TECHNISCHE HOGESCHOOL DELFT
AFDELING DER MARITIEME TECHNIEK
LABORATORIUM VOOR SCHEEPSHYDROMECHANICA

SUMMARRY OF WORK DONE AT THE DELFT SHIP HYDROMECHANICS LABORATORY PLANING CRAFT AND SWATH

by

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Introduction

At the Delft Ship Hydromechanics Laboratory high speed vessels of all kinds have always been under consideration. Among the types investigated were fast displacement ships, planing craft, hydrofoil boats and small water plane area twin hull ships. Emphasis has commonly been placed on the semi-planing and craft due to the fact that they offered the most readily available ships for many purposes and there is a active industry building these types of vessels in Holland. The swath concept has been studied in coöporation with the Royal Dutch Navy, which considers them to be a possible replacement of their present frigates. The investigations are focussed on two main areas, i.e. resistance and the motions of the ships in waves.
In this lecture a rough outline of these investigations will be presented in which only the work on planing and semi-planing craft and on swath ships will be mentioned.

Semi-planing and planing craft

The distinction between semi-planing and the planing condition is arbitrary and only a function of forward speed, therefore these craft will be referred to as planing craft.
Planing craft became popular during world war II as a relatively easely build ship with a high speed potential. The hard chine and the transom stern gave it the possibility to generate dynamic lift at speed to such an extent that a large portion of the ships weight (up to 75%) is carried by it, so reducing displacement and resistance. A typical example of a planing hull form is presented in figure 1.
Important parameters that influence the resistance and trim angle of a planing hull are: the length to beam ratio of the planing surface, the longitudinal position of the centre of gravity with respect to the centroid of the planing surface, the weight of the craft and the deadrise angle. Using these parameters a variety of resistance calculations methods for these craft is available, i.e. de Groot Ref [1] Savitsky Ref [2] or Clement and Blount Ref [3] .
This last method is based on an extensive model experiment with a systhematic series of planing hull forms with different $^{L}/B$, LCG positions and weight of the craft. All models had the same deadrise, i.e. 12^{5} degrees. The results of these series are widely used.
One of the severe draw backs of planing craft is their rather poor seakeeping

behaviour. Due to their hull geometry in even moderate seas severe slamming and vertical accelerations do occur which strongly limit the operability of the craft at sea.

A very important parameter in the seakeeping behaviour of the planing craft appeared to be the deadrise angle of the bottom of the ship. Among others this was clearly demonstrated by Van den Bosch from the Delft Ship Hydromechanics Laboratory Ref [4]. He compared the motions of the parent model of the Clement series, with 12^{5} degrees deadrise angle, with the motions of a similar model, but with a deadrise angle of 25 degrees. The geometry of both models is presented in figure 2. Experiments have been carried out in both regular and irregular waves and the motions as well as the vertical accelerations forward have been measured. A result of these measurements is presented in figure 3 in which the vertical acceleration as function of forward speed and wave length is presented.

From this figure it may be concluded that the vertical accelerations may be reduced by as much as 75% in certain conditions by the increase in deadrise angle from 12^{5} to 25 degrees.

In figure 4 the results of the tests in irregular waves is presented for one wave spectrum only. From this figure it can be concluded that extremely high vertical accelerations are very much less likely to occur with the 25 degrees deadrise craft.

Because deadrise has an adverse influence on the resistance it was decided to investigate this in the Delft Ship Hydromechanics Laboratory by extending the original Clement series with a similar series of models with 25 degrees of deadrise. A comparison between the two parent models is presented in figure 5 from which the difference in deadrise can be clearly seen. The new develloped hull resembled the model of Van den Bosch. For the experiments five models have been constructed with different L over B ratio's, varying from 2 to 7. The outlines of these are presented in figure 6.

Each of these models have been tested with four different longitudinal positions of the centre of gravity and four different loading factors, i.e. the weight related to the area of the planing surface: $^{A_p}/_{\nabla^{2/3}}$. The resistance, the trim and the vertical displacement of the centre of gravity have been measured. The results are presented in Ref [5]. From this report the figures 7 and 8 are selected to show the influence of the deadrise on trim and resistance for two different L over B ratio's.

From these figures it can be seen that the difference for the high L/B ratio is very small (about 5%) and for the lower L over B ratio of

3.1 the increase of resistance with increasing deadrise is in the order of 10% - 15%. These differences in resistance remain of the same order of magnitude with the other loading factors and longitudinal positions of the centre fo gravity. The differences in the trim angle due to the change in deadrise are even smaller with a maximum of about one degree.

In the near future this series will be extended with a series of similar hulls with a deadrise of 30 degrees. This is done because there is growing tendency to use hulls with even larger deadrise angles to further improve the seakeeping behaviour.

Based on this series and the original Clement and Blount series a resistance prediction program has been develloped. This program uses polynominal expressions for constant values of volumetric Froude numbers and contains expressions with the deadrise, the length to beam ratio, the loading factor and the longitudinal position of the centre of gravity. The results of this prediction method compare well with actual measurements and this method is frequently used now by designers. An extension of the prediction method to include the trim angle is under consideration.

To be able to improve the seakeeping behaviour of planing craft, methods have been sought to calculate the motions of these craft in waves. Two methods have been used:

First calculations have been made using a lineair strip theorie model with a frequency domain solution method develloped at the Delft Ship Hydromechanics Laboratory. From comparison of the calculated results with actual model measurements it appeared that even at high speeds the motions and accelerations were very well predicted, although the theory is used far beyond the commonly accepted range of application.

Secondly use has been made of a computer program develloped by Zarnich Ref 6 . This program is based on a non lineair set of equations solved in the time domain. With this method non lineair effects as peak accelerations and bow slamming could be calculated. A comparison between the calculated pitch response and the measured pitch response of a planing craft is presented in figure 9.

With the aid of the first program the motions in waves of a large number of systematically varied hull forms have been calculated to find the trends for improving the operability of the craft in a seaway, this has been reported by Beukelman. The second program has been used to investigate usable methods for improving the seakeeping behaviour, among others for a study on an alternative method to reduce the motions of a planing craft in a seaway. This has

been carried out at the Laboratory by prof. Wang Ref [7]. He investigated the use of controllable trim tabs at the transom of the boat to reduce the heave and pitch motions. Using a control algorithm based on the pitch amplitude and velocity, he was able to achieve a considerable reduction in the heave and the pitch motions of the craft. This theory was confirmed with experiments in the towing tank of the Delft Ship Hydromechanics Laboratory. A result of the calculations is presented in figure 10 in which the heave and pitch response functions in regular waves are presented for different gain factors of the controler. The vertical accelerations at the bow and amidships can be reduced by as much as 30% using this technique. See figure 11.
One final remark relating to the improvement of the operability of planing craft in a seaway must be made. It is kwown both from calculations and measurements aboard full scale ships that the vertical accelerations, which are the limiting factor in the operability of ships at sea, vary considerably along the length of the ship. The maximum is at the bow, the minimum at 30% of the length aft. A carefully chosen position of the working space, that is the bridge in most cases, may reduce the vertical accelerations by as much as 50% such as shown in figure 11. In this figure the frequently used bridge location far forward and another further back to the stern are compared for the measured vertical accelerations at these positions in a given seaway. The difference is obvious. This fact is often overseen by the designers.

Swath ships

Small Waterplane Area Twin Hull Ships are an object of intensive research during the last decade in particular in the United Stated of America, but also in Europe and Japan.
A swath ship is composed of two large fully submerged cilindrical hulls. On these hulls, two (or four) surface piercing struts are placed which support the cross structure high above the water. See figure 12. The biggest part of the volume of displacement is placed far below the water surface and the area of the surface piercing struts is only small and therefore the structure as a whole is only very moderately affected by the disturbative influence of the surface waves. The swath is a typical example of a vessel designed to minimise the motions in waves. Ref [8].
Due to the small waterplane area of the struts of the swath sufficient static stability must be achieved by using a large strut separation. The longitudinal stability however remains small. The damping of the vertical motions heave and pitch is also small due to the small waterplane area of the struts. This leads to large natural heave and pitch periods and large amplitudes of motions at

resonance. To increase the damping of the motions of the swath fins were added inside of the fully submerged hulls. These may be fixed but in most practical situations they are actively controlled. These fins however do not only add damping but they also increase the wave forces on the structure which excite the motions. So an optimum configuration must very carefully be sought.

In figure 13 the motion caracteristics of a monohull and a swath of comparable size are presented. The swath is fitted with fixed fins. The superior motion characteristics of the swath in a large frequency range are clearly demonstrated.

Because most of the damping of the pitch motion and to some extent also of the heave motion is delivered by the fins, there is a strong influence of the forward speed on these motions. In general the motions amplitudes decrease with increasing forward speed. This is clearly demonstrated in figure 14 in which figure the vertical displacement forward is presented for the monohull and the swath for different forward speeds and sea states. The vertical displacements forward of the swath decrease considerably with forward speed while those of the monohull increase with forward speed. In the condition with no forward speed the vertical displacements forward of the monohull are even smaller than those of the swath.

The Delft Ship Hydromechanics Laboratory became involved in the research on swath ships in the beginning of 1980, when the Royal Dutch Navy became interested in swath ships.

An extensive experiment was carried out to validate the results of a computer program put at our disposal by D.T.N.S.R.D.C. to calculate the motions of a swath in waves. The tests were more or less first in their kind and included:

- forced oscillation tests with an unappended model of the swath 6A in the heave, the pitch, the yaw and the sway mode to determine the added mass and the damping as function of the forward speed and the frequency of oscillation.
- a series of tests with the model of the swath 6A in regular head and following waves to measure the heave and the pitch motion. For these tests the model was fitted with fixed fins.

