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ON DESIGN AND USE OF DUTCH TRADITIONAL CRAFT AS SAILING YACHTS

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G.Moeyes and J.W.Kooijman

Delft University of Technology
Ship Hydromechanics Laboratory
Mekelweg 2
Delft 2208
Netherlands

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by: Ir. G. Moeyes[x)]
Mr. J.W. Kooijman[xx)]

Abstract

A review of Dutch traditional inland and coastal ship types is given and their characteristic features and suitability for conversion or newbuilding as sailing yacht of today is discussed.
Finally, some results of recent hydrodynamic research on a Vollenhovese bol and a grundel are presented.

x) Delft Shipbuilding Laboratory/Seaquest B.V.
xx) Kooijman en De Vries Jachtbouw B.V.

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1. INTRODUCTION

Up till half a century ago land and water were still of equal importance in The Netherlands. Transport was mainly watertransport, on waterways of several nature, wide or narrow, deep or shallow, with ebb and flood, or flowing.
The ships of this region had to meet special and more or less contradictory requirements:

- seaworthiness on bigger lakes and coastal waters
- ability to sail in shoal waters and to ground on the banks for loading or unloading
- good windward performance in narrow waters
- big load capacity
- easy handling for a limited crew
- low building and maintenance costs

The necessity of combining these controversial demands resulted in the type of sailing vessel which we call the traditional Dutch ship, including Flemish vessels. The main characteristics of these ships are:

- shallow draught, for shoal water
- great beam, for stability
- leeboards, for windward performance
- full ends, to give sufficient displacement
- sailplan with gaff-mainsail and staysail, for economy in maintenance and handling

Of course this type was a compromise, but a compromise in which culminated the skill of skippers and builders to an almost perfect solution to fulfil its contemporary tasks. During the three hundred years from 1600 untill 1900 there was no need for significant modifications. One of the most important contributions to the development of this ship type, the "invention" of leeboards, dates already from before that time. E. van Konijnenburg [1]* could state in the 20th century that Dutch ships had not changed during the preceding three centuries.

Three groups of Dutch ships can be distinguished: cargo vessels, fishing boats and yachts. Cargo vessels and fishing boats had finally to be replaced by motorized vessels, at first with unmodified hull forms. However, traditional craft never vanished. Rebuilt, adapted or newbuilt as sailing yacht they appear to be a constantly growing part of the Dutch fleet of pleasure craft, showing a revival which is enjoyed by all those who love their shape.

*See reference at the end of the paper.

This revival is one of the reasons why in this symposium a paper is dedicated to the use and design of traditional Dutch craft as yachts. Adding the last two words to the title means that the scope of the paper is restricted. First the demands will be stipulated which have to be put to a sailing yacht. Secondly those traditional ship types will be analysed which can fulfil these demands more or less. Suitable types might be improved as a sailing yacht by careful designing, while the traditional characteristics of the concerned ship should be preserved. Section I deals with these design subjects.

Though for traditional sailing yachts speed is not a primary design objective, as it is for racing yachts, tank testing of such types is very interesting. Because of centuries of experience a traditional type is evaluated to a compromise, an equilibrium of form, dimensions and construction which may be supposed to be optimal for contemporary purposes, e.g. cargo and passenger transport and fishing. From the scientific point of view it is interesting how this optimum is realised and whether this is in agreement with modern technology. Because of this interest the Delft Shipbuilding Laboratory has included in its program the testing of two traditional types, e.g. a Vollenhovese bol and a grundel, recently designed by J.K. Gipon and built in steel by Kooijman and De Vries Jachtbouw for use as sailing yacht. With the models not only standard sail performance tests have been carried out, but also a series of systematic measurements with hull, leeboards and rudder. The results are discussed briefly in section II to contribute to a better understanding of the hydrodynamic properties of traditional ships, and thus to result in better design and more efficient use.

It must be noted that the two tested ships form only a spot in the whole region of traditional craft, with regard to size and type, and can therefore not pretend to present all aspects of the region. To get a more complete understanding of all hydrodynamic aspects additional testing of other types should be necessary.

Section I: DESIGN ASPECTS

I.1. General characteristics of Dutch traditional craft

I.1.1. Appearance of the hull

As mentioned already in the introduction Dutch traditional craft can be characterized with respect to hull form and dimensions by:

- shallow draught with flat or round bottom
- great beam-draught ratio
- heavy displacement with respect to length
- full form
- no keel, but leeboards

Some of these properties are illustrated by the data in table I, where also comparable values for modern keel yachts are given.

The heavy displacement is characterized by the length-displacement ratio and the block coefficient, which is the ratio of displacement to the product of waterline length and beam and draught. From the values in table I it appears that a traditional ship is 1½ to 2 times as heavy as a keel yacht of equal waterline length. Should waterline beam and draught be considered too, as is done in the block coefficient, then the traditional ship is about 1½ times more "full" than a keel yacht. The reason of this heavy displacement is the high constructional weight, often the need to transport cargo and, as will be explained in paragraph I.1.3., the requirement for sufficient stability.

The high prismatic coefficient indicates that the ends are not fine, but still displace a lot of water.

The high breadth-draught ratio is primarily the effect of the shallow draught. This shallow draught, and therefore the impossibility to fix a keel, has been caused by the mostly undeep Dutch coastal and inland waters. Besides, the necessity to ground a ship now and then played a more or less significant role.

Instead of a keel two leeboards give the necessary side force production for sailing to windward.

The length-breadth ratio is strongly varying, as is shown in table I, due to the widely different ships collected under "traditional craft".

In general the shorter ships, like fishing vessels or yachts, are relatively beamy to obtain sufficient stability. The longer ships were mostly cargo ships and are relatively narrower.

Some hydrodynamic aspects of hull and appendages will be discussed further in section II.

I.1.2. Appearance of rig and equipment

Visually the rig of traditional craft is characterized by:

- fore and aft rigging
- loose footed, lashed and mostly gaffed mainsail
- staysail, sometimes overlapping the main
- sometimes jib on jibboom
- possibility to decrease mainsail area by hoisting the under part of the luff (Dutch: "katten")

Usual values of sail area related to waterline length, displacement and wetted area and of centre of effort height to waterline length, are given in table I, in comparison with values for keel yachts.

The data illustrate that traditional craft has in general relatively less sail area than a keel yacht. The sail plan has a broader base and less height, so the aspect ratio of the righ is less than in the case of a keel yacht. The reason must be sought in the different stability characteristics of traditional craft and keel yacht, which will be discussed in the following paragraph. An extreme example of such a low aspect ratio sail plan is the tjalk rig, illustrated in figure 2.

Another feature of traditional rigs is the absence of vast downwind sails like spinnakers. On running courses the traditional vessel takes its advantage from a number of smaller sails like aap, waterzeil, bonnet, which are easier to handle.

I.1.3. Stability

Figure 1 shows the righting arms and moments of a 8.70 m Lemsteraak (see for an example of this ship type figure 3), which is representative for a traditional fishing vessel, of a 10 m waterline length ocean cruiser-racer and of the 12 m yacht "Columbia", as a representant of an ultimate racing keel yacht. Because these ships have very different dimensions, righting arms and moments are made non-dimensional for comparison purposes: righting arms are divided by waterline breadth and righting moments in ton meter are divided by the product of waterline length, waterline breadth squared and hull draught. In fact the moment reduced in this way is not completely non-dimensional but it is suitable for comparison of different hull forms and hull sizes. As is shown in figure 1 the righting arms of the Lemsteraak have about the same magnitude as the arms of other vessels. This is thanks to the great breadth-draught ratio of the Lemsteraak, while the ship has little or no ballast and a corresponding unfavourable high position of the centre of gravity. When also the relatively high displacement of traditional craft is taken into account, it is clear that the initial righting moments of this craft are very high (see figure 1). Together with the relatively low, small rig this will result in low heeling angles giving the impression of a stiff ship. At heeling angles of 30 to 50 degrees, however, the great beam looses its advantageous effect. Then, the righting arms of the Lemsteraak decrease, where the low ballast of the keel yachts still causes an increase in stability. This difference is characteristic for flat-bottomed craft and keel yachts. The occurrence of maximum righting moments at relatively low heeling angles restricted the height of sailplan of traditional craft, because an ample safety margin from capsizing had to be maintained for these open or partly decked vessels.

I.1.4. Sailing properties

As will be discussed in paragraph II.2. the sailing properties have some typical features, e.g.:

- a flat-bottomed type does not sail as close to windward as a keel yacht. Angles between course and true wind of 45° to 60° are usual.
- the speed in light winds is relatively low.
- because of the full forebody the added resistance in waves may be substantial and may have an adverse influence on windward performance.

I.2. Analysis of Dutch traditional craft with respect to its suitability as sailing yacht

I.2.1. General

Though another paper in this symposium will extensively deal with the demands which have to be put to any good cruising yacht, the most important points will yet be mentioned here.

These points can be classified, with regard to safety:

- sufficient stability, also at higher heeling angles
- easy manoeuvring, in all winds and waves
- good windward performance to get free from a leeshore
- possibilities for easy and quick sail handling
- sufficiently strong, stiff and watertight construction

with regard to comfort and recreational efficiency:

- ample space and standing room
- seaworthiness, with respect to easy motions and shipping of less water
- high initial stability, to restrict heeling angles
- speed, to increase action radius in cruising
- easy sail handling with a small crew

To obtain an idea about traditional craft which will be suitable as sailing yacht, available types have to be analysed with respect to the foregoing demands. Table II gives an enumeration of well known Dutch boats of the 19th and 20th century. The list is not complete, because bigger ships like blazer, zeetjalk, klipper, Groninger tjalk have been omitted. At first sight they are not suitable as a yacht because of their dimensions and corresponding high costs of building and operation. Other types which have been developed for a very special purpose or region, like somp, waterschip, trekschuit, have neither been mentioned. In Table II a division has been made according to the destination of the boat as cargo vessel, fishing boat or yacht. Each group has features which makes it more or less suitable for conversion of redesigning as a nowadays yacht. Cargo vessels for instance had the mast placed more forward than fishing boats or yachts. They were longer, had fuller ends and a lower sailplan. Fishing boats had a rather high bow and a low stern, to handle the nets. Yachts had a higher mast and more sail area. In the following paragraphs the features will be discussed of different groups and types and the degree to which they fulfil the mentioned demands.

I.2.2. Aspects of hull form

With regard to hull form the following features might be distinguished, apart from hydrostatic data:

- length-breadth ratio
- midship section with bottom width
- contours of bottom and sheerline
- forebody shape with stem form
- afterbody shape with stern form

Length-breadth ratio is widely varying among traditional craft. Cargo vessels, which need a long length for load capacity but which breadth can not grow proportionally, have in general large length-breadth ratios. Examples are tjalk (figure 2), klipper and praam. Fishing boats and yachts, which do not need length in doing their job, need breadth for stability, to carry the required sail area. They have smaller length-breadth ratios. In principle slender ships go better to windward in shorter waves, but are more different in manoeuvring, which is an important point in nowadays busy waterways and yacht harbours. A long ship like a tjalk gives ample opportunities to design a spacious accommodation with separated cabins and saloons. However, because of its relatively small depth-length ratio a certain minimum length is necessary to create standing room, unless an ugly high superstructure will be created. Furthermore a great length increases costs of building, insurance, harbour, maintenance, etc. So, in the authors' opinion a small length-breadth ratio meets on the average better the demands of paragraph I.2.1.

The position and shape of the midship section is very characteristic for a certain type, but has more strict design consequences. Van Loon [2] states that the best longitudinal position of midship section is 8/20 of the ships' length behind the stem. This rigid statement has not yet been justified. Anyhow the position of midship section is related to the distribution of displacement over the ship length. A full forebody and slender afterbody will tend to a relatively forward position of midship section. Influences of displacement distribution will be discussed later in this paragraph.

At first, midship section forms can be divided in round bottom and flat bottom types. Examples are respectively Lemsteraak (figure 3) and botter (figure 4). The flat or round shape in itself does not give principal differences in design.

The possibility to construct with a thick flat bottom plate a smooth, frameless cabin floor with more standing room above it, can be created in many "flat" round bottom vessels too. However, building costs of steel flat-bottomed boats will be lower, especially when the sides can be composed of flat plates.

Whatever its main form may be, the midship section can have the wide bottom, firm bilges and nearly vertical sides of the poon (figure 5) and the tjalk, or the narrow bottom and considerably flaring sides of the pluut (figure 6) or schokker. The wide bottom form, with its great waterline breadth and high breadth-draught ratio, gives more initial stability than the narrow bottom form when displacement is equal. The last one, with more constructional weight at a deeper draught, might give a lower centre of gravity and consequently more stability at higher heeling angles.

The shape of midship section influences interior design too. The narrow bottom shape gives generally a greater depth and consequently more standing room. When the ship is so big that standing room is no problem a wide flat bottom might provide more possibilities in cabin lay-out and construction.

The contour shape of bottom line and sheerline are not only decisive on silhouette and appearance of the ship. The bottom line contour is related to form of fore- and afterbody, which influence will be discussed hereafter. However, a bottom line with much rocker gives generally more draught and depth amidships and consequently more standing room than a nearly straight or horizontal bottom line. This aspect gives advantages to schouw, grundel (figure 9) etc. above hengst (figure 8), hoogaars (figure 11), and the like. A disadvantage of the excessive rocker of a schouw, however, is the decreased accessibility and space in the fore-peak.

Some ships have a sheerline which is almost horizontal (see tjalk and boeier in figures 2 and 7). Some have a sheerline with a very high bow and a low stern (see the botter in figure 4). The botter is beautifully designed for its use as a fishing boat, with its low afterbody to handle the nets and its higher forebody to keep this dry. Unmodified however, the botter would make a poor yacht. The additional weight of cabin, motor and crew will lower the fine afterbody and rise the bow, causing the danger of too little freeboard aft and too little outlook forward for the helmsman. Thus boeier and tjalk seem a better choice for cruising and manoeuvring than the unmodified botter, though their low foredecks will ship more water in waves of vast open waters.

A good compromise might be found in fishing boat types like bol, schouw, Lemsteraak or pluut, or all purpose vessels like grundel, poon or Zeeuwse boeier.

The <u>form of fore- and afterbody</u> is generally related to the midship section shape. The wide bottomed midship section, which mostly belongs to cargo vessels, is normally extended in full fore- and afterbodies with U-form sections and rather steep stem and stern contours. These full forebodies provide ample interior space, but can give high added resistance and a wet ship in waves. On the contrary, the relatively finer, flared forebodies with overhanging stem of pluut, grundel and schokker might give better seegoing qualities, e.g. less resistance, a dry ship and easier motions.
The afterbody form does not only depend upon midship section shape but also upon stern arrangement. The canoe body with stern post of botter, pluut, hengst, schokker, etc. gives finer and narrower waterlines and less displacement aft than the stransom stern of the grundel. When a traditional ship will be used as nowadays sailing yacht there will be a concentration of weights in the afterpart: a heavy motor, a mass of equipment under the cockpit floor and benches, heavy cabin interior and carpentry and a sometimes numerous pleasure crew in the cockpit. This requires more displacement aft and a corresponding aftward position of the centre of buoyancy to maintain the proper trim, compared with the days when the ship was only arranged for its fishing or transport job. Ships with relatively fuller afterbodies like Lemsteraak, bol and with transom sterns like grundel, are therefore principally more suitable for conversion or redesigning as a sailing yacht than fine-tailed types like botter or hengst. It is obvious, that these aspects are most important for smaller ships, because crew and equipment weights with its adverse effects on trim are then relatively high.

