeller, rudder and hull interaction coefficients,
- Viscous roll damping due to hull and bilge keels according to the ITTC Recommended Procedure (to be published),
- Autopilot steering with rudders.

PANSHIP is used at MARIN mainly for seakeeping predictions for fast and unconventional ships; however it can also deal with low speed ships.

MODEL TESTS

The model tests were performed at MARIN on a scale 55 C11 class container ship, the same hull form and experimental data have been used for the ITTC benchmark on parametric roll. For a detailed description of the experimental arrangement and the results of this benchmark study one is referred to Reed (2011). The model was tested with propeller, rudder and bilge keels. The model was free to move in six degrees of freedom and was self-propelled and steered by an autopilot. The main particulars of the ship are given in Table 1 while Figure 1 shows the hull form of the model.

Table 1: Main Particulars of the Vessel

Designation	Symbol	Magnitude
Length between perpendiculars	L_{PP}	262.00 m
Breadth	B	40.00 m
Depth	D	24.45 m
Draft moulded on FP	T_F	11.72 m
Draft moulded on AP	T_A	12.86 m
Displacement weight	Δ	76020 t
Transverse metacentric height	GM_T	2.08 m
Natural roll period	T_ϕ	25.20 s

Table 2 below shows the experimental test conditions. The nominal speed was 5 knots for all three tests. The duration of each test was about 2500 sec full scale. The experiments showed no parametric roll for the lowest wave height (Test 307002), appreciable parametric roll for the intermediate wave height (Test 307001) and heavy parametric roll for the highest sea state (Test 307004).

Table 2: Tests in Irregular Head Seas

Test no.	Wave conditions	
	Significant wave height [m]	Peak period [s]
307002	3.500	14.40
307001	4.125	14.40
307004	5.250	14.40

DETERMINISTIC WAVES

A way to circumvent the need for lengthy model tests and simulations when validating simulation methods for predicting rare events is to run the simulations in the same wave train as the experiments, i.e. deterministic validation. This is very relevant to parametric roll, as shown by Reed (2011).

The presently adopted procedure for deterministic validation starts with determining the wave spectrum components from the experimental wave train. During the model tests, the wave height was measured by two wave probes attached to the carriage (following the model). One probe was mounted in front of the model while the second one was mounted at the side of the model at a distance sufficient to avoid interference from ship radiated waves.

The wave spectral densities S for each wave spectrum were determined by means of spectral analysis of the wave train signals measured while travelling at very low speed through the basin (without the model present). This yields an "average" wave spectrum valid anywhere in the basin. Next, the phase angles ε are determined by means of a non-linear minimization procedure (IMSL routine RNLIN). In this procedure the difference between the measured and reconstructed wave trains, ζ_m and ζ_e respectively, is minimized at each time step by varying the phase angles. The measured wave train ζ_m is that measured during the actual model tests. The object function F at time t, and the reconstructed wave train at wave probe #j are defined by:

$$F_j(t) = \zeta_{mj}(t) - \zeta_{ej}(t) \qquad (1)$$

$$\zeta_{ej}(t) = \sum_{i=1}^{n} A_i \cos\left(k_i x_j - \omega_i t + \varepsilon_i\right) \qquad (2)$$

where $A_i = \sqrt{2\Delta\omega_i S_i}$ is the wave amplitude of spectral component i, $k=\omega^2/g$ is the wave number and ω is the wave frequency. The position of wave probe j in the wave field, x_j, is given by

$$x_j = x_{0j}(t)\cos(\psi) + y_{0j}(t)\sin(\psi) \qquad (3)$$

and (x_{0j}, y_{0j}) is the basin fixed position of the wave probe and ψ is the wave direction.

