Motions of a High Speed Planing Boat in Regular Head Sea

by

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1. Introduction

Motions of high speed planing boats in sea way are violent and it is natural to fear the application of theory which predicts successfully motions of displacement ships. Even so, the first step to study this problem must be to follow the research for displacement ships. Among all assumptions in the theory of ship motions, the linear superposition principle is fundamental and is it applicable to motions of high speed boat? This is first and most important question because, if not, we must treat the non-linear problem and could not hope any solution in near future.

To answer this question model experiments must be carried out in regular waves with various heights.

At the same time, of course, the applicablity of the so-called strip theory must be testified.

As naturally imagined, the answer is negative at high speed in strict sense, but as a whole heaving and pitching motions are proportional to wave height although they do not agree with the prediction by the strip method calculation.

Thus, questions now become why the strip theory does not agree with experiment and from where the non-linearity or high frequency components are derived. The only reason presumable is violent variation of the wetted surface and this is also the very different point from displacement ships.

It is a long way to reach final answers because there is few such study in the past, but we shall propose a theoretical approach to this problem.

2. High frequency components and dependency on wave height

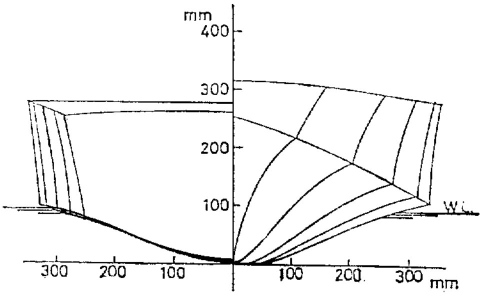

Fig. 1 Body Plan of Model

Table 1. Principal Particulars of Model

Length overall, Loa	2.690m
Length on load waterline, Lwl	2.469m
Breadth, B	0.634m
Draft, d	0.0938m
Displacement	59.949kg
Initial trim	0
Block Coefficient, Cb	0.4083
Midship Coefficient, Cm	0.5448
C.G. from Midship	0.246m aft
Longitudinal Gyradius	0.2055 Loa

As the first preliminary appoach to our problem, we carried out model tests of a torpedo boat shown in Fig. 1 and Table 1 in waves at Meguro Model Basin.[1)]

Typical oscillograms of ship motions are shown in Fig. 2. which contain higher frequency components especially for acceleration of motion. By Fourier analysis of these data we obtained their spectra like as shown in Fig. 3.

At a first sight ship motions are very much confused but the higher frequency components of pitching and heaving oscillation are rather less than the fumdanental frequency component, and if we define the

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Table 2. Nomenclature

ρ	Density of water
g	Acceleration of gravity
L	Length on water line
V	Ship speed
F_n	Froude Nomber ($V/\sqrt{gL}$)
λ	Wave length
k	Wave number ($2\pi/\lambda$)
H_w	Wave height
a	Wave amplitude ($H_w/2$)
Z_a	Amplitude of heaving Oscillation
Q_a	Amplitude of pitching Oscillation
A_{cc}	Amplitude of Acceleration
W_e	Encounter circular frequency
C_n	Fourier coefficient
δ	Distortion factor
K	W_e^2/g

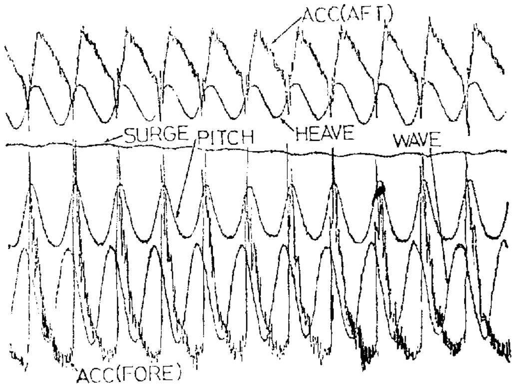

Fig. 2 An Illustration on Records ($F_n=1.2$, $\lambda/L=1.206$)

distorsion factor δ from a sinusoidal motion like as

$$s=\sqrt{\sum_{n=2}^{N} C_n^2}\Big/C_1, \tag{1}$$

when motions are described as

$$f(t)=\sum_{n=0}^{N} C_n \cos(n\omega_e t+\varepsilon_n), \tag{2}$$

it is observed as shown Fig. 4.

That is, the distorsion factor becomes greatest at nearly $\lambda/L=1$.