The results of these tests have been reported in Ref [9].

From these tests it appeared that the added mass and damping calculations correlated poorly with the measured results. This was partly due to numerical instabilities in the calculation procedure and to the fact that both the mutual interference of the hulls and the influence of forward speed was not properly accounted for in the strip theory used. Also viscuous effects on the two hulls appeared to be of importance. In particular in the heave and the pitch mode the added mass and the damping of the hulls appeared to be small when compared with the forces excerted on the fins. This implied that in the calculation procedure of the vertical motions of the swath in waves these hydrodynamic forces are of minor importance. Nevertheless substantial improvements in the calculation procedure have been inplemented by D.T.N.S.R.D.C. using these experiments which yielded satisfactory results Ref [10] and the program is now frequently used for design studies.

The motion measurements with the swath 6A in head waves clearly demonstrated the great potential of the swath concept as a superior design concept. The results of these tests are presented in figure 15.

The motion measurements have been carried out at three different Froude numbers, i.e. Fn=0.22, Fn=0.44 and Fn=0.78. The influence of this forward speed can clearly be seen from the response functions for both heave and pitch. Only at the lowest Froude number heave shows a resonance peak in the wave length range investigated.

The phase angle between heave and pitch is favourable, i.e. the relative motion at the bow with respect to the waves was small as could also clearly be observed during the experiments. The correlation between the measured and calculated respons functions was reasonable.

In following waves the situation was quite reverse.The heave motion response function shows a large response for all three speeds investigated. This is shown in figure 16. Due to the relative low frequency of encounter, the long natural periods and the low damping of the swath high resonance response did occur. The phase lag between the heave and the pitch motion and the wave caused the swath to dig its nose into the waves. The relative motion of the bow of the cross structure with respect to the waves was so severe and adverse that only the addition of a large amount of buoyancy on the cross structure could save the swath during the test from an all too frequent crash. Nevertheless at the highest speed the swath crashed several times and the measurements had to be abrupted in these situations. The correlation with the calculated motions was generally poor.

The results of these tests focussed the attention of many research parties on the optimalisation of the motions of the swath in following waves.

One way of achieving this is by putting active control on the fins. To investigate this possibility a calculation method was developed at the Delft Ship Hydromechanics Laboratory using a set of non lineair coupled differential equations incorporating all the forces on the fins and a solution method in the time domain Ref [11] . Forces on the wings due to heave and pitch motions and orbital velocities were incorporated. Active control of the fins could be simulated. Using another method this was also being done by Livingstone Ref . The accuracy of the prediction method was first checked using the motion measurements in the following waves situation with the fixed fins on the swath 6A. From these tests it could be concluded that the motion prediction corresponded reasonably well with the measured results. So the program could be used for the pilot study on the effect of active control on the motions of the swath.

Using the computer program active control of the fins was added on the same fin configuration and the tests in following waves were repeated.

The results of these calculations are presented in figure 17.

The control algorithm was based on the pitch angle and the pitch angular velocity, and incorporated a time lag due to the hydraulic system and a limited angular velocity of the fins. The control could be established to "platform" or "contour" the waves.

From the calculations it appeared that the motions of the swath can be significantly reduced using such an active control. In the platforming mode the motions could be reduced to about 10% of their original value.

In no situation a crash of the swath did occur, such as happened with the configuration with the fixed fins. The swath can sail in following waves savely with active control. This poses the problem of inherent stability, i.e. the stability of the swath when a failure in the control does occur. This inherent control was investigated further by changing the fins layout. But from additional calculations with fixed fins in which the respective area's and positions of the fins were altered it appeared that the motions altered only slightly, even with 50% larger fins. It may be concluded from this that the fins do not only contribute to the motion reduction but also add a considerable part to the exciting forces. Furthermore the phase between motions and exciting forces is unfavourable with fixed fins. The calculation method was extended to include effects of surge and it appeared that this had a large influence on the motions in following waves. However this was not investigated in detail.

From this study it was concluded that an investigation on the motion characteristics of a swath should include active control on the fins. Special time domain calculation methods are necessary to perform these kinds of calculations. Therefore emphases in the near future will be placed on the development of these methods.

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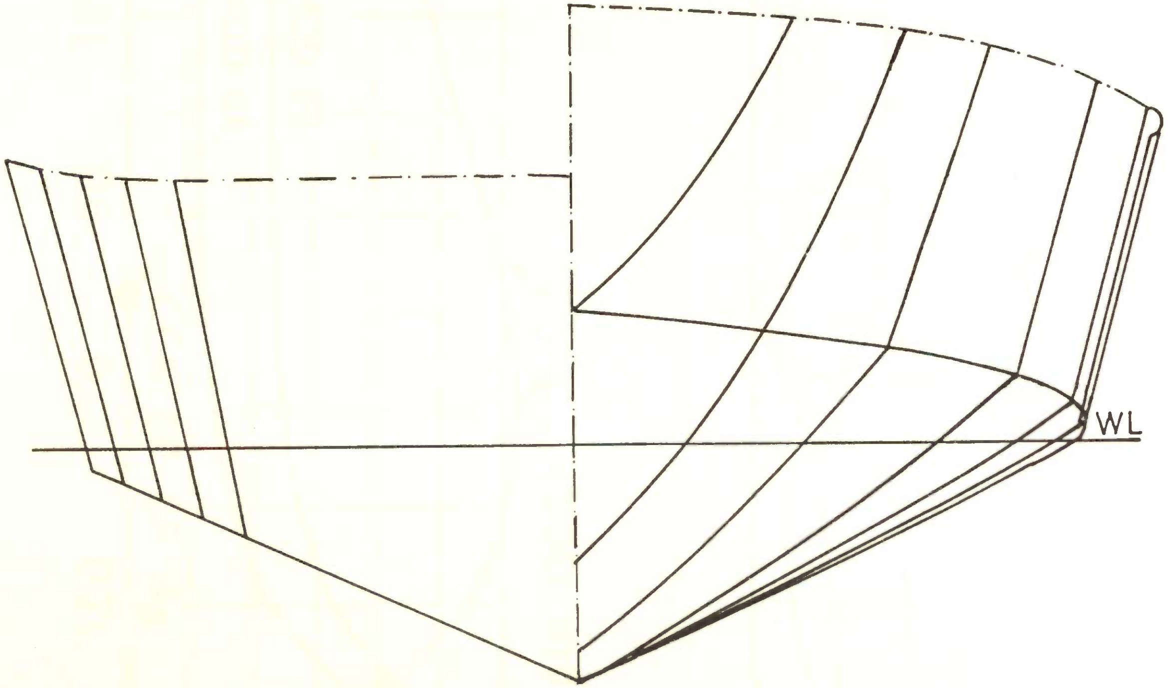


Figure 1. Planing hull.

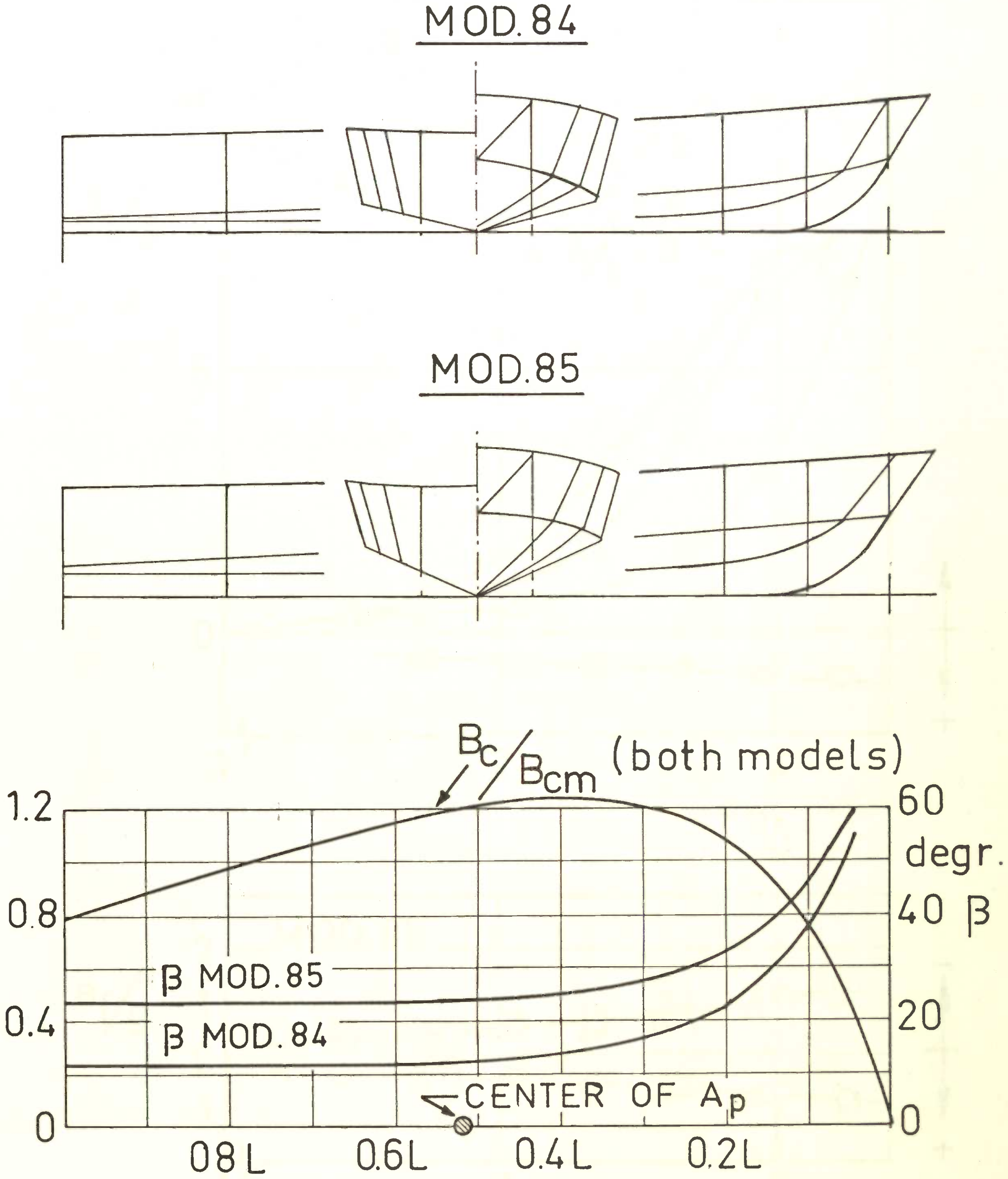


Figure 2. Model with 12.5 and 25 degrees deadrise.

