The effect of deadrise on the performance of a simplified planing hull in irregular waves

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The Effect of Deadrise on the Performance of a Simplified Planing Hull in Irregular Waves

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Abstract

The deadrise angle of a planing hull is a significant parameter affecting its resistance and accelerations in waves, once the length, beam and displacement have been set. Model experiments provide the most reliable motion predictions to date for planing hulls, due to the fact that the responses are not linear with wave height. However, previously published model test data are outside the range of modern hull forms for small boats, which have a length to beam ratio of approximately three.

This paper presents the results of experiments in irregular waves for three simplified planing hulls with a length to beam ratio of three, with deadrise angles of 10, 20 and 30 degrees. Each hull was tested at three speeds, covering a speed range from displacement speeds to fully developed planing, in three sea states. The hull with 20 degree deadrise angle was tested at two loading conditions, for the highest speed only, to investigate the effect of displacement on motions and added resistance. Recommendations are made for selecting an appropriate hull form, based on interpreting the trade-offs between calm water resistance and performance in waves.

Nomenclature

B Maximum beam, at waterline, ft.
C_Δ $\Delta/(B^3\rho)$
g Acceleration due to gravity, ft/sec^2
Hs Significant waveheight, ft.
L Overall length, ft.
R Resistance of model, lb.
V Speed, knots.
Δ Weight of model, lb.
ρ Density of water, lb/ft^3

Introduction

A significant proportion of the models tested at the Ocean Engineering Centre (OEC) of B. C. Research had the hard chines and constant deadrise angles characteristic of planing hulls. However, only a small proportion of these hulls were tested in waves, and usually for qualitative observations, rather than for quantifiable measurements. The authors recognized that the towing carriage, wavemaker and data acquisition system at the OEC were capable of measuring performance parameters such as pitch and heave displacements, accelerations and resistance for a planing hull running in waves.

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Reference [1] described the development of a series of simplified hulls, extending the work of Fridsma [2, 3] and Zarnick and Turner [4] to cover the range of length to beam ratios typical of the hulls tested for clients at the OEC. Fridsma's work also showed how important deadrise angle was to vessel responses induced by waves. This paper compliments Reference [1] by presenting the results of a series of experiments with the same simplified hull form, at a length to beam ratio of 3, but with three deadrise angles (10, 20 and 30 degrees). The value of length to beam ratio was chosen since it was very close to the average of the OEC project data.

The work was carried out as part of an 'Agreement for Collaboration' between the National Research Council of Canada, the British Columbia Research Corporation and the University of British Columbia.

A Simplified Hull Form for Wide Beam Planing Hulls

Figure 1 shows loading coefficient, C_Δ, plotted against length to beam ratio (L/B) for the OEC project data, together with the original Fridsma Series and the Fridsma Series Extension, described in [1]. It is clear from this figure that the project data are well outside the original Fridsma Series parameters. It can also be seen that the average value of L/B for the project data is approximately 3, so this set the length to beam ratio for the deadrise angle study.

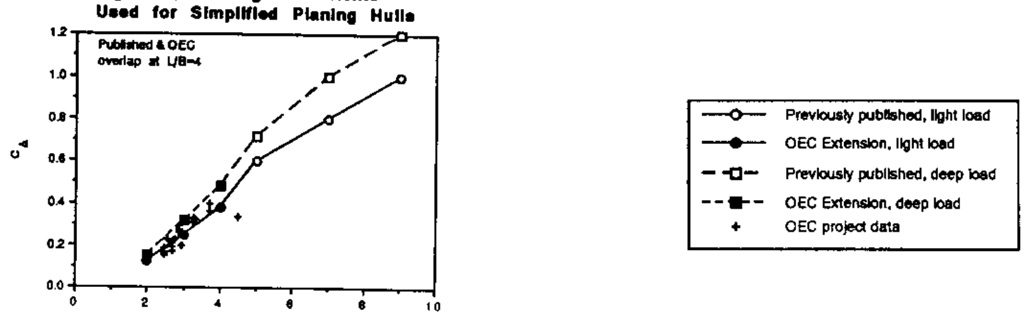
The original Fridsma Series was designed as a constant deadrise prism, with centreline profile, chine line and deck edge all defined as elliptical lines. The deadrise angles selected by Fridsma were 10, 20 and 30 degrees, which also covered the range of the OEC project data. In keeping with the character of the original series, these angles were maintained for the Fridsma Series Extension. The body plans for the three designs are shown in Figure 2.

