Investigation into the Roll Behaviour of Landing Craft in Deep Water

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ABSTRACT

Understanding and predicting the seakeeping and stability behaviour of a landing craft in both deep and shallow water is critical to assuring their safe and effective operation. The Australian Defence Science and Technology Organisation (DSTO) and the Australian Maritime College (AMC) are undertaking a research program to develop a numerical based capability to predict the motions of landing craft during operation. A series of model scale experiments have generated data for landing craft roll decay and motion response in calm water and in beam seas for both deep and shallow water conditions.

This paper presents the outcomes of an investigation into the roll behaviour of a geometric series of landing craft hull forms in deep water. Numerical simulations were performed using FREDYN, a non-linear, six degree of freedom time-domain ship motion prediction code. The results are validated using experimental data. An empirical method proposed by Ewers and Freathy [1] for calculating roll damping coefficients of barge like hull forms, in addition to the Ikeda-Himeno-Tanaka (IHT) and Fast Displacement Ship (FDS) methods, are evaluated against experimental data using the existing roll damping functionality within FREDYN [2].

The significance of predicting the seakeeping and stability performance of conventional landing craft, without the need for scale model testing, is discussed as well as the potential to use the tool to develop stability criterion, enhance platform operability and safety and facilitate simulator based operator training.

INTRODUCTION

The Australian Defence Organisation is currently undertaking an acquisition program (JP2048) to upgrade its existing amphibious capability. This acquisition program is split into several Phases with Phase 3 being the replacement of its amphibious watercraft. These watercraft are required to deliver personnel and equipment from ship to shore through a variety of wave environments. The environments include that experienced within the well dock of the parent ship to deep water offshore and the inshore surf zone. Understanding the seakeeping and stability behaviour of the landing craft in both deep and shallow water is critical to their safe operation. The Australian Defence Science and Technology Organisation (DSTO) and the Australian Maritime College (AMC) are undertaking a research program to develop a numerical based capability to predict the motions of landing craft in a variety of operational environments.

Part of this capability includes the modification and validation of an existing ship motion prediction software tool (FREDYN). Once validated for landing craft hull forms, this numerical tool will have a variety of applications and provide significant benefits to many of the world's Navies. The application of this tool will support the development of more appropriate intact and damage dynamic stability criteria for landing craft. The stability criterion that is currently applied to landing craft by many Navies is based on an empirically derived criteria developed during the 1960's for Naval combatants operating in a deep water environment [3]. This criterion is not necessarily applicable to the barge like hull forms of conventional landing craft or to operations in a shallow water environment.

FREDYN can also be integrated into ship handling training simulators and utilised by landing craft operators to ensure that amphibious operations are performed with the highest level of preparedness and competency. Some of the potential advantages of classroom based simulation training, as opposed to "hands on" training, are a reduction in training costs, an increase in training capacity, an increase in the proficiency and awareness of operators and an inherently safe training environment. Studies undertaken by the United States Coast Guard have shown that these benefits can be achieved through their use of a small boat simulator as a training tool [4].

Another application of this capability is the ability to define and fully understand the operational boundaries of both an intact and damaged landing craft. The tool might also form the basis of cargo loading software to assist the management of the landing craft's load condition and support the safe and effective completion of amphibious operations.

If this tool is to be utilized by Navy in the applications described above it is imperative that the accuracy of the predictions is verified. DSTO's research program is focused on developing and validating components within the tool that significantly influence the prediction of the motions of the landing craft. These include: viscous roll damping formulations, ship motions, manoeuvring, resistance and propulsion.

SCOPE

The focus of this paper is the development and implementation of a viscous roll damping method for the accurate prediction of landing craft roll motion. The preliminary results of both an experimental and numerical study into the roll behaviour of a geometric series of landing craft hull forms in deep water are presented. For an accurate prediction of landing craft roll motion, an appropriate roll damping method is required. Ewers and Freathy [1] have proposed an empirical method for the prediction of the viscous roll damping method coefficients for offshore barge type hull forms. Numerical predictions using this method and other roll damping formulations, including the Ikeda-Himeno-Tanaka (IHT) and Fast Displacement Ship (FDS) methods were completed using FREDYN. The results of these predictions are evaluated against experimental data.