In the past much attention has been paid by builders to the afterbody shape because of its influence on speed. In general it was believed that the finer should be the better, which is in contradiction with the requirements discussed above. Though no special towing tank research has been done to afterbody shape of traditional craft, it might be stated that earlier thoughts on its fineness were based on avoiding flow separation. With the full hull forms of traditional craft the flow separation point should be shifted as far aft as possible to avoid excessive pressure resistance. Smooth, faired water- and/or buttock lines are advantageous to this and not the fineness of the afterbody in itself, as may be believed by some designers.

It is probably because of the reasons mentioned above that the substitution of the original afterbody of hengst and hoogaars by the Lemsteraak afterbody was reported to give an improvement in speed [3]. The resulting types, called Lemmerhengst and Lemmerhoogaars, were the fastest to bring the fish to the Antwerp market.

I.2.3. Aspects of appendages

The leeboard is no Dutch privilege, but it is such a general phenomenon in the fleet of Dutch traditional ships that it is one of the most characteristic details of this category. Only one type, the Staverse jol, has no leeboards, but a long keel. Three kinds of leeboards can be distinguished:

1) the leeboards of tjalk and boeier: short, broad and flat, plank made
2) the leeboard of Zeeland, shaped more or less between 1)and 3)
3) the leeboard of the Zuiderzee fishing boats: long, narrow and modelled to the shape of an aeroplane wing, the most advanced of the three

As will be discussed in paragraph II.1.2. leeboard 3 is the most efficient to prevent the ship from drifting. It has the possibility to be put in optimal position at each side of the ship. Though leeboard nr. 3 is the best for sailing, it may be necessary to choose leeboard 1 or 2, when the yacht has usually to sail in shallow waters.

The rudder plays an important role in the hydrodynamic system of the boat. Dutch boats invariably have the rudder behind the stern. Various models and constructions are in use. Two types are shown in figures 2 and 11, namely the rudder of a tjalk and of a hoogaars. Two remarks can be made. At first: the hoogaarsrudder is deeper than the ship. Motives for a so called "fishing rudder" can be more effectiveness in manoeuvring and better windward performance (see also paragraph II.1.3.). Secondly: the rudder post of the tjalk is almost vertical while the rudder post of the hoogaars shows a considerable rake. From a resistance point of view the tjalk system is the best one because it merely pushes the water aside. The hoogaars rudder pushes the water upward too, causing unnecessary resistance and hence unnecessary speed loss, especially when the ship goes about.

I.2.4. Aspect of the sailplan

The sailplan gets roughly its character from two aspects: height and mast position. The base length of the sailplan is generally determined by the ship length.

The height of the sailplan determines not only the sail area, but the aspect ratio of main- and foresails too. Yachts like boeiers (figure 7), Frisian yachts and tjotters, which were intended to sail fast, had very high sailplans for which the necessary stability was provided by a great beam. This height gave their sails a relatively high aspect ratio which improved the performance to windward. However, these ships with huge sailplans had to be sailed carefully and by strong hands because of the increased chance of capsizing, which does not make them always suitable for the cruising family. The sailplans of moderate height of fishing boats like Lemsteraak (figure 3), botter (figure 4), bol (figure 10) or pluut (figure 6) should then provide a better answer to combined demands of performance and manageability. On running courses the sail area of these ships can be enlarged by a number of additional sails (see figure 4).

Table III gives a classification of ships with respect to the longitudinal position of the mast, which is decisive for the distribution of sail area over mainsail and foresails. An extremely forward position which was necessary to obtain a long unrestricted cargo hold in for instance a tjalk (figure 2) or grundel (figure 9), gives a vast mainsail with a low aspect ratio and a small, high staysail. Though the high aspect ratio staysail forms a good leading edge and might improve the flow along the leeside of the main, the low aspect ratio of this mainsail, on the contrary, is worse for sailing to windward. Besides, the mainsail on the long boom asks for a considerable amount of weather helm on running courses and requires strong men to handle it.
A more aftward mast position offers more advantages for use on sailing yachts. The concerning higher aspect ratio of the mainsail and the greater area of the relatively very effective staysail promises a better performance to windward, while the balance on running courses can better be maintained. Van Loon [2] states that with respect to sailing qualities the best mast position will be 7/20th of the ship's length behind the stem.

I.2.5. Aspects of rigging and outfit

It would be a mistake to draw too much attention to the hullshape. Such a mistake has been made by F.N. van Loon [2] , who concentrates his attempts to design a better and faster Dutch ship on hull shape. To his opinion the rigging of Dutch boats had no need of improvement. Nowadays we know better. But let us be careful. Improvements are limited by the character of the ship. No alterations may be made which might harm this character. So, features of rigging and equipment which have to be maintained are for instance:

- the loose footed mainsail with the standing clothes
- the lashes to attach the mainsail to the mast
- the bending reef
- the gaff
- the mainsail sheet on a horse

etcetera

These features have been developed in the search for ease in handling and maintenance and therefore classify the ship as a cruising vessel.

There is no reason why the rules of yachtdesign should be neglected in such a way as it is sometimes done nowadays. Many a Dutch yacht is fixed with such heavy equipment that one cannot expect this ship to show good sailing performance. Engines, batteries, refrigerators, watertanks of 1000 litres and more, furniture, teak decks, woodcarving, central heating, battery chargers, and so on encroach upon the wanted sailing properties.
On top of this often comes the neglection of hydrodynamic and aerodynamic aspects. The sails for instance have much camber. How much is necessary? Nobody seems to care. The sheeting point of the foresail is unvariably at the deck's side. Why not considering the optimal sheeting angle, which may be different for various types of ships?
It is not difficult to put other more or less equivalent questions forward. They clarify that the sailing performance of the average Dutch yacht can be improved in a rather simple way without doing harm to its specific character. An alteration which would to everybody's opinion harm the ship's character would be the introduction of a spinnaker, though it would improve the downwind performance.

Section II: HYDRODYNAMIC AND SAILING PERFORMANCE

II.1. Hydrodynamics

II.1.1. General

For a hydrodynamic description the wetted part of the ship can be considered to consist of three items, e.g.

1) hull with all fixed appendages
2) movable rudder, behind the hull and mostly behind a skeg with propeller aperture
3) hoistable leeboards

Each item has resistance and generates a certain side force when it has been given an angle of incidence to the flow.

In downwind or running conditions the resistance determines the forward speed. When sailing to windward the sideward component of the sail force must be counteracted by a hydrodynamic side force. In that condition both resistance and side force production are important.

When all three parts, hull, rudder and leeboard are added, it may be assumed that the properties of the total system are not equal to the sum of properties of all components. The difference is due to what is called interference and may be positive or negative. In the following paragraphs the hydrodynamic characteristics of the three mentioned items and interference effects are briefly discussed. For a more detailed description the reader is referred to [4], which is to be published in the near future. The experimental data have been obtained with models of a grundel [5] and Vollenhovese bol [6], which main particulars are given in table IV.

II.1.2. Hydrodynamics of the single leeboard

Three leeboards have been tested, which particulars are given in table V. The low aspect ratio leeboard I can be seen on inland ships like tjalk, grundel and boeier (see also par. I.2.3 and figure 12), the highest aspect ratio leeboard III is typical for the Zuiderzee. Leeboard II resembles the moderate aspect ratio leeboards of Zeeland (see paragraph I.2.3),though they had in practice less camber than the tested specimen. With all leeboards, running in the towing tank separated from the hull, side force and resistance are measured with variable angle of incidence, speed and, for leeboard III, heeling angle and sweep angle.

When no lift (side force) is generated the resistance of the leeboard consists only of frictional and wave-making resistance. In this zero-lift condition wave-making resistance is relatively small with respect to frictional resistance, which is in its turn small compared to hull resistance. Therefore profile drag of leeboards can be approximated by frictional resistance for design purposes.

In figure 13 lift coefficients of all leeboards are given. Although the test speeds of leeboard I differ from those of II and III it can be remarked that the lift slope increases with increasing aspect ratio, which is in agreement with wing theory.

The influence of speed on lift curve slope depends upon aspect ratio. At the high aspect ratio leeboard III only a small decrease of side force with increasing speed could be observed. From figure 13 it can be seen that with the low aspect ratio leeboard I a speed increase results in a considerable decrease in lift curve slope. This will be caused by the wave formation due to the pressure field around the leeboard. At the low aspect ratio leeboard I this pressure field is relatively close to the free water surface and creates therefore corresponding high waves alongside the leeboard. A deep wave trough has the effect of a virtual decrease in lateral area and aspect ratio and thus gives a decrease of lift curve slope. At the high aspect ratio leeboard III wave formation is less serious and therefore less dependent on speed because the concerning pressure field is relatively deeper under the water surface, while the intersection with the surface is smaller.

Furthermore, in figure 13 the zero-lift angle should be noted for the significantly cambered leeboards II and III.

When the leeboard is hoisted or swept around a point at a fixed distance above the water surface, the side force rapidly decreases (figure 14), due to both a decrease in laterial area and aspect ratio. In sailing practice this means that the leeboard should be as vertical as possible when a large side force is needed on windward courses. Reaching and running the need for side force decreases and so the leeboard can be gradually hoisted. An additional advantage of this partially hoisted leeboard is its favourable effect on weather helm. For broad, undeep leeboards like leeboard I these effects are less pronounced.

In figure 15 the drag coefficients are plotted versus lift coefficients. These curves are considered to be a criterion for the effectiveness of a wing. The faster the increase of drag coefficient at a certain increase of lift coefficient, the worse the wing effectiveness is. From wing theory it is known that effectiveness increases with aspect ratio. This tendency is fully confirmed by the curves in figure 15.

When lift and drag characteristics (figure 13 and 15) will be compared with equivalent characteristics of usual keels or keel-hull-rudder configurations the leeboard in itself appears to be a more effective side force generator. Its lift curve is steeper while drag characteristics are more favourable. However, the leeboard has to be combined with the hull, which has less favourable characteristics according to paragraph II.1.4.

II.1.3. Hydrodynamics of the rudder

The rudder has not been investigated separated from the hull, but forces and moments have been measured when the rudder was behind the hull, set at different angles.

With zero rudder angle the rudder will hardly generate waves, so the profile resistance will mainly consist of frictional resistance. Because of the small wetted surface it is supposed to be low with respect to hull resistance.

The side force of the grundel rudder is shown in figure 16 with 0 and 5 degrees leeway of the hull. In both cases the slope of the curve is the same, while the vertical distance between the curves is fairly equal to the rudder force at 5 degrees rudder angle. This indicates that the leeway angle of the hull does not influence rudder force. When the centre of effort of the side force is calculated from the measured moment and force value, it appears to be at the forward half of the rudder. The same phenomena were observed at the Vollenhovese bol. Apparently the considered typical rudder on a traditional flat bottomed vessel may be supposed to work independent of the hull. It does not influence the pressure field around the afterbody or the skeg, probably because of screw aperture and partly raised bottom. So, with wing theory it can easily be explained that the deeper "fishing" rudder of the hoogaars is more effective than the broad tjalk rudder because of its higher aspect ratio.

The rudder force turned out to be proportional to the speed squared, which again is in agreement with wing theory.

When the slope of the side force coefficients of the rudder is compared with corresponding values for the leeboards (see figure 13) it is demonstrated that the effective aspect ratio of the rudder is less.

In figure 17 is shown the resistance of the hull-rudder combination of the grundel, when the hull has no heel or leeway, but when the rudder has certain angles. It should be remarked that a rudder angle of about 30 degrees, nearly doubles the total resistance compared to a zero rudder angle. When the induced drag coefficients of the rudder are calculated its values show that the rudder is less effective than the leeboards with higher aspect ratios.

II.1.4. <u>Hydrodynamics of the hull</u>

Contrary to rudder and leeboard the normal resistance of the hull without heel or leeway, which may be called "profile drag" is not small compared to its induced drag. This is not only due to the large wetted area, which increases the frictional resistance, but also due to the substantial wavemaking resistance at higher speed. Figure 18 shows the total resistance of grundel and Vollenhovese bol, both upright, with the leeboard hoisted above the water and with the rudder amidships. The frictional resistance, as it has been estimated with the ITTC-extrapolation method is also given. For comparison a keel yacht of about equal waterline length has been selected and its total resistance has been plotted in figure 18. The reason of the difference in resistance between keel yacht and traditional craft is clear when the resistance per ton displacement at given Froude numbers is determined and compared to each other. These values in table VI have the same order of magnitude, which indicates that the difference in total resistance is mainly due to the relatively higher displacement of the traditional craft. As has been said in paragraphs I.1. this high displacement has design, construction and stability reasons. Consequently, the relatively high resistance of traditional craft is characteristic for this type. How the high total resistance of traditional craft effects the sailing performance will be illustrated in paragraphs II.2.

For a further analysis the residuary resistance, which consists mainly of wavemaking resistance, is calculated with the ITTC-extrapolation method, and given in table VI.

The low values of the keel yacht in the middle speed range, compared to the traditional yachts, indicate that this ship has more favourable wavemaking properties. However, due to its higher wetted area-displacement ratio its frictional resistance per ton hull displacement is higher and compensates for the advantage in residuary resistance, as has been shown by the values of total resistance in table VI.

Though the hull form does not remind of a wing it has its principal characteristics. When the hull is given an angle of incidence, a leeway angle, it generates a side force, as is shown in figure 19 for the hull-rudder combination of the Vollenhovese bol under 15° keel. However,the slope of the side force curve is rather low. When the side force coefficients are calculated the slope of this curve indicates a very low effective aspect ratio (figure 13).

It should be remarked that the side force curve does not pass through the origin, so a "zero-lift" angle exists. This is caused by the asymmetry of the hull when it heels and which gives it the properties of a cambered wing. Unfortunately the concerning side force acts in the wrong direction, to the leeward side of the ship.

When the centre of effort of the side force is determined from moment and force measurements, it appears to be at about ¼ of the waterline length from the fore perpendicular.

Some types of traditional craft have a short, fairly deep, skeg under the forebody, aft of the fore perpendicular, which is called "loefbijter". To investigate the influence of such a "loefbijter" the hull of the Vollenhovese bol was tested with it. Figure 19 shows that the side force production of the hull-rudder combination is about doubled, after the "loefbijter" has been fixed. Though the lateral area of a "loefbijter" is small compared to hull and rudder, its position in an undisturbed flow and its rather high aspect ratio make it very effective. The centre of effort of the side force shifted forward over a distance of about 4% of the waterline length after fixing the "loefbijter", so it can also be used to correct the balance of the ship.

The small side forces of the hull too are produced at the cost of induced resistance. When side force and induced drag are expressed in non-dimensional coefficients it appears that the hull is far less effective as a side force producer than rudder and leeboards, which is in agreement with its very low aspect ratio.

