A COMPARISON OF THE FISHING CHARACTERISTICS AND EFFICIENCIES OF DIFFERENT OTTERBOARD DESIGNS UNDER FIELD CONDITIONS

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G. GOEDEN and R. COLES

NORTHERN FISHERIES RESEARCH CENTRE

DEPARTMENT OF PRIMARY INDUSTRIES

CAIRNS   QUEENSLAND

INTRODUCTION

Unlike the majority of engineered equipment, the design of fishing gear is tested ultimately in its ability to take or capture live animals which are able to modify their escape responses. For this reason, increases in the efficiency of operation and optimization of hydrodynamic design are not always incorporated in the same objective. Fishermen have not strayed too far from the goal common to all hunting strategies - to catch as much as possible in the shortest time.

The fishing industry has followed conservative lines in gear design and reduced the chances of losing revenue through experimentation. Thus, in the absence of a better understanding of the interaction of fish and fishing gear, most design changes have been based on small modifications to proven industry standards. Unfortunately, there is rarely any scientifically-based testing of the modification. Industry-instigated gear comparisons, which are usually of catch-capability, have frequently been made between different vessels, different locations, or different seasons and the added variability has masked the true results. Because fishing gear is acted upon by water resistance, buoyancies, towing forces which may be changed by surface water conditions, and varying bottom friction, its operation must be viewed as a very dynamic system where performance should be measured only under the most stringently enforced conditions.

In addition to the dynamic nature of the gear, the designer is faced with the problem of having to satisfy conflicting requirements and therefore to arrive at compromises which offer solutions to opposing design strategies. For example, the need to maximise catch-capability, which is of paramount importance, may be in direct conflict with other objectives such as minimum hydrodynamic drag, minimum construction costs, or ease of handling on deck.

Because the designer cannot assess the catch-capability of fishing gear during the design stages, final tests must be conducted under actual conditions to establish this most important parameter.

This study takes up where the fishing gear designers have left off. An attempt was made to assess the catch-capability and hydrodynamic efficiency under field conditions of each of three different otterboard designs commonly used by the Australian prawn trawling industry.

HISTORICAL BACKGROUND

The first otterboard was patented in 1894 in England when the introduction of steam engines to fishing boats allowed fishermen to move away from sail power and beam trawls. When the otterboard was introduced, it was fastened directly to the net ends and became a more convenient substitute for the beam in terms of handling. As fishermen discovered that otterboards behaved differently to beams in the hydrodynamic sense, net design and attachment points were rethought and redesigned. By the 1920's, trawls with wing panels and floated headlines had been introduced, and otterboards were moved to the sides and forward of the trawl with bridles and sweeps.

Since then, fish trawls and especially midwater trawls have continued to evolve as our understanding of hydrodynamic forces and effects improved. Unfortunately, the demersal prawn trawl has not enjoyed the same flexibility of development as the midwater gear. Prawn trawl development has been limited largely to variation in otterboard design and the number and arrangement of the nets towed.

The chronological development of otterboards on a world-wide basis is:

* 1890's - rectangular, flat, wooden low aspect ratio boards set on iron frames
* Early 1930's - rectangular, multifoil steel boards
* Late 1930's - cambered, high aspect ratio all steel boards
* 1950's - oval, flat, slotted wooden boards and rectangular, V-form steel boards
* Late 1960's - oval, cambered slotted steel boards (polyvalent)
* Late 1970's - super-high aspect ratio steel; foils; kites; and multi-slotted rectangular boards

While many of the more recent designs are quite exciting from an engineering point of view, they have not been generally accepted by the industry. This is particularly true of Australian prawn trawlers where high operating costs and low profit margins make risk-taking on new fishing gear unacceptable.

METHODS

Full scale gear trials usually suffer from their own complexity. It is not often possible to standardise conditions to the extent that they can be considered identical from experiment to experiment, and thus the quantitative analysis of a full set of hydrodynamic results relies on adequate replication to overcome the variability inherent in the experimental programme. For these reasons, scale models are more often employed to determine the hydrodynamic characteristics of fishing gear and designers often use the model gear test results for confirmation of a gear's "overall" performance.

When they are used, full scale gear trials provide the designer with a check on his extrapolated values of the model's hydrodynamic performance, a final checking of the industrial version, and calculation of the economic effectiveness of the completed project. As far as catch-capability assessment of the fishing gear is concerned, full scale trials are the only practical method available.