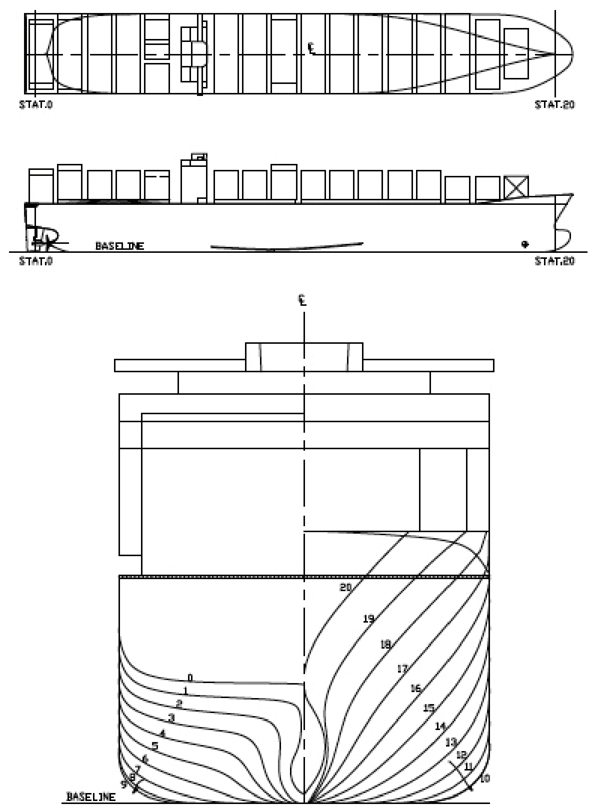

Fig. 1: General Arrangement and Small Scale Body Plan

The object function F is minimized using the observations (measurements) at the two wave probe positions sequentially, yielding the phase angles ε. The length of a single model test run was 2500 seconds with a time step of 0.074 sec (full scale values). The number of observations used per run was about 3300 per wave probe. The wave height time traces were cut in to 20 parts of 125 sec length and for each part the phase angles were determined for 80 spectral components.

The assumption is now that equation (2) is valid for arbitrary positions (x, y) in the neighborhood of the ship. Figure 2 shows a comparison between the measured wave train and the reconstructed wave train at one of the wave probes for a typical segment of the time trace.

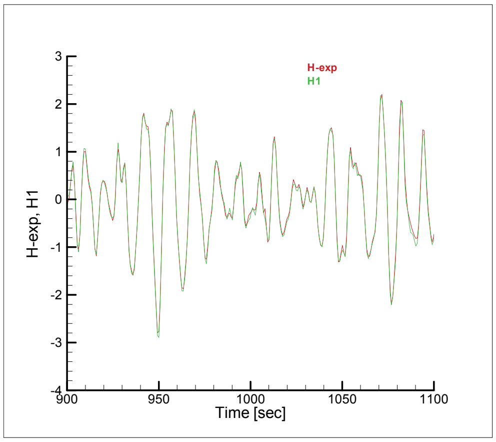

Fig. 2: Comparison between measured and reconstructed wave trains (red: measured; green: reconstructed)

The reconstructed wave spectral properties (amplitudes and phase anges) were imported in the simulation method so that simulations in the experimental wave train could be performed. The propeller RPM was set to have the same mean velocity as during the model tests. The experimentally used autopilot coefficients were used during the simulations as well.

In principle one can now perform the deterministic validation study. However, simulation methods can not predict the motions of the ship perfectly and sooner or later the x-y track of the ship will deviate from that in the experiments. A different position in the wave field means that a different wave will be met and the deterministic comparison needs to stop.

This problem can be circumvented by forcing the position and speed in the horizontal plane in the simulation method to be equal to that of the experiments. This is a viable solution for the present head sea simulations, but for simulations in oblique seas the vertical plane motions will be affected due to this forcing, which is undesirable. A more elegant and general approach is to use an interpolation table for the model x-y position versus time when determining the wave kinematics in the simulation method. In this way the actual tracks may be different, but still the wave kinematics are evaluated at the position corresponding to that of the experiments.

DETERMINISTIC VALIDATION RESULTS

With respect to the initial conditions for the simulations, the positions in six degrees of freedom and the forward speed were set to those measured in the model tests. The roll damping coefficients were tuned to match calm water roll decay tests, for the nominal forward speed of 5 knots. The duration of the simulations was 1800 sec.

The first comparison concerns Test 304004, i.e. the highest sea state. Figures 3 through 6 below show comparisons for heave, pitch and roll versus time. The signals in red are the experimental time traces, the green lines denote the simulation time traces obatined from PANSHIP.

It is seen that the comparison between the measured and simulated heave, pitch and roll motions is fairly good.

Figures 7 and 8 show a comparison of the forward speed for Test 307004. Although the simulation method only partially accounts for second order wave forces (added resistance in waves) the global comparison in Figure 7 looks reasonable, i.e. low frequent forward speed variations are similar. Figure 8 shows that the wave frequent variations in speed tend to be underestimated in the simulation method.