II.1.5. Hydrodynamics of the total system

In the preceeding paragraphs the side force production and resistance of separated leeboard and hull-rudder combination have been described. When the leeboard is fixed to the hull it can be expected that the properties of the total system, with which we have to sail, differ from the sum of properties of components. It is assumed that the leeboard will have a negligeable influence on the side force of the hull itself because this component is mainly generated by the forebody and the "loefbijter". The position of the leeboard is far aft of this point. The same assumption is made for the mutual influence of rudder and leeboard, so only the influence of hull on leeboard remains as interference effect. Without going into details, for which is referred to [4], it can at first be said that the zero-lift angle of the leeboard increases due to the local direction of flow around the hull. This increase, which can amount to some degrees, has a favourable effect on side force production. Secondly the flow around the hull, e.g. local water velocity and wave formation, affects the lift curve slope of the leeboard in an extent which depends upon its aspect ratio. The deep, narrow leeboard, with the high aspect ratio, operates relatively far from hull and water surface and is therefore less susceptable to hull and speed influences. When leeboard III was fixed to the Vollenhovese bol model an increase in lift curve slope of roughly 10% could be observed, which was not significantly depending upon speed. Because this change means an increase in side force it can be called a positive interference effect. In the case of the broader, low aspect ratio leeboard I of the grundel interference effects are strongly dependent upon speed, because the leeboard position is relatively closer to hull and water surface. At low speeds a decrease in lift curve slope up to about 25% could be derived when the leeboard was fixed to the hull instead of running free. At increasing speed this unfavourable change rapidly decreased in magnitude and finally turned into an increase of lift curve slope up to 50% at high speed. In terms of sailing to windward this means that it is safer to sail too fast than too slow when the optimum can not exactly be found. Pinching with traditional yachts will be disastrous for performance to windward.

II.2. Sailing performance

II.2.1. General

In the Delft Shipbuilding Laboratory standard performance tests have been carried out with the models of grundel and Vollenhovese bol. The rudder is then set in the centre line position. The grundel is fitted with leeboard I at a toe-in angle of 3.5°. The Vollenhovese bol is fitted with leeboard III at 1.5° and 6° toe-in angle and with leeboard II at 1.5° toe-in angle.

II.2.2. Downwind performance

From resistance measurements in the upright condition, with zero leeway and leeboard hoisted, the downwind speed can be calculated, assuming that no rudder angle is necessary to keep the ship on that course. The driving force is then equal to the measured resistance. Furthermore the rig downwind is supposed to consist of mainsail and staysail boomed to luff. The resistance coefficient of the rig is assumed to be 1.2. The downwind speed curves in fig. 20 are obtained in this way. Though the grundel is shorter than the Vollenhovese bol she nearly reaches the same speed in medium winds. In light and heavy weather her speed will be less. When the different waterline lengths are taken into account by comparing downwind speed non-dimensionalized as a Froude number (see table VII) both ships are close together, with the grundel at the better side of the balance.

II.2.3. Performance to windward

The optimum speed-made-good to windward can be derived from measurements of side force and resistance at several heeling angles, speeds and leeway angles. For the calculation a method is used which has been developed by Davidson [7] and which uses his Gimcrack-sailcoefficients. The Gimcrack was a 5.5 m keel yacht with Bermudan rig, so it may be doubted whether these coefficients are valid for the highly cambered sails of flat-bottomed craft. Though the use of the Gimcrack coefficients for this ship type might result in not completely realistic performance predictions, they are supposed to be useful for comparison purposes. The speed-made-good of all tested ships is shown in figure 21. At medium and higher wind speeds the grundel is faster to windward than the Vollenhovese bol. When the shorter waterline length is taken into account in the comparison (see table VII), the grundel is even more better.

The reason of this difference must be found in the resistance curves and the relatively higher stability of the grundel.

In figure 21 are also given some points calculated from measurements with other toe-in angles. As calculated, the influence on speed-made-good is not significant, but the concerned leeway angle decreases rapidly when the toe-in angle increases. In the Davidson/Gimcrack performance prediction method the influence of leeway upon sail coefficients or apparent wind angle is not taken into account, so the insensibility of speed-made-good to toe-in angle is probably not realistic. It may be expected that in reality the smaller leeway angle resulting from the larger toe-in angle, may have some advantage, especially when at higher wind speeds a larger side force is required.

II.2.4. Influence of rudder angle and toe-in angle on sailing performance

The total side force which is required when sailing to windward can be generated by hull, rudder and leeboard with numerous combinations of leeway angle, rudder angle and toe-in angle. As an example the contributions to total side force of hull, rudder and leeboard for a 7 m/s true wind at toe-in angles of zero and six degrees are given in figure 22. Values of rudder angle and leeway angle which are then necessary to obtain the total prescribed side force are indicated along the horizontal axis. From the data which are discussed in the foregoing chapter the amount of induced drag involved in generating a certain side force is calculated for each item and plotted in figure 22. Because hull, rudder and leeboard are not equally effective side force producers the total induced drag shows a minimum, which will not be far from the point of maximum speed-made-good (optimum performance) to windward. General rules for arriving at an optimum, in trimming the ship, can not be given. They depend upon the relative efficiency of hull, rudder and leeboard, that will say upon ship type, and upon wind conditions. However, from figure 22 it is obvious that the contribution of less effective side force producers like rudder and, in a more serious degree, the hull, shall be restricted. In average conditions this might be obtained with toe-in angles of about 2 to 4 degrees and rudder angles of about 5 degrees.

From figure 23, where leeway angles are shown as a function of rudder and toe-in angle, some idea about the interrelations of these parameters can be obtained, for the case the ship has to be trimmed. With regard to this the important longitudinal position of the centre of effort of the total side force is given too in figure 23. It is demonstrated that rudder angle has a large influence on this position, and thus on trim. The influence of toe-in angle is less because the leeboard is not so far from amidships as the rudder.

CONCLUDING REMARKS

1. General

The naval architect who has to design a Dutch traditional yacht will have to solve three problems:

a) choice of the appropriate type
b) maintaining in his design the character of the chosen type
c) giving the chosen type a design, construction and equipment as good as possible for its use as sailing yacht nowadays

2. Choice of the appropriate type

If we try to find the best compromise, thinking of the benefits and disadvantages of the various types, we once again have to face the classification in three groups, cargo vessels, fishing boats and yachts. If the proprietor wants a very spacious accommodation, the designer may do wise to chose a cargo vessel, for instance the tjalk. If seaworthiness is a main goal a fishing boat seems to be the best. If sailing performance has to be as good as possible the group of the yachts comes into view.

Once having established the initial choice between the three groups there still has to be decided on the exact type of this group. In table VIII an enumeration is given of types in two categories, which are less suitable respectively more suitable for use as a sailing yacht.

3. Maintaining the character of the type

It is the opinion of the "Stichting Stamboek Ronde- en Platbodemjachten", (a foundation which tries to preserve, restore and classify traditional craft) not only that the main characteristics of the Dutch vessels must be maintained (no keels, no spinnakers etc) but that the differences between the various types must be maintained too.

For many reasons this opinion can be accepted as the right one. A botter must be a botter and a tjalk a tjalk. Though, minor adjustments may be tolerable. See the examples of the Lemmerhoogaars and the Lemmerhengst referred to in par. I.2.3.

4. Design improvements

Improvements of a certain type are tolerable and desirable, alterations are essentially not. To underline this statement two general remarks can be made:

First of all: In a new design the balance between the two main purposes sailing and cruising can better be fulfilled than in a converted barge. The old barges had other goals, sailing and cargoing or sailing and fishing. Converting such a boat will often harm the perfect balance it had before. Dr. T. Huitema, Secretary of the "Stichting Stamboek Ronde- en Platbodemjachten" complains in one of his circular letters "another tjalk afloat, but they ruined the boat". It can be stated therefore that in most cases a new design is fundamentally a more original Dutch boat than a converted one can be, provided that the design is completed in accordance with all those particulars which establish a Dutch boat, as discussed before.

Secondly: The old Dutch boats, beautiful products of nautical history are worth to be preserved. Preserving the way of sailing which is specific for such a boat is of equal importance. The skill and knowledge to do so is an achievement of cultural value, worth to be kept alive. Either old or newly built all the Dutch boats with proper sailing capacities can serve this purpose. No doubt that the newly built someday will outnumber the old ones and that the performance of these boats will be one of the conditions for the survival of this way of sailing.

If we contribute to the improvement of the design of Dutch yachts we are contributing to a living phenomenon of recreational activity. Not the uncritical imitation is serving this goal, but critical and careful boatbuilding and designing. The results of hydrodynamic and hydrostatic calculations and tests, as mentioned in Section II, may be helpful in this respect.

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Table I:

Main particulars of flat bottomed and keel yachts

variable	average values for flat bottom	keel
length-breadth ratio (L_{WL}/B_{WL})	2.2 - 4.5	3.0 - 4.5
breadth-draught ratio of hull (B_{WL}/T_H)	4.5 - 6.5	3.5 - 5.5
length-displacement ratio ($L_{WL}/\nabla_H^{1/3}$)	3.6 - 4.2	4.6 - 6.0
block coefficient hull (C_{B_H})	0.48-0.60	0.31-0.41
prismatic coefficient hull (C_{P_H})	0.58-0.72	0.52-0.58
relative length centre of buoyancy (LCB_H/L_{WL})	0 - 6%	(-2) - (-5)%
wetted area-displacement ratio ($\sqrt{S}/\nabla^{1/3}$)	2.4 - 2.8	2.6 - 2.9
sail area-displacement ratio ($\sqrt{SA_{eb}}/\nabla^{1/3}$)	2.5 - 3.5	3.5 - 4.5
sail area-length ratio ($\sqrt{SA_{eb}}/L_{WL}$)	0.70-0.86	0.75-0.90
height centre of effort - length ratio (Z_{CE}/L_{WL})	0.50-0.65	0.55-0.73

Table II:

Dutch boats of the 19th and 20th century which may be used as a yacht nowadays.

fishing boats	cargo vessels	yachts
Zeeland and southern part of Holland		
boeieraak	Hollandse aak	Dordtse boeier (1)
Bruinisser yacht	Hollandse tjalk	Zeeuwse boeier (1)
hengst	klipper	
hoogaars	poon	
Zeeuwse schouw	Zeeuwse schouw	
zalmschouw		
Friesland and northern part of Holland and The Netherlands		
bol	Friese tjalk	Friese boeier
bons	Groninger tjalk	Friese schouw
botter	praam	Friese tjotter
Lemsteraak	snik	Fries jacht
pluut		grundel (1)
schokker		punter (1)
Staverse jol		statenjacht (2)
Wieringeraak		
zeeschouw		

(1) These boats, classified as yachts may better be called "all purpose boats", which were used for cargo and passenger transport as well as for pleasure sailing.

(2) Does not exist any more, but recently some examples have been discovered existing in the 19th century (See "Amsterdam gefotografeerd 1869-1905" by Jacob Olie).

Table III:

Review of types with respect to mast position

extremely forward	moderate	more aft
tjalk	hengst	botter
snik	hoogaars	schokker
grundel	bol	Lemsteraak
punter		boeier
Zeeuwse schouw (cargo vessel)		

Table IV:

Particulars of tested boats

	Voll. bol	grundel
length over all	8.50 m	8.00 m
waterline length	7.00 m	6.53 m
maximum breadth of hull	2.90 m	2.80 m
waterline breadth	2.60 m	2.42 m
maximum hull draught	0.58 m	0.48 m
hull displacement	5611 kg	4144 kg
total displacement	5680 kg	4222 kg
long. position centre of buoyancy	+0.166 m (1)	-0.066 m (1)
prismatic coefficient of hull	0.69	0.677
length-displacement ratio	3.94	4.07
relative length centre of buoyancy	+2.37 %	-1.01 %
breadth-draught ratio	4.48	5.03
total wetted area	20.9 m^2	17.26 m^2
vertical position centre of gravity above waterline	0.20 m	0.20 m
effective sail area beating	32.8 m^2	26.4 m^2
effective sail area downwind	34.4 m^2	27.7 m^2
effective centre of effort above waterline	4.28 m	3.64 m

(1) + is before mid waterline length, - is behind mid waterline length

Table V:

Particulars of tested model leeboards

leeboard	I	II	III
total depth	0.465 m	0.552 m	0.552 m
draught	0.273 m	0.339 m	0.339 m
maximum chord x)	0.194 m	0.113 m	0.170 m
average chord x) of wetted part	0.163 m	0.146 m	0.098 m
geometric aspect ratio of wetted part	1.68	2.32	3.48
cambered	no	yes	yes

x) chord is often referred to as breadth

Table VI:

Resistance per ton hull displacement

Fn	grundel		Voll. bol		keel yacht	
	R_R/Δ_H kg/ton	R_T/Δ_H kg/ton	R_R/Δ_H kg/ton	R_T/Δ_H kg/ton	R_R/Δ_H kg/ton	R_T/Δ_H kg/ton
0.15	0.7	1.8	-	-	-	-
0.20	1.3	3.1	1.1	2.5	1.0	3.7
0.25	2.7	5.5	2.3	4.6	2.1	6.1
0.30	6.0	9.8	6.5	9.5	3.7	9.2
0.35	12.6	17.6	13.6	17.7	8.1	15.4
0.40	22.7	29.1	24.5	29.6	21.8	31.4
0.45	45.3	53.3	46.2	-	53.1	65.0

$Fn = \frac{V}{\sqrt{gL_{TWL}}}$: Froude number

V = speed in m/s

g = 9.81: gravity acceleration in m/s^2

L_{TWL} = test waterline length in m

R_R = residuary resistance

R_T = total resistance

Table VII:

Sailing performance

V_{tw}		grundel	Voll. bol	keel yacht
3.5	V_d	1.37	1.47	1.89 (3)
	$V_d/\sqrt{gL_{TWL}}$	0.171	0.177	0.226
	V_{mg}	1.20	1.23	1.60
	$V_{mg}/\sqrt{gL_{TWL}}$	0.150	0.149	0.192
	V_s	1.64	1.87	2.20
	$V_s/\sqrt{gL_{TWL}}$	0.205	0.226	0.264
	ϕ	4.9	6.1	9.2
	β	2.6(1)	-	3.0
7.0	V_d	2.44	2.48	3.25 (3)
	$V_d/\sqrt{gL_{TWL}}$	0.304	0.299	0.389
	V_{mg}	1.84	1.88	2.24
	$V_{mg}/\sqrt{gL_{TWL}}$	0.230	0.226	0.268
	V_s	2.41	2.44	2.76
	$V_s/\sqrt{gL_{TWL}}$	0.301	0.294	0.331
	ϕ	12.2	14.4	21.8
	β	4.0 (1)	5.2 (2)	4.8
10.0	V_d	3.06	3.08	3.82 (3)
	$V_d/\sqrt{gL_{TWL}}$	0.382	0.372	0.458
	V_{mg}	2.13	2.04	2.33
	$V_{mg}/\sqrt{gL_{TWL}}$	0.266	0.246	0.279
	V_s	2.76	2.88	2.78
	$V_s/\sqrt{gL_{TWL}}$	0.345	0.347	0.333
	ϕ	19.0	22.6	30.3
	β	4.3 (1)	5.4 (2)	7.7

(1) : with toe-in angle of 3.5 degr.