In this study, the fisheries research trawler "Gwendoline May" was employed to test two identical nets each fitted with a different set of otterboards. The field work was carried out using two Florida Flyers each spread by either wide-keeled rectangular flat otterboards, standard rectangular cambered boards, or 'high aspect ratio' cambered boards. Each set of cambered boards measured about $0.6m^2$ (6.5 square feet) and the rectangular flat boards measured about $1.0m^2$ (11.25 square feet) in projected area. Table 1 lists the measurements of the otterboards tested.

TABLE 1 - MEASUREMENTS OF OTTERBOARDS TESTED

MEASUREMENT	RECTANGULAR FLAT	RECTANGULAR CAMBERED*	HIGH ASPECT CAMBERED
Projected Area	$1.04m^2$	$0.55m^2$	$0.62m^2$
Aspect Ratio	0.47	1.00	1.73
Thickness	1.7%	0.9%	12.5%
Camber (% of chord)	0.00	13.5%	14.5%
Weight (in water)	60kg	70kg	90kg
Cost Per Unit Area	$\$463/m^2$	$\$1055/m^2$	$\$1419/m^2$

* refer to Hughes (1981) for description of sea-trials

The Florida Flyers had six fathom headropes and 35 mesh wings. They were rigged with Texas drops of 8mm standard link chain with an extra 5m of 6mm standard link chain fitted across the centre of the groundchain. Nets were 30 ply 50mm mesh with 45mm mesh cod ends.

When each set of gear was deemed by the skipper to be operating properly , each otterboard combination was alternatively fished on the port and then on the starboard sides of the vessel throughout the night. Trawling took place over five nights in May and in July 1985, during which a total of 35 trawls of one hour duration and 20 trawls of 1/2 hour duration were completed. The gears were trialed over a range of weather conditions and bottom types between Low Isles (Port Douglas, Qld) and Fitzroy Island (Cairns, Qld). Each trawl was maintained at 3.3 knots. The total commercial prawn catch for each trawl for each otterboard set was weighed and the prawn and trash fish components subsampled for laboratory analysis. In the laboratory, the by-catch was further sorted into trash fish and trash invertebrates, the latter representing the more benthic organisms such as crabs and sponges.

The hydrodynamic data sets were gathered in the Northern Fisheries Research Centre tow tank. Each full size otterboard was suspended by load cells set to measure the horizontal vector components of drag and spreading force (lift). Three 'runs' were made with each otterboard at a fixed angle of attack. Angles of attack ranged from 10-50 degrees(covering the usual range of otterboard operation) in 10 degree steps. Low variability within the hydrodynamic data set allowed simple averaging of results.

RESULTS

The catch rate of prawns and by-catch groups varied according to the time of night and geographic location (presumably substrate) while using the same fishing gear. This kind of variability confuses the comparison of different fishing gears when the trials are carried out at different times and/or different places without adequate replication.

The catch rate, in kilograms per hour, of prawns, total catch, fish by-catch, and non-fish by-catch were not significantly different for half hour and one hour trawls taken at the same time and place. This permitted data from both short and long trawls to be pooled according to the kind of otterboards fitted to the nets. Pooling the data created larger sample sizes and increased the sensitivity of the statistical analyses (Mann-Whitney U Test after Siegel, (1956)).

Analysis of the catch rates for identical nets spread by wide-keeled rectangular flat otterboards and by standard rectangular cambered otterboards showed no significant differences ($p > .05$) between them (Appendix 1).

Although there was some indication that the standard rectangular cambered otterboards caught more non-fish by-catch than the wide-keeled rectangular flat otterboards, this difference was not quite large enough to be considered significant ($p = .07$).

Analysis of the catch rates for wide-keeled rectangular otterboards and for 'high aspect ratio' cambered otterboards showed no significant differences ($p > .05$) in any of the catch categories. The same was true for comparisons between standard rectangular cambered otterboards and 'high aspect ratio' cambered otterboards; there were no significant differences in catch rates ($p > .05$) for either prawns, total by-catch, fish by-catch, or non-fish by-catch.

It is clear that the best otterboard performance will occur when its hydrodynamic lift is at a maximum and its hydrodynamic drag is at a minimum. Hydrodynamic efficiency (K) is related to both lift and drag functions by the relationship:

$$K = \frac{l}{d}$$

where l equals the lift or spreading force and d equals the drag force. There is no method of estimating these hydrodynamic forces analytically for complex otterboard shapes and for otterboards working at large angles of attack. Thus it is not possible to confirm extrapolations from our tow tank trials to larger otterboards without full scale tests.