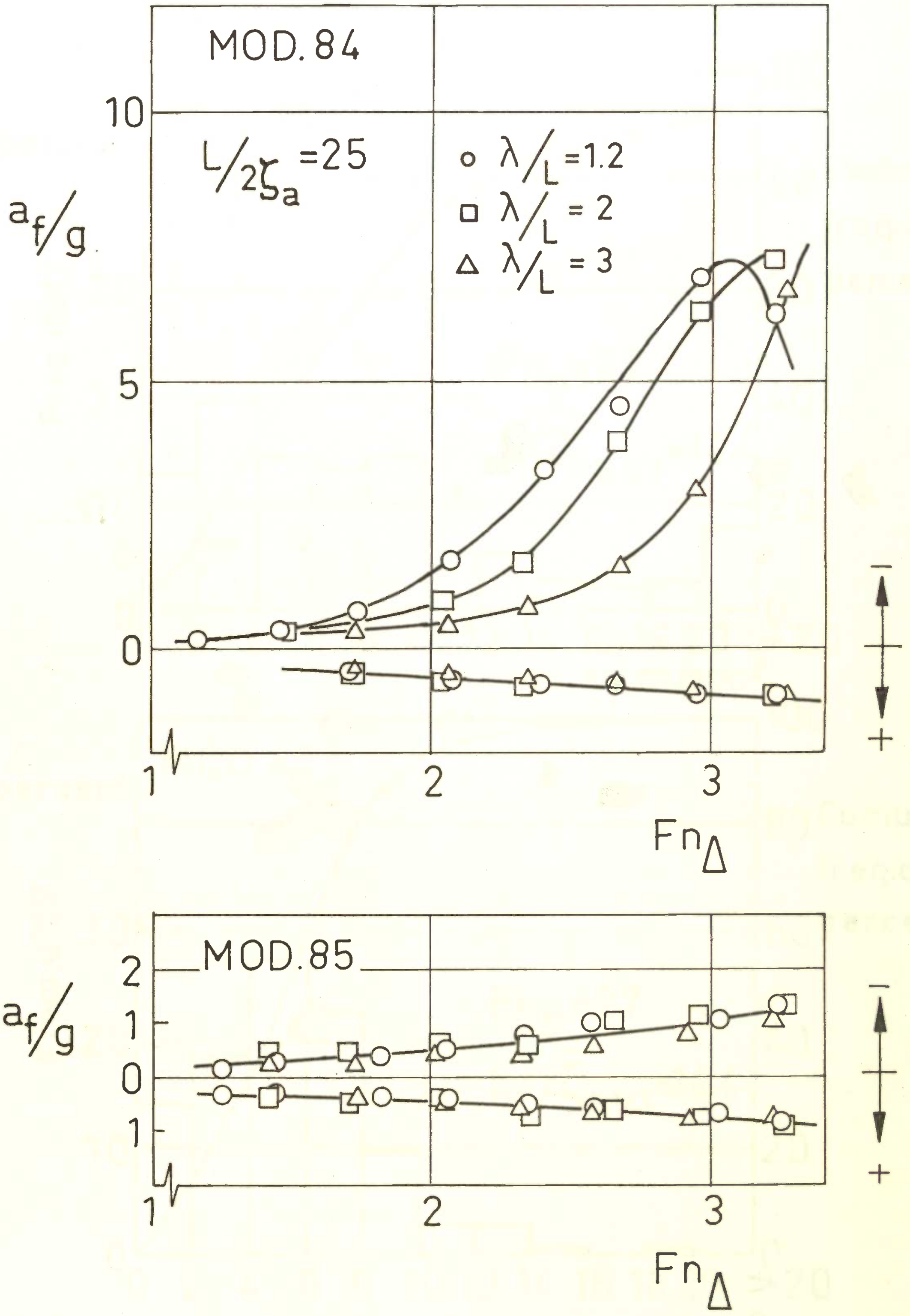


Figure 3. Vertical accelerations forward as function of forward speed.

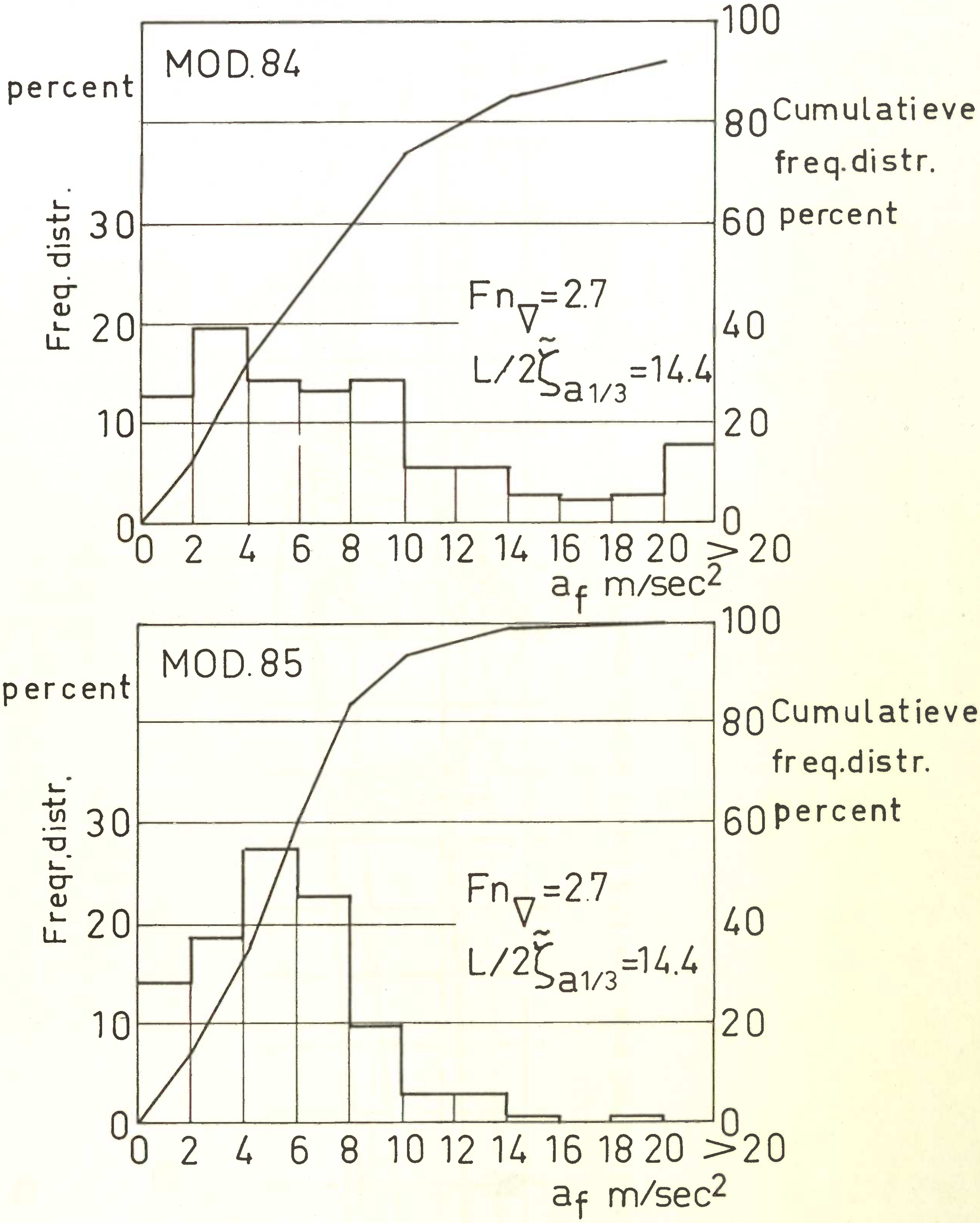


Figure 4. Cumulative frequency distribution vertical accelerations forward.