EXPERIMENTAL STUDIES

A series of model tests were undertaken at the Model Test Basin at the AMC in Launceston, Tasmania. Roll decay tests with initial heel angles of 5, 10 and 15 degrees were conducted for three different landing craft models with varying length to beam (L/B) ratios. The L/B = 3.12 and 4.37 models are geometrically similar and represent the typical size relationships of landing craft. The L/B = 3.77 model is representative of a conventional naval landing craft. The particulars of the three models are shown in Table 1. Figure 1 shows a photograph of the L/B = 3.12 model during testing.

L/B	Draught AP (m)	Draught FP (m)	Displacement (kg)	Roll Gyradius k_{xx} (m)	VCG (m)	Beam (m)	Scale Factor
3.12	0.113	0.113	59.99	0.144	0.131	0.481	16.067
3.77	0.100	0.100	100.59	0.230	0.210	0.640	10.000
4.37	0.123	0.123	54.51	0.125	0.135	0.372	14.831

Table 1 Model particulars

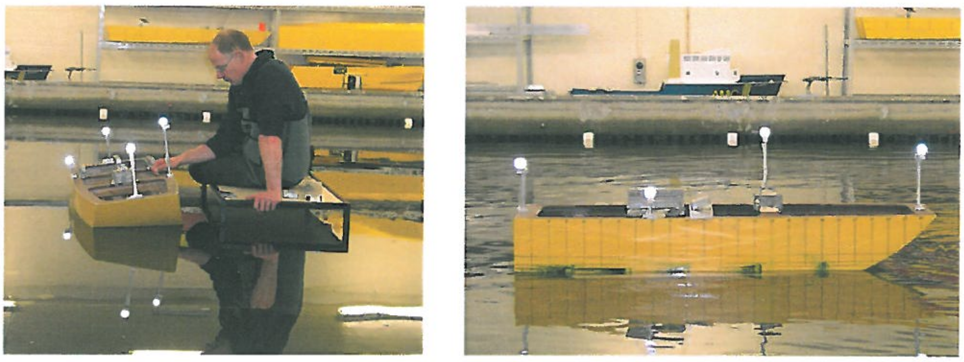

Figure 1 Model (L/B = 3.12) during roll decay test

The motions of the landing craft models were measured in all six degrees of freedom using a QUALISYS three-dimensional digital video motion tracking system. This system is calibrated using a series of 16 permanent reference markers which have been surveyed into position.

The model setup and test procedures adopted were consistent with the standard Model Test Basin experimental procedures and are based on the recommended procedures of the International Towing Tank Conference (ITTC) [5].

The estimated level of uncertainty associated with the model's measured parameters is presented in Table 2. Both the L/B = 3.12 and 4.37 models' vertical centre of gravity (VCG) was determined through the conduct of an inclining experiment while the VCG of the L/B = 3.77 model was determined using the tilt frame. The roll radius of gyration (k_{xx}) was measured using a tilt frame for all of the models.

Estimated levels of uncertainty (to 95% confidence level)	
Model beam	± 1.00 mm
Model length	± 1.50 mm
Model displacement	± 100 grams
Model VCG	± 1.00 mm
Measurement of roll	± 0.10 degrees

Table 2 Estimated measurement uncertainty for the landing craft models

NUMERICAL STUDIES

The Cooperative Research Navies (CRNav) currently comprises the Navies of Australia, Canada, France, The Netherlands, the United Kingdom and the United States Coast Guard. The CRNav Dynamic Stability group was established in 1989 to initiate a research program focussed on increasing the understanding of the dynamic stability of naval vessels. This was to be done from a physics based approach rather than an empirically derived approach such as that developed by Sarchin and Goldberg in the 1960s. The work of CRNav has led to the development of FREDYN, a non-linear time domain numerical tool capable of predicting the motions of a ship in moderate to extreme seaways.