The relationships between the hydrodynamic lift forces, the drag forces, and the hydrodynamic efficiency without the influence of bottom friction are shown for different angles of attack for the wide-keeled rectangular flat otterboard (Fig. 1), the standard rectangular cambered otterboard (Fig. 2), and the 'high aspect ratio' cambered otterboard (Fig.3). It can be seen that the hydrodynamic lift (l) increased up to a certain maximum for each otterboard design and then decreased again. The angle of attack at which the maximum lift occurred is called the critical angle of attack.

For low aspect ratio wings and foils such as the rectangular flat otterboard and the standard rectangular cambered otterboard, critical angles of attack usually range between 30° and 50° (Friedman *et al*, 1979). Results of the tow tank tests indicate critical angles of 43° for the rectangular flat board and 40 for the standard cambered board.

For wings and foils with very high aspect ratios, the critical angle of attack typically ranges between 12° and 18° (Friedman *et al.* 1979). The critical angle of attack for the high aspect ratio cambered board was 32° or about 10° less than that of the low aspect ratio boards.

DISCUSSION

Bearing in mind that the three types of otterboards were set up by a professional fisherman to optimise their performance in terms of handling and landed catch, it is interesting to find that there were no significant differences in catch rates. Each otterboard type apparently spread the net to an equal degree (as measured by catch). The only indication of possible overspreading ($p = .07$) was with a small increase in non-fish by-catch associated with the standard rectangular cambered otterboards. This could have resulted from the relatively high spreading force of the boards (see Fig.2) or they may have been inadvertantly set to fish the bottom a little 'harder' than the other otterboards through the adjustments provided (refer to Appendix 2 for skipper's comments on setting up the boards). If prawn catch rate is compared with otterboard area, then it can be seen that the wide-keeled rectangular flat design required an increase in area of between 67% ("high aspect ratio")and 89% (standard rectangular)to equal the catch of the cambered boards. This conclusion is supported by the tow tank results which showed an increase in lift per unit area of 76% for the standard rectangular cambered otterboards over the wide-keeled rectangular design at an angle of attack of about 40°. The lift forces for the "high aspect ratio" cambered boards are actually somewhat smaller than the wide-keeled rectangular boards at a 40° angle of attack and do not explain the substantial increase in catch rate per board area described above.

It is our contention that at large angles of attack the drag component of the otterboards tends to pull the towing bridles together and thus works against the lift forces. If this is correct, then the apparent increase in fishing efficiency for the "high aspect ratio" cambered otterboards would be the result of reduced drag (21% less at 40^{o}) and not increased lift.

When the otterboards operated at subcritical angles of attack, the water on the outside of the board flowed relatively closely to the board's surface and was not very turbulent. When the otterboards operated at supercritical angles of attack, there was a rapid increase in turbulence as the boundary layer broke away from the leading edge. The resultant eddy outside the otterboard reduced lift and increased drag, with a consequently significant reduction in hydrodynamic efficiency.

Efficiency of the standard rectangular cambered otterboards was very high at small angles of attack. At angles of attack greater than about 30^{o} , heavy turbulence formed behind the otterboard and efficiency was rapidly reduced. The "high aspect ratio" cambered otterboards were more efficient at greater angles of attack and less efficient at smaller angles. This was probably due to their blunt leading edge which, while presenting a high drag frontal area, helped to maintain laminar boundary layer flow at angles between about 30^{o} and 40^{o} .

For greatest hydrodynamic efficiency, otterboards, like all hydrofoils, must be operated at subcritical angles of attack. Values of 5^{o} to 15^{o} below the critical angle would appear to be optimum in terms of hydrodynamic efficiency for the three otterboards tested. From Figure 1 it can be seen that wide-keeled rectangular flat otterboards with aspect ratios of about 0.5 would be best operated at between 30^{o} and 35^{o} to the vector of undisturbed water flow. Although angles of attack in the range of 20^{o} to 30^{o} result in very efficient hydrodynamics, spreading forces are so low that the net would probably not be held open. While increasing the area of rectangular flat otterboards and operating them at reduced angles of attack will improve hydrodynamic efficiency for a particular set of fishing gear, few fishermen would be willing to work with such large otterboards for the limited benefits gained.