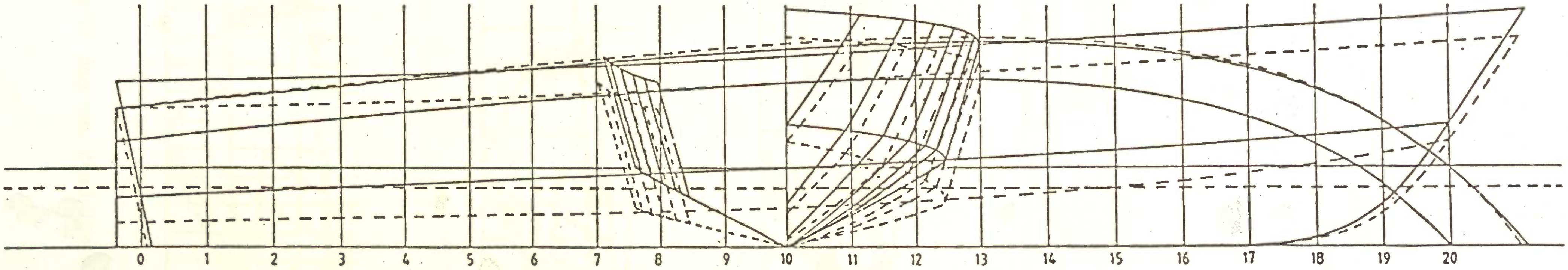
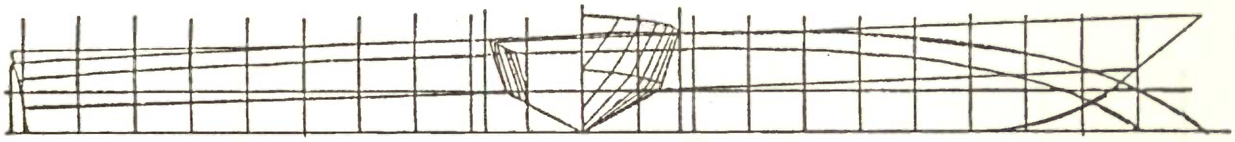
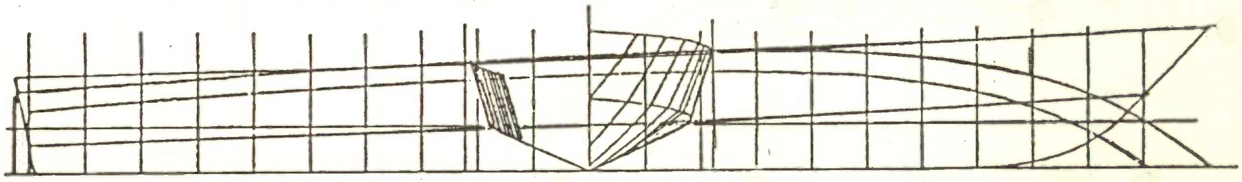


Figure 5. Parent models of 12.5 and 25 degrees deadrise series.



Model 190



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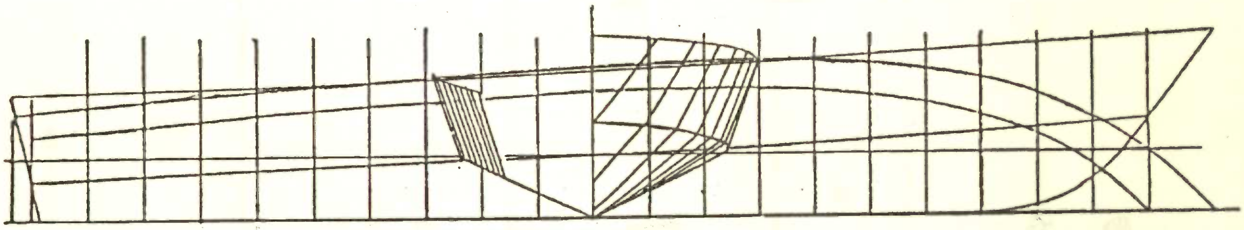

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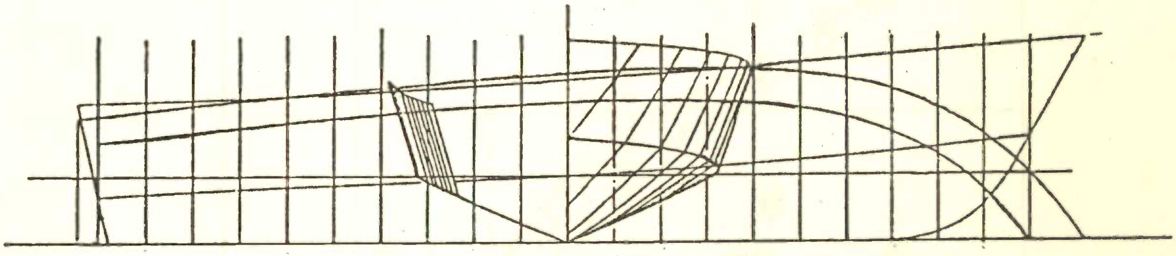

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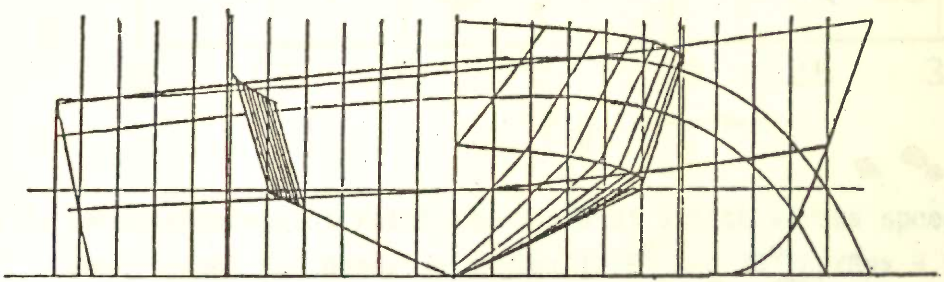

Model 186

Figure 6. Models of the 25 degrees deadrise series.

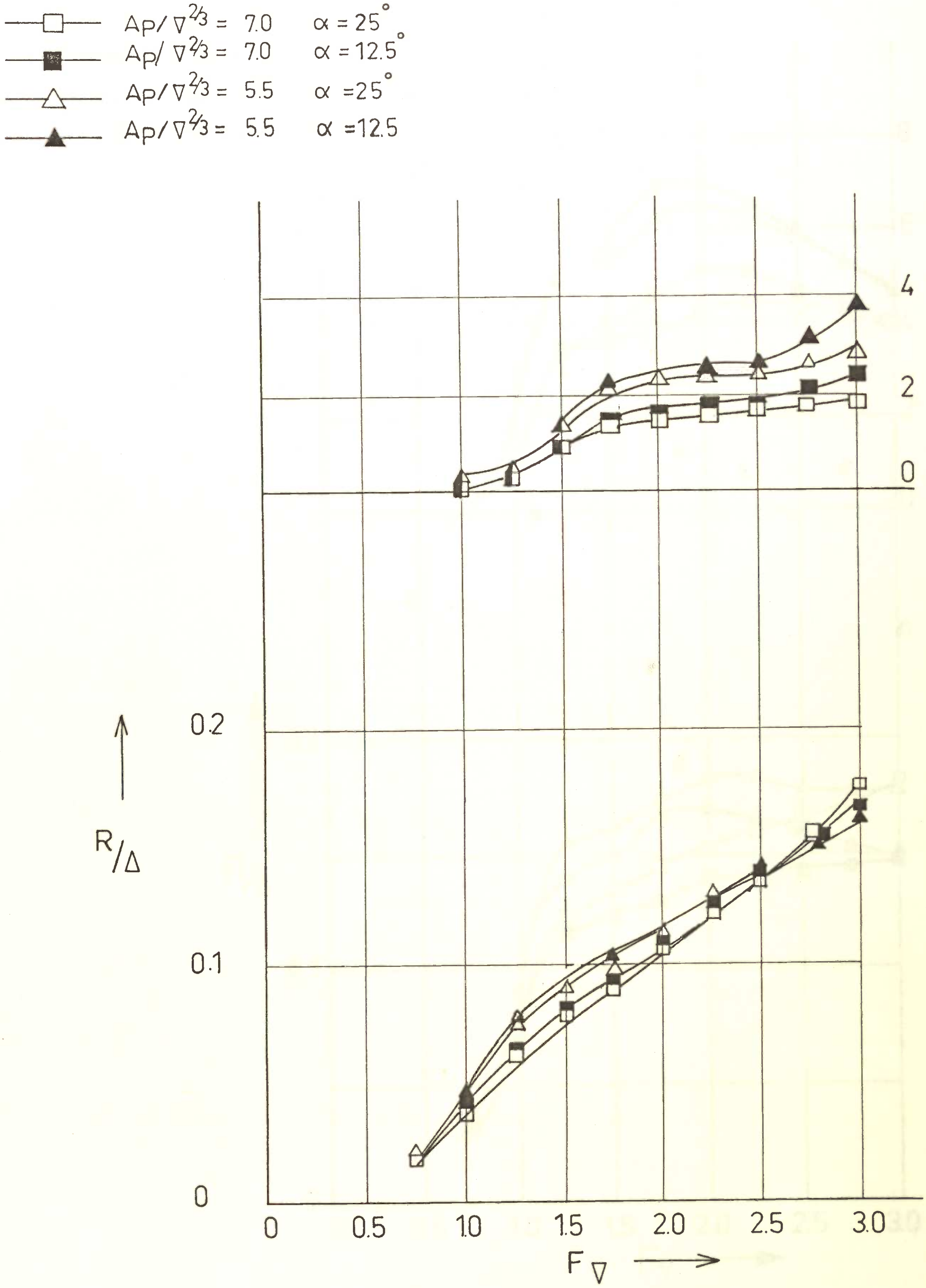

Figure 7. Resistance/weight ratio and angle of attack versus speed coefficient for deadrise angles 12.5° and 25° Lp/Bpx = 7.0 LCG = 8%.