Moreover, it depends on the speed and wave height as shown in Fig. 5. that is, when the speed is lower than $F_r=0.5$ it does not depend on the wave height but when the speed is higher than $F_n=1$ it increases with wave height.

Thus, the higher frequency components of motions are not so large that we decided to take a half of peak-to-peak value as the amplitude of motion in the following analysis.

The second question was the dependency on the wave-height of ship motions. Fig. 6 shows that the pitching and heaving oscillations are nearly proportional to wave height, but Fig. 7 shows that the accelaration does not at high speed.

From these preliminary observations, we may conclude that the pitching and heaving motions are por-

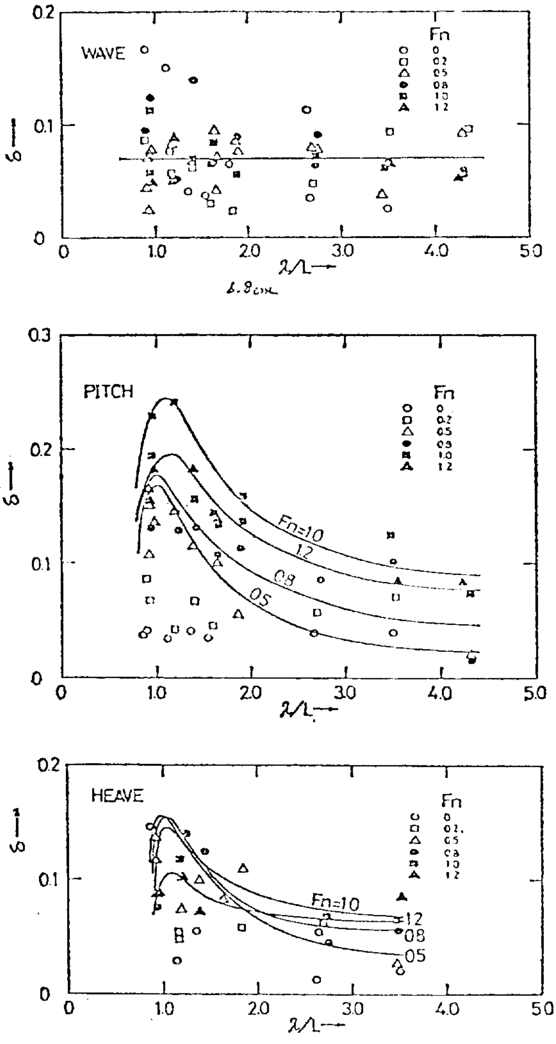

Fig. 4 Distortion Factor for Wave, Pitch and Heave (H_w=12cm)