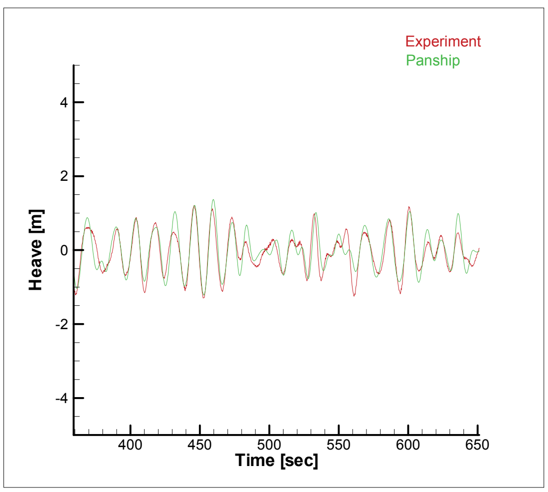

Fig. 3: Comparison heave Test 307004 (detail)

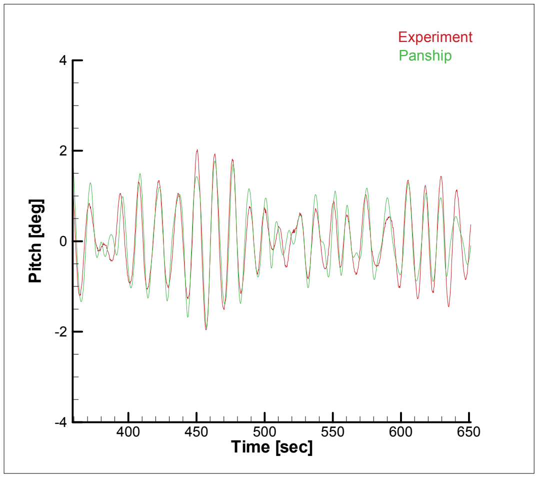

Fig. 4: Comparison pitch Test 307004 (detail)

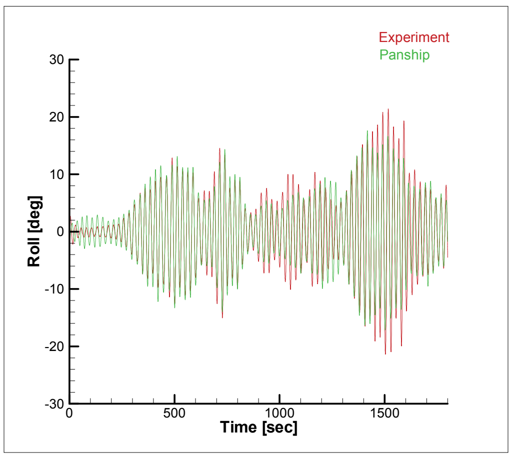

Fig. 5: Comparison roll Test 307004

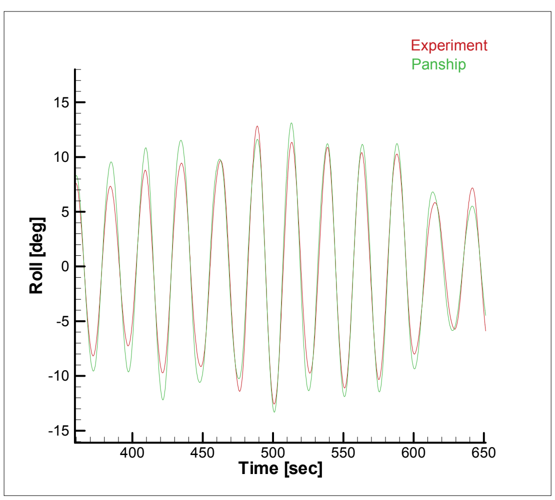

Fig. 6: Comparison roll Test 307004 (detail)