When otterboards operate in contact with the bottom, the incidence of tip vortex (escape of water from the high pressure side of the wing to the low pressure side) is greatly reduced, and hydrodynamics are changed for the better with an increase in lift forces at subcritical angles of attack. Operation on the bottom produces the additional component of ground friction which the trawler must pull against. Ground friction is related to the angle of attack in a complex way depending on the design of the otterboard shoe or keel (bottom edge in contact with the substrate), characteristics of the sediments, and weight of the otterboards. Vedyeneev (in Friedman et. al., 1979) has shown that increasing the weight of otterboards brought about a rapid increase in ground friction, especially at higher angles of attack. Although ground friction was not measured in this study, the standard cambered board with the keel oriented parallel to the direction of the board movement appeared to provide the lowest ground friction of the three designs. It is likely that many otterboards in use in the industry are unnecessarily heavy and thus operate at less than optimum efficiency with respect to ground contact.

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APPENDIX I

The probabilities associated with the analyses of catch rate differences for different otterboard combinations are listed below. (Mann-Whitney U Test, Siegel, 1956).

WIDE-KEELED RECTANGULAR FLAT

VS.

STANDARD RECTANGULAR CAMBERED

CATCH RATE COMPONENT	PROBABILITY
Prawn Catch	0.963
Total By-Catch	0.232
Fish By-Catch	0.927
Non-Fish By-Catch	0.073

WIDE-KEELED RECTANGULAR FLAT

VS.

'HIGH ASPECT RATIO' CAMBERED

CATCH RATE COMPONENT	PROBABILITY
Prawn Catch	0.250
Total By-Catch	0.448
Fish By-Catch	1.000
Non-Fish By-Catch	0.520

STANDARD RECTANGULAR CAMBERED

VS.

'HIGH ASPECT RATIO' CAMBERED

CATCH RATE COMPONENT	PROBABILITY
Prawn Catch	0.798
Total By-Catch	0.366
Fish By-Catch	0.338
Non-Fish By-Catch	0.949

APPENDIX II

Mr. W. Pollard, Master of the "Gwendoline May", has provided these notes on setting up the standard cambered otterboards and the 'high aspect ratio' cambered boards.

1. The standard cambered boards were adjusted to the designers' specifications, i.e. heel was set on centre position and the spider was set 190mm or 1/3 back from the leading edge measured along the chord of the otterboard. The net was shackled level in the sixth hole from the following edge of the otterboard on all towing points.

2. The high aspect ratio cambered boards were adjusted so that the spider sat 1/3 back from the leading edge as measured along the chord of the otterboard. Heel was set 25mm below centre. The net was shackled level in the eighth hole from the following edge of the otterboard on all towing points.

3. Both board types were shot away. The standard cambered boards could not be made to submerge. They lay on their faces and kept sliding together on the surface.
The high aspect ratio cambered boards performed well for the first try. They did not break the surface but stood too upright. They looked to be stalled and would not spread the net properly. The adjustments needed were easily recognized.

4. Following several more trials, the standard cambered boards had the headline shortened by 65mm and all towing points were moved back to the fifth hole from the following edge. The spider was moved forward by 25mm.

The high aspect ratio cambered boards had the headline released a total of 90mm, and all towing points were moved back to the seventh hole from the following edge. The spider was moved forward by 25mm.

5. Both board types were shot away again. The standard cambered boards still would not work and getting them to submerge was virtually impossible. The high aspect ratio cambered boards set very well, but were still working at too high an angle of attack.

6. It was decided that the standard cambered boards would require significant changes in their settings. The heel was set 25mm below centre, the spider was set 1/3 back from the leading edge along the chord, and the headline was released 150mm. All towing points were shackled in the fifth hole from the following edge.
The towing points on the high aspect ratio otterboards were moved back to the sixth hole from the following edge.

7. Both board types were shot away and both seemed to work quite well. They were trawled on the bottom long enough to develop a polish on the shoes to indicate the next set of adjustments.

8. The standard cambered boards had all the towing points moved back to the fourth hole from the following edge, the headline was lengthened to 230mm and the groundchain was shortened by 50mm.
The high aspect ratio boards had the spider moved forward 25mm so that it was now 1/4 back from the leading edge measured along the chord. The ground chain was shortened by 65mm.

GENERAL

1. The research vessel "Gwendoline May" is 19m in length and powered by a V12 71 series G.M. of 340BHP with a 4.5:1 Omega reduction gear driving an open propeller.