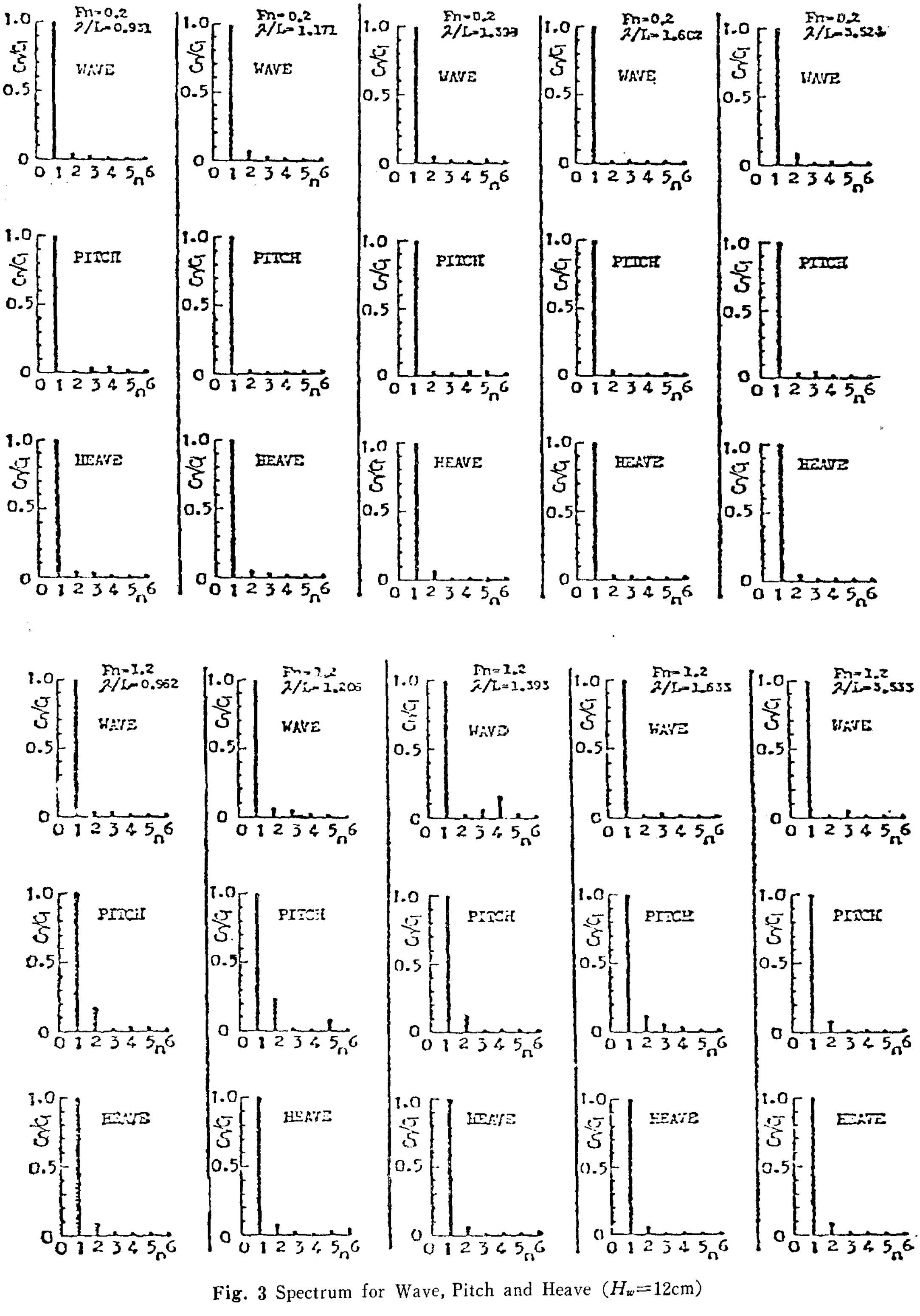

Fig. 3 Spectrum for Wave, Pitch and Heave (H_w=12cm)