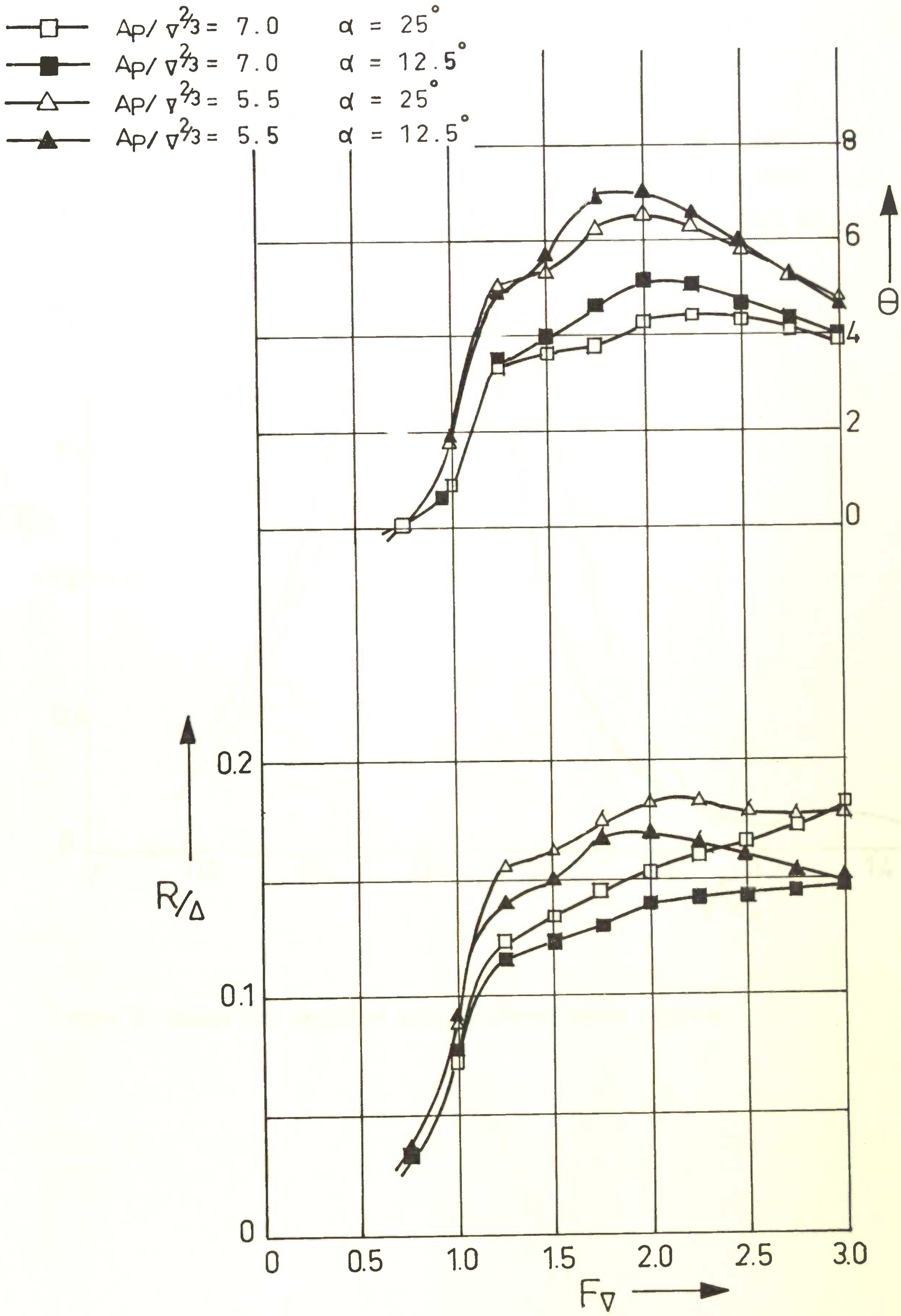

Figure 8. Resistance/weight ratio and angle of attack versus speed coefficient for deadrise angles 12.5° and 25° Lp/Bpx = 3.06 LCG = 8%.

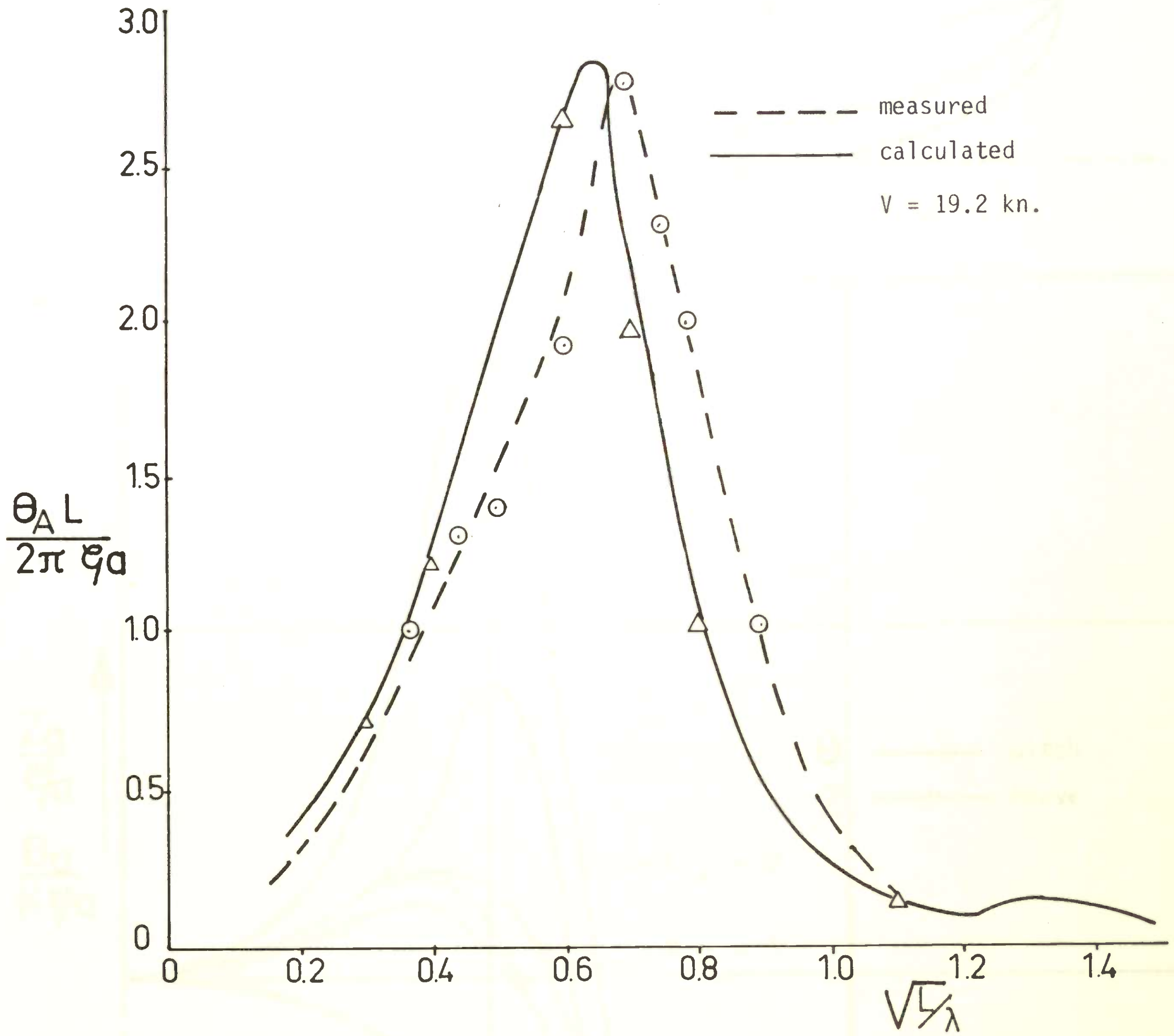

Figure 9. Comparison measured and calculated heave respons.

