Validation of Time Domain Panel Codes for Prediction of Large Amplitude Motions of Ships

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ABSTRACT

The paper describes the validation of two time domain methods to simulate the behaviour of a frigate operating in stern quartering seas. The simulation methods differ in the way the seakeeping problem is linearized. The first method is partially body exact while the second method is fully body exact. The validation is based on a statistical analysis as well as a deterministic comparison of simulated and experimental motion time traces.

Keywords: *time domain panel method, statistics, deterministic validation*

1. INTRODUCTION

The operability and safety of a ship depends amongst others on its behaviour in waves. At higher speed in steep waves from aft ward directions dynamic stability risks may exist. These risks can be investigated by means of model tests. Provided these 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, some limitations in representation of the physics of ship behaviour in waves from the stern quarter 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, in some of the smaller components of the roll damping, in components of the manoeuvring reaction forces and in the (dynamic) stall of the rudders. The neglect of wind on the roll damping and excitation, the wind heel and the propeller loading and related steerage has an effect. Issues that are modelled implicitly correctly are the natural peak-trough asymmetry 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 modelling has been pursued for 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 modelling the generation, propagation and absorption of steep waves in a limited computational domain and partly 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 calculation methods, which combine the efficiency of potential flow theory with empirical modules covering the non-linear aspects of manoeuvring and roll damping.

After validation, these models are particularly used in assessing capsize risk.

The present paper deals with validation and comparison of two such simulation methods for a frigate hull form operating in stern quartering seas. A brief description of the simulation methods is given first. Next, the experimental arrangement is described followed by a discussion on the effect of non-linear body boundary conditions on the simulation results.

The simulation methods have been partially developed in a joint industry project on high speed craft called FAST3. Participants are Damen Shipyards (NL), Delft University of Technology (NL), Defence Science Technology Organisation (AUS), MARIN (NL) and the Royal Netherlands Navy (NL).

2. SIMULATION METHODS

Predicting the motion performance of ships operating in stern quartering sea states is more complicated than that for beam or head seas. In stern quartering seas motion amplitudes may be large and both vertical and horizontal plane motions (course keeping) are important. Ideally, prediction methods should be capable of accounting for:

- Six degrees of freedom motions, especially the coupling between sway, yaw and roll,
- Large motion amplitudes,
- Non-linear waves: dynamic stability problems are generally most severe in steep waves for which non-linear effects are of importance,
- Time-varying wetted hull geometry and its effects on restoring forces, wave excitation, wave diffraction and wave radiation forces,
- Forward speed and the effects of friction and flow separation on hydrodynamic properties: in stern quartering seas the wave encounter frequency is low so that potential flow damping is relatively low,
- Propulsion and steering: the speed variations in the horizontal plane should be predicted adequately, and course keeping is important with respect to broaching,
- The contribution of the wind to the roll damping and the roll excitation.

Prediction methods that are capable of handling the above are in principle capable to simulate phenomena like capsize due to loss of stability in waves, surf riding and broaching. However, fully non-linear simulation methods are scarce and rather computationally intensive. When a large number of conditions needs to be investigated the required simulation times are impractical. Therefore, there is a need for fast(er) time simulation methods.

One approach that has been proven to lead to reasonable simulation results within a practical time frame is a time domain potential flow simulation. By inserting empirical and semi-empirical components, the errors due to neglecting viscosity, rotation and compressibility, can be minimized. However, also among the time domain potential flow simulations, choices have to be made between simulation time and accuracy. One of these choices is the handling of boundary conditions on the boundaries of the fluid domain.

In an attempt to quantify the effects of linearising boundary conditions, two simulation methods are compared that are identical except for the handling of body boundary conditions. Both simulations are implemented in Panship (Van Walree 2002, De Jong 2011, Van Walree and Turner 2013), a time domain panel method characterised by:

- 3D transient Green function to account for linearized free surface effects, exact forward speed effects, wetted surface, radiated and diffracted wave components along the hull and a Kutta condition for ventilated transoms,
- 3D panel method to account for Froude-Krylov forces on the instantaneous submerged body,
- Cross flow drag method for viscosity effects,

- Resistance (calm water and in waves) is obtained from pressure integration each time step,
- Propulsion and steering using propeller open water characteristics, semi-empirical lifting surface characteristics and propeller-rudder interaction coefficients,
- FDS (Blok and Aalbers 1991) viscous roll damping,
- Autopilot steering,
- Unsteady wind loading based on wind tunnel derived wind load coefficients.