Each model was tested for a C_Δ value of 0.253, given as the light displacement in [1]. To investigate the influence of displacement, the hull with 20 degree deadrise was also tested at a C_Δ value of 0.316 (deep displacement). All of the models were ballasted to a radius of gyration in pitch of 0.238L and towed from a point 0.294B above the keel, which corresponded to the values given by Fridsma.

Experiment Procedures

The test matrix for each hull consisted of three speeds ($V/\sqrt{L}=2$, 3, 4) in each of three nominal

Figure 1, Loading Coefficients Used for Simplified Planing Hulls



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seastates (Hs/B=0.22, 0.44, 0.66). In order to ensure that the same nominal running trim was obtained for all the experiments, the longitudinal centre of gravity was adjusted for each speed and deadrise angle combination. This was verified by calm water experiments carried out to ensure that the running trim angles were within tolerance (±0.2 degrees) of the nominal running trim of 6 degrees.

The seakeeping experiments were carried out in long-crested irregular waves, with a frequency distribution based on an ITTC 1978 Spectrum (which was equivalent to the Pierson-Moskowitz spectrum used originally by Fridsma). Wavemaker drive signals were generated to produce pseudo-random waves and the wave profiles were measured at the midpoint of the tank and analyzed to check that the required wave properties had been obtained.

During the experiments in waves, measurements were made of carriage speed, wave height, resistance, heave and pitch displacements, acceleration at the centre of gravity and acceleration at the bow (90 percent of the overall length forward of the transom). Data was sampled at 100 Hz on each channel, with 50 Hz low pass filters. The model was free to pitch and heave but it was restrained in surge, sway, roll and yaw. A single speed and wave height combination was tested for at least 100 wave encounters. If multiple tank lengths were required to obtain this number, then the runs were numerically spliced together and analyzed as a continuous record.

The time histories of each channel were analyzed with a computer program written specially for the purpose. The program calculated the mean, root mean square deviation, number of peaks, the mean peak and its root mean square (RMS) deviation and the number of peaks less than the mean value. A similar analysis was performed on the troughs. The sizes of the thresholds used by the program to detect a peak (or trough) were based on four times the RMS value observed for that record in calm water. The thresholds are given below in Table 1.

The analysis procedures were the same as those used in [1] and were based on those given by Fridsma [3]. The statistics used in determining the responses are given in Table 2 and were determined from the portion of the experiment when the

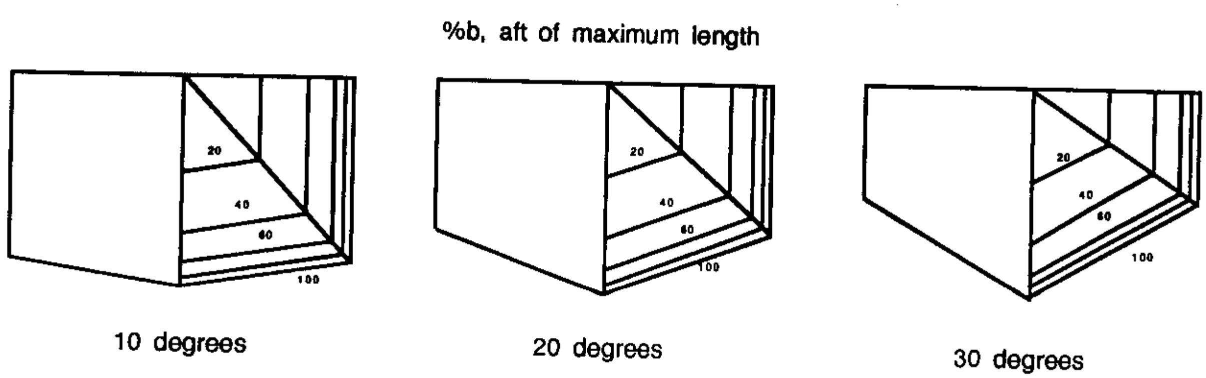

Figure 2, Bow sections for simplified planing hulls, with three deadrise angles

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Channel	Units	Threshold
Resistance	lb	none
Heave	inches	0.1
Pitch	degrees	0.4
Wave height	inches	0.1
CG Acceleration	g	0.1
Bow Acceleration	g	0.1

Table 1
Threshold Amplitudes for Measurements

model was travelling at constant speed.