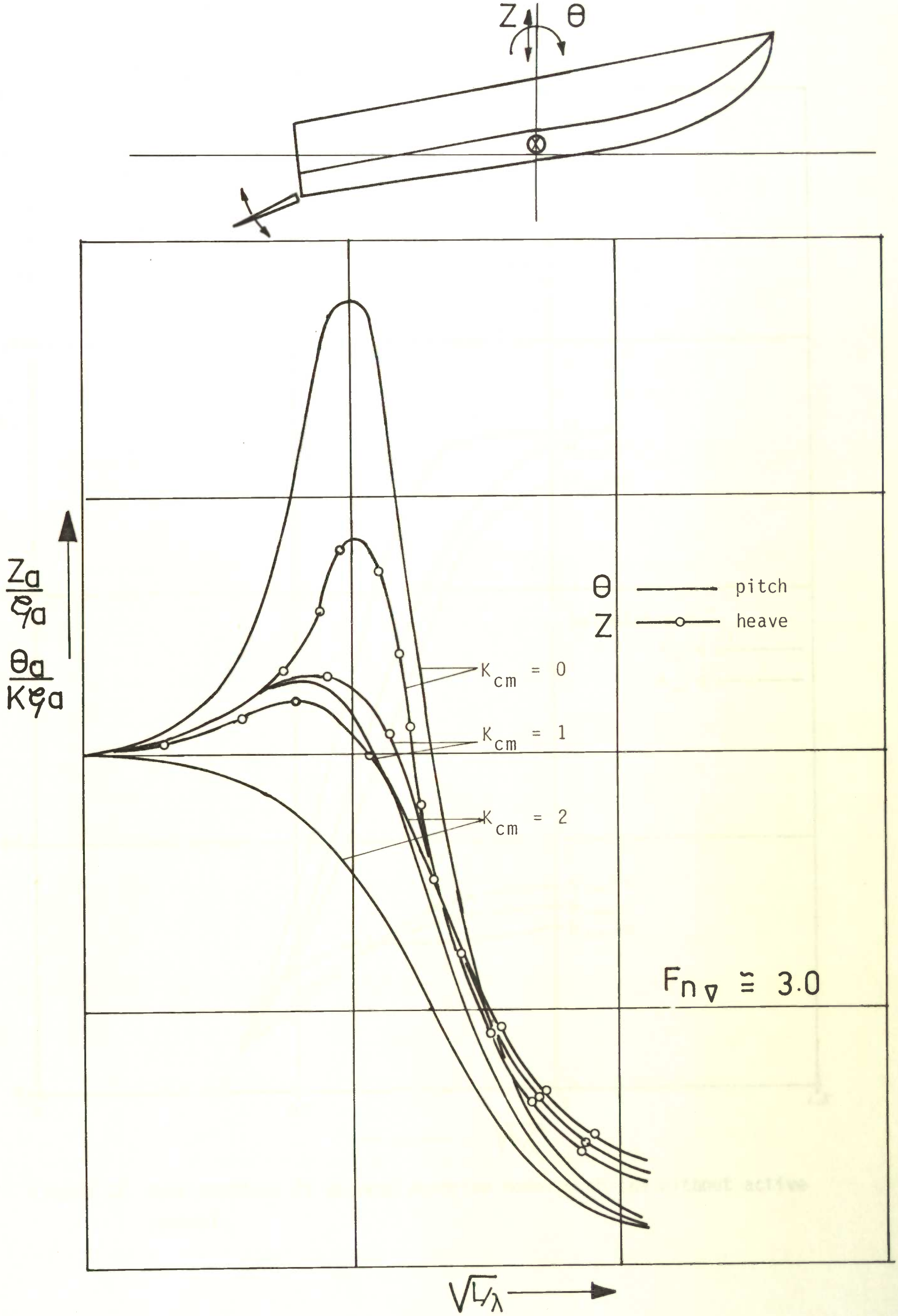

Figure 10. Influence of flap control.

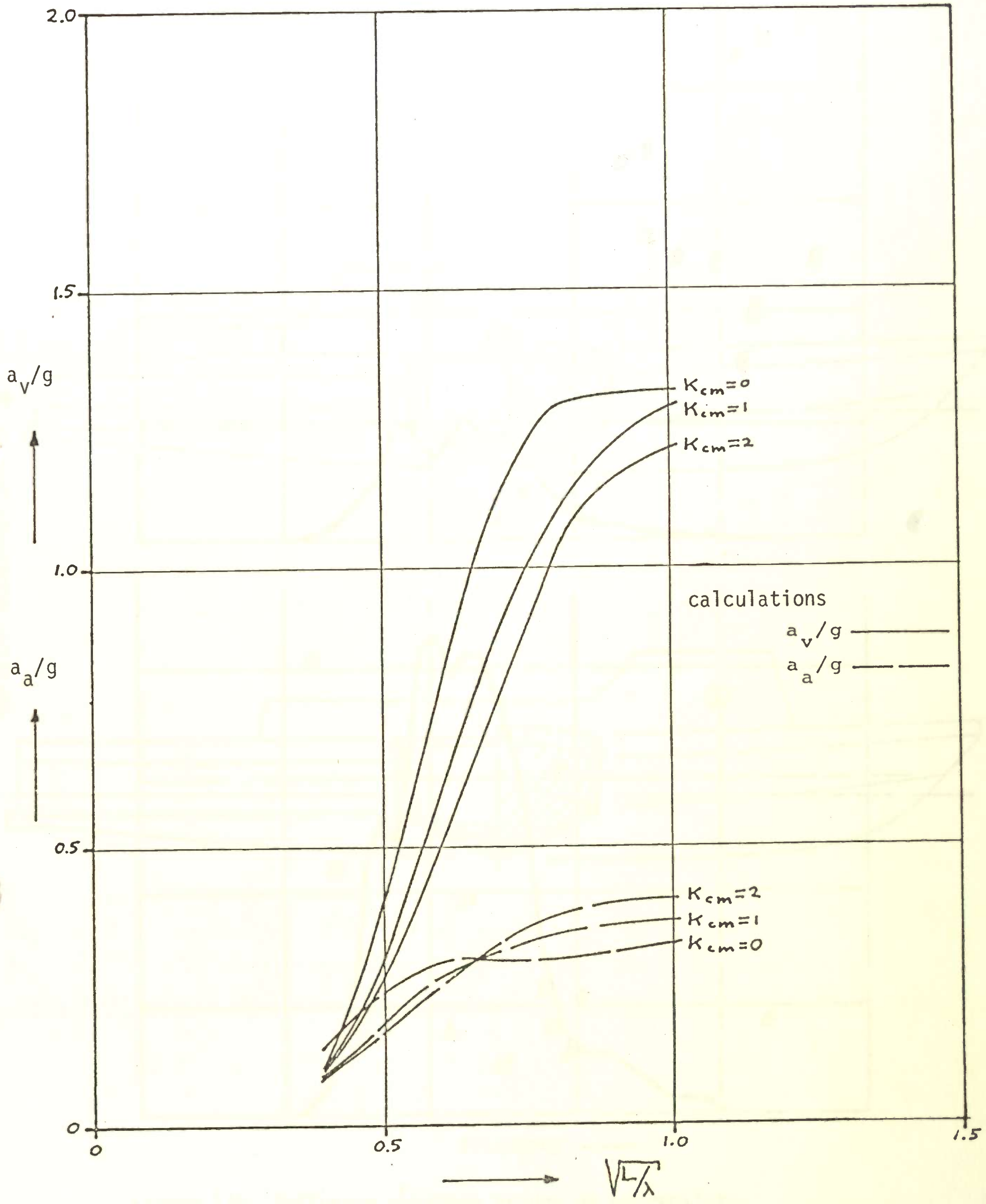

Figure 11. Accelerations 25 degrees deadrise model with and without active control.

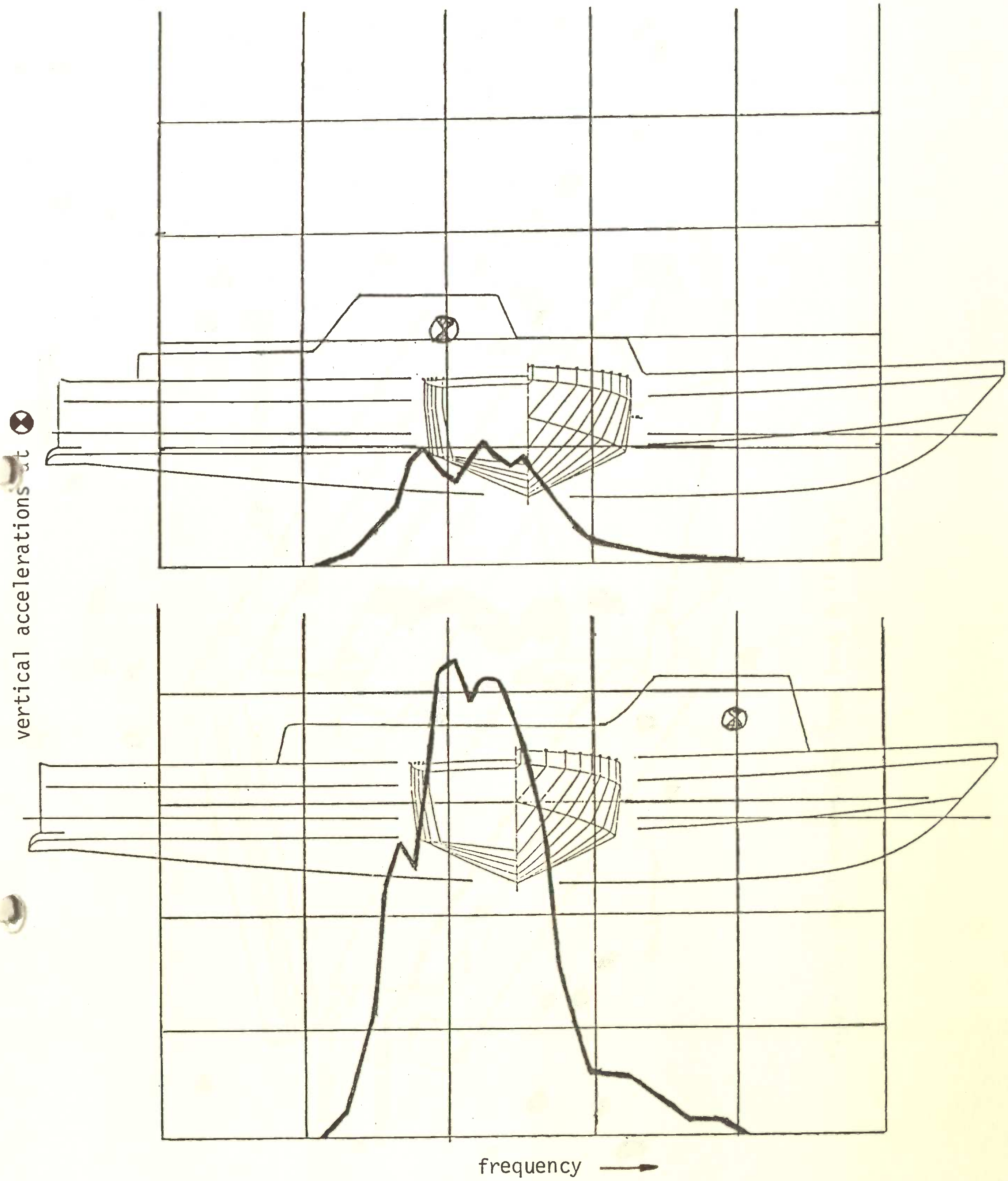

Figure 11b. Influence position bridge on operability.