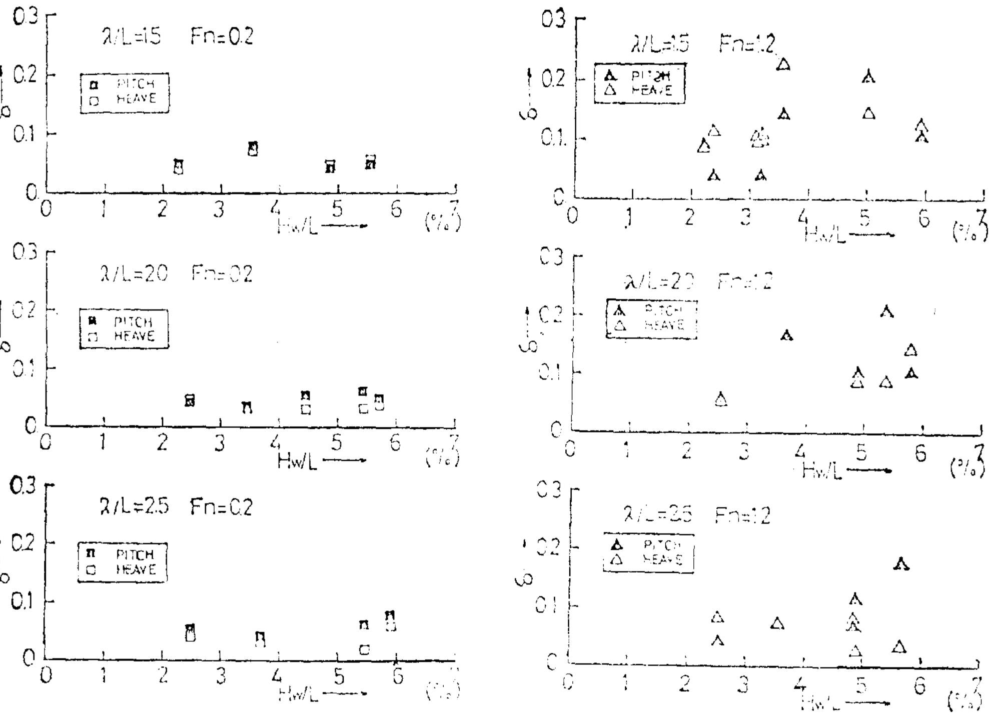

Fig. 5 Variation of Distortion Factor with Wave Height

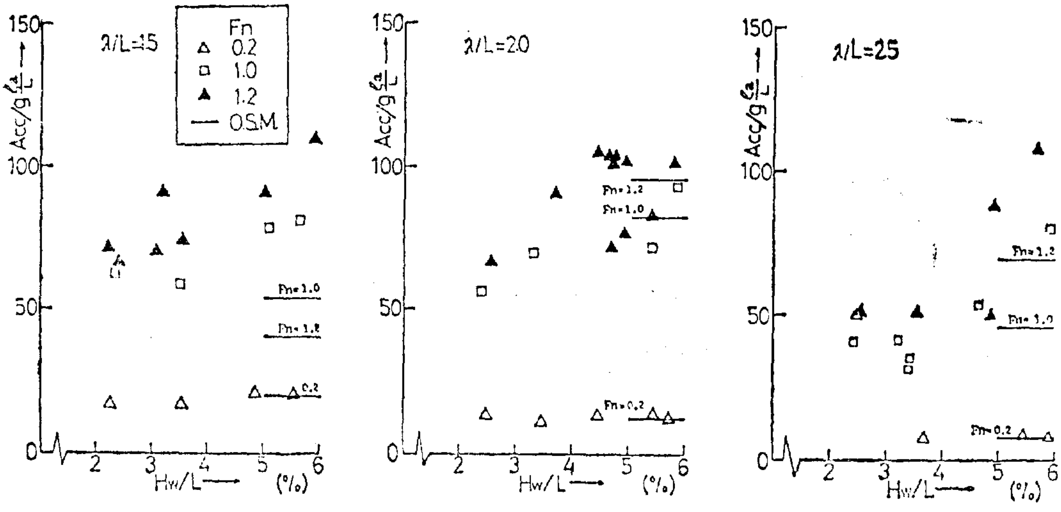

Fig. 7 Variation of Acceleration at Bow with Wave Height

portional to the wave height as a whole but they contains some higher frequency component at high speed and the wave length comparable with own boat length.

3. Motions in regular head waves

Fig. 8 shows the pitching and heaving responses in regular head waves.

Fig. 9 shows the acceleration at bow. Full and broken lines are theoretical ones calculated by the strip method. By full lines the added mass and damping coefficient are calculated from Lewis from approximation ordinarily (O.S.M), but by broken lines from a flat plate (F.P) because the draft of boat is so