Roll damping is an important component of any ship motion simulation. FREDYN currently has three roll damping methods to choose from [2]. The Fast Displacement Ship (FDS) method is recommended for frigate type hull forms operating at moderate to high speeds. The Ikeda-Himeno-Tanaka (IHT) method is for conventional merchant type hull forms operating at low to moderate speeds. FREDYN has a third option for the roll damping formulation referred to as MANDAMP. This method allows the user to input appropriate damping coefficients obtained from either model tests or other formulations. The coefficients required are:

- B_0^{lin} the linear speed independent roll damping coefficient;
- B_u^{lin} the linear speed dependent roll damping coefficient;
- B_0^{qua} the quadratic speed independent roll damping coefficient; and
- B_u^{qua} the quadratic speed dependent roll damping coefficient.

Collectively, these coefficients are used to calculate a roll moment as a reaction to the ship's rolling rate.

Ikeda, Himeno and Tanaka have developed an alternative approach to that described above to calculate the roll damping coefficients. This approach gives consideration to the pressure distribution around the hull that results in the formation and shedding of vortices [6]. Predictions using this method showed improvements over earlier formulations but the solution is sensitive to the pressure distribution at the bilges. Ewers and Freathy [1] extended this work and developed an empirical formula for the quadratic term (B_0^{qua}) of the roll damping method for barge like hull forms, see Equation 1. In this formulation B_0^{lin}, B_u^{lin} and B_u^{qua} are considered to be equal to zero, however, care is required when completing numerical simulations to ensure that these parameters are only accounted for once. Therefore, in the application of FREDYN it is necessary to set B_0^{lin} = -40 kN-m-sec as the linear component is pre-calculated as part of the hull's non-viscous added mass and damping coefficients. Numerical predictions were completed using the MANDAMP method in conjunction with the Ewers and Freathy formulation for B_0^{qua}.

$$B_0^{qua} = \frac{4L\rho R_r^2 \omega \cdot \left(3.9 - 51.4\frac{R_b}{B}\right) \cdot \left[(0.5B - R_b)^2 + (D - R_b) \cdot (D - R_b + 1.5H_h)\right]}{9\pi} \qquad \text{Equation 1}$$

Where:

L = Length between perpendiculars (m)
ρ = Density of water (kg/m^3)
R_r = Distance from bilge to centre of gravity (m)
R_b = Bilge radius (m)
B = Beam (m)
H_h = KG – D (m)
D = Draft (m)
KG = Vertical location of centre of gravity above the keel (m)
π = Pi [3.1416] (constant)
ω = Natural roll frequency (rad/sec)

RESULTS

Numerical simulations of roll decay were completed for three L/B ratio landing craft models and at three different initial heel angles using the viscous roll damping methods previously described. In all cases the roll response (as a function of time) predicted using the FDS method was the same as that predicted by the IHT method. For this reason, only the results of the IHT simulations will be shown in this paper. Figure 2 to Figure 10 show the comparison between the experimental and numerically predicted roll decay time traces for the three landing craft models at the three different initial heel angles.

It is evident that the predictions made using the IHT method and the Ewers (B_0^{qua}) based method (Equation 1) do not match the experimental results in either period or amplitude. The roll period is a function of the model's mass and its added mass and can be modified by changing the k_{xx} value. Within FREDYN, the added mass is calculated using a strip theory approach. This approach is valid only for slender hull forms (L/B > 4). Therefore, the numerically predicted added mass may need tuning for low L/B hull forms such as those considered in this study.