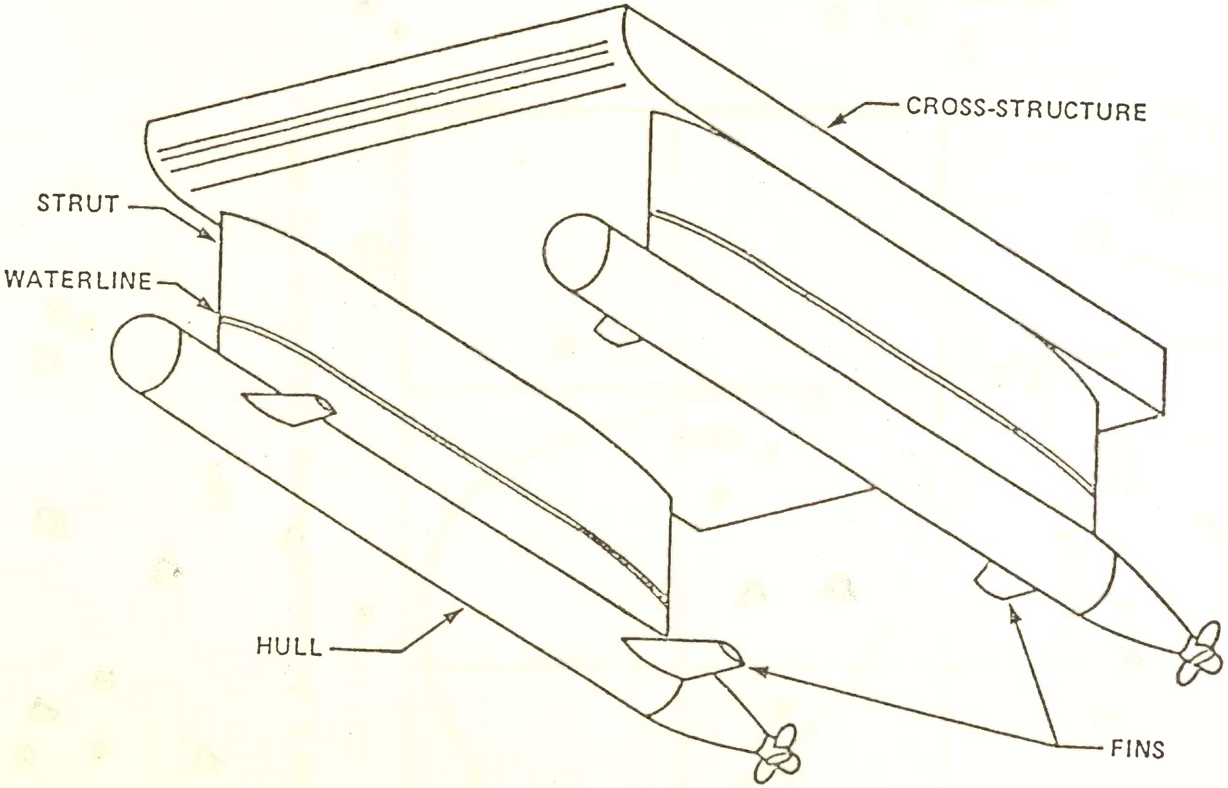

Figure 12. Small Waterplane Area Twin Hull ship.

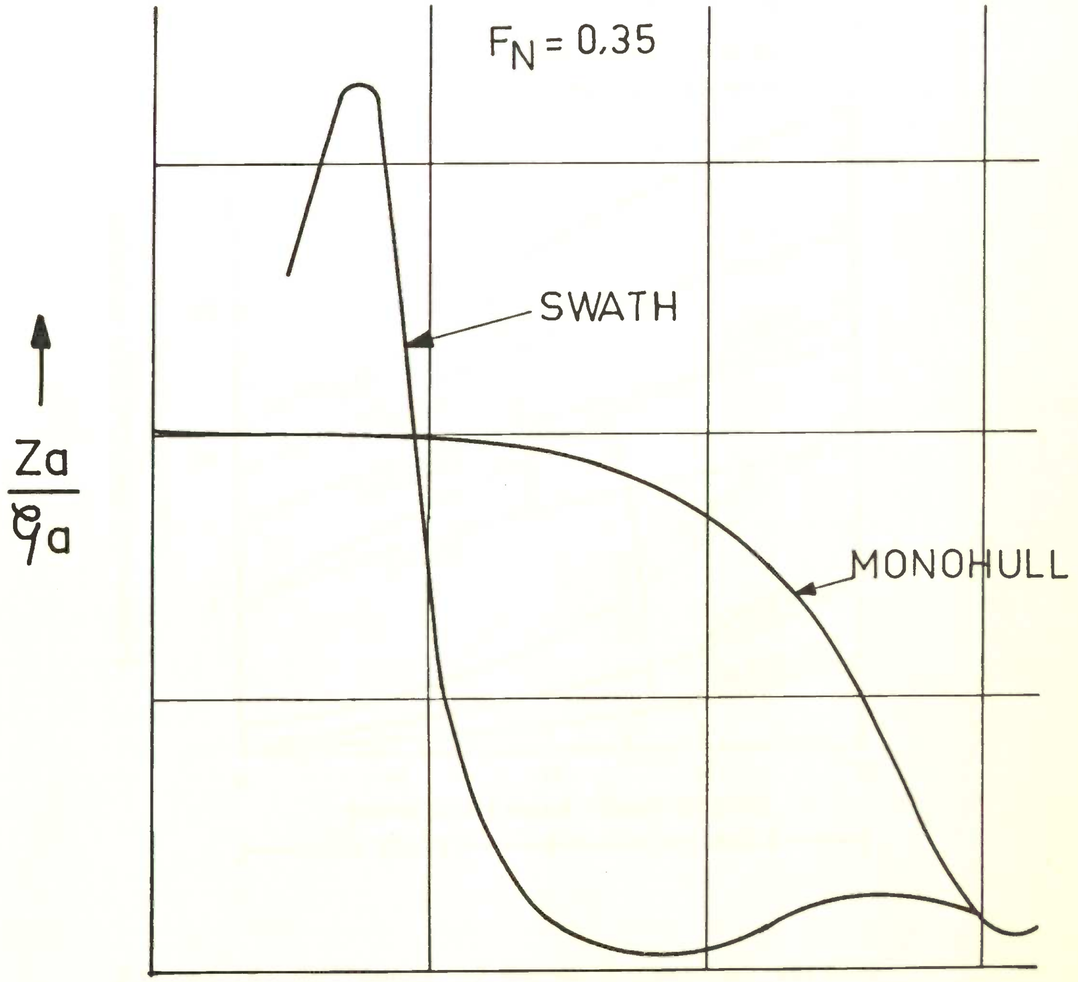

Figure 13. Comparison heave respons of a mono hull and a swath.

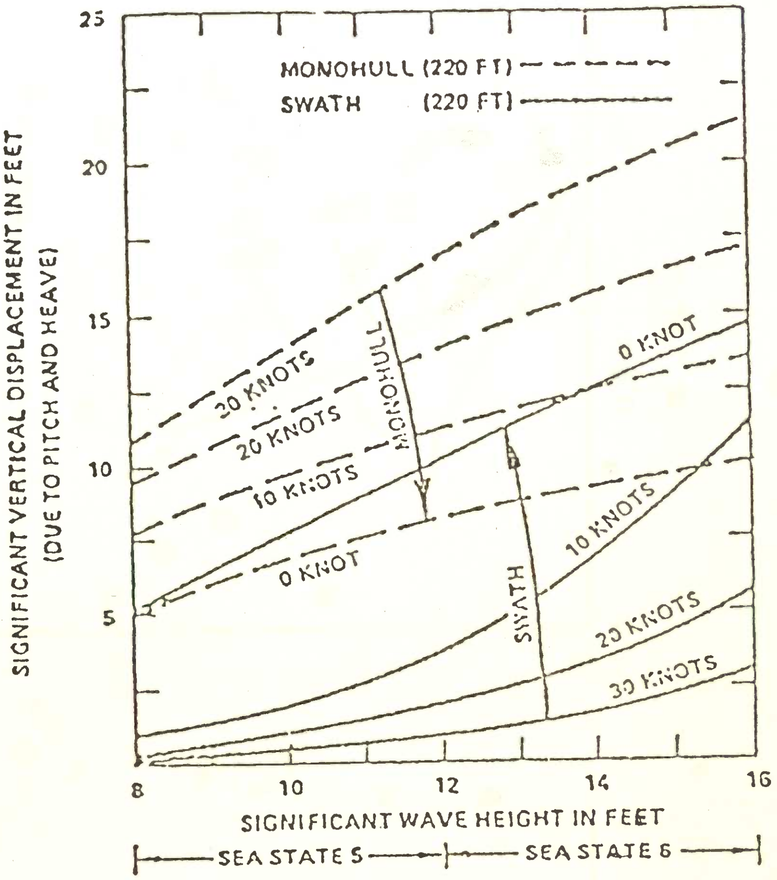

Figure 14. Influence of forward speed on vertical displacement forward of mono hull and swath.