Resistance in waves was the average value from the entire record. For heave and pitch, there was an offset relative to the static (zero speed) value, due to the dynamic lift generated by the hull. Heave and pitch peaks in waves were referenced to the deviation from the mean. For accelerations, which were measured relative to the vessel axes, the values were referenced to a baseline at zero speed. It was found that the peak response was more severe than the trough response and so for this paper only the data for the peaks are presented.

For presentation purposes, resistance was non-dimensionalized by the model displacement and heave was non-dimensionalized by model beam. Pitch is given in degrees and acceleration in units of gravity. This convention was used to present the results in the same format as those given by Fridsma.

The Effect of Deadrise on Performance in Waves

Pitch and Heave

Figures 3 and 4 show the mean peak heave and pitch for the three deadrise angles, for a $V/\sqrt{L}$ of 4.0. It can be seen that there was no significant effect of deadrise angle on the motions. The dominant factor affecting vessel heave and pitch was wave height. There was very little influence of speed on the results and so the other speeds have not been plotted here.

Resistance in Waves

Figures 5, 6 and 7 show the effect of deadrise on resistance in waves for $V/\sqrt{L}$ values of 2, 3 and 4 respectively. It can be seen from these figures that the total resistance in waves increases with deadrise angle throughout the speed range tested. The increase between 10 and 20 degrees was more than the increase between 20 and 30 degrees. Deadrise however had little effect on the change in resistance due the change in waveheight and this can be seen by the fact that the three curves are almost parallel to each other for each speed. This trend is approximately linear over the range of wave heights studied. It was unfortunate that the data for the 10 degree deadrise hull at Hs/B value of 0.66 was unavailable, due to an equipment malfunction.

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Figure 3, Effect of deadrise on mean peak heave displacement, V/√L=4