It should be noted that apart from the cross flow drag method there are no “manoeuvring” terms present in Panship. For instance the sway force and yawing moment due to a drift angle or yaw rate are obtained from the potential flow panel method.

Panship is used at MARIN for seakeeping predictions for fast and unconventional ships. In the semi non-linear version, the transient Green function is solved for linearized free surface and body boundary conditions. Radiation and diffraction forces are then based on the mean wetted surface and the mean forward speed of the vessel. Since these are both known prior to the start of the time domain simulation, the Green function terms for all time steps can be calculated before the actual simulation starts, resulting in a significant reduction of the computational effort. Froude-Krylov forces are based on the exact wetted surface geometry including ship motions, incident and diffracted waves.

The purpose of the non-linear Panship version development is to determine wave impact loads on high speed ships. In the non-linear version of Panship, the Green functions are evaluated at each time step for the instantaneous position of the vessel in the incident and disturbed wave. Since the transient Green function relies on linear free surface boundary conditions, the wetted hull surface relative to the disturbed water surface ζ is used, i.e. the vertical coordinate z is replaced by $z-\zeta$. For more detailed information on Panship see Van Walree and Turner (2013).

The present purpose is to investigate the merits of both Panship versions for a frigate operating in stern quartering seas. This is achieved by comparing simulation results of both methods with experimental results.

3. MODEL TESTS

Model tests were carried out on the parent hull of the FDS systematic hull form series; see Blok and Beukelman (1984). The tests have been performed in MARIN's Seakeeping and Manoeuvring Basin which measures 170x40x5 m in length, width and depth respectively. Table 1 shows the main particulars of the full scale vessel; Figure 1 shows the experimental setup. The model scale used was 15, resulting in a relatively large model.

L_{PP}	100.00	m
L_{WL}	99.982	m
B	12.502	m
T_F	3.125	m
T_A	3.125	m
C_b	0.401	-
Δ	1568.40	m^3
S	1212.30	m^2
GM	2.50	m

Table 1 Main particulars of frigate

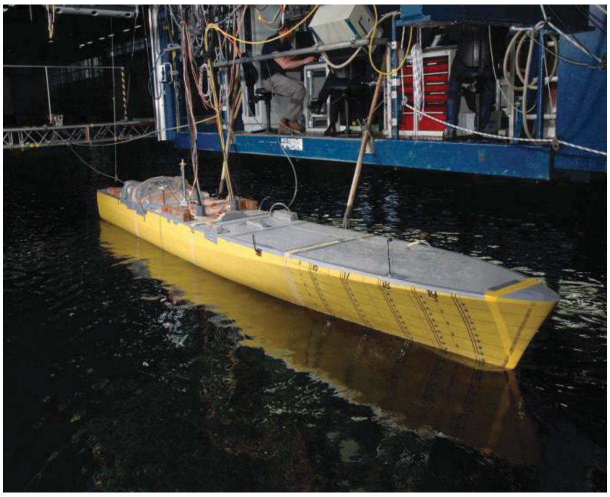

Figure 1 Experimental setup

During the tests the model was free sailing in six degrees of freedom and self propelled. Course keeping was realized by an autopilot actuating twin rudders. In order to ensure a negligible effect of the cables connecting vessel and towing carriage, the carriage was able to follow the vessel in its surge, sway and yaw motions.

4. VALIDATION

When validating simulation methods for (irregular) stern quartering waves, a number of aspects have to be taken into account. First, compared to head waves, accelerations, impact pressures and structural loads due to slamming are less relevant. Instead, course keeping and stability are the phenomena that are of interest. However, the low wave encounter frequencies combined with a large, strongly non-linear dependency of the vessels response on the initial speed and position in the wave make the acquisition of reliable statistical data time consuming and expensive.

In this paper two types of validation will be performed. First, a statistical comparison of simulations and model tests is shown. Next, individual model test runs will be used for a deterministic comparison of the vessels motions in stern quartering seas.

4.1 Statistical Validation

The main issue when it comes to validating statistical data for a vessel operating in stern-quartering waves is the acquisition of sufficient data. Due to the low encounter frequency, obtaining a reasonable number of wave encounters can be very time consuming. The model tests discussed here had a duration of 850 seconds (prototype value), obtained by performing 5 to 7 runs (depending on the operational speed) for every condition.

For the statistical validation of the simulation results, two conditions have been selected as shown in Table 2. In both conditions a JONSWAP spectrum has been used with a different wave train realization in each run. A 360 deg wave direction means following seas.