(2) : with toe-in angle of 1.5 degr.

(3) : with spinnaker

continued

Table VII (continued)

V_{tW} : true wind speed, in m/s

V_d : downwind speed, in m/s

V_{mg} : speed-made-good to windward, in m/s

V_s : ship speed, sailing to windward, in m/s

ϕ : heeling angle, sailing to windward, in degr.

β : leeway angle, sailing to windward, in degr.

g : gravity acceleration = 9.81 m/s^2

L_{TWL}: test waterline length, in m

Table VIII:

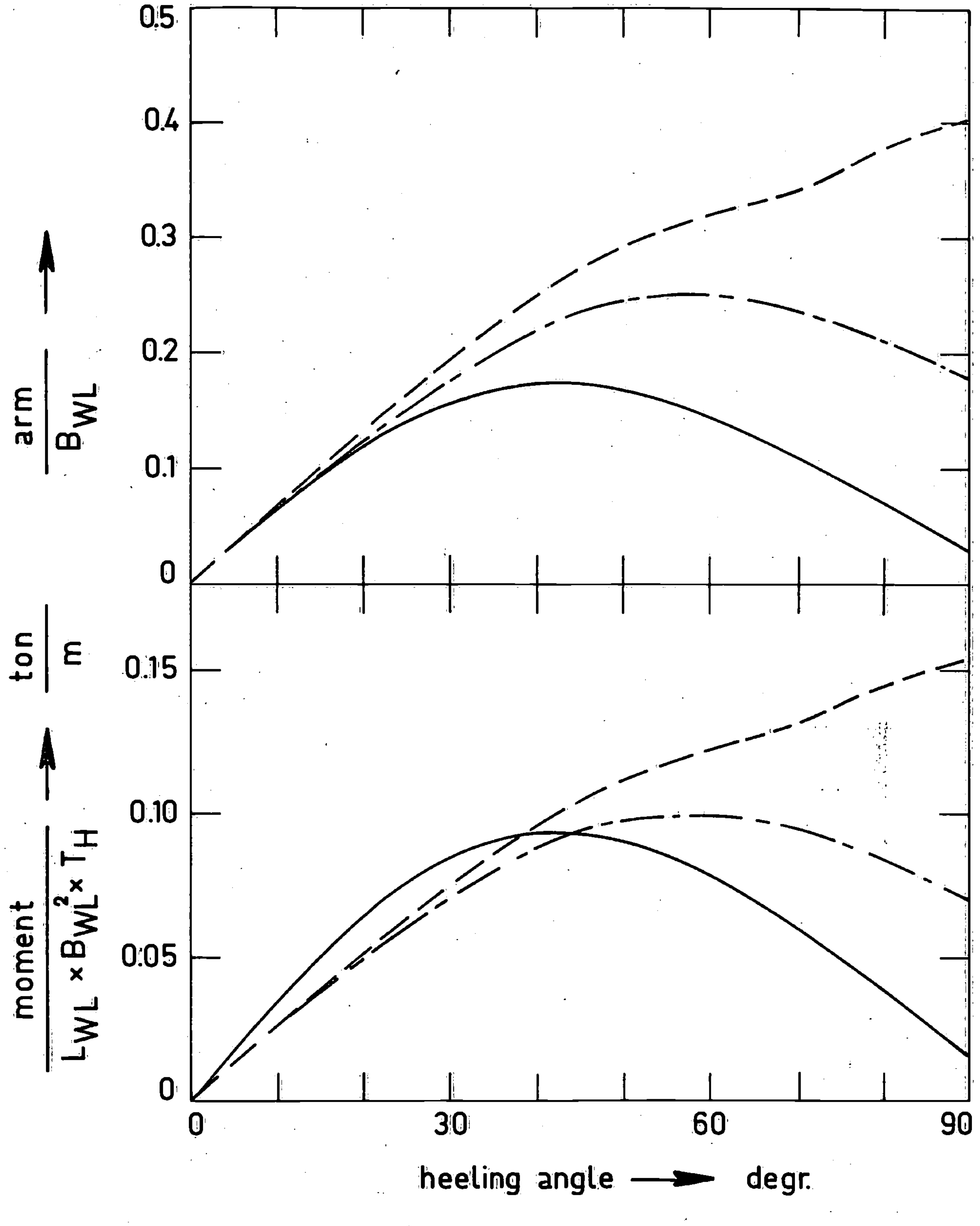
Suitability of different Dutch traditional ship categories for use as a sailing yacht

less suitable:	because of:
big cargo vessel	too big for most marinas; too expensive in building and operation; too difficult to sail with a small crew; mast too much forward.
fishing boats of Zeeland	on the average less advanced sailboats than fishing boats of the Zuiderzee (leeboards); two improvements may be considered: 1) design a better afterbody (Lemmerhoogaars) 2) choose the more advanced leeboard of the Zuiderzee.
botter (Zuiderzee fishing boats)	good sailboats, but stem too high, stern too low; afterbody too fine.

more suitable:	because of
Vollenhovese schuit (little schokker) (Zuiderzee fishing)	good sailing performance; moderate high bow and moderate low stern; flared forebody to avoid shipping of water; good, aftward mast position.
Vollenhovese bol (Zuiderzee fishing)	good sailing performance; moderate high bow and moderate low stern; beauty of the round bow.
Lemsteraak (Zuiderzee fishing)	very good sailing performance; beautiful lines; slight disadvantage is that accommodation of this round-bottom boat cannot be as good as in a flat-bottomed ship of the same size.
zeeschouw (Zuiderzee fishing)	good sailing performance; chined hull form, which is easy and cheap to build.
grundel (general purpose)	good sailing performance; hull form with hard chine, straight stem and transom stern, which make it easy and cheap to build.
boeier (yacht/general purpose)	pure and beautiful Dutch type; if attention will be paid to "seaworthiness" it might have preference above all; good, fast sailing properties.

Table VIII (continued)

small tjalk (cargo/general purpose)	so-called "beurtscheepjes" were good sailing boats with handy rig and higher bow than tjalk normally has; mast position and midship section need consideration.
Staverse jol (Zuiderzee fishing)	no leeboards, which makes it suitable for single handed cruising; unfortunately moderate sailing performance.



		w. l. length	displ.
———	lemsteraak	7.41 m	6.02 ton
– – – –	ocean cruiser-racer	10.04 „	9.88 „
—·—·—	12 m yacht	14.52 „	27.95 „

Fig. 1: Non-dimensional righting arms and moments.

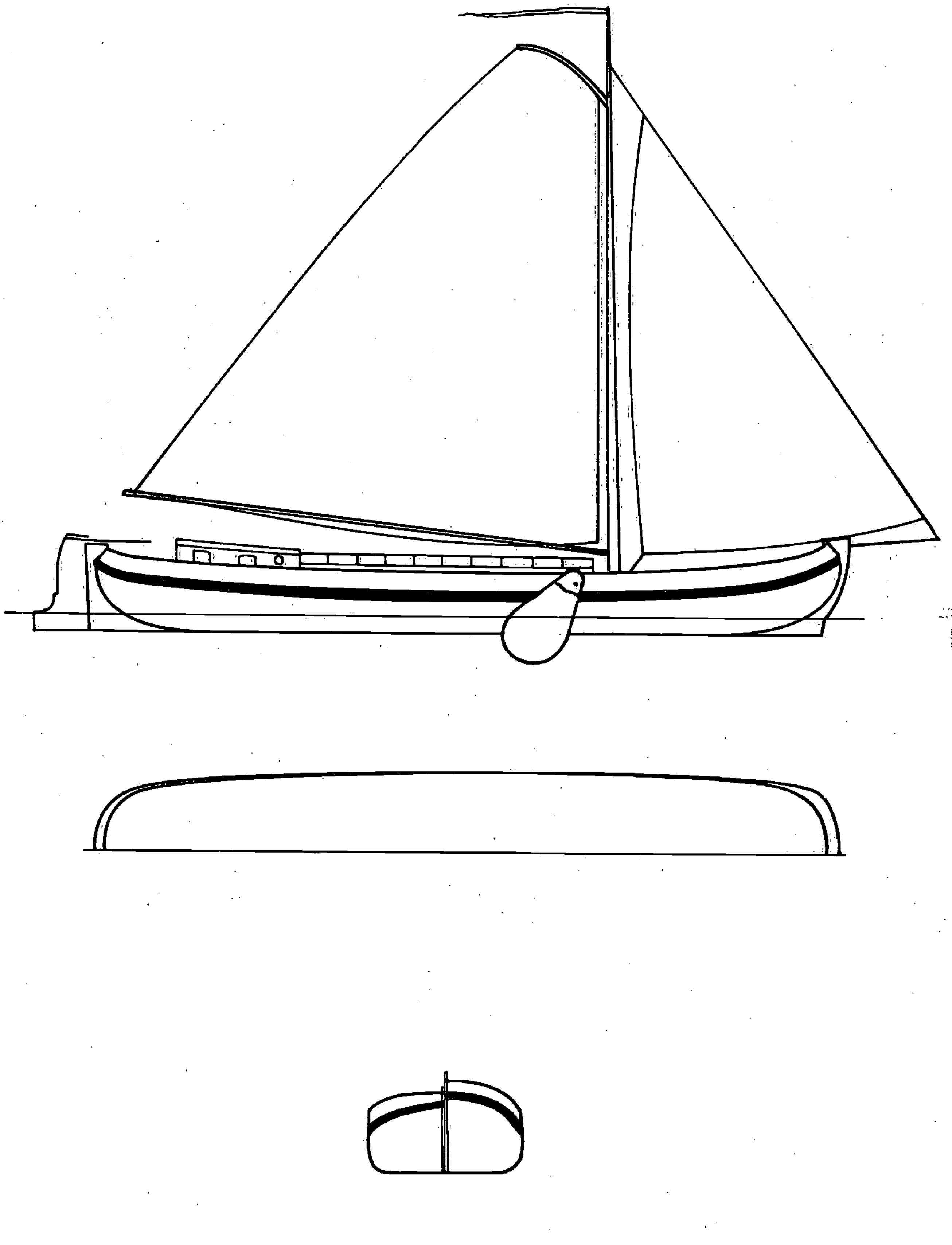


Fig. 2 : Plans of a tjalk.

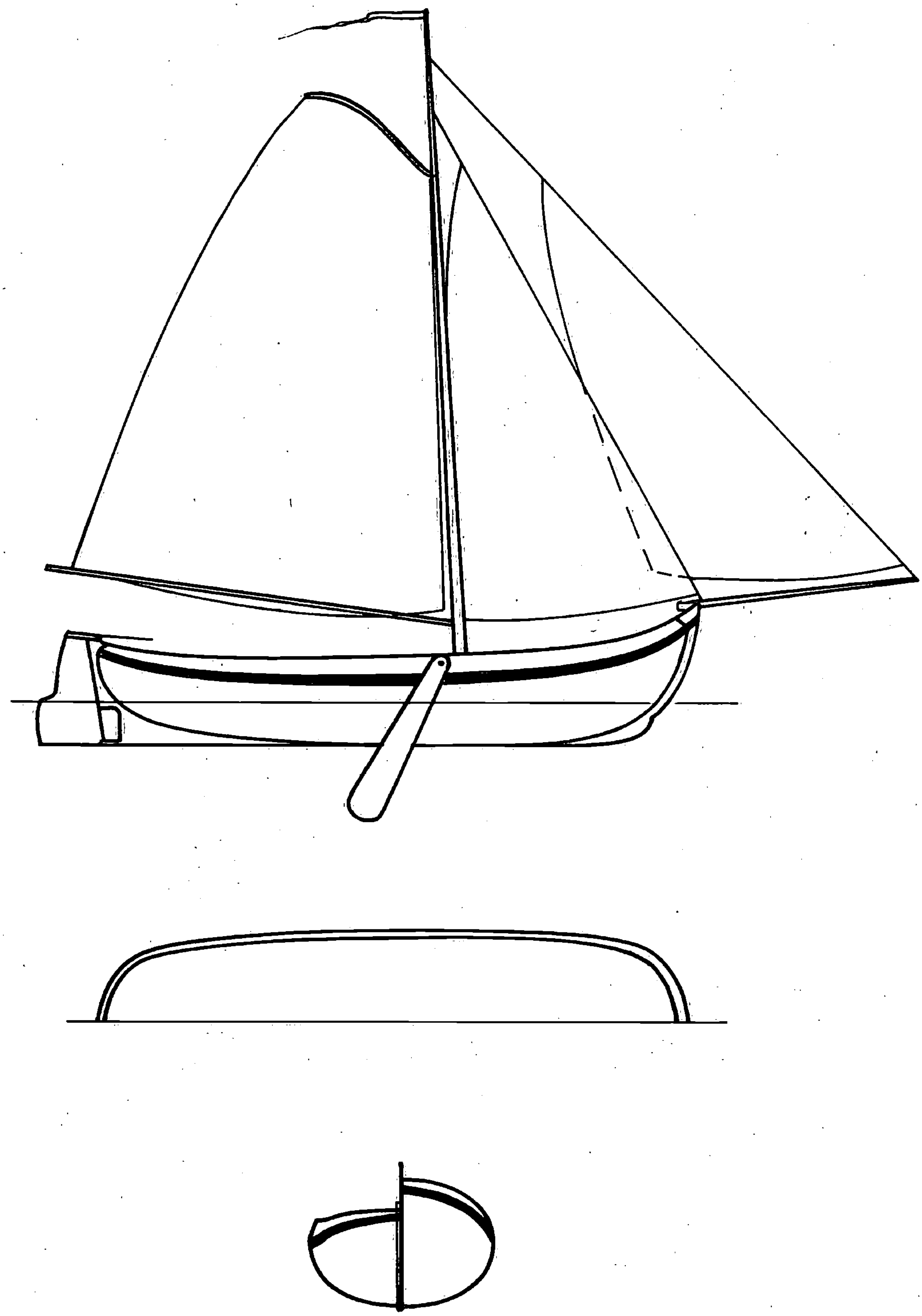


Fig.3: Plans of a lemsteraak.