It was decided to investigate the effect of changing the initial k_{xx} for each of the models with the aim of tuning the numerical prediction to the experimental results. Consequently, additional simulations were completed to obtain a match in the roll response period by modifying the roll radius of gyration (k_{xx}) input value. The vertical centre of gravity of the model was assumed to be fixed and therefore GM_T remained unchanged.

Once the predicted roll response period was matched to the experiment, and an appropriate k_{xx} value was obtained, a new B_0^{qua} based on the revised k_{xx} was calculated using Equation 1. A comparison between the numerical predictions with this revised B_0^{qua} value and the experimental results are also shown in Figure 2 to Figure 10. The percentage change in k_{xx} required to tune the numerically predicted roll period for each of the models is noted in each figure. These results show that when using the revised B_0^{qua} value, a significant improvement in both the roll period and amplitude can be achieved for the MANDAMP with Ewers method for all of the conditions when compared to the experimental data.

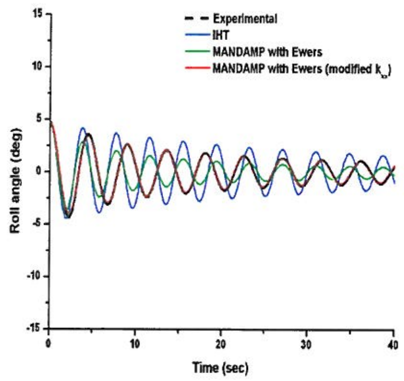

Figure 2 Roll decay response; Model L/B = 3.12; Initial angle of heel = 5 degrees; k_{xx} increased by 21%.

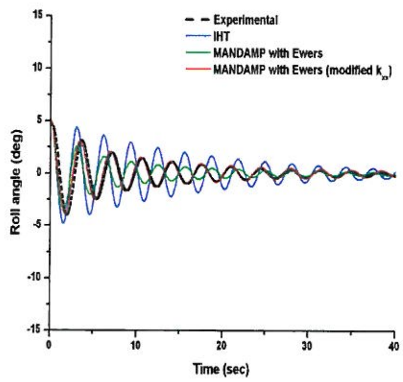

Figure 3 Roll decay response; Model L/B = 3.77; Initial angle of heel = 5 degrees; k_{xx} increased by 15%.

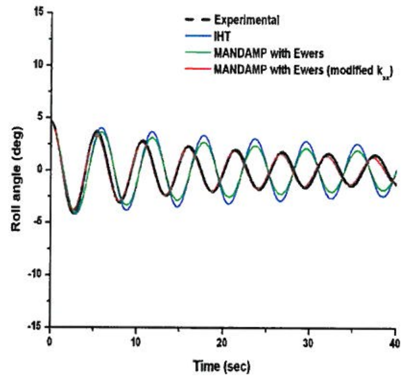

Figure 4 Roll decay response; Model L/B = 4.37; Initial angle of heel = 5 degrees; k_{xx} reduced by 15%.

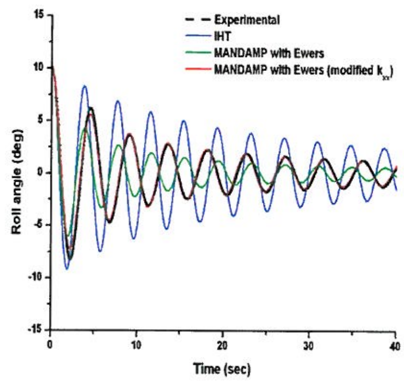

Figure 5 Roll decay response; Model L/B = 3.12; Initial angle of heel = 10 degrees; k_{xx} increased by 21%.

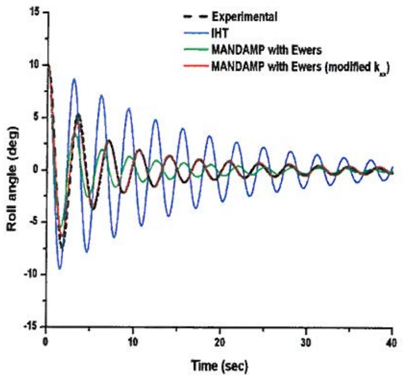

Figure 6 Roll decay response; Model L/B = 3.77; Initial angle of heel = 10 degrees; k_{xx} increased by 15%.