Test case	Speed [kt]	Wave direction [deg]	Wave height [m]	No. of wave encounters [-]
707	17	315	3.8	79
709	23	300	3.8	37

Table 2 Test conditions

As indicated in Table 2, the number of wave encounters during the model tests varied roughly between 40 and 80. In order to get an idea of the statistical significance of the data obtained, 10 simulations in identical conditions with different wave train realizations have been performed with the semi non-linear version of Panship. Each run had a duration of 850 seconds. Mean values and standard deviations of all six degrees of freedom have been determined for each run. An indication of the scatter in results can be obtained from Figures 2 through 5. Figures 2 and 3 show the mean values for all six degrees of freedom, Figures 4 and 5 the standard deviations. Note that for the x-direction the speed is shown instead of the surge motion. In the bar graphs, the left most (darkest) bar describes the values obtained during the model test, the next ten bars are values obtained from simulations for different wave train realisations (seeds)

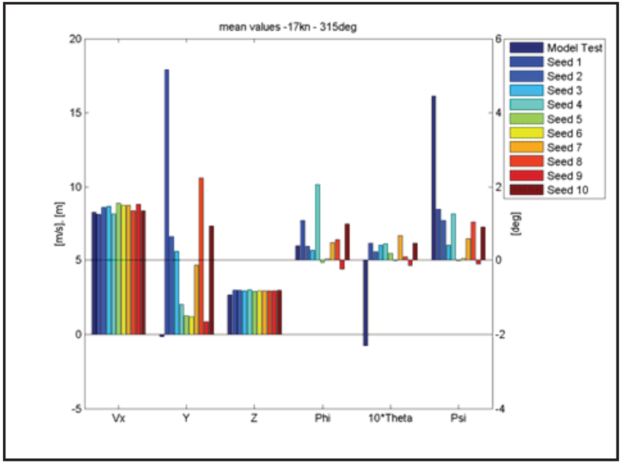

Figure 2 Mean values case 707

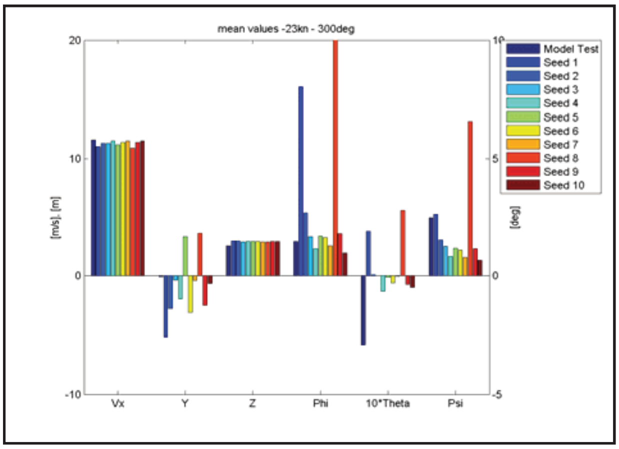

Figure 3 Mean values case 709

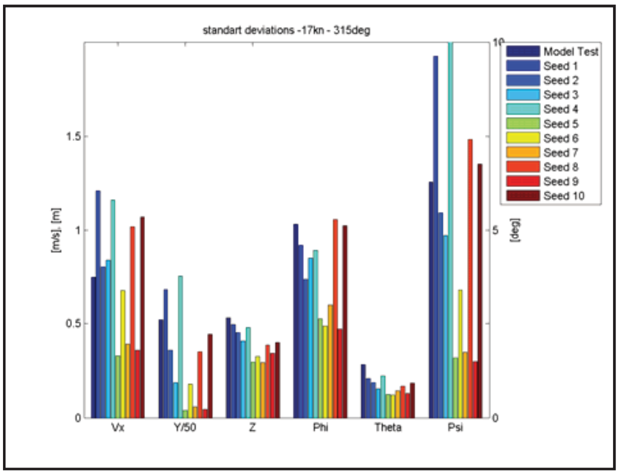

Figure 4 Standard deviations case 707

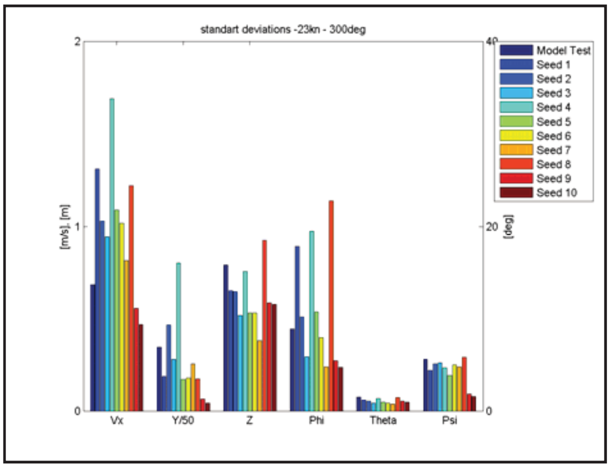

Figure 5 Standard deviations case 709

Individual runs show a significant variation in standard deviation for speed, heave and pitch. This is to be expected when between 40 and 80 waves are met per simulation run. The variation in mean value and standard deviation for sway, roll and yaw is quite large. The plots show that in almost all cases the model test results lie within the scatter of the simulations. The only conclusion that can be made about the validity of the simulation results on basis of these plots is that they are in the right order of magnitude.

In more detailed approach the 95% confidence bounds have been determined on basis of the variance of the variance of individual runs, following methods provided by Belenky et al (2007). Figures 6 through 11 show the mean standard deviation and 95% confidence intervals for sway, roll and yaw for the model tests and the simulations.

It can be seen that for all cases the mean standard deviation of the Panship simulations (indicated by the square symbol) is within the confidence bounds of the model test result. This suggests that Panship simulations are accurate in a statistical sense. The uncertainty in the model test results is expected to be much larger than that of the simulations since its duration is about 10 times lower. Apparently this is only so for case 709 for roll and yaw.