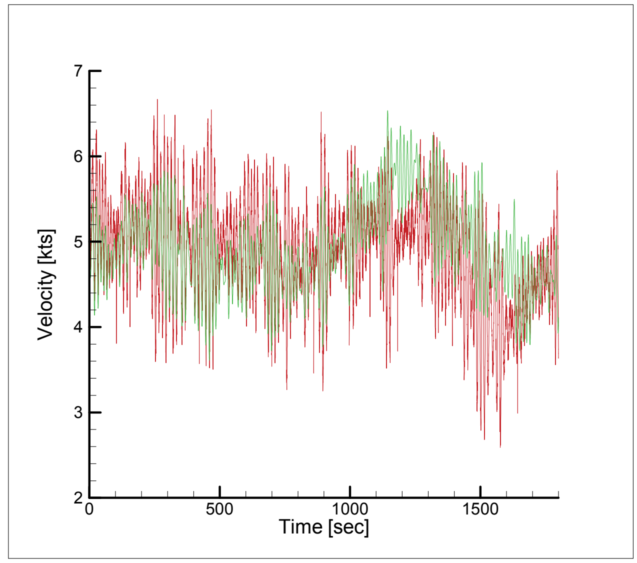

Fig. 7: Comparison velocity Test 307004

For the intermediate wave height (Test 307001) Figures 9 and 10 show the comparision for roll. It is seen that the resemblance is again fairly good, although around 800 and 1500 seconds of simulation differences start to appear. Probably the less strong roll forcing for this case makes the results more sensitive to inevitable differences between the simulation method and reality.

The last comparison given is for the lowest sea state (Test 307002) in Figures 11, 12 and 13.

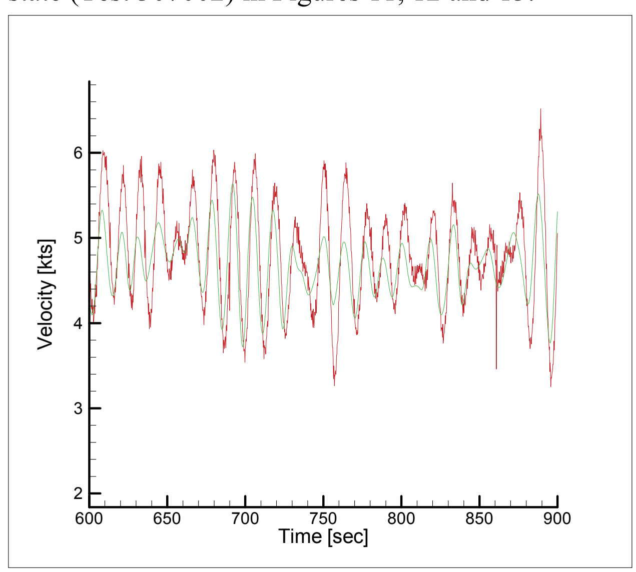

Fig. 8: Comparison velocity Test 307004 (detail)

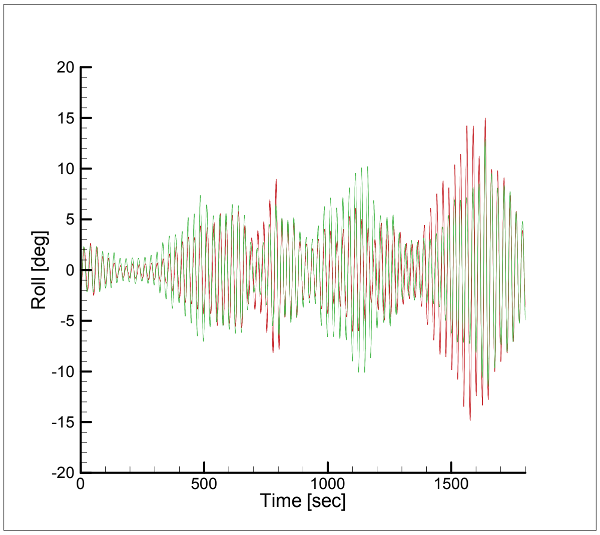

Fig. 9: Comparison roll Test 307001

The heave and pitch motions are again in good agreement. While parametric rolling is indeed virtually absent in the simulation results, the method can not accurately reproduce the low amplitude roll motions. This may be due to differences in course keeping, a slight asymmetry in the model configuration, small differences in the wave reproduction, the speed independent roll damping and the fact that the memory effect at the start of the simulations was not initialised. The latter may have caused the decaying initial rolling motion in the first segment of the time trace during the build-up of the memory effect.