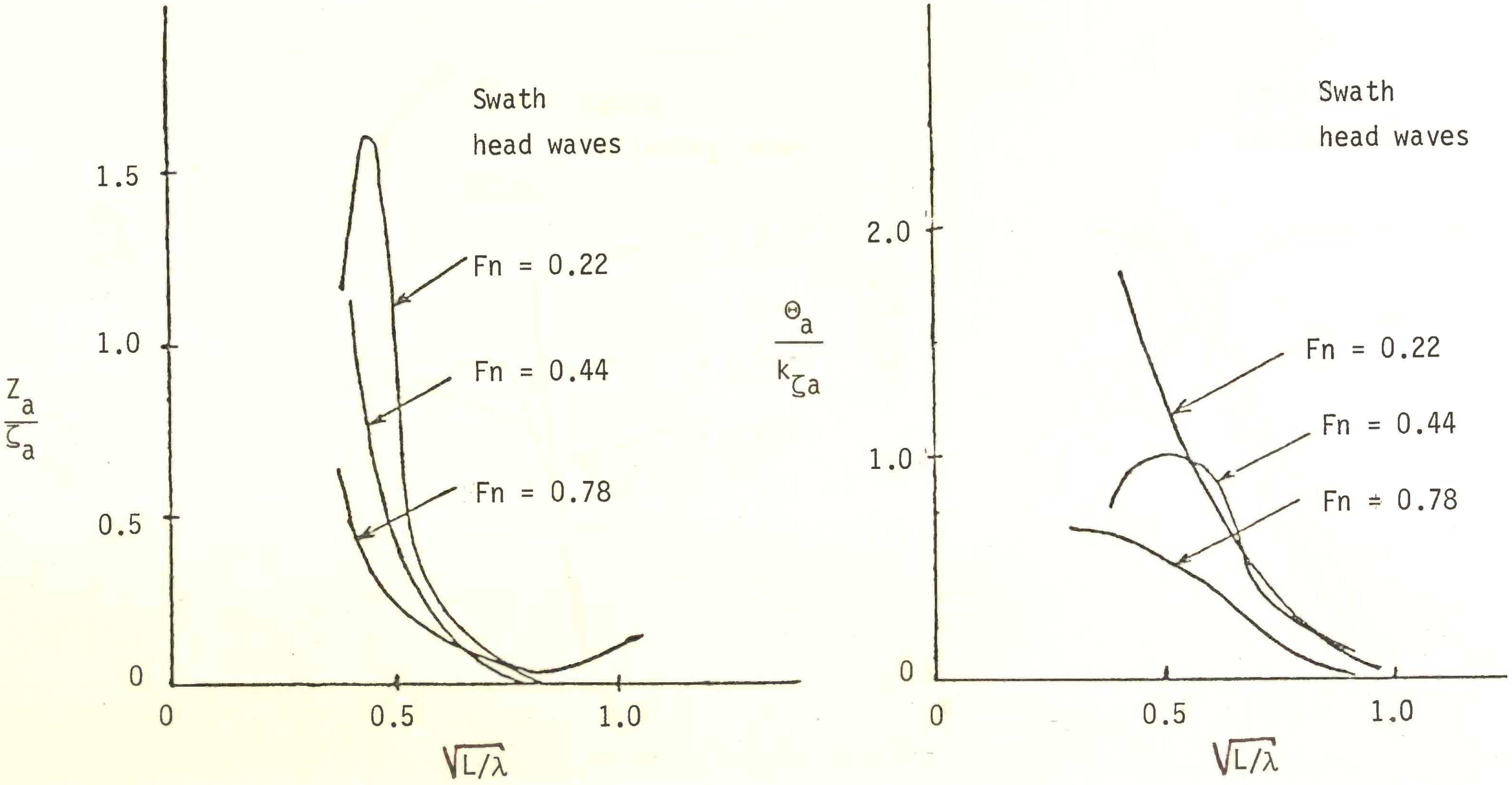

Figure 15. Response functions swath.

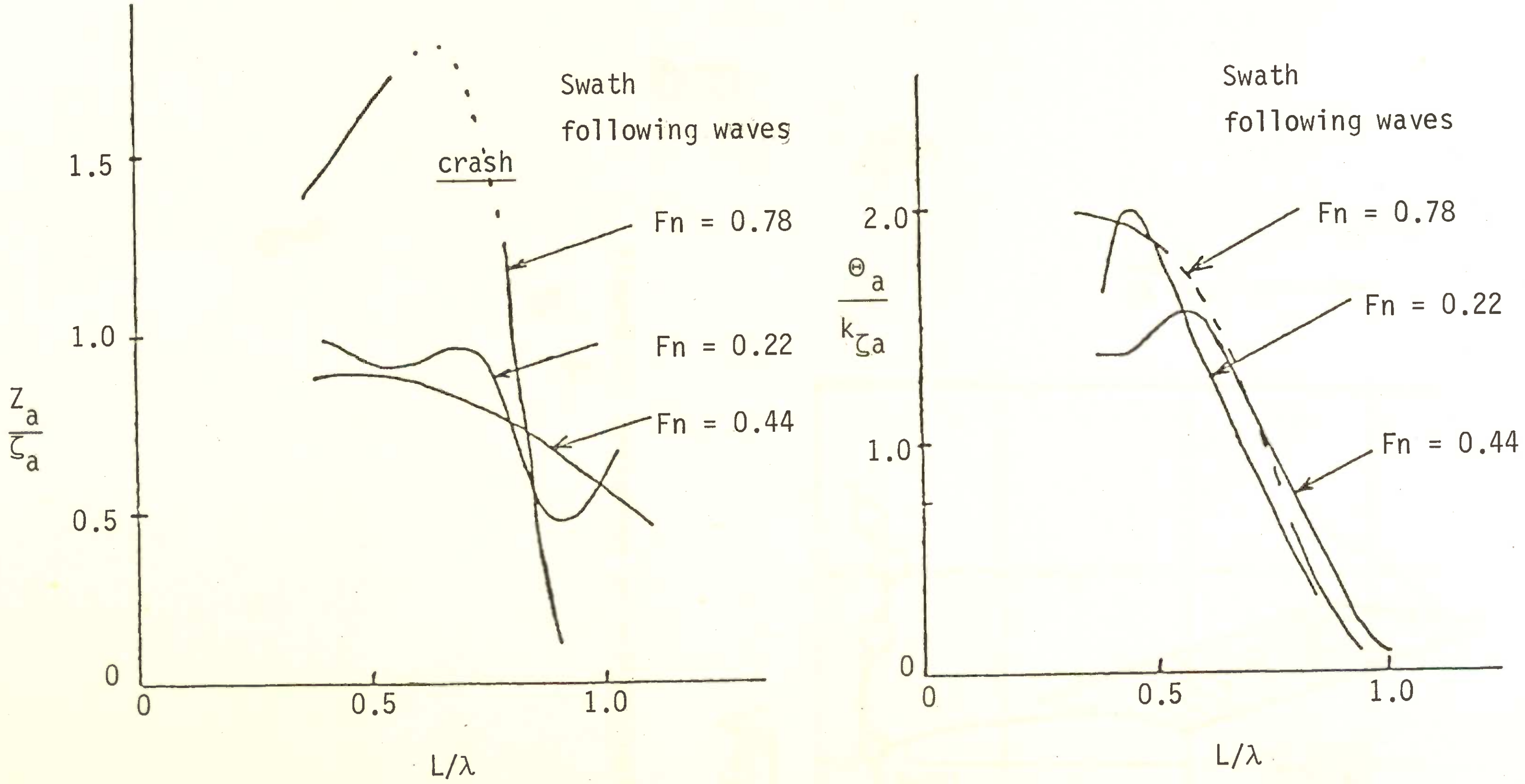

Figure 16. Response functions swath.

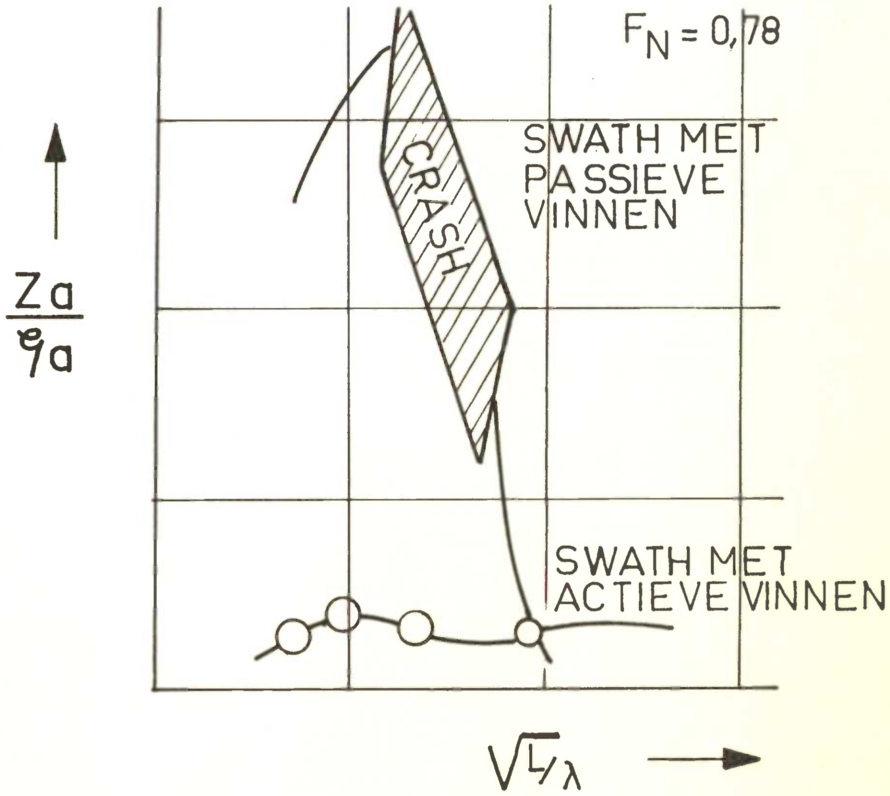

Figure 17. Influence of active control on swath motions.