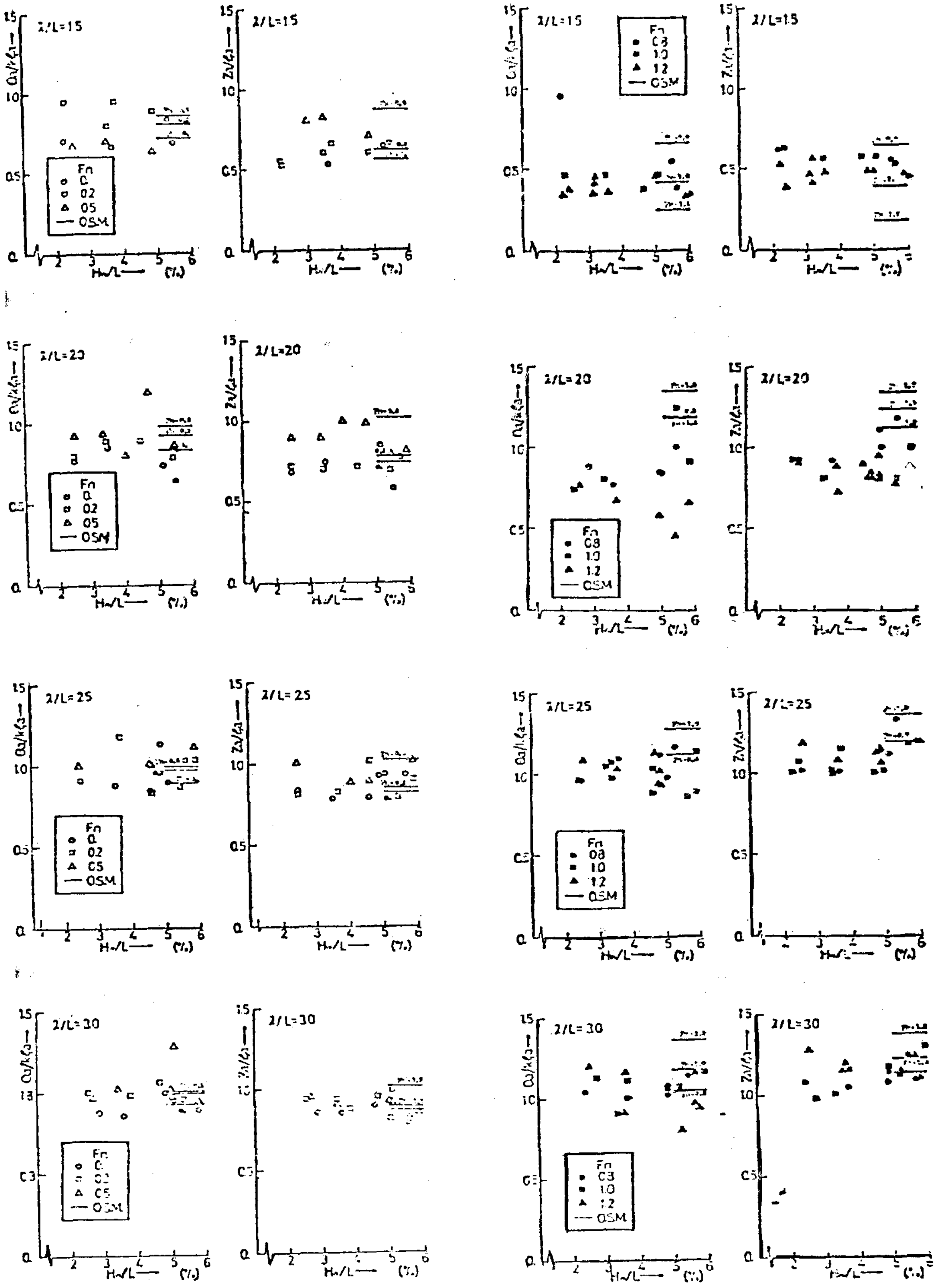

Fig. 6 Variation of Pitch and Heave Response with Wave Height

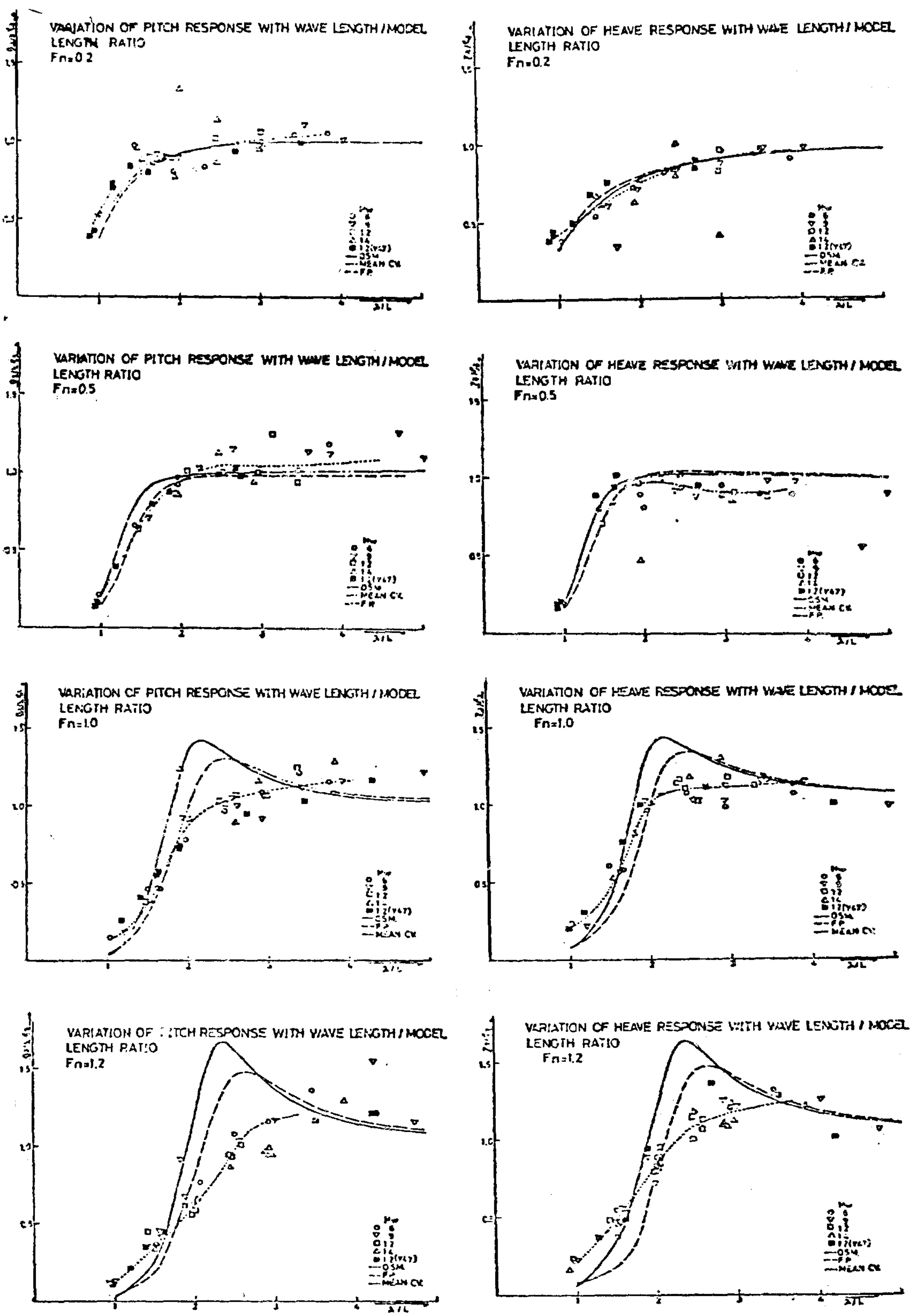