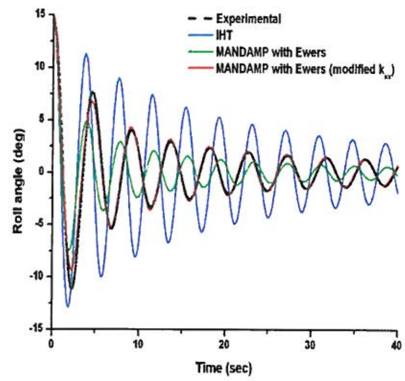

Figure 8 Roll decay response; Model L/B = 3.12; Initial angle of heel = 15 degrees; k_{xx} increased by 21%.

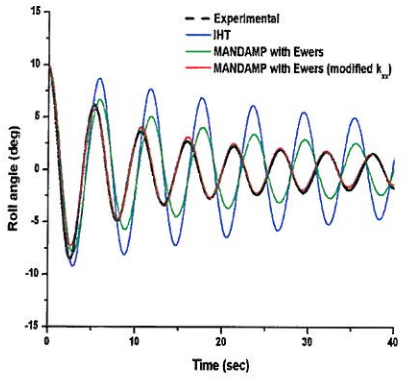

Figure 7 Roll decay response; Model L/B = 4.37; Initial angle of heel = 10 degrees; k_{xx} reduced by 15%.

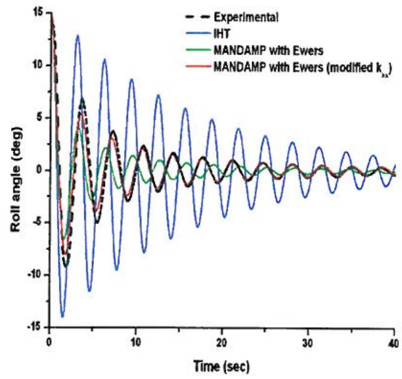

Figure 9 Roll decay response; Model L/B = 3.77; Initial angle of heel = 15 degrees; k_{xx} increased by 15%.

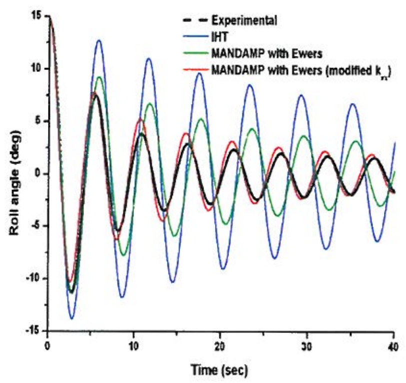

Figure 10 Roll decay response; Model L/B = 4.37; Initial angle of heel = 15 degrees; k_{xx} reduced by 15%.

Figure 2 to Figure 4 show the predicted roll decay for the 5 degree initial heel angle condition. Excellent agreement with the experimental results for all models was observed for the predictions using the MANDAMP with Ewers method with the revised k_{xx} and B_0^{qua} values appropriate for each landing craft.

Figure 5, Figure 6 and Figure 7 show a comparison between the numerical predictions and experimental results for the 10 degree initial heel angle for the L/B = 3.12, L/B = 3.77 and L/B = 4.37 models respectively. The results show that in comparison with the experimental data, both the period and the amplitude are predicted with a good level accuracy for all models when initially heeled to an angle of 10 degree.