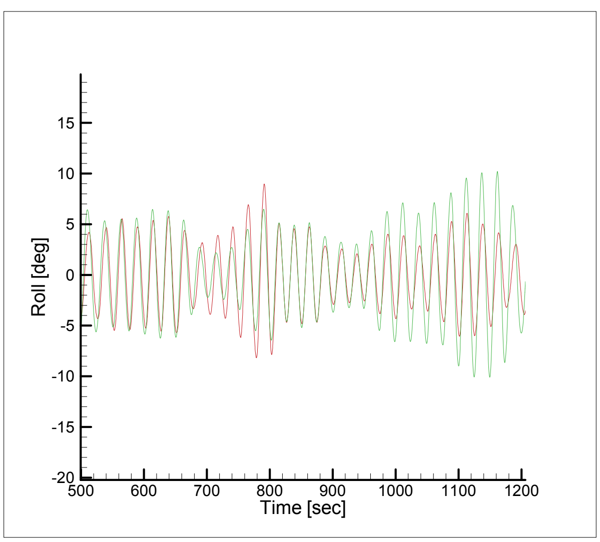

Fig. 10: Comparison roll Test 307001 (detail)

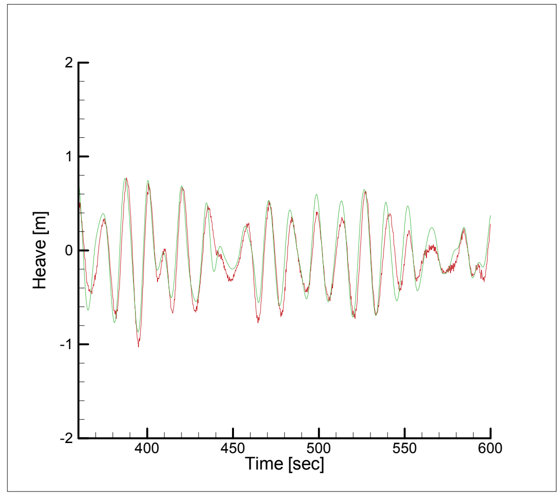

Fig. 11: Comparison heave Test 307002 (detail)

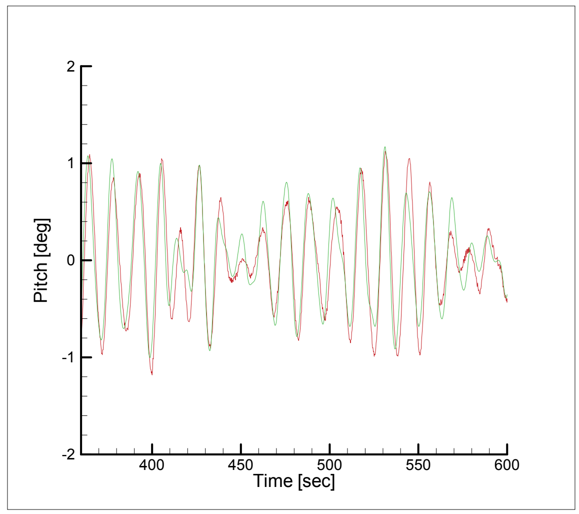

Fig. 12: Comparison pitch Test 307002 (detail)

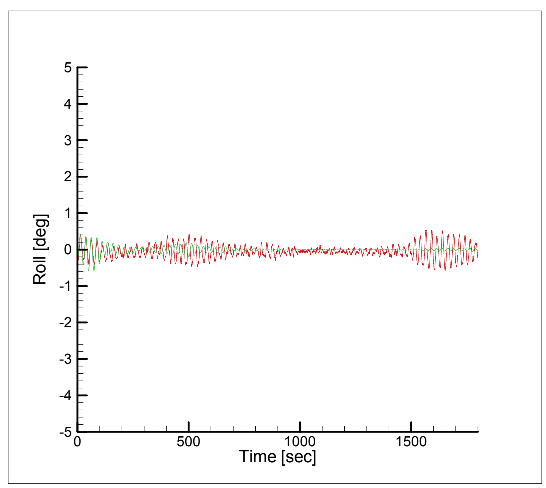

Fig. 13: Comparison roll Test 307002

CONCLUSIONS AND FUTURE WORK

A method has been developed to reconstruct experimental wave trains in a time domain simulation method.

The problem of inevitable deviations between the position of the model and simulated ship in the wave field has been circumvented by using the experimental position in the wave field to determine the wave kinematics.

The experimental and simulated time traces show a fairly good resemblance for heave, pitch and roll

motions. The best resemblance for roll is found for the highest sea state.

Future work will focus on deterministic validation for a high speed ship operating in steep stern quatering seas. In this work the focus will not only be on roll but also on the motions in the horizontal plane (sway and yaw).

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