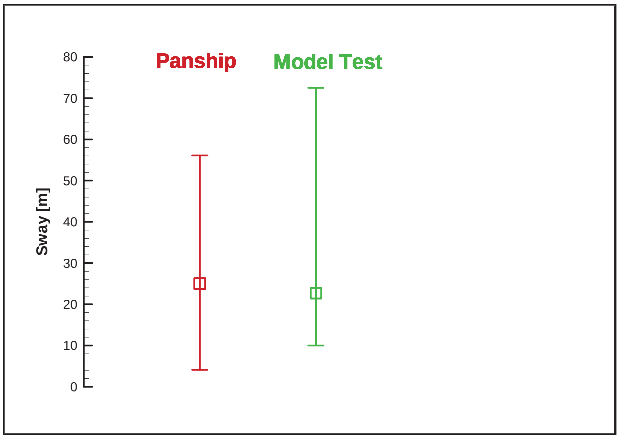

Figure 6 Confidence bounds for sway standard deviation, case 707

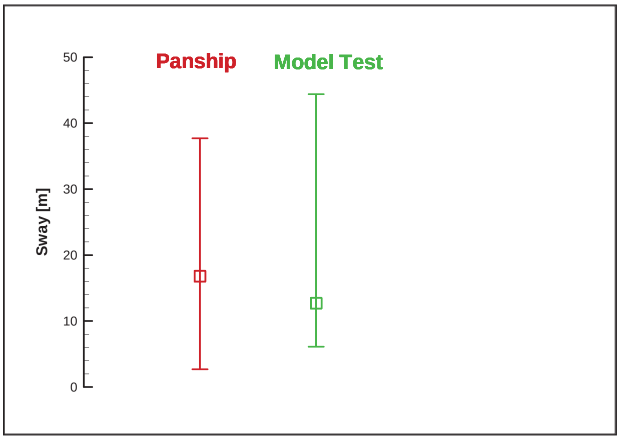

Figure 9 Confidence bounds for sway standard deviation, case 709

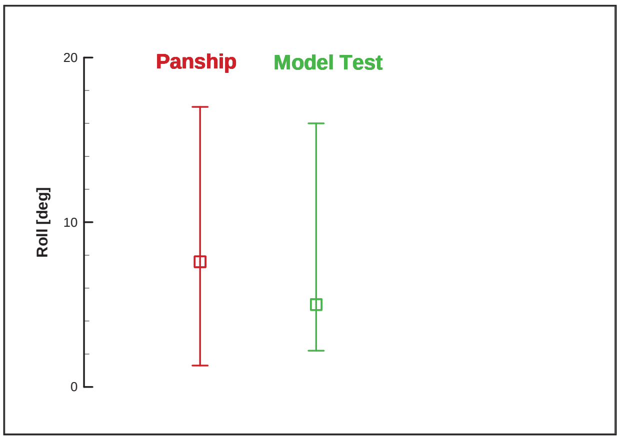

Figure 7 Confidence bounds for roll standard deviation, case 707

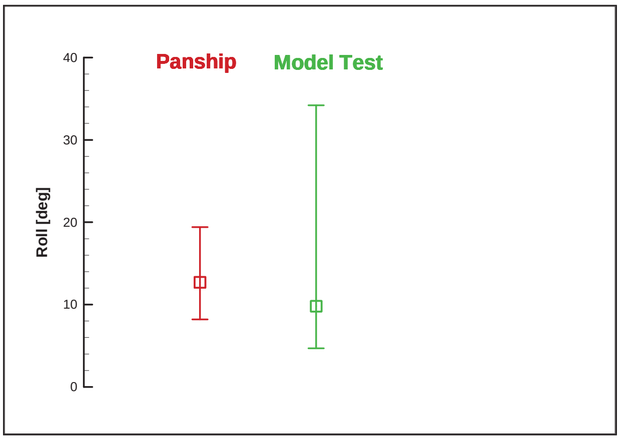

Figure 10 Confidence bounds for roll standard deviation, case 709

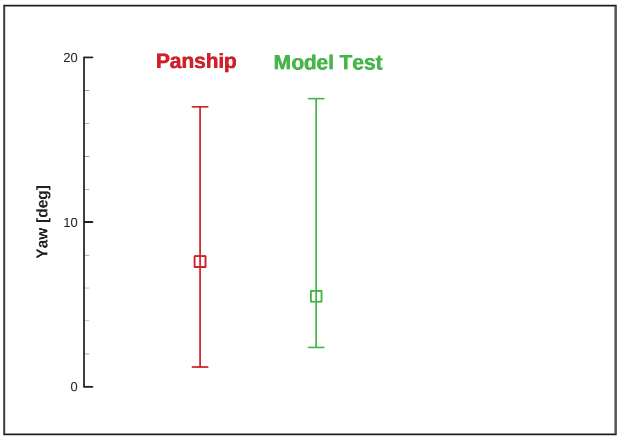

Figure 8 Confidence bounds for yaw standard deviation, case 707

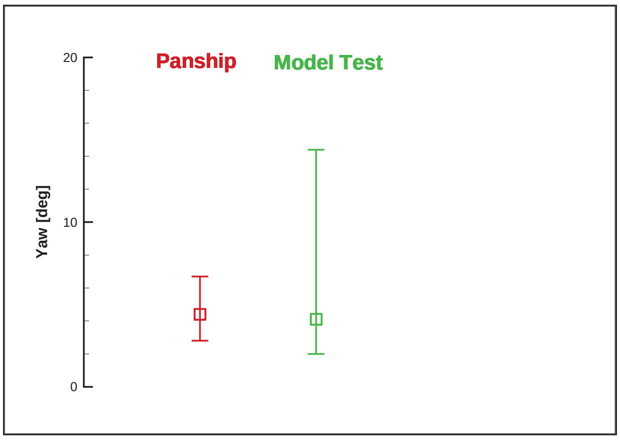

Figure 11 Confidence bounds for yaw standard deviation, case 709

4.2 Deterministic Validation

Next to the statistical method, a deterministic approach has been taken to validate the simulated responses of the vessel. First the experimental wave train needs to be reproduced in the simulations, so that time traces of motions can be compared. For this deterministic validation, single model test runs of about 175 seconds duration have been selected from the model tests runs for cases 707 and 709. For deterministic validation a number of aspects have to be taken into account.

The first point that has to be taken into account is the accumulation of errors over time. In stern quartering waves, the response of a vessel to a wave train is strongly dependent on its initial position, orientation and speed in that particular wave. Hence, in identical wave trains small errors in the simulated position would quickly accumulate, rendering the rest of the validation useless. In order to overcome this problem, during the simulation the vessel's X-Y position required to evaluate the wave kinematics is taken identical to that measured during the model test. In this way, for each time step the wave trains at the centre of gravity for model test and simulation are identical, provided the wave train reconstruction is perfect.

Secondly, attention should be paid to the initial conditions when the simulation is started. During the model tests, when the measurements are started the vessel has already sailed a number of ship lengths in the given conditions. During this period, any forward speed effects and the wave system are fully developed. However, when a simulation is started, there are no memory terms in the Green's function, creating the equivalent of the vessel being instantly accelerated from zero to operational speed the moment the simulation starts. For the deterministic simulations, this has been overcome by forcing the vessel to attain the velocity of the model test during the first 30 seconds of each run.

The process to reconstruct the experimental wave train in the simulation method is detailed by Van Walree and Carette (2011). Figure 12 shows a typical comparison between the measured and reconstructed wave trains. The reconstruction is reasonably good but not perfect, which will cause some differences between the measured and simulated motions.