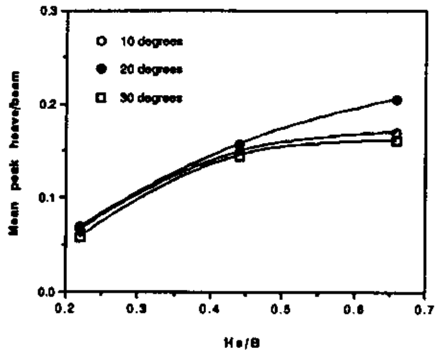


Figure 4, Effect of deadrise on mean peak pitch angle, V/√L=4

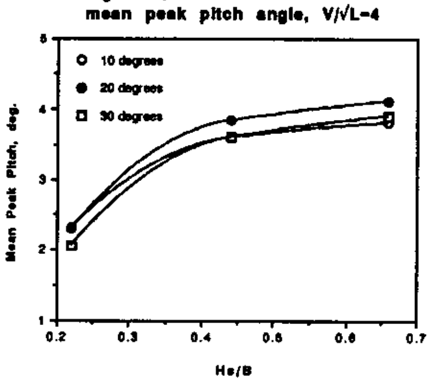


Figure 5, Effect of deadrise on resistance in waves, V/√L=2

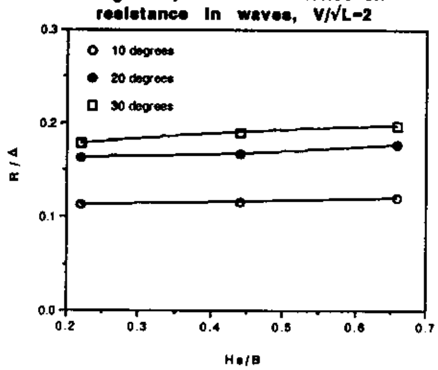


Figure 6, Effect of deadrise on resistance in waves, V/√L=3

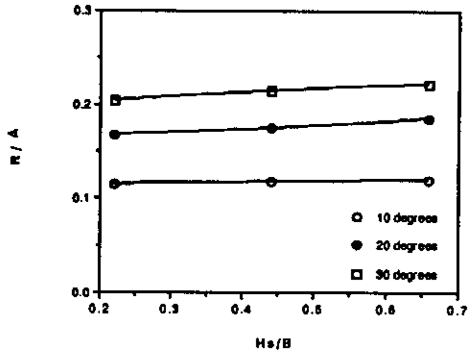


Figure 7, Effect of deadrise on resistance in waves, V/√L=4

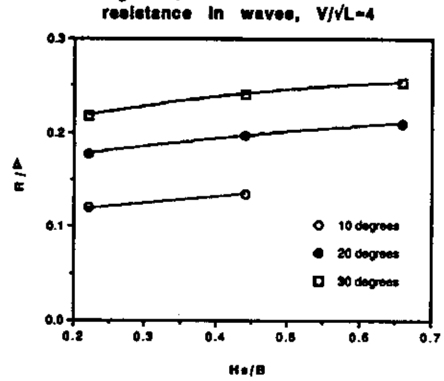
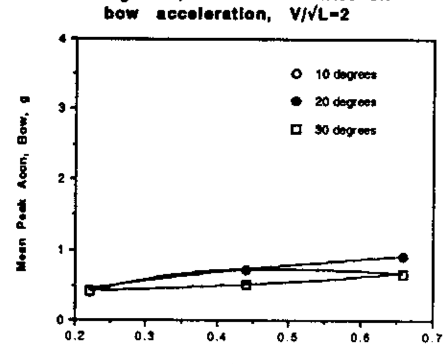


Figure 8, Effect of deadrise on bow acceleration, V/√L=2



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Channel	Mean	RMS	Mean Peak	RMS Peak	# peaks > mean
Resistance	•	•			
Heave	•	•	•	•	•
Pitch	•	•	•	•	•
Wave height		•			
CG Acceleration		•	•		
Bow Acceleration		•	•		

• used in analysis

Table 2
Statistics Used in Data Analysis

Accelerations at Bow and Centre of Gravity

The measured acceleration data are plotted against significant wave-height in Figures 8 to 10 for the bow acceleration and Figures 11 to 13 for the centre of gravity acceleration. The magnitudes of the accelerations show strong trends with deadrise angle and speed. For the bow acceleration at $V/\sqrt{L}$ of 2, there is no significant trend with deadrise angle. As the speed increases the influence of deadrise angle becomes more significant. At $V/\sqrt{L}$ of 3, the acceleration for the hull with 10 degree deadrise is up to 67 percent higher than the hull with 30 degree deadrise. As $V/\sqrt{L}$ is increased to 4, the difference in acceleration due to deadrise becomes even larger, with the 10 degree hull having accelerations up to twice those of the 30 degree hull. The same general trends were observed with the accelerations at the centre of gravity, except that the difference in acceleration between the 20 and 30 degree deadrise hulls is hardly noticeable, especially at the two higher speeds. It is interesting to note that the lowest acceleration for $V/\sqrt{L}$ of 4 occurs with the 20 degree deadrise.

Loading Coefficient

The effect of loading coefficient was evaluated at one deadrise angle. The hull with the deadrise of 20 degrees was tested at a C_Δ value of 0.316, in addition to the basic condition of 0.253, for a $V/\sqrt{L}$ of 4 only. The changes in the performance parameters were;

- R/Δ increased by 0.025 (average over range of Hs)
- no change to heave or pitch
- Centre of Gravity acceleration increased by 0.11g (average over range of Hs)
- Bow acceleration reduced by 0.85 g (average over range of Hs)

Discussion of Results

Savitsky and Brown [5] gave an analysis of Fridsma's data, in the form of simple predictor equations for added resistance and accelerations at the bow and centre of gravity. The trends from these equations showed that for $V/\sqrt{L}$ value of 2, deadrise angle had no effect on added resistance. This trend can also be seen from the data presented here. At $V/\sqrt{L}$ of 4,