5 m

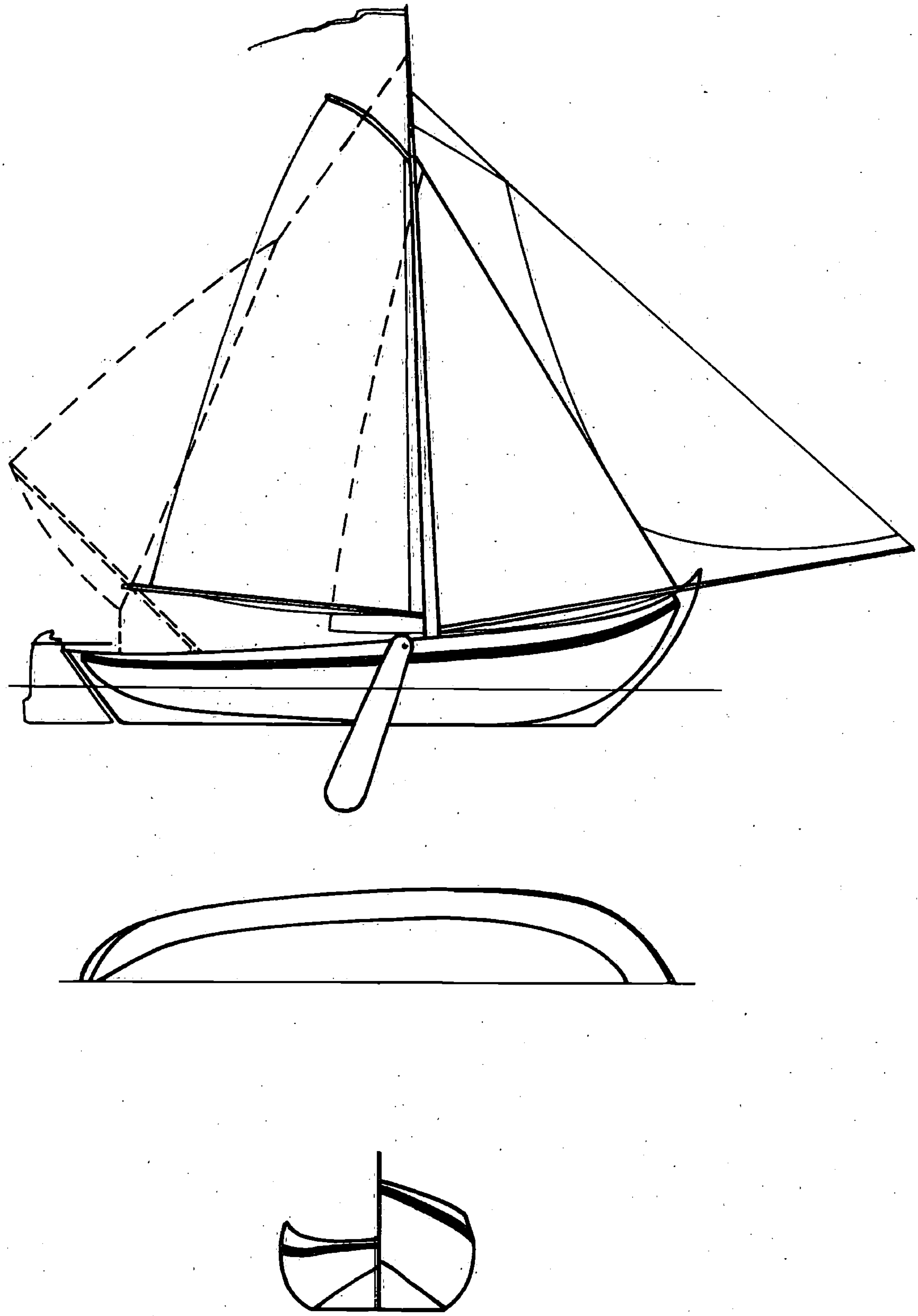
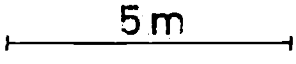


Fig. 4 : Plans of a botter.



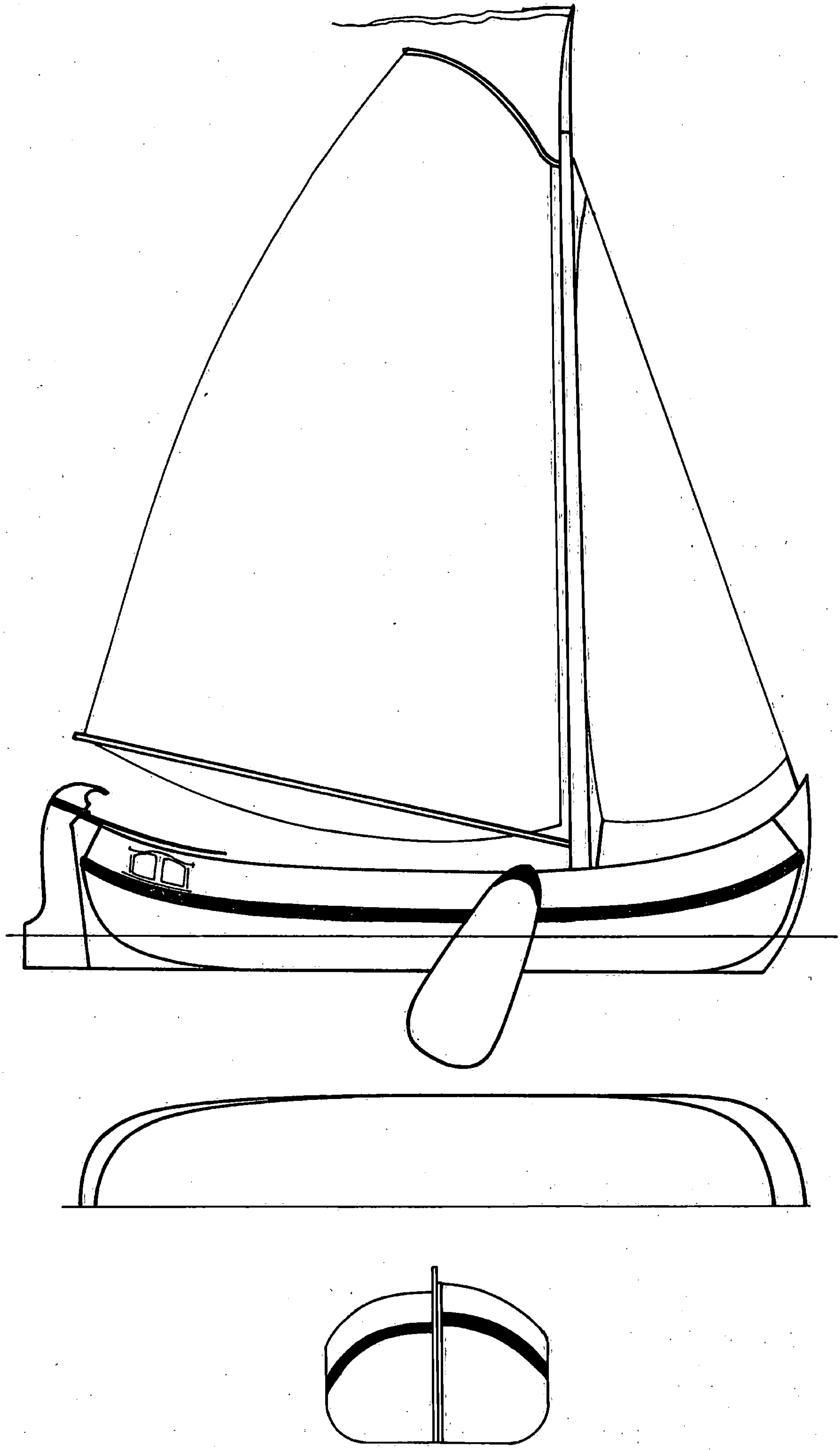
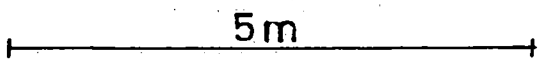


Fig. 5: Plans' of a poon.



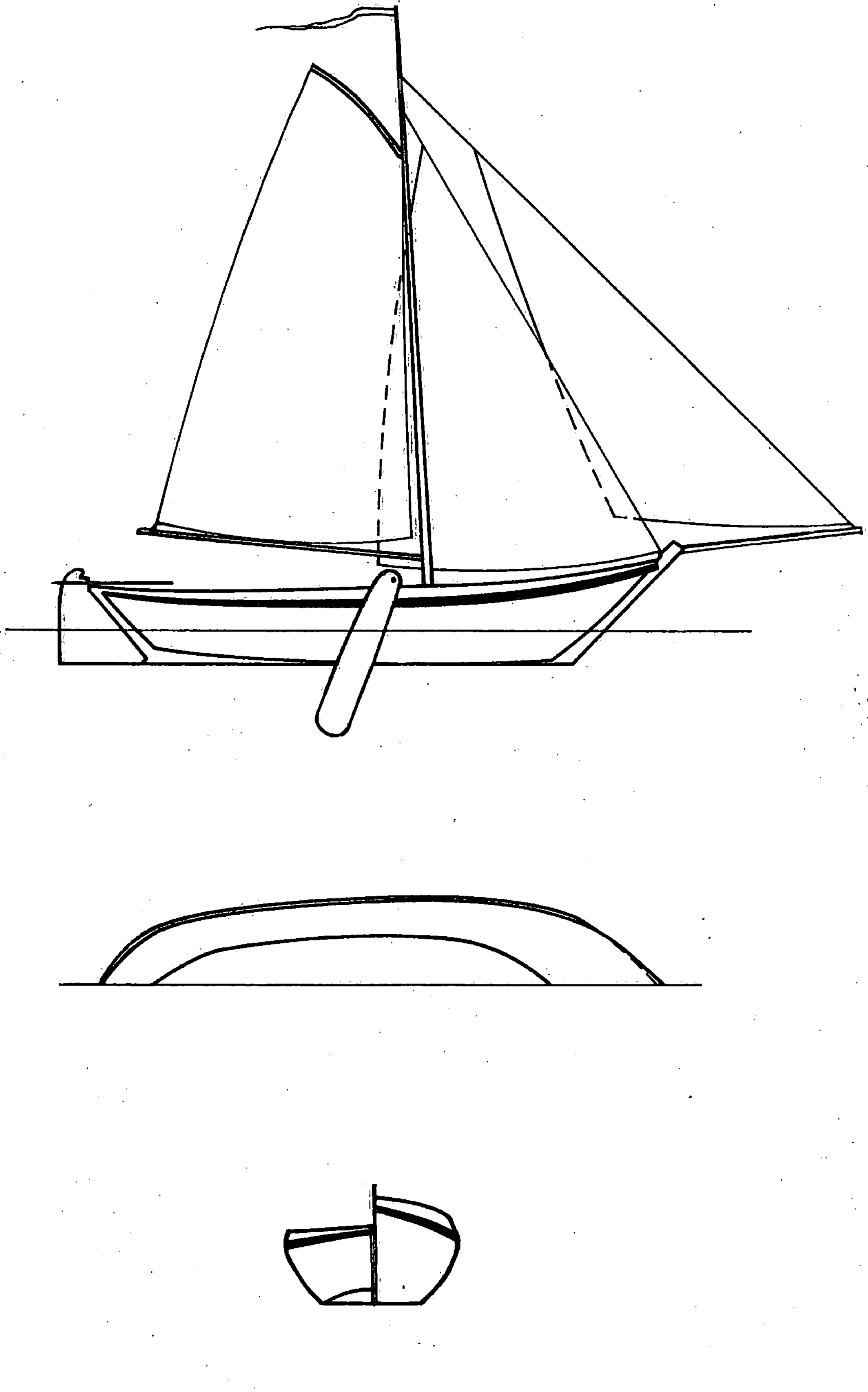
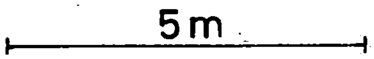


Fig. 6: Plans of a pluut.



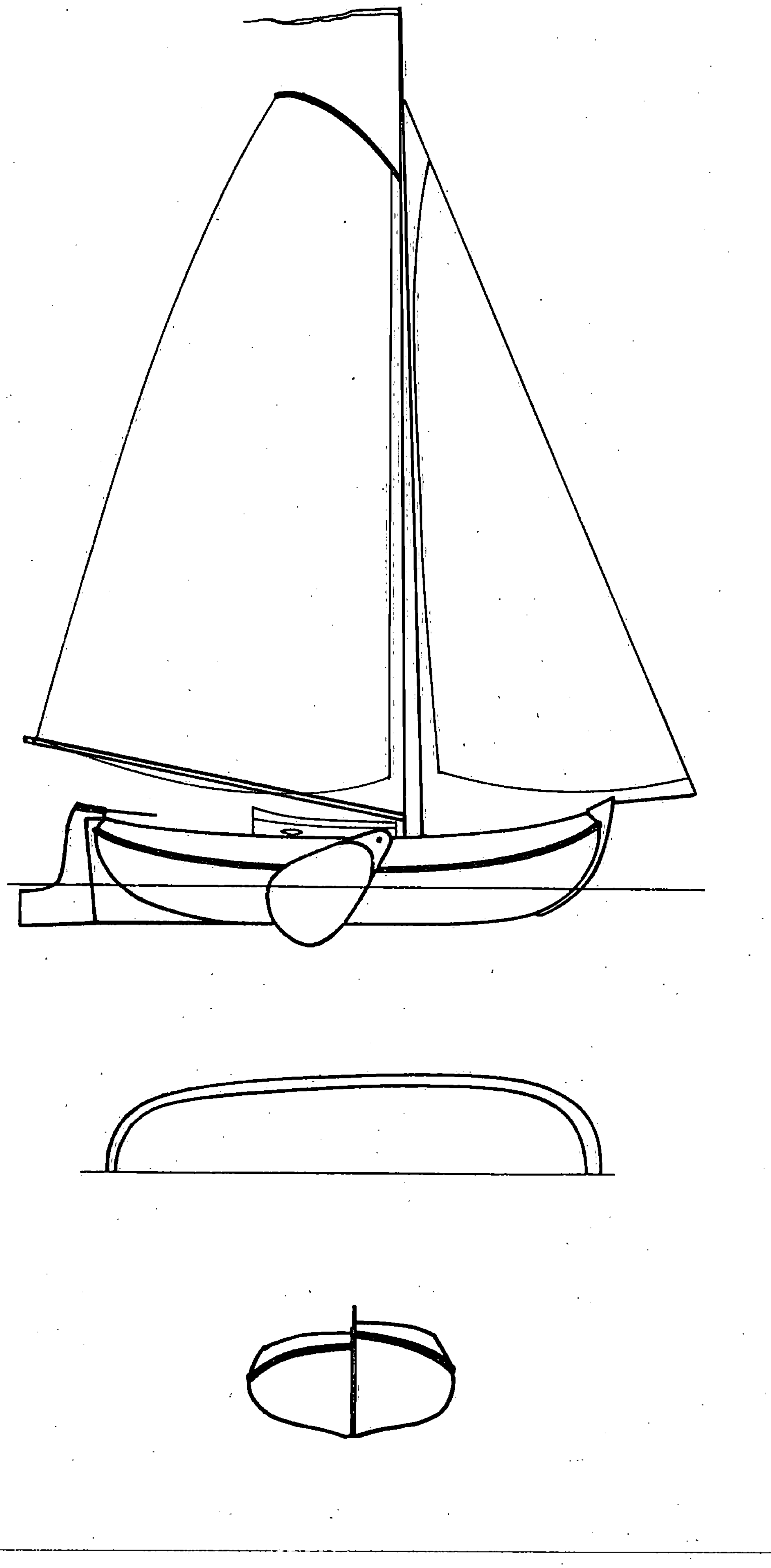


Fig.7 : Plans of a boeier.