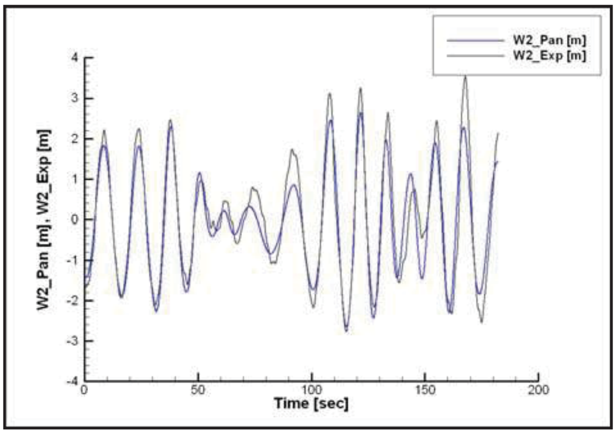

Figure 12 Comparison between reconstructed (blue) and experimental (black) wave trains

Figures 13 through 24 show a comparison between the measured and the simulated ship motions. The red signals denote the non-linear PanshipNL results, the green signals denote the semi-linear Panship results and the blue signal represents the experimental data.

Heave, roll and pitch are adequately predicted by both the semi non-linear and non-linear Panship methods for run 707005. For both methods the sway motion is off mainly due to a persisting difference in the yaw motion. The variations in forward speed are better predicted by the non-linear method.

For run 709003 differences between the semi non-linear and non-linear Panship versions are not large, except near the end of case 709 where relatively large roll and yaw motions occur which are better captured by the non-linear method. Again the speed loss is better predicted by the non-linear method.