2. A trawl speed of 3.3 knots was maintained with the rectangular flat otterboards with the engine runing at 1525 R.P.M. The same speed could be maintained with the cambered boards when the engine was running at 1300 R.P.M. This indicated a saving in towing power of about 15%.

3. The reduction in towing force required for the cambered boards was further supported when they were trawled at 3.3 knots against the rectangular flat boards. Trawling R.P.M. was 1375 (10% below that required for two sets of flat boards), and a rudder angle of 3° was required to compensate for the extra drag regardless of the side of the trawler that the flat boards were pulled from.

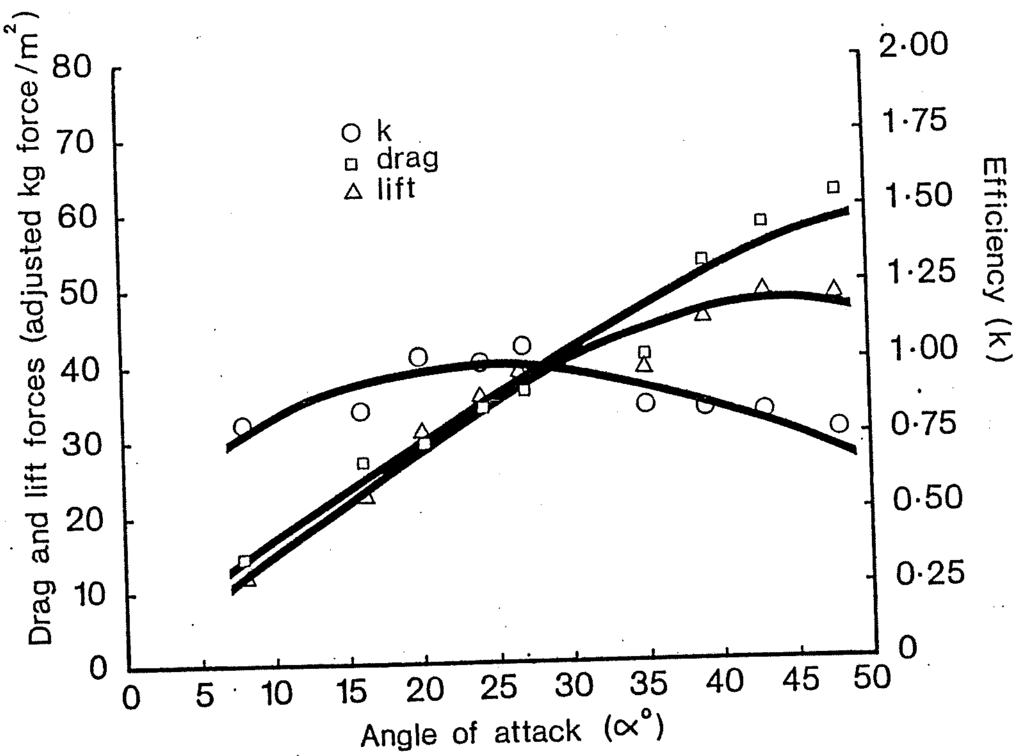

FIGURE 1 The relationships between the hydrodynamic lift forces, the drag forces, and hydrodynamic efficiency for the wide-keeled rectangular flat otterboard.