Fig. 8 Variation of Pitch and Heave Response with Wave Length

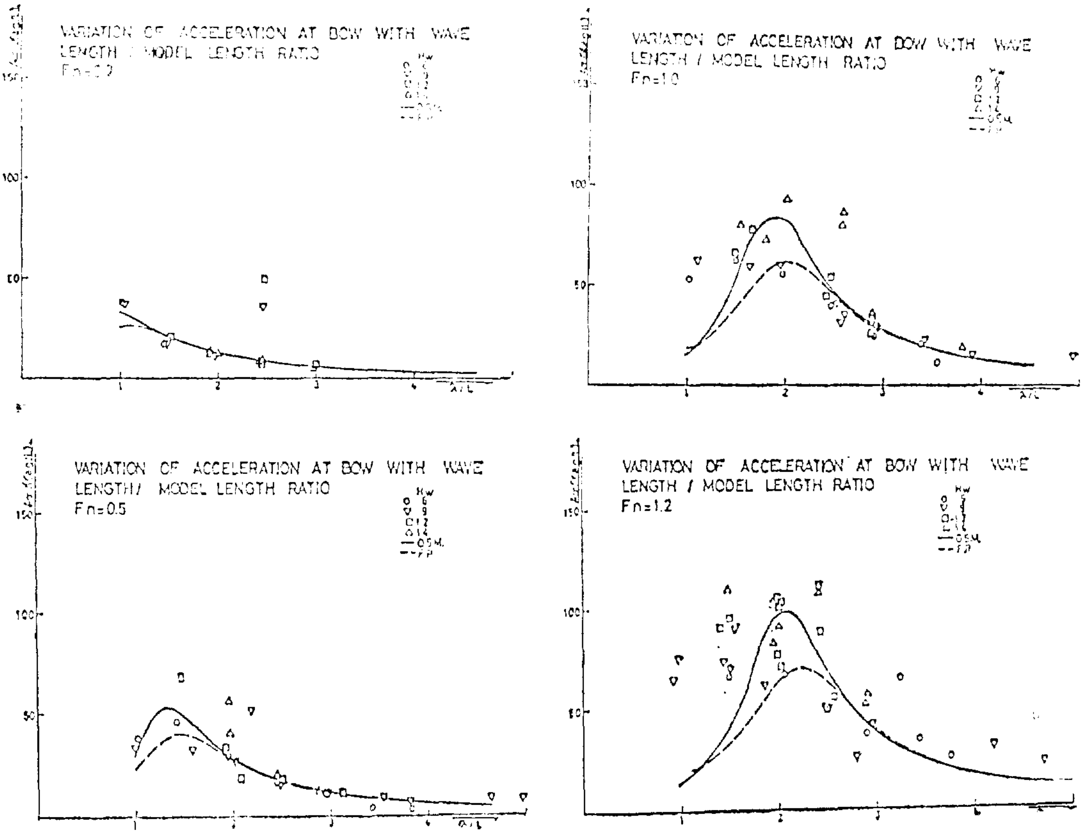

Fig. 9 Variation of Acceleration at Bow with Wave Length

shallow.