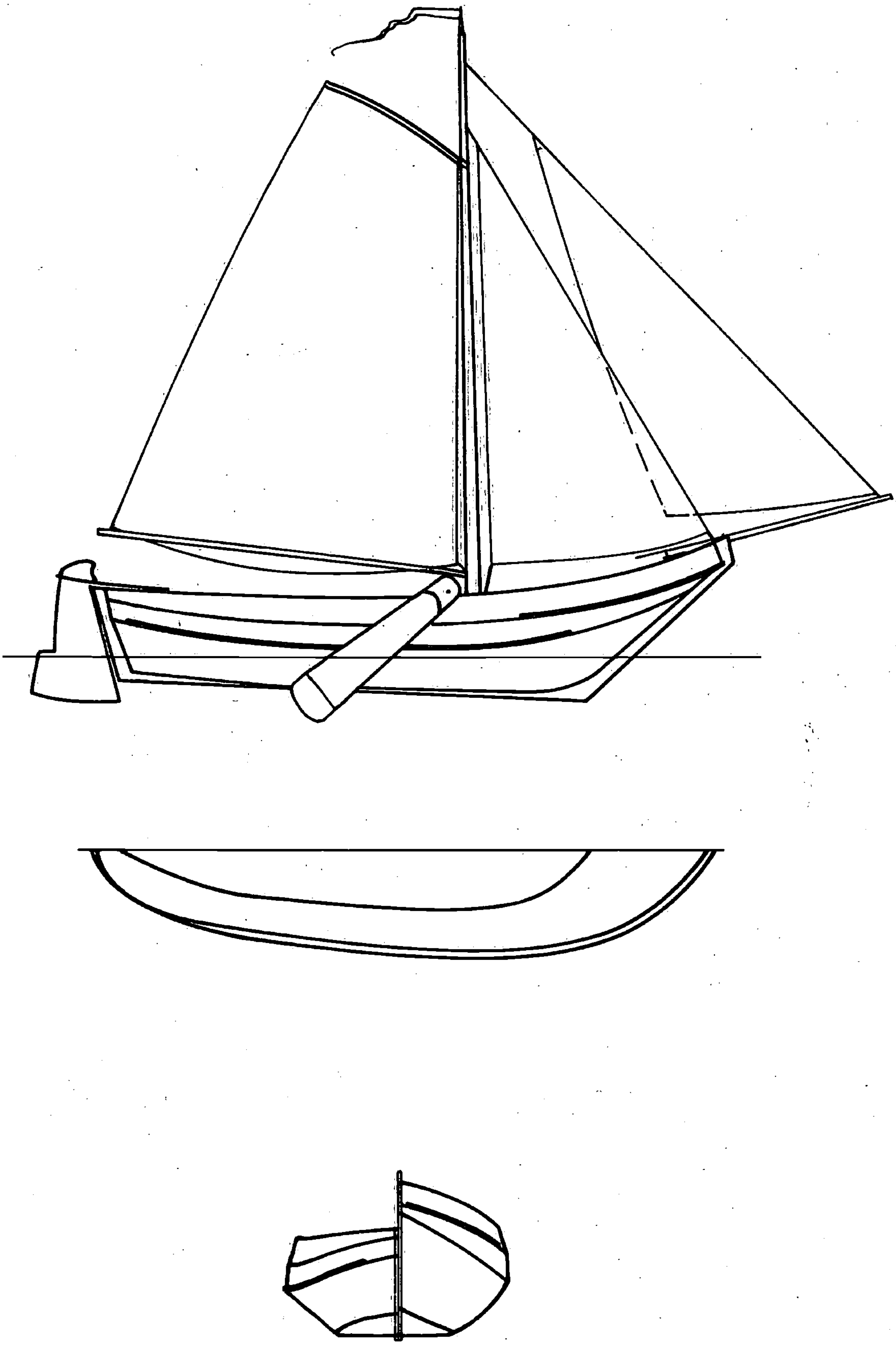


Fig. 8: Plans of a hengst.

5m

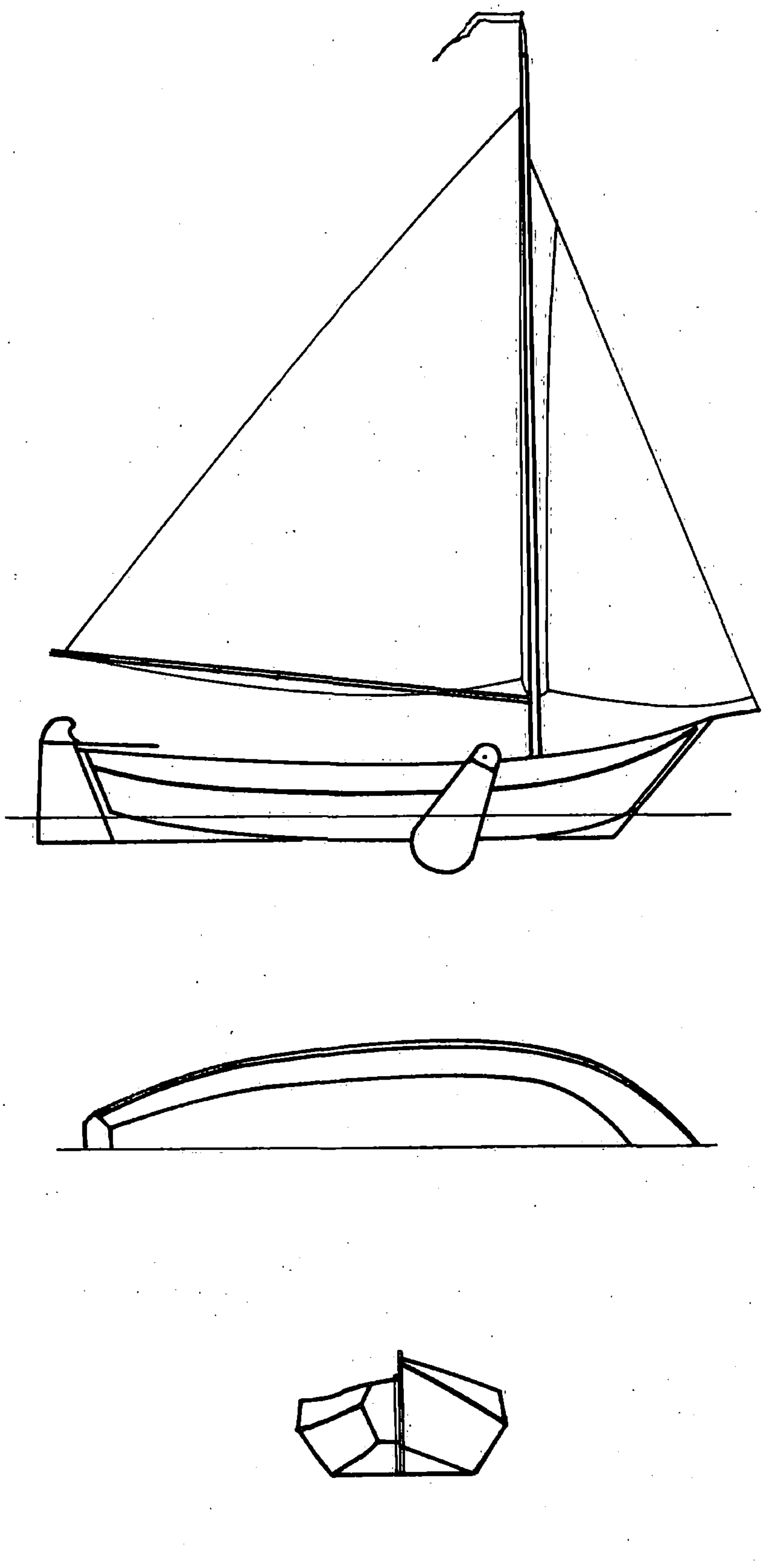


Fig. 9: Plans of a grundel.

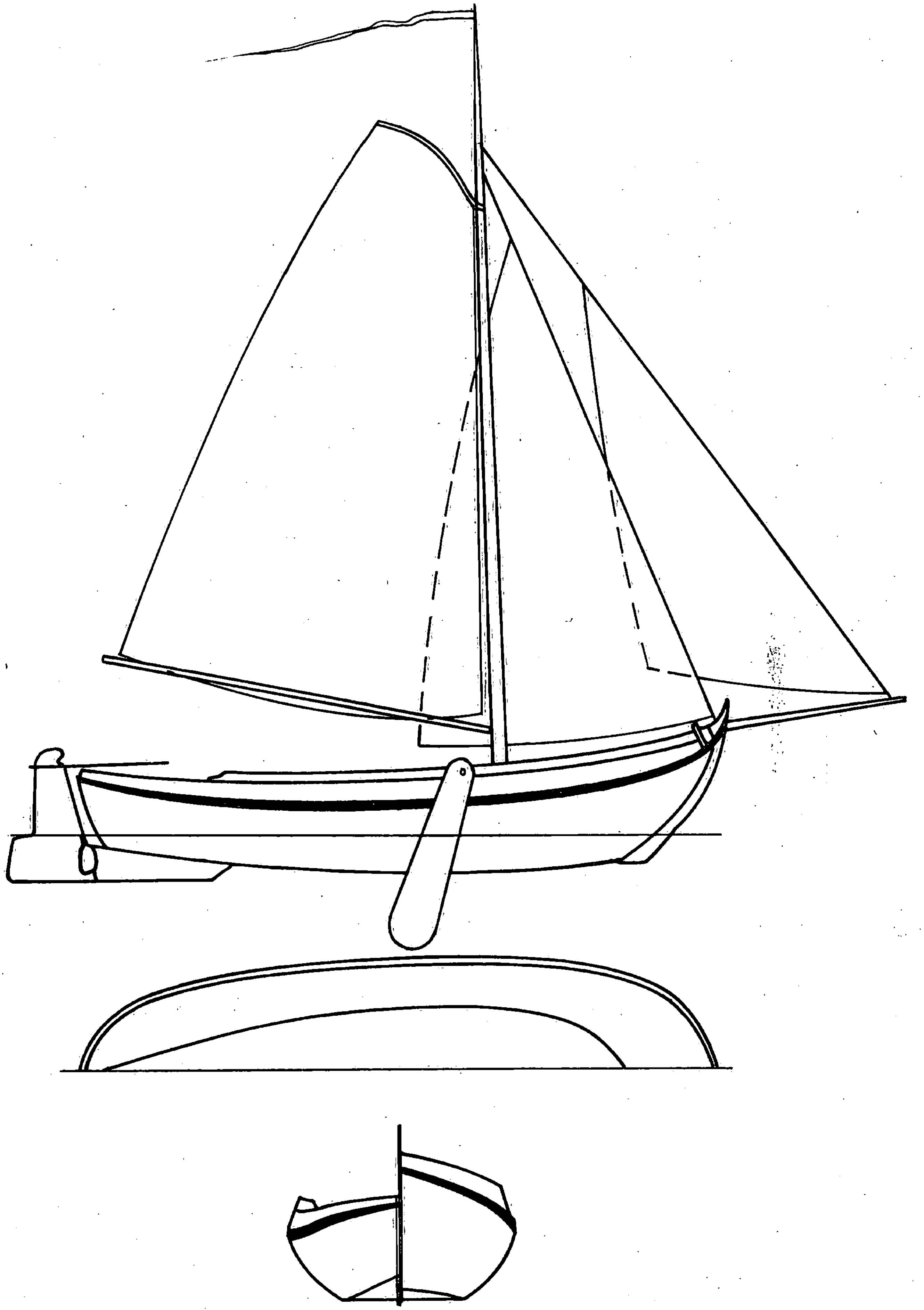


Fig. 10: Plans of a bol.