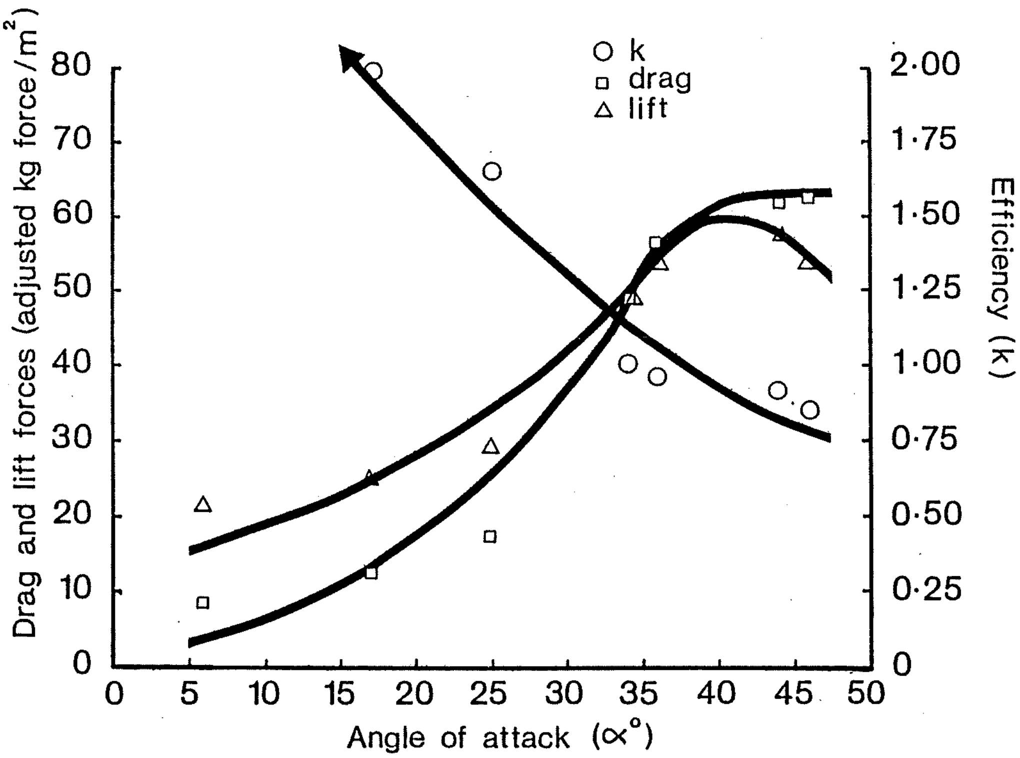

FIGURE 2 The relationships between the hydrodynamic lift forces, the drag forces, and hydrodynamic efficiency for the standard rectangular cambered otterboard.

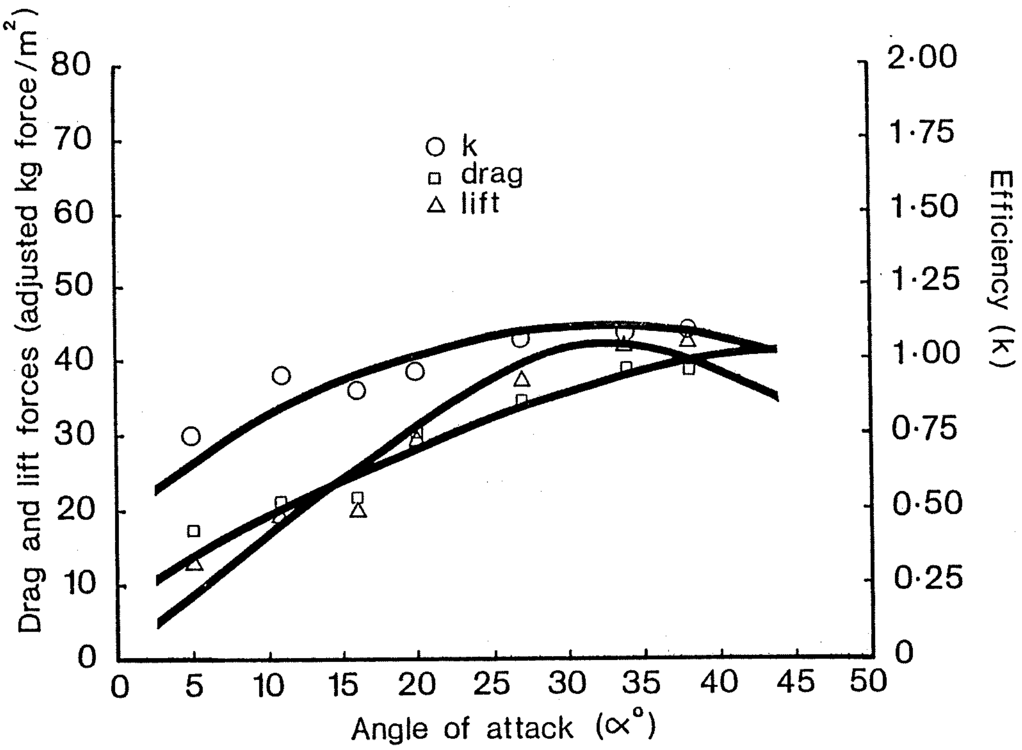

FIGURE 3 The relationship between the hydrodynamic lift forces, the drag forces, and hydrodynamic efficiency for the "high aspect ratio" cambered otterboards.