As seen in figures, the theory agrees well at lower speed than $F_n=0.5$ but does not at higher speed than $F_n=1$ and it is not simply decided which theory is preferable.

Applying the strip method, we took the cross section under the water as the one at still water. Of course, we could take it alternatively as the one at cruising in calm sea.

Thence, comparing both calculations we concluded to take the former because it is rather better than the latter in agreement with experiments and simpler in calculations.

Especially, the flat plate approximation is the simplest.

Therefore, we tried to analyse the series test results by G. Fridsma at Davidson Laboratory⁵⁾ by this method for comparison with our conclusions.⁴⁾

General tendency is the same as the present conclusions and moreover it is reliable qualitatively to predict motions in waves like as the displacement ship but not quantitatively.

4. Theoretical approach

We could realize in the preceding the difficulties accompanying with the research of rough sea performance of high speed boat. At the same time, we could observe her violent motions in waves as if she would be jumping from crest to crest of waves.

This means that her wetted surface area varies much in one period, but the available theory including the strip method does not presume such variation.

Therefore, we have started as a first step to investigate the effect of variation of wetted surface area.

At first, let us consider a two-dimensional water motion at any sectional plane in the same way as in the strip theory.

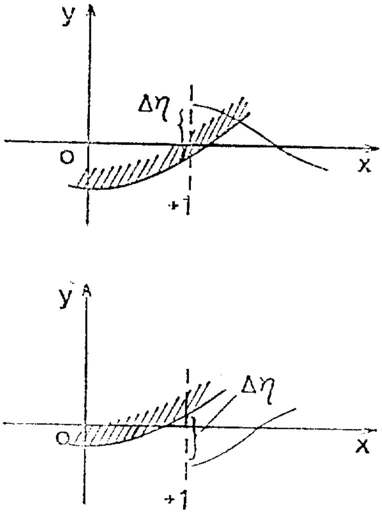

Fig. 10 Variation of Wetted Surface

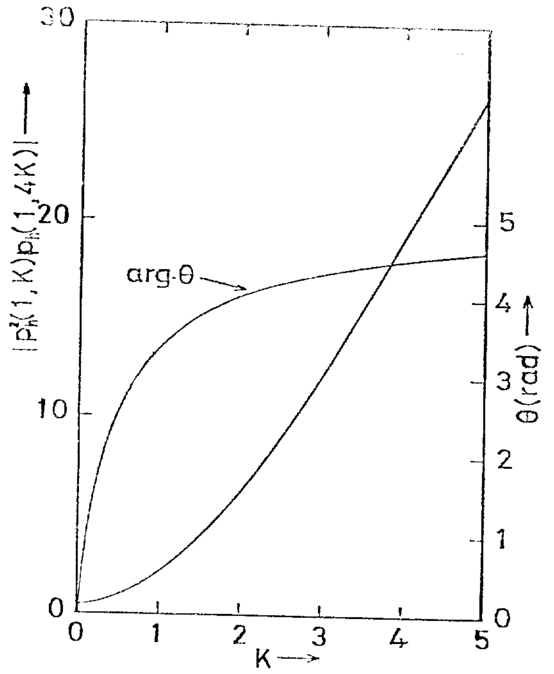

Fig. 11 Component of Second Harmonics

Fig. 10 shows schematically that if the angle α between the frame line and the water line is small the wetted breadth varies very much. Assuming this variation infinitely small, we can assume its effect is proportional to the displaced area, that is.

$$\triangle A=\frac{Y}{4\tan\alpha}[|p(1)|^2+R_e\{|p(1)|e^{2iw_et}\}], \qquad (3)$$

where Y is the amplitude of vertical displacement and $p(1)$ is the pressure at end devided by ρgY and the one part of the increment of force is the stationary and independent of time:

$$\varDelta F_s=\frac{\rho gY^2}{\tan\alpha}|p(1)|^2, \qquad (4)$$

and the other is the second harmonics

$$\varDelta F_D=\frac{\rho gY^2}{\tan\alpha}Re[p^2(1;k)p(1;4k)e^{2iw_et}] \qquad (5)$$

and both are proportional to the square of heaving amplitude and the inverse of tangent of inclining angle.[3,6)]

This result explains well, for example, that the distorsion factor as in Fig. 5 is nearly proportional to the square of the wave height because, as seen in Fig. 3, it depends almost on the second harmonics.