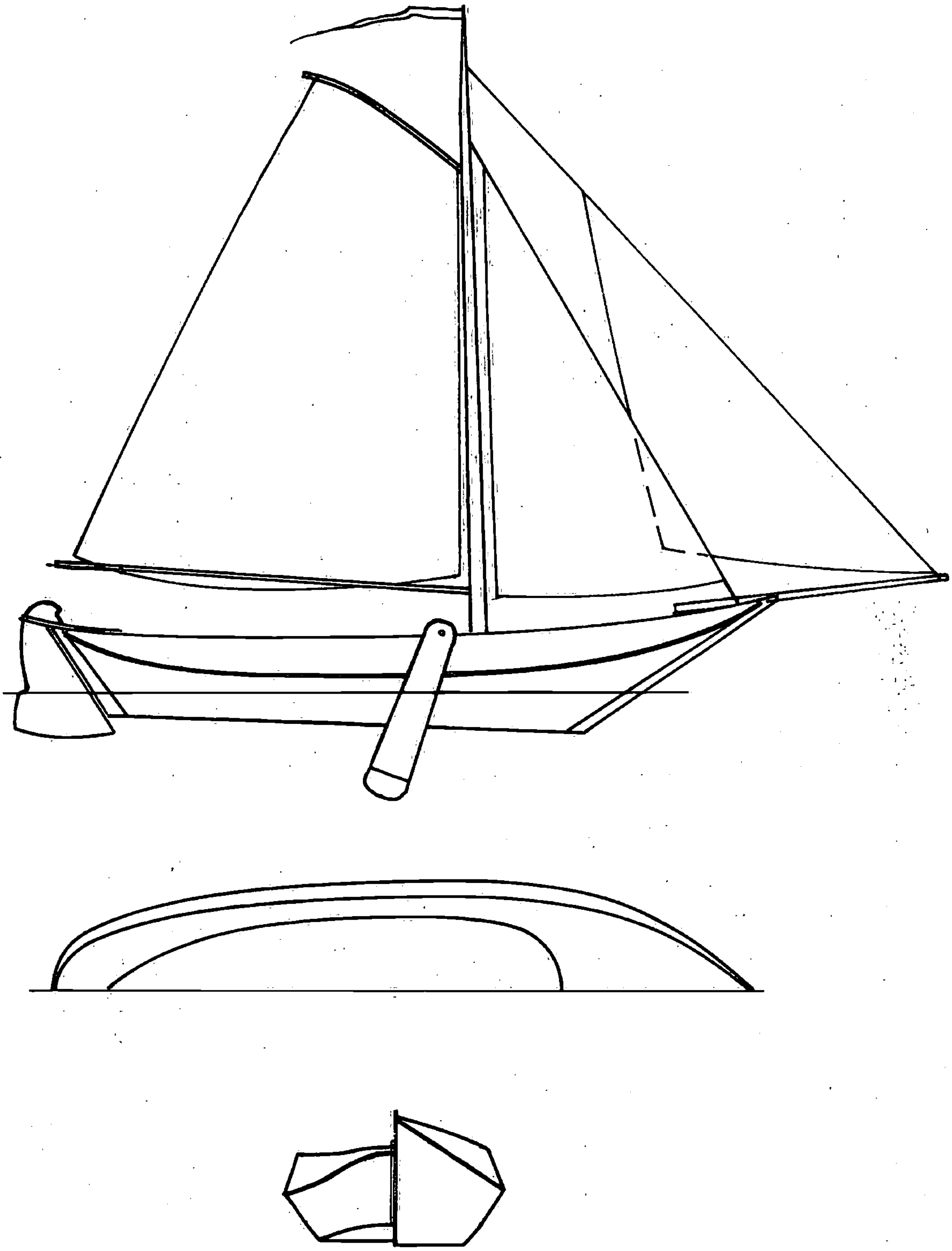


Fig.11: Plans of a hoogaars. 5 m

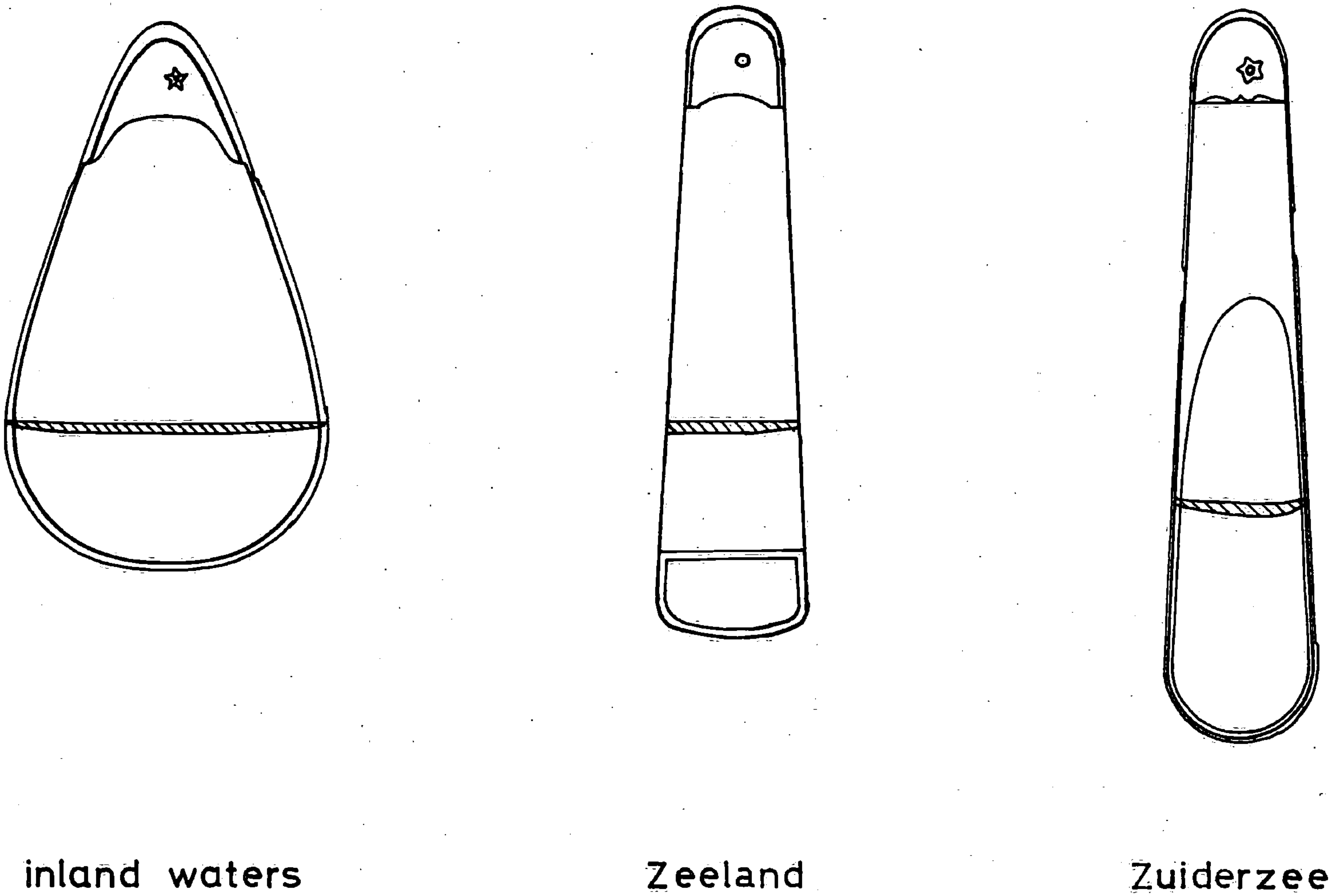


Fig. 12: Characteristic leeboard types

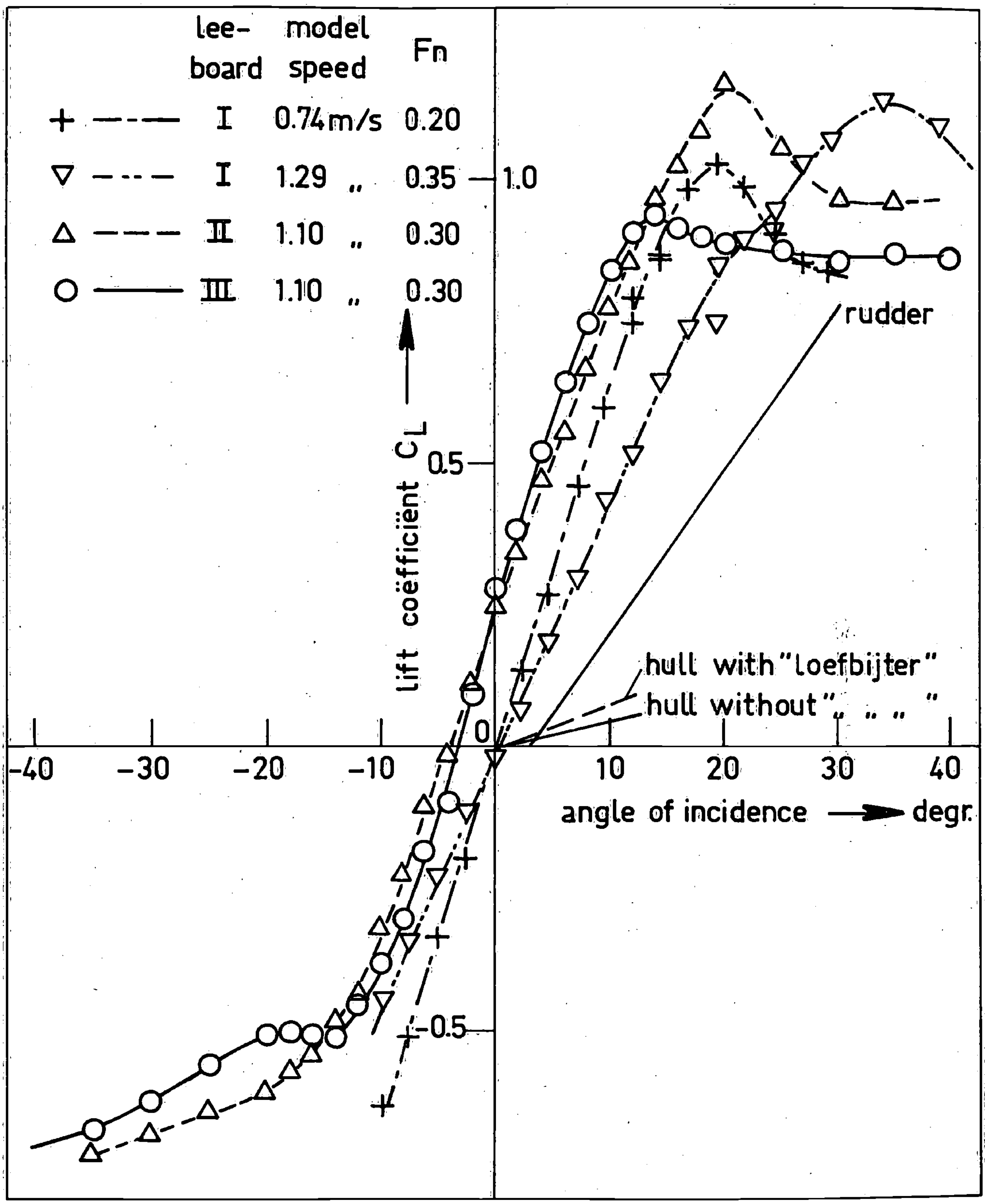


Fig. 13: Lift coëfficiënts of leeboards.

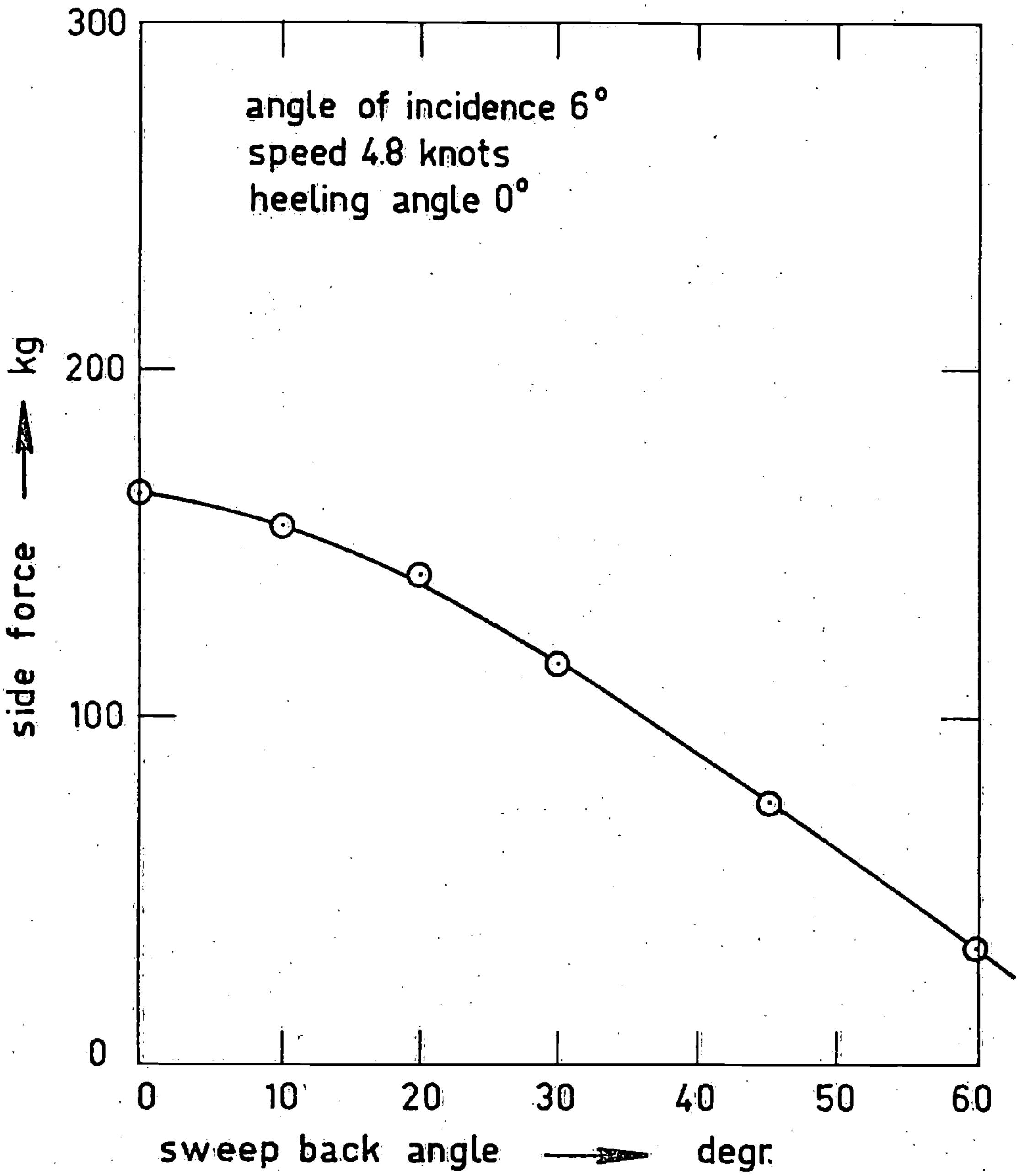


Fig. 14: Side force of leeboard III with sweep back angle.

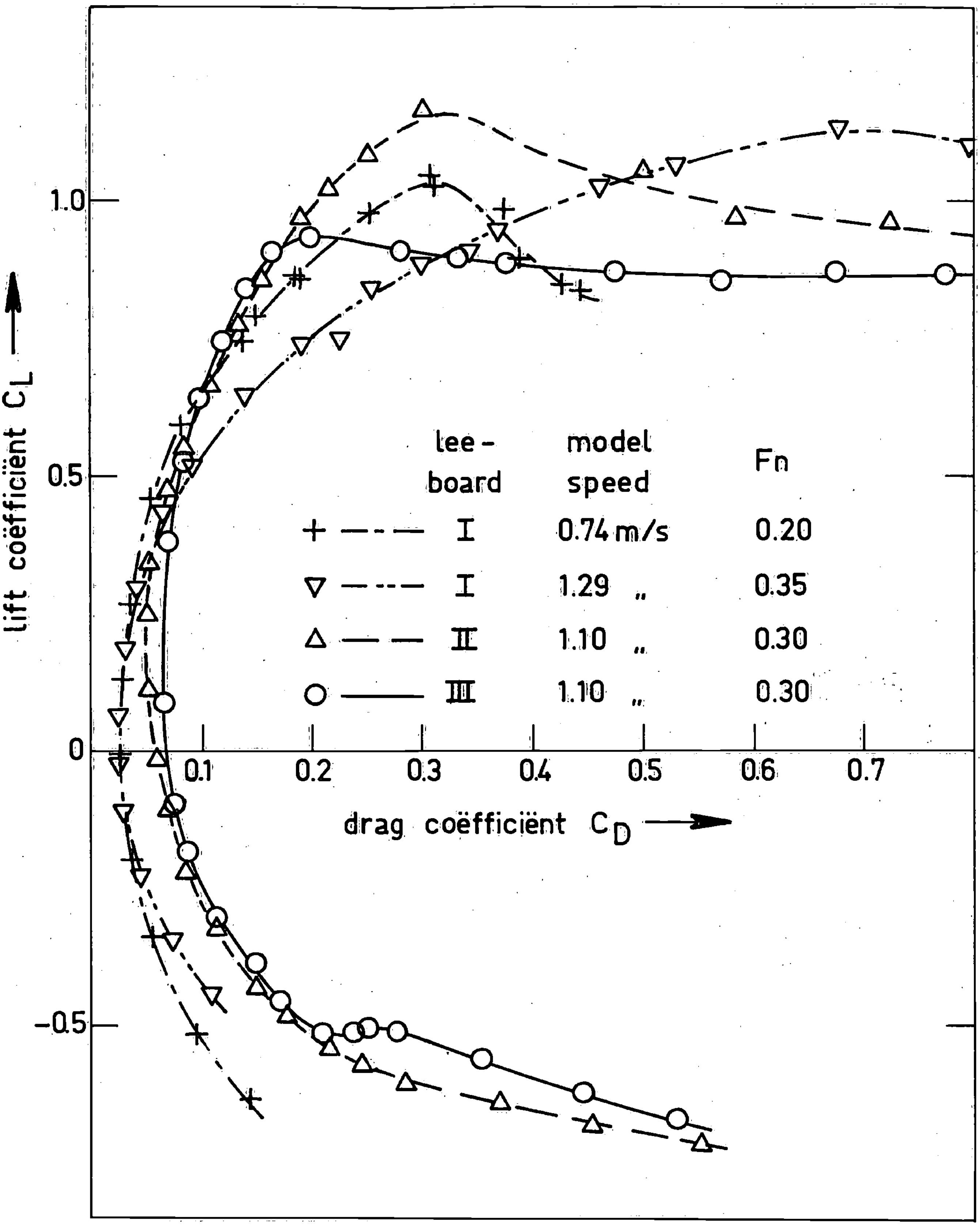


Fig.15 : Drag coëfficiënts of leeboards.