At the larger initial heel angle of 15 degrees the MANDAMP with revised Ewers predictions show good agreement with the experiment in both period and amplitude for the L/B = 3.12 and L/B = 4.37 models, see Figure 8 and Figure 10 respectively. The results for the L/B = 3.77 landing craft show that the MANDAMP with revised Ewers method slightly under predicts the amplitude but is in excellent agreement with the period, see Figure 9. It was noted that the L/B = 3.77 landing craft had a shallower draft than the other two models. It is surmised that at the larger initial angle of 15 degrees there may be additional interaction between the viscous flow around the bilge and the free surface resulting in an increase in roll damping. This is consistent with the observations made by Ewers and Freathy [1].

DISCUSSION

For ship motion prediction it is important that motion damping is accurately modelled. The majority of ship motion damping arises from the oscillating hull radiating energy in the form of waves. In roll motion the amount of energy dissipated in the form of the radiated waves is small relative to other forms of damping which include the energy lost due to skin friction, vortex shedding and appendage forces [7]. Hull forms with relatively sharp bilges, for example landing craft and barges, will shed vortices as they roll. This vortex shedding phenomenon absorbs a significant amount of energy and is therefore a significant contributor to the roll damping of these types of hull forms. Numerical seakeeping codes account for this loss of energy by applying a roll moment based on viscous roll damping coefficients.

As previously discussed, FREDYN currently offers three methods to predict the viscous roll damping coefficients for ships. Of these methods, the FDS formulation was obtained from analysing systematic model tests on fast displacement type vessel (frigates) and is applicable for frigate type vessels at forward speeds of Froude number 0.15 and greater. The IHT approach is based on model tests of conventional merchant type ships at low to moderate speeds [2]. The results presented in this paper show that neither the FDS or IHT methods are suitable for barge like hull forms such as conventional landing craft.

The Ewers and Freathy formulation based predictions using the MANDAMP method show significant improvement in the accuracy for both the amplitude and period for all landing craft models considered. As the L/B ratio increased, the difference between the experimentally obtained and the numerically predicted amplitudes of the roll decay increases slightly. This may be due to the slenderness of the hull form tending towards the limits of the roll damping method's range of application.

A factor that may need to be considered is the relationship between roll damping and roll velocity when vortex shedding is the dominant source of energy loss. Viscous roll damping is generally proportional to the square of the roll velocity but in the case of barge type hull forms this relationship may no longer be valid, that is, the roll damping may vary to some other power.

Overall, the Ewers and Freathy formulation for the calculation of the viscous roll damping coefficient has been shown to be acceptable for the simulation of the roll behaviour of a landing craft in deep water. Further studies are now required to determine if this formulation is still applicable when modelling the response of these low L/B type vessels in shallow water and in waves.

CONCLUSION

To enable an accurate numerical simulation of landing craft hull form roll behaviour to be achieved, an appropriate viscous roll damping method is required. This paper has shown some of the preliminary outcomes of a study into the identification of such a method. Experimental studies were undertaken to validate the numerical simulations of the roll decay behaviour of several landing craft models with varying L/B ratios. This data was used to evaluate the performance of the three different viscous roll damping methods available within the CRNav time domain seakeeping tool, FREDYN. The FDS and the IHT methods proved to be unsuitable when modelling landing craft type hull forms. The FREDYN simulations which used the MANDAMP method, with roll damping coefficients based on the formulation proposed by Ewers and Freathy [1], showed reasonable accuracy when predicting the roll decay of the three hull forms considered. The accuracy of these simulations was found to be strongly dependent on the value of roll radius of gyration used.

Further work is required to develop a process to determine the appropriate roll radius of gyration to be used as the basis of the viscous roll damping component for any landing craft motion simulation. This process should eliminate the need to undertake any model testing and the associated resource requirements. Additional investigations into the applicability of the Ewers and Freathy formulation to model the landing craft roll behaviour for different loading conditions, in shallow water and in regular and irregular waves should also be undertaken.

Once the method is developed and implemented, FREDYN can be used for various applications such as ship handling simulators to ensure that amphibious operations are performed with the highest level of safety and mission readiness.

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