However, there appears no contributions to the fundamental frequency components.

This conclusion could not be adequate in the practical case.

Then, the bottom plane pushed down the water by the velocity v independent of time,

$$v=V\times(\text{time mean of attack angle}), \qquad (6)$$

and the breadth varies undulatorily, so that this disturbance may cause a sinusoidal increment of forces.

Namely, in general, the time mean motion and the oscillatory motion can be considered mutually as indepent but it connot be if there is the variation of wetted surface area.

Such study does not yet finished but it suggests hopeful way of investigatigation.

A final way, of course, must be to solve the boundary value problem which is formulated when the boat is represented pressure distributions as usual. This way may be long but a royal road to be traced.

At a first step, however, it is found that the available theory could not represent oscillations of a planing boat mathematically, so that it may be an only conceivable way to help this inconsistency to take in account the sinusoidal variation of her wetted surface area.

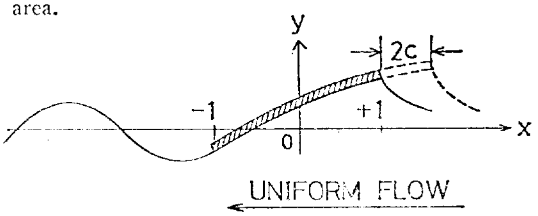

Fig. 12. Co-ordinate System

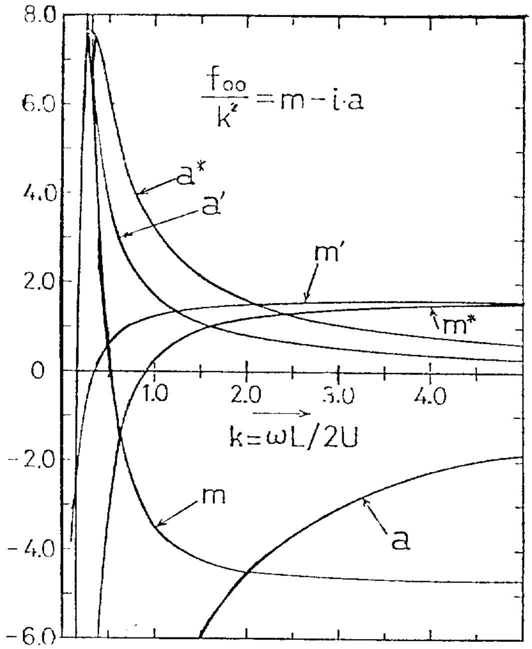

Fig. 13. Added Mass and Damping of Gliding Plank

Such theory was formulated in two-dimensional motion like as Fig. 12 and the forces was calculated analytically in the case of infinitely large Froude number, which is solved by the theory of an oscillating wing.[7]

Fig. 13 shows the added mass m and damping coefficient a and curves with prime mark are of an oscillating wing, with the asterisk of a surface planing plank and without mark of a shallow draft ship which does not satisfy the planing condition at tail end. As seen in this figure, there is much difference between them especially in high speed or more accurately small reduced frequency. This theory is also now at the starting point and that it contains various theoretical difficulties but no doubt it must propose also a powerful tool to investigate the rough sea performance of a planing boat.

5. Conclusion

As a preliminary research in the rough sea performance of a high speed planing boat we carried out model tests in regular head waves and concluded from its analysis that:

1) Higher frequency components appear in pitching and heaving oscillations at higher encounter frequency, that is, at higher speed and shorter wave.
2) The motions calculated by the strip theory agree fairly well with test results at lower speed than $Fn=0.5$, but do not at the higher speed.
3) Amplitudes of pitching and heaving oscillations measured from peak-to-peak are proportional as a whole, to the wave height even at high speed.
4) The appearance of higher frequency components and discrepancy with the strip theory at high speed seem to be explained by taking in account the variation of the wetted surface area in the theory at least qualitatively.

Thus, although we can not yet predict the motions theoretically we can predict statistically rough sea performance by making use of model test data on the ground of these experimental verifications except higher frequency components.

Reference

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