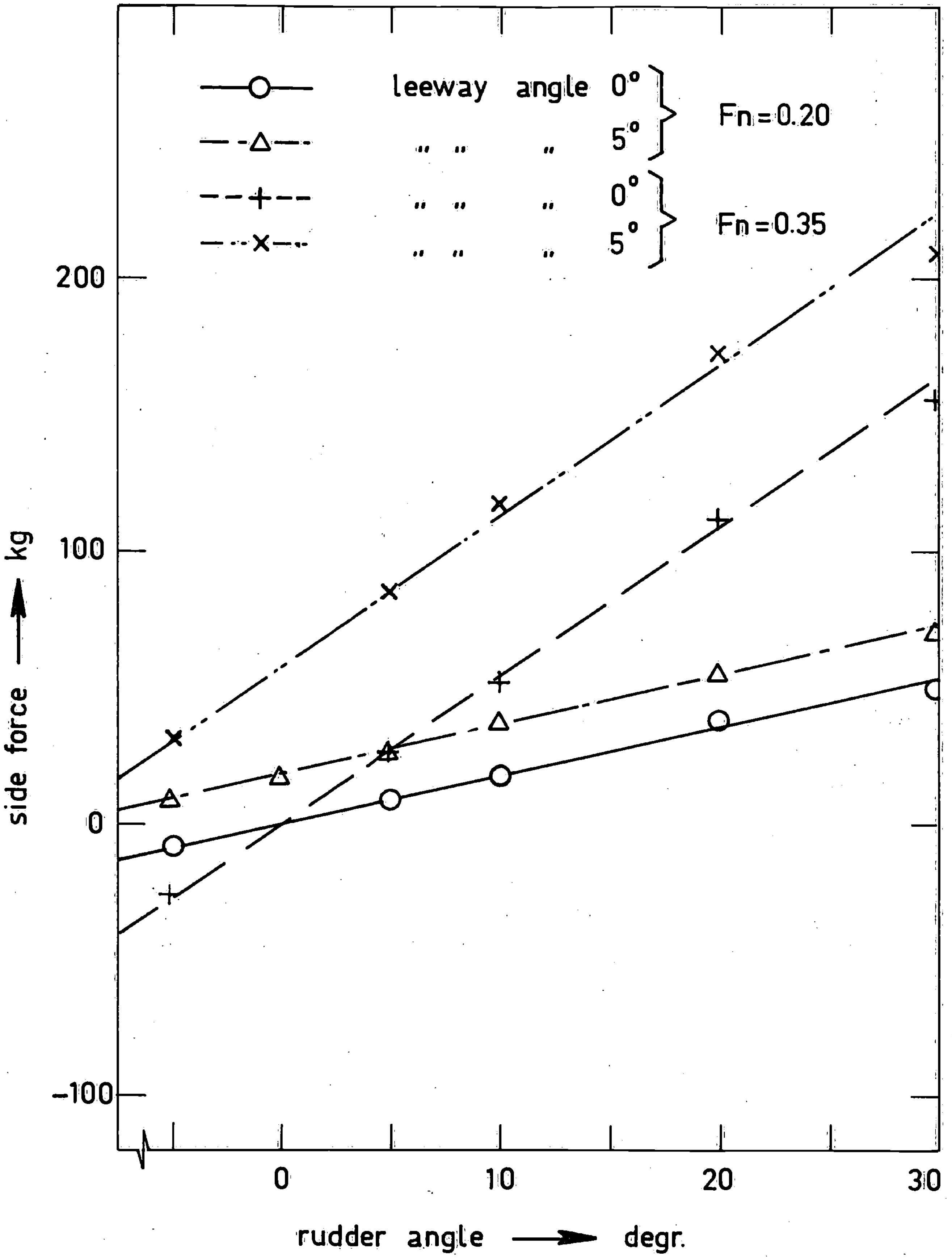


Fig. 16 : Side force versus rudder angle. (grundel)

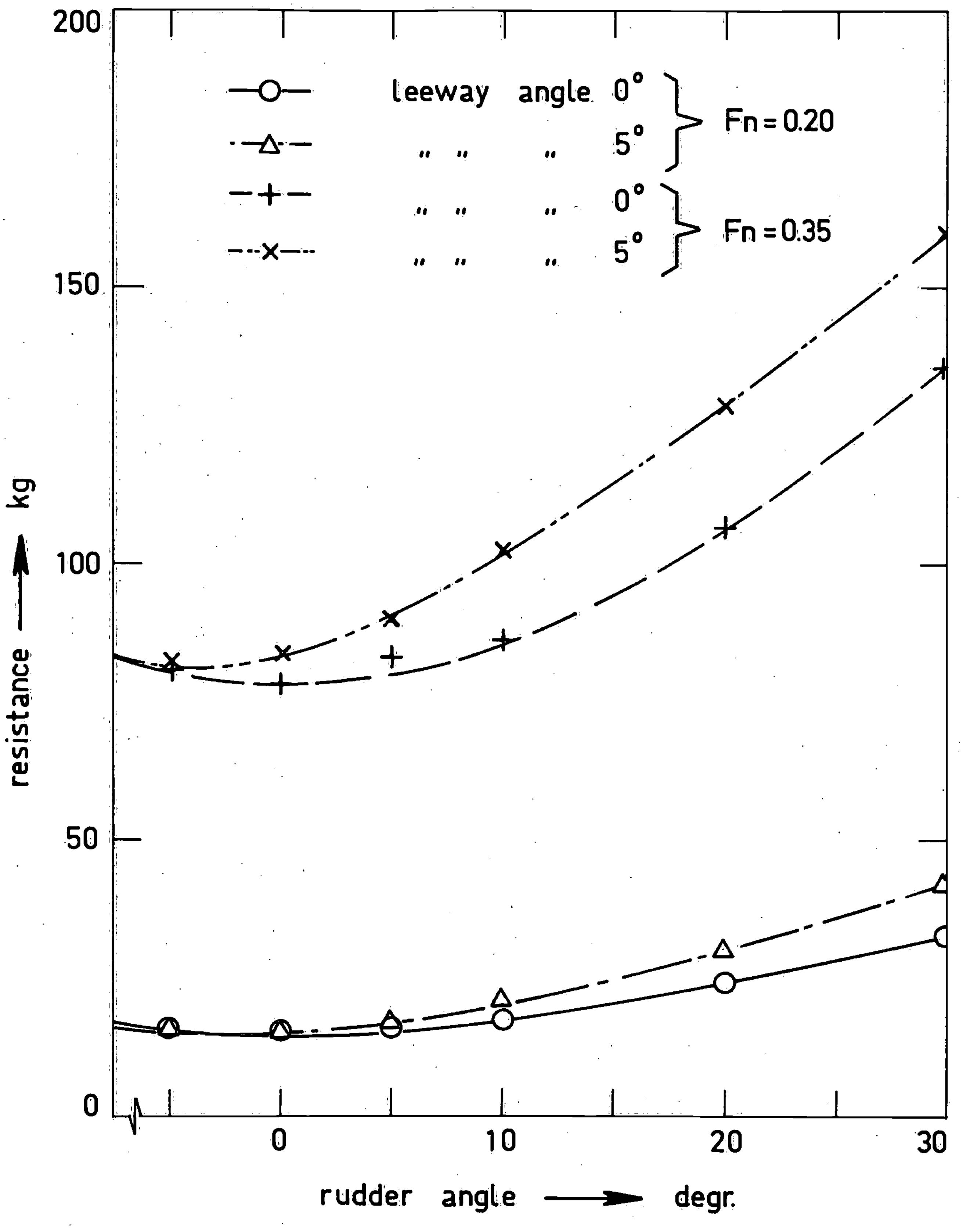


Fig. 17 : Resistance versus rudder angle. (grundel)

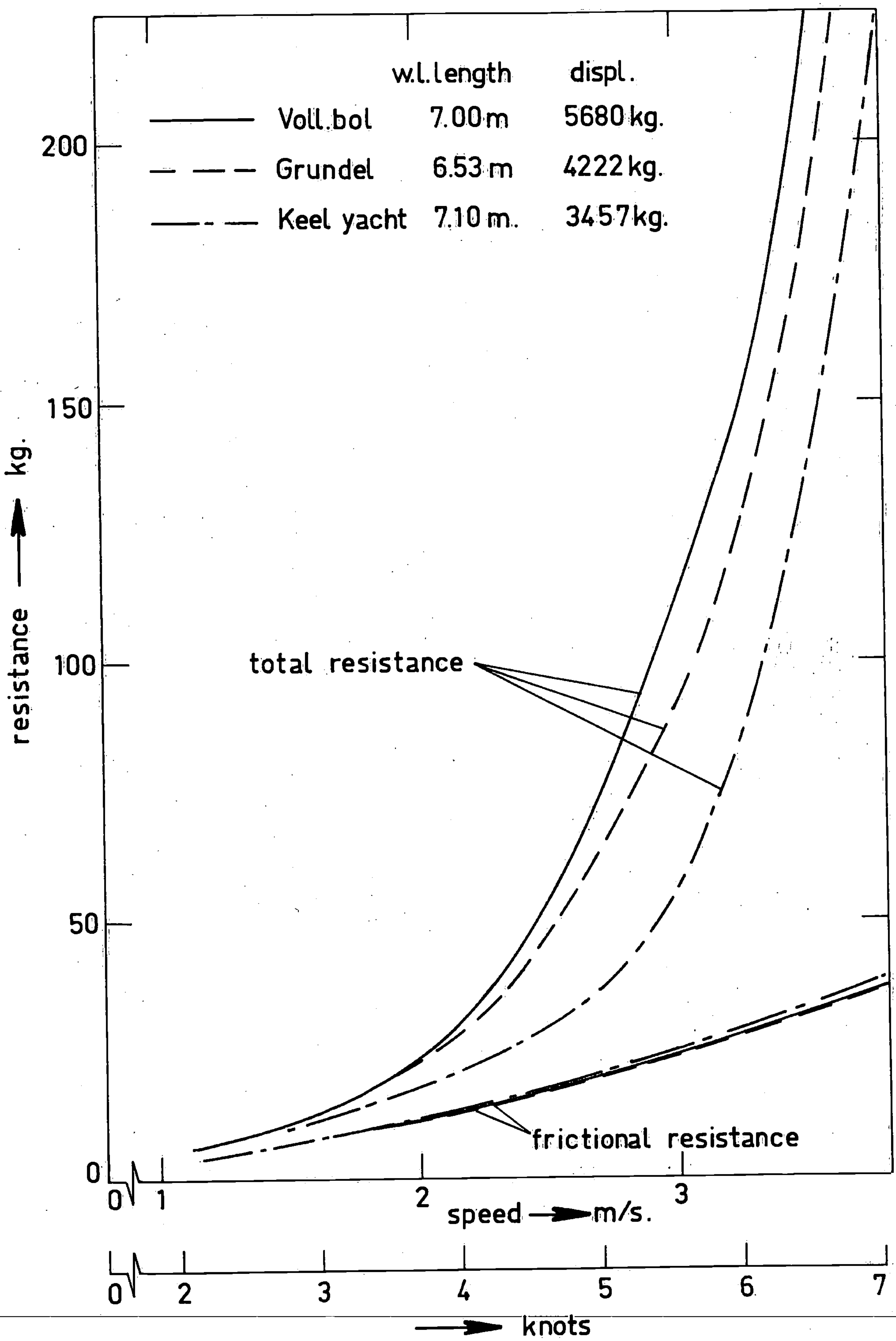


Fig.18: Upright resistance of hulls.

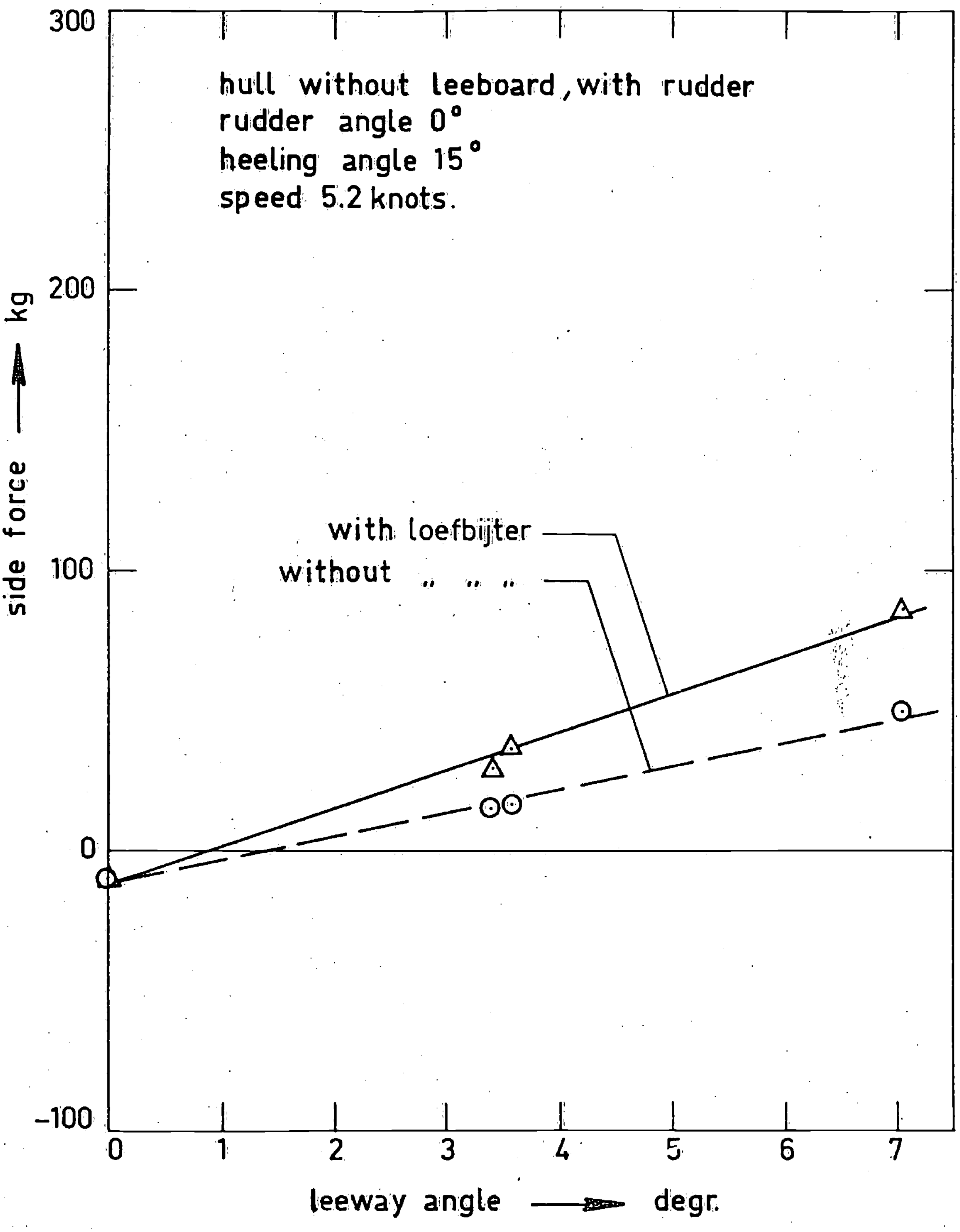


Fig.19: Side force of Vollenhovese bol hull.