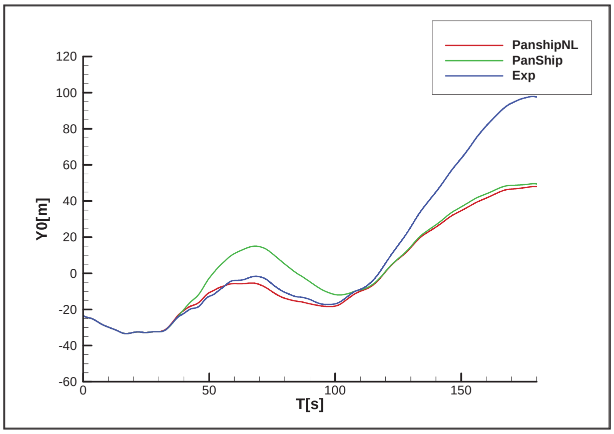

Figure 13 Comparison of sway for run 707005

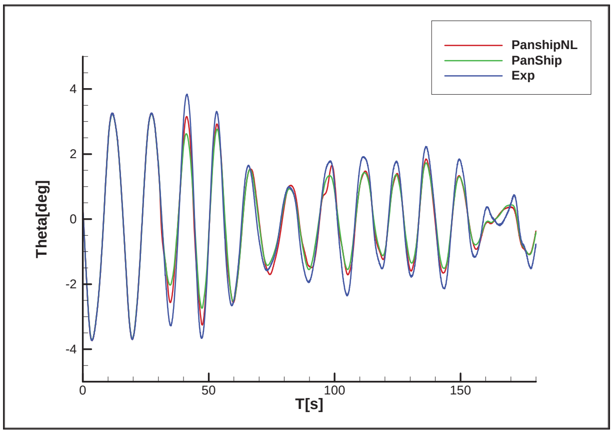

Figure 16 Comparison of pitch for run 707005

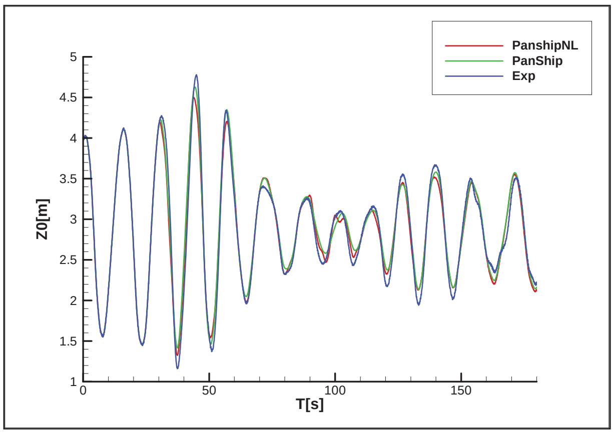

Figure 14 Comparison of heave for run 707005

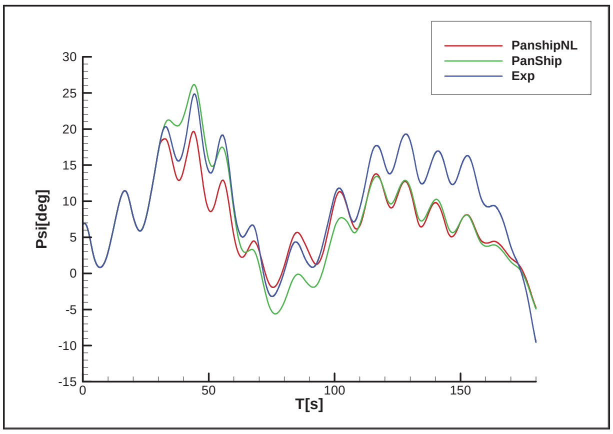

Figure 17 Comparison of yaw for run 707005

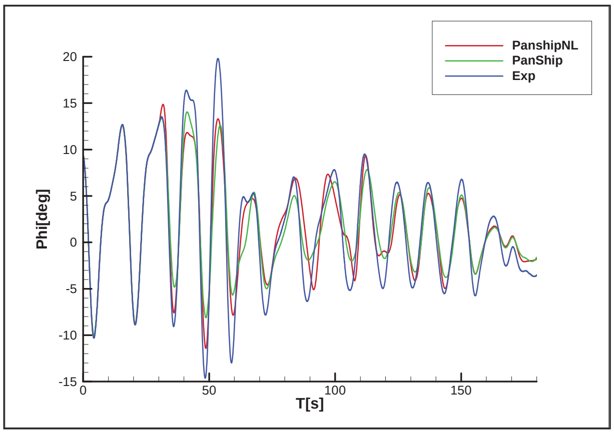

Figure 15 Comparison of roll for run 707005

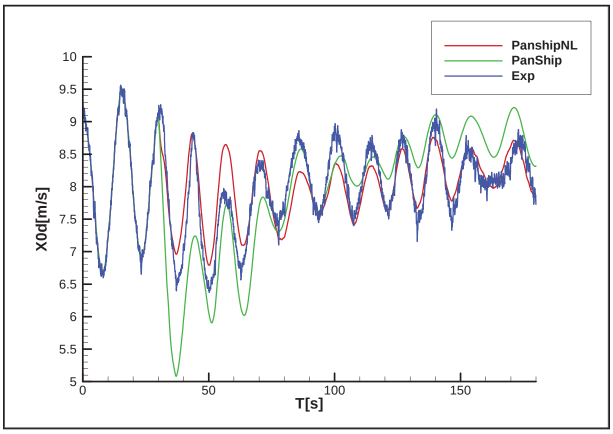

Figure 18 Comparison of speed for run 707005

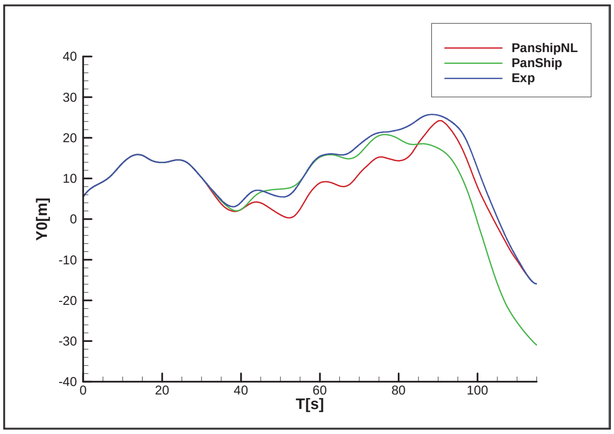

Figure 19 Comparison of sway for run 709003

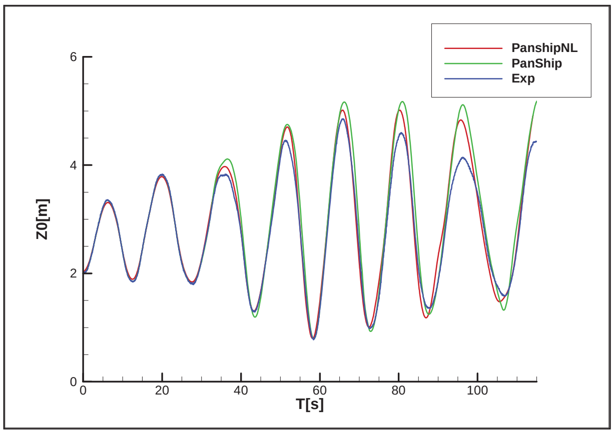

Figure 20 Comparison of heave for run 709003

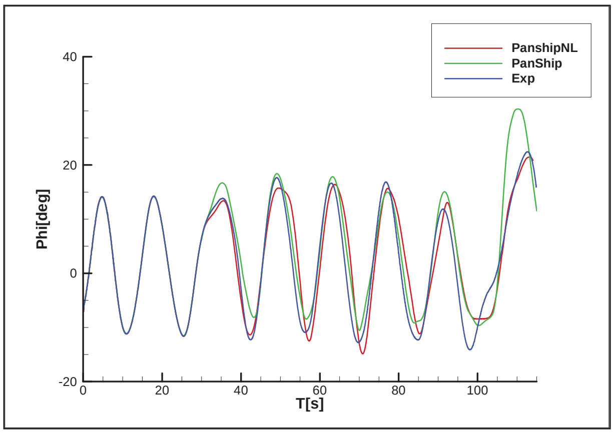

Figure 21 Comparison of roll for run 709003

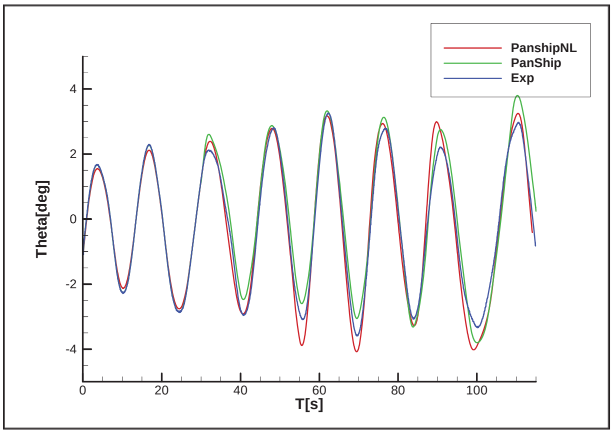

Figure 22 Comparison of pitch for run 709003

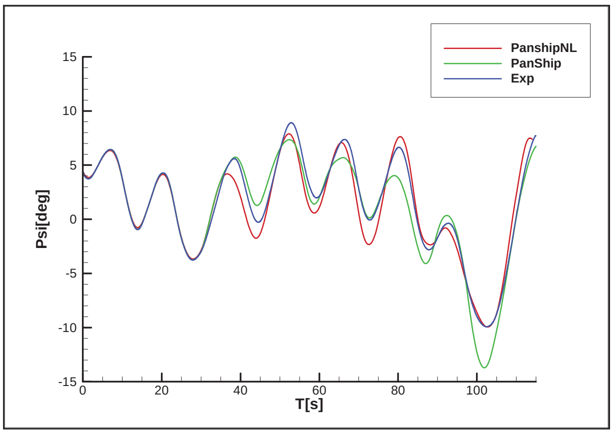

Figure 23 Comparison of yaw for run 709003

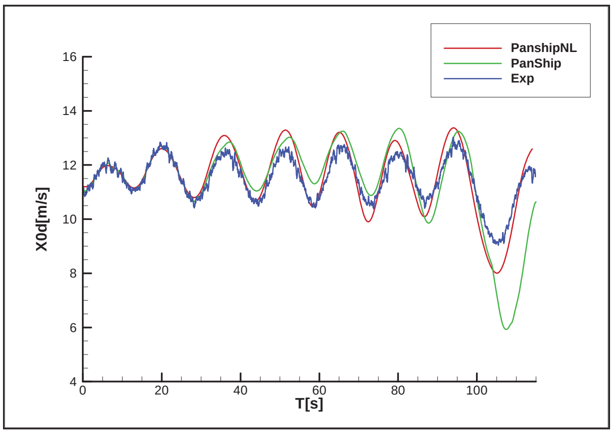

Figure 24 Comparison of speed for run 709003

7. CONCLUSIONS

As is well known for ships operating in stern quartering seas the horizontal plane motions show significant variation in mean value and standard deviation. The mean standard deviation of sway, roll and yaw motions of simulation results are found to be within the experimental confidence range for the standard deviation. Although the duration of the simulations is much greater than that of the model tests for most cases the confidence limits for simulations and model tests are quite similar.

Deterministic validation shows that both the semi non-linear and the non-linear simulation methods yield a fair prediction of motions and speed variations in stern quartering seas. This is not true for case 707 where the sway motion is offset due to a persistent difference in yaw motion. The non-linear simulation methods yield better predictions for the forward speed variations and the large amplitude roll and yaw motions, otherwise differences between the semi non-linear and non-linear simulation methods are small.

8. ACKNOWLEDMENTS

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