Figure 9, Effect of deadrise on bow acceleration, V/√L=3

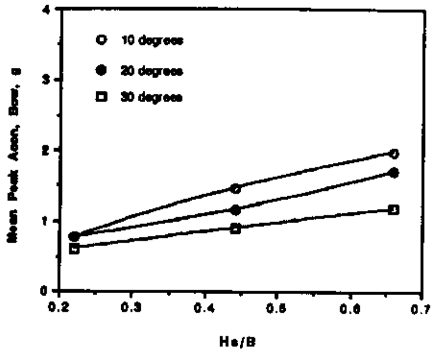


Figure 12, Effect of deadrise on centre of gravity acceleration, V/√L=3

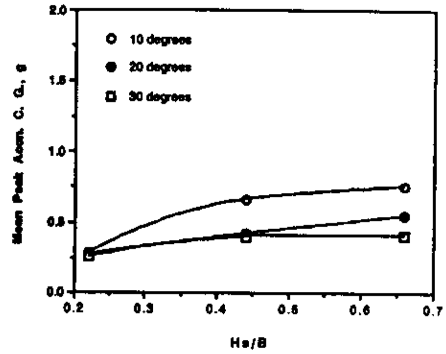


Figure 10, Effect of deadrise on bow acceleration, V/√L=4

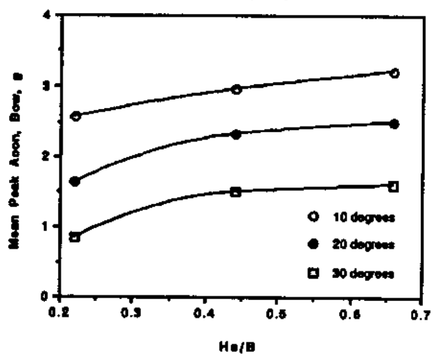


Figure 13, Effect of deadrise on centre of gravity acceleration, V/√L=4

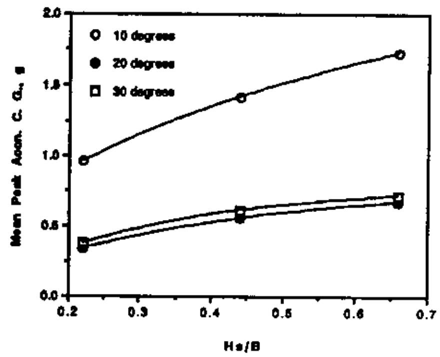
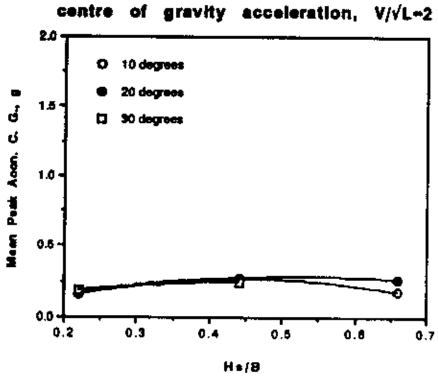


Figure 11, Effect of deadrise on centre of gravity acceleration, V/√L=2



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Savitsky and Brown showed that the deadrise affected the added resistance with higher added resistance for lower deadrise angles. This trend was much less pronounced in our data, but the value of the length to beam ratio may have had an effect. Our models were shorter, in relation to the wave lengths, than the models tested by Fridsma. The shorter model will tend to contour the waves rather than slam into them. This will reduce the magnitude of the added resistance due to wave impact forces.

The formulae given in [5] showed that the bow and centre of gravity accelerations were directly proportional to deadrise angle, when all other parameters were held constant. The acceleration data presented in this paper show the same trend, but the magnitudes were much lower than would have been expected from a simple extrapolation of Fridsma's data using Savitsky and Brown's expressions, especially for high sea states.

Savitsky and Brown did not give equations for predicting pitch and heave, and so the original data must be used for comparison purposes. The trends observed from the OEC data agreed with the equivalent data derived from [3], using $V/\sqrt{L}$ values of 2 and 4. It was found that the trends in the acceleration data, for hulls with length to beam ratio of 5 were less definite than might have been expected from Savitsky and Brown's predictions. Fridsma's data showed slightly less distinct trends with deadrise angle, but the lowest acceleration was always observed for the highest deadrise angle.

The trade-off for the vessel designer is to provide acceptable levels of both resistance and accelerations. Total resistance in waves influences the powering requirements, and a low deadrise angle would be most desirable. However, the lowest deadrise angle has the highest accelerations, at both the bow and the centre of gravity. High levels of acceleration are difficult for the crew to endure for an extended period of time, and so it is most likely that fuel economy will be sacrificed for the sake of comfort. The compromise deadrise angle would appear to be between the two extremes of 10 degrees and 30 degrees, and could be picked depending on the expected wave conditions. Low deadrise hull forms would be able to exploit the potential benefits of saving fuel if the expected waveheights were low, but high deadrise angles would be required for maximum endurance in larger waves.

Conclusions

Modern planing hull designs for small ships and boats are outside the range of all previously published parametric seakeeping studies. This paper presents data to describe the influence of deadrise angle on the seakeeping performance of a planing hull, with a length to beam ratio of 3. From these data, we may conclude that deadrise angle is very important for minimizing accelerations, with high deadrise angles having the lowest accelerations. Deadrise angle also has an important effect on total resistance in waves with low deadrise angles having the lowest total resistance. This presents the designer with an interesting compromise having to trade-off increased crew comfort against installed power and fuel economy. Deadrise angle has little effect on motions (pitch and heave) and on added resistance in waves. The trends established for a hull with L/B of 3 are consistent with those previously published for L/B of 5, but the magnitudes could not have been obtained by extrapolation of the earlier results.

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