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THEORETICAL INVESTIGATION INTO THE VALIDITY OF STRIP THEORY FOR SEAKEEPING ANALYSIS OF SHALLOW-DRAUGHT TRAWLERS

by

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Abstract. To study seakeeping, a number of analytical tools have been developed; the most popular of which is the two-dimensional strip theory. Due to the slenderness assumption inherent in the theory, doubts arise on the validity of the application of such method to small boats particularly those with low length to breadth ratio and shallow-draught.

This paper presents the results of a theoretical investigation into the validity of strip theory for shallow-draught fishing boat. Response amplitude operators of a series of fishing boats having varying length to breadth ratio were computed using computer programs based on a two-dimensional strip theory and a three dimensional method. The comparison of the two sets of results indicates that the strip theory is reasonably robust particularly at low forward speeds.

1. INTRODUCTION

Seakeeping is the study of the behaviour of ships and other floating structures in waves. With the advent of the computers, solutions to the complex equations in seakeeping studies are made possible and a number of methods and approaches were established to assess the seakeeping characteristics of floating vessels.

The most common analytical tool being used in current seakeeping studies is the two-dimensional linear strip theory. The main advantage of this theory is that it requires significantly less rigorous computation than the 3D analysis methods. It is a popular tool used in the ship preliminary design suite since it can be readily incorporated into seakeeping design methodologies such as those described for example by Sarioz et.al. [1], Grigopoulos and Loukakis [2] and Lloyd [3].

Strip theory is based on a number of assumptions which are summarised by Lloyd [4] as follows:

a. The ship is slender.
b. The hull is rigid.
c. Moderate forward speed without planing.
d. Motions are small.
e. The ship hull sections are wall-sided.
f. Water depth much greater than wavelength.
g. Presence of hull has no effect on waves.

For large ships, these assumptions are satisfactory. However for small fishing vessels which normally have low boat length (L) to beam (B) ratios, the validity of the assumptions is doubtful. Also, those boats found in developing countries have high beam to draught (T) ratios by virtue of their shallow-draught. As such, due to the slenderness assumption inherent in the strip theory (i.e. small transverse dimensions-length ratios and cross-sections vary gradually in the longitudinal direction), application of this analytical method to fishing boats hull forms is questionable. On the other hand, some authorities have expressed confidence in the robustness of the theory. The Seakeeping Committee of the 18th ITTC for example concluded that strip theory appears remarkably effective for predicting the motions of ships with length to beam ratio as low as 2.5 [5]. Also, Karppinen [6] compared heave and pitch transfer functions and phase lags for a very wide and short fishing vessel and concluded that strip theory gives a good prediction of heave in head seas while pitch prediction were less accurate particulary at higher Froude number and lonnger waves.

To confirm these conflicting findings, this paper reports the results of a theoretical investigation that was carried out to compare the motion responses of a set of three small shallow-draught fishing boats. The motion responses were produced by two computer programs each of which are based on a two-dimensoinal (2D) strip theory and a three-dimensional (3D) analysis respectively.

2. METHODOLOGY

In the present study, the validity of strip theory motion predictions was investigated by analysing a set of three shallow-draught trawler hull forms having L/B ratios between 3.7 and 5.00. This investigation consists of:

- the creation of a series of hull forms having similar displacement but with varying L/B ratios.
- the determination of seakeeping characteristics by running 2D and 3D computer analysis programs.
- the comparison of the respective results.

A shallow-draught hull form of a salmon trawler was selected from Kawashima et.al.[7]. This hull form was considered representative of the size and shape of small fishing vessels particularly those from developing countries. It has similar characteristics and has a similar body plan to the Malaysian trawler reported in [8]. Details of the masses, loading condition, draughts and radii of gyration of this hull are also available. To investigate the effect of varying L/B ratios, two variant hulls each with the same displacement and block coefficient but having a different L/B ratio were produced using the proprietary hull design software *AutoSHIP*. The principal particulars of the three hulls are given in Table 3.1 while the body plans are shown in Figure 1. The offsets from each variant were used as input data for the 2D strip theory and the full 3D hydrodynamic analysis programs.

The 2D program reads in the data regarding the geometry and weight distribution of the boats together with the seakeeping problem definition. Calculation of the hydrodynamic coefficients, and the wave excitation forces and moments for all the strips were made using the theory of Salvesen, Tuck and Faltinsen [9], while sectional hydrodynamic coefficients were obtained using a Frank Close-Fit approach. The 3D hydrodynamic data was also corrected for forward speed using the Salvesen, Tuck and Faltinsen theory. Using coefficients, moments and forces thus obtained, the response amplitude operators (RAOs) for relative bow motions were then produced. The programs were run at zero speed and a forward speed of four knot (Fn=0.1685). The vertical plane responses were selected and the heading was kept constant at 180° because it was assumed, as suggested by Lloyd [3], that the seakeeping performance in head waves is indicative of the performance at other headings and that it is sufficient to calculate these vertical plane responses in long crested head waves.

The 3D diffraction program uses the singularity distribution-based method. Integral equations formulated and solved are expressed in terms of unknown velocity potentials. The wave excitation is determined using Haskind's relationship and the appropriate radiation potentials.

When calculating the motion amplitudes, the following equations were solved:

$$(-\omega_e^2(\Delta + A_{33}) - i\omega_e B_{33} + C_{33})\overline{\eta}_3 + (-\omega_e^2 A_{35} - i\omega_e B_{35} + C_{35})\overline{\eta}_5 = F_3 \quad (1)$$

$$(-\omega_e^2(I_{55} + A_{55}) - i\omega_e B_{55} + C_{55})\overline{\eta}_5 + (-\omega_e^2 A_{53} - i\omega_e B_{53} + C_{53})\overline{\eta}_3 = F_5 \quad (2)$$

The symbols and notations used in the above and following equations are standard notation as specified in [10]. The forward speed corrections based on Salvesen, Tuck and Faltinsen method were applied to the reactive hydrodynamic coefficients and the wave exciting forces and moments for coupled heave and pitch as follows [11]:

$$\begin{aligned} A_{33}^{\;U} &= A_{33} \quad A_{35}^{\;U} = A_{35} - \frac{U}{\omega_e^{\;2}} B_{33} \\ B_{33}^{\;U} &= B_{33} \quad B_{35}^{\;U} = B_{35} + UA_{33} \end{aligned} \quad (3)$$

$$\begin{aligned} A_{53}^{\;U} &= A_{53} + \frac{U}{\omega_e^{\;2}} B_{33} \quad A_{55}^{\;U} = A_{55} + \frac{U^2}{\omega_e^{\;2}} A_{33} \\ B_{53}^{\;U} &= B_{53} - UA_{33} \quad B_{55}^{\;U} = B_{55} + \frac{U^2}{\omega_e^{\;2}} B_{33} \end{aligned} \quad (4)$$

$$\begin{aligned} F_3^U &= F_{K_3} + F_{D_3} \\ F_5^U &= F_{K_5} + F_{D_5} + \frac{U}{i\omega e} F_{D_3} \end{aligned} \quad (5)$$

where

$$\begin{aligned} Fk_j &= -i\rho\omega_o \int_{Sw} \phi_I n_j dS \, \exp(-i\omega_e t) \\ FD_j &= -i\rho\omega_e \int_{Sw} \phi_o n_j dS \, \exp(-i\omega_e t) \end{aligned} \quad (6)$$

and the superscript U indicates a forward speed value.

In the above formulae for forward speed corrections, following the recommendation of Lewis [10] and Karppinen [5], end corrections originally proposed by [9] were omitted.

3 RESULT AND DISCUSSION

Results of this initial investigation are given in Figures 2 to 4 which show the variation of relative bow motion (RBM) response amplitude operators (RAOs) for a set of wavelength, Lw, to boat length, L, ratios. The plots are for the three variants at zero speed and a forward speed of 4 knots.

Figures 2(a) and 2(b) show the RBM amplitudes of the parent hull (model B) at zero and four knots respectively. At zero speed, clearly there is a very good correlation between 2D and 3D results. The RBM responses given by strip theory-based method closely resemble the results from 3D-based method. However, the level of correlation slightly degrades at the forward speed of 4 knots. The difference in heave amplitudes are significant in regions of low Lw/L ratios (high frequencies) and where resonance occurs. The natural heave frequency of the three hulls are around 2.00 rad/s^{-1} which corresponds to Lw/L ratio of around 2.00. It is also shown that although the general shape of the curve connecting the points are similar, compared with 3D method, the 2D results underestimate the RBM RAOs for Lw/L greater than 2.0.

The effect of changing L/B can be seen by examining Figures 3 and 4 which show the results for variant A (L/B=3.7) and variant C (L/B=5.0), at zero speed and four knots. The similarity in the relative difference between 2D and 3D results from the two variants indicate that the effect of changes in L/B on the accuracy of the 2D prediction is not significant. For all the three variants, the relationships between 2D and 3D results are consistent and there is no appreciable change as L/B is increased or reduced from the parent hull value. In other words, at zero speed, the strip theory provides a close enough estimation for the 3D motion responses within the range of length-breadth ratios investigated.

The RBM RAOs were computed by compounding the vertical heave and pitch amplitudes and phase at the bow of the boats. The pitch and heave predictions were obtained by solving equations (1) and (2) which are functions of added masses, fluid damping and exciting forces and moments. Figures 5 and 6 show the heave and pitch related coefficients, forces and moments of the parent hull at 0 and 4 knots. It is observed that, 2D heave fluid damping and heave exciting forces are bigger than the 3D values while the heave added masses show the opposite trend. Also, there was no appreciable difference between 2D and 3D pitch exciting moments except at Lw/L less than 2.00. As a result, the values of 2D heave amplitudes are not significantly different from 3D values. As for pitch amplitudes, it seems that they are strongly affected by fluid damping which accounts for the big differences in the amplitudes. At zero speed, as Lw/L ratio increases, Figure 6 shows a wider variation of 2D fluid damping from 3D values, resulting in lower pitch amplitudes. At a forward speed of four knots, the differences in damping and forces are exarcebated giving slightly larger differences as shown in Figure 3.

4 CONCLUSION

The results of this theoretical investigation confirm the findings of previous researchers that generally the strip theory can also be applied to vessels of lower L/B ratio such as fishing boats, particularly at low forward speeds. Within the practical bounds of preliminary design, strip theory is robust enough to be valid for applications in seakeeping design of the shallow-draught fishing vessels with low L/B ratio although the level of accuracy deteriorates slightly as the forward speed is increased. However even in those cases, although the absolute values of the responses from 2D and 3D methods are not exactly similar, their trends and relative values are sufficiently close for design purposes. Since fishing vessels run at low to moderate speed and the critical activities carried out at low or zero speed, this method can be used with confidence for analysing seakeeping parameters during the critical periods.

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Table 3.1 Principal Characteristics of the Varians Hull Form (linear dimension in meter)

Model	**A**	**B(parent)**	**C**
Lenght (L)	14.2	15.2	17.3
Breadth (B)	4.14	3.8	3.46
Depth (D)	1.4	1.4	1.4
Draught (T)	1.36	1.36	1.36
C_b	0.65	0.65	0.65
Displacement (D) tonnes	54.0	54.0	54.0
L/B	3.4	4.0	5.0
B/T	3.0441	2.794	2.5441

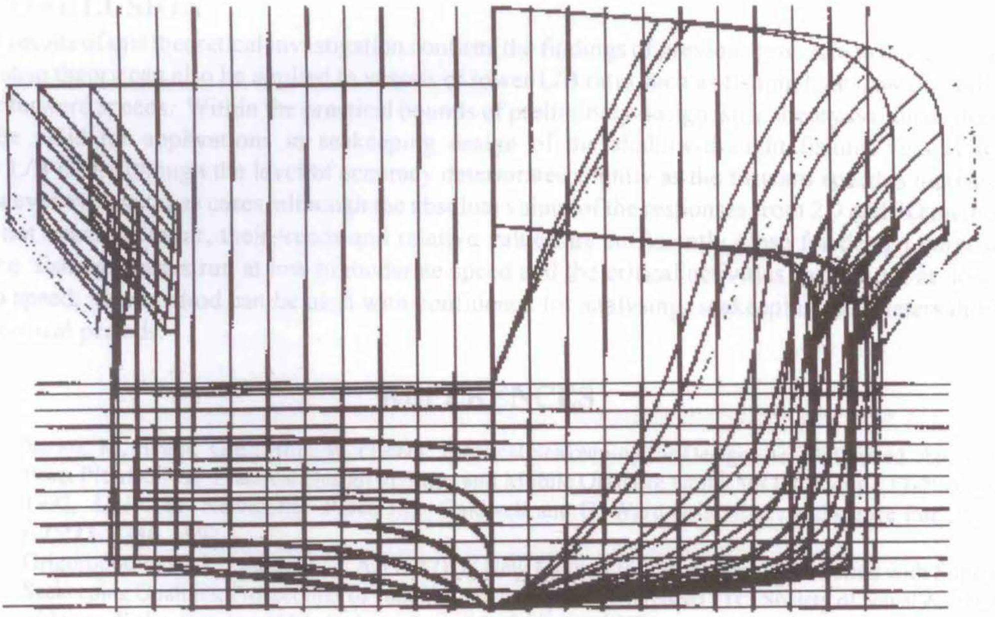
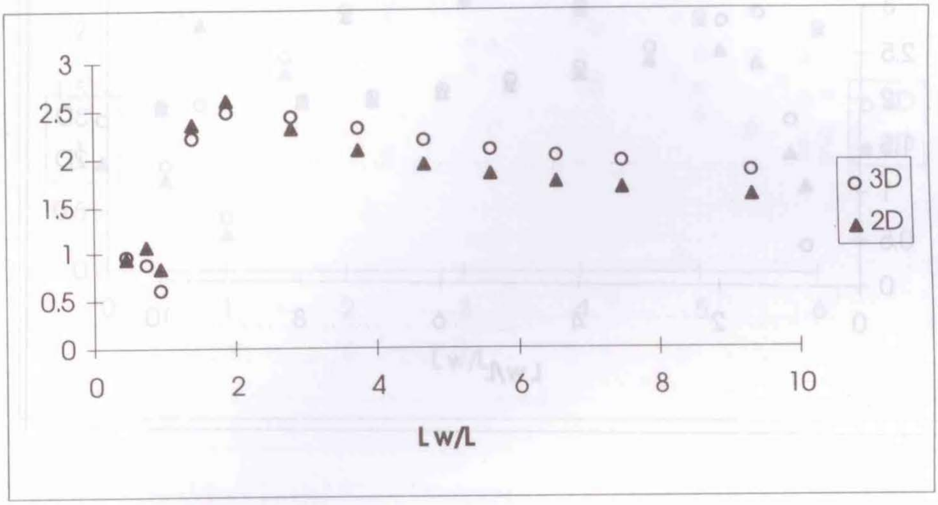
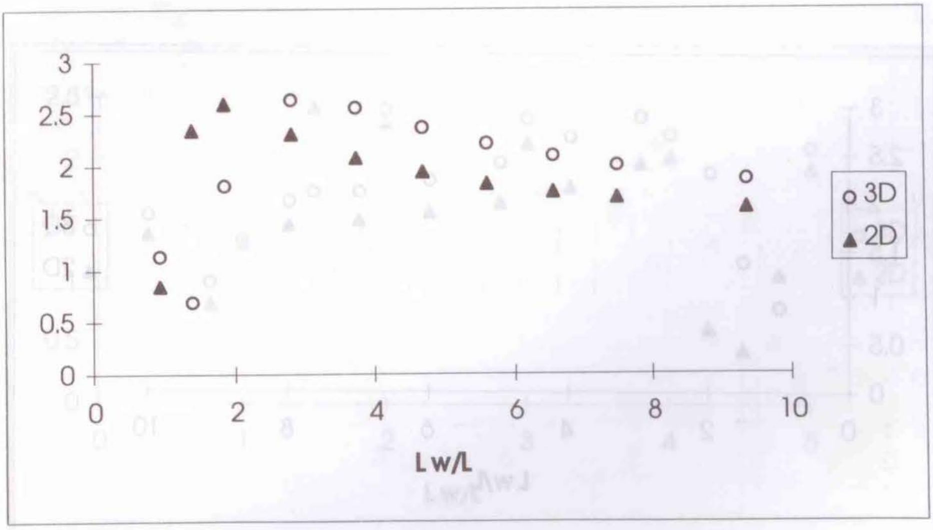


Figure 1 The Body Plan of the Varians Hull Form

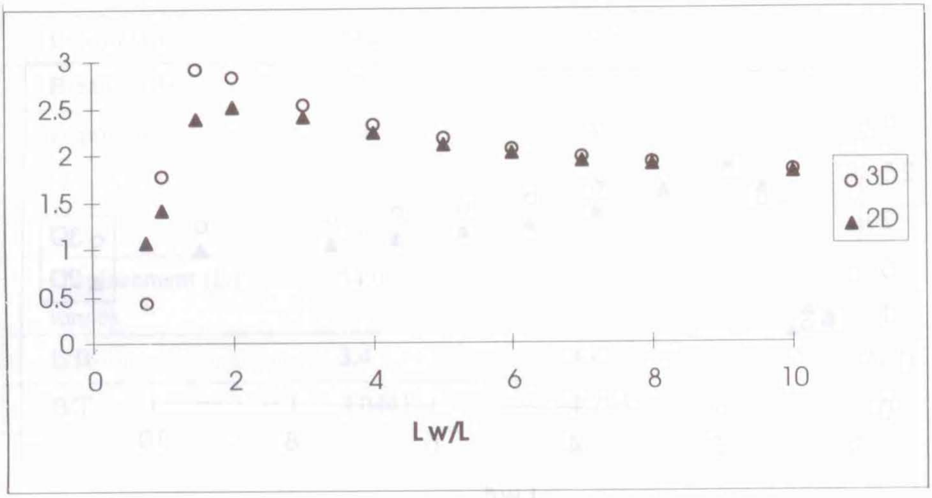


(a) Zero knot

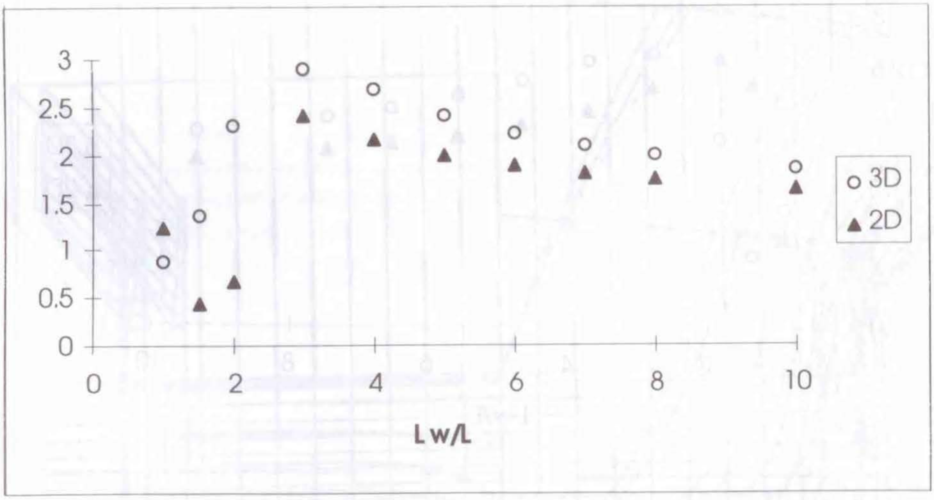


(a) Four knots

Figure 2 Relative Bow Motion Amplitudes for Parent Hull L/B = 4.0 (Zero and Four Knots)

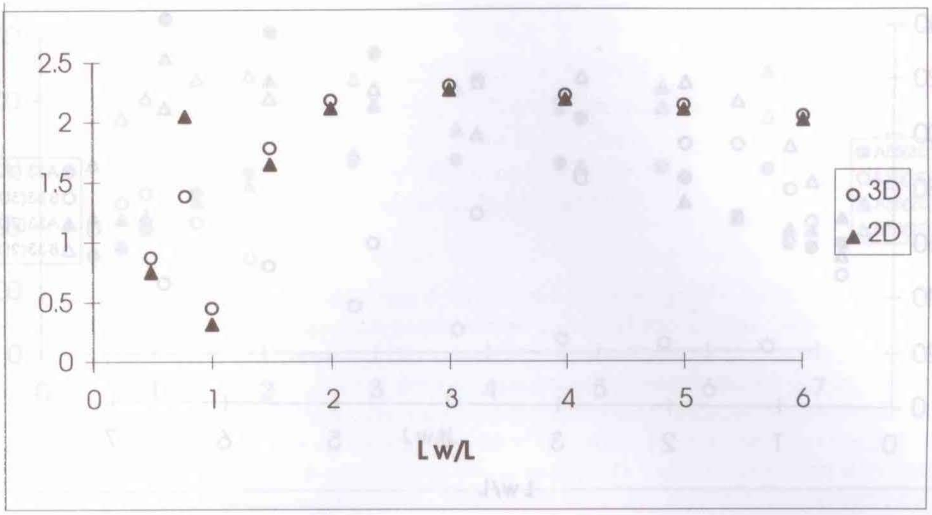


(a) Zero knot

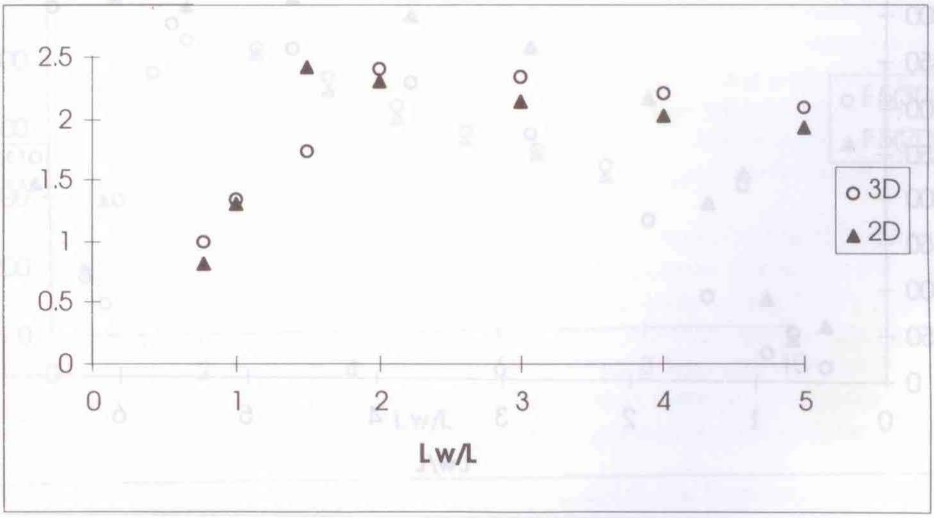


(a) Four knots

Figure 3 Relative Bow Motion Amplitudes for Varians A L/B = 3.7 (Zero and Four Knots)

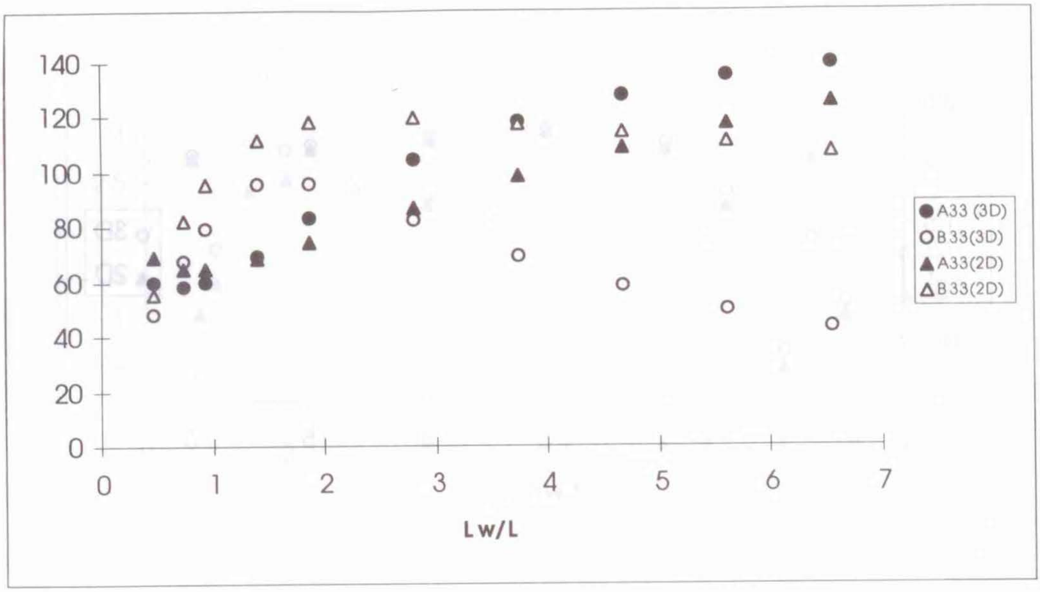


(a) Zero knot

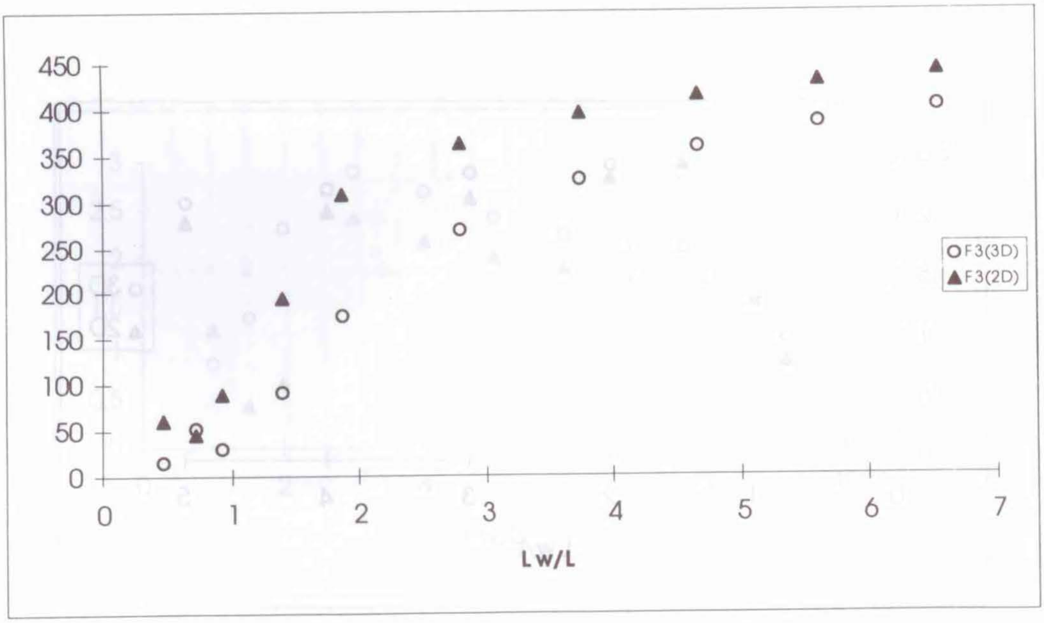


(a) Four knots

Figure 4 Relative Bow Motion Amplitudes for Varians C L/B = 5.00 (Zero and Four Knots)

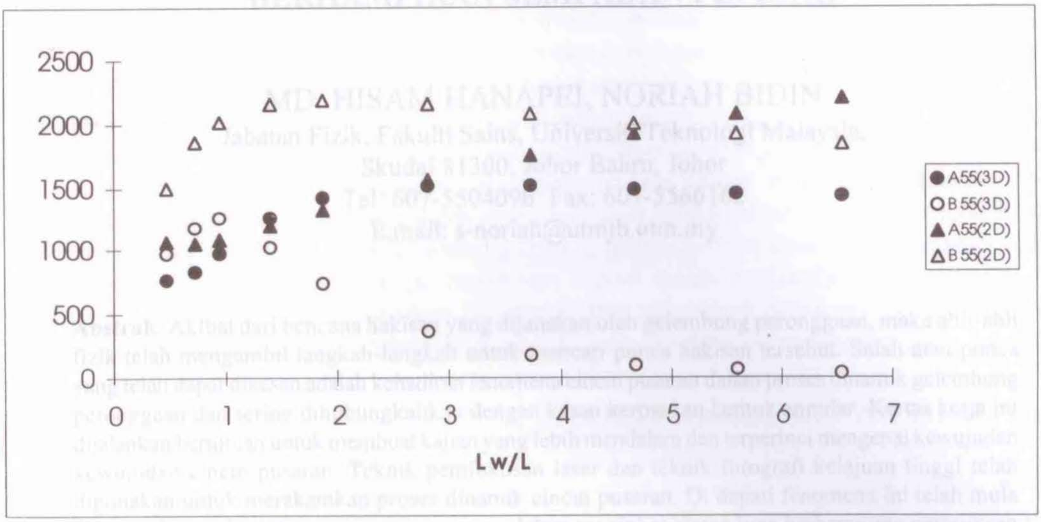


(a) Added Mass and Fluid Damping

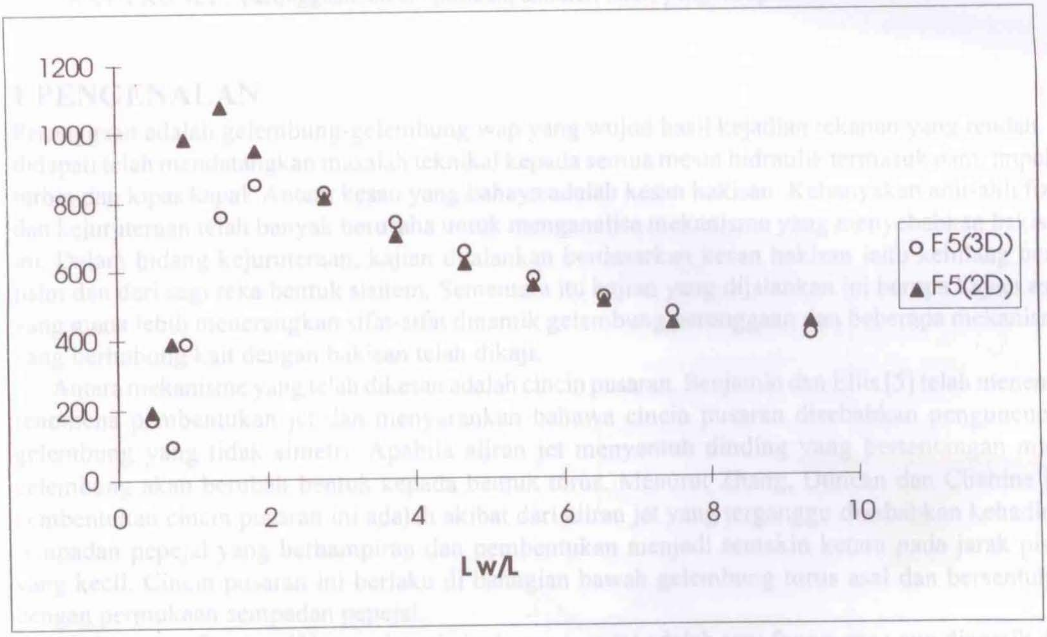


(a) Exciting Forces

Figure 5 Comparison of Parent Hull Added Mass, Fluid Damping and Exciting Forces (zero knot)



(a) Added Inertia and Fluid Damping



(a) Exciting Moments

Figure 6 Comparison of Parent Hull Added Inertia, Fluid Damping and Exciting Moments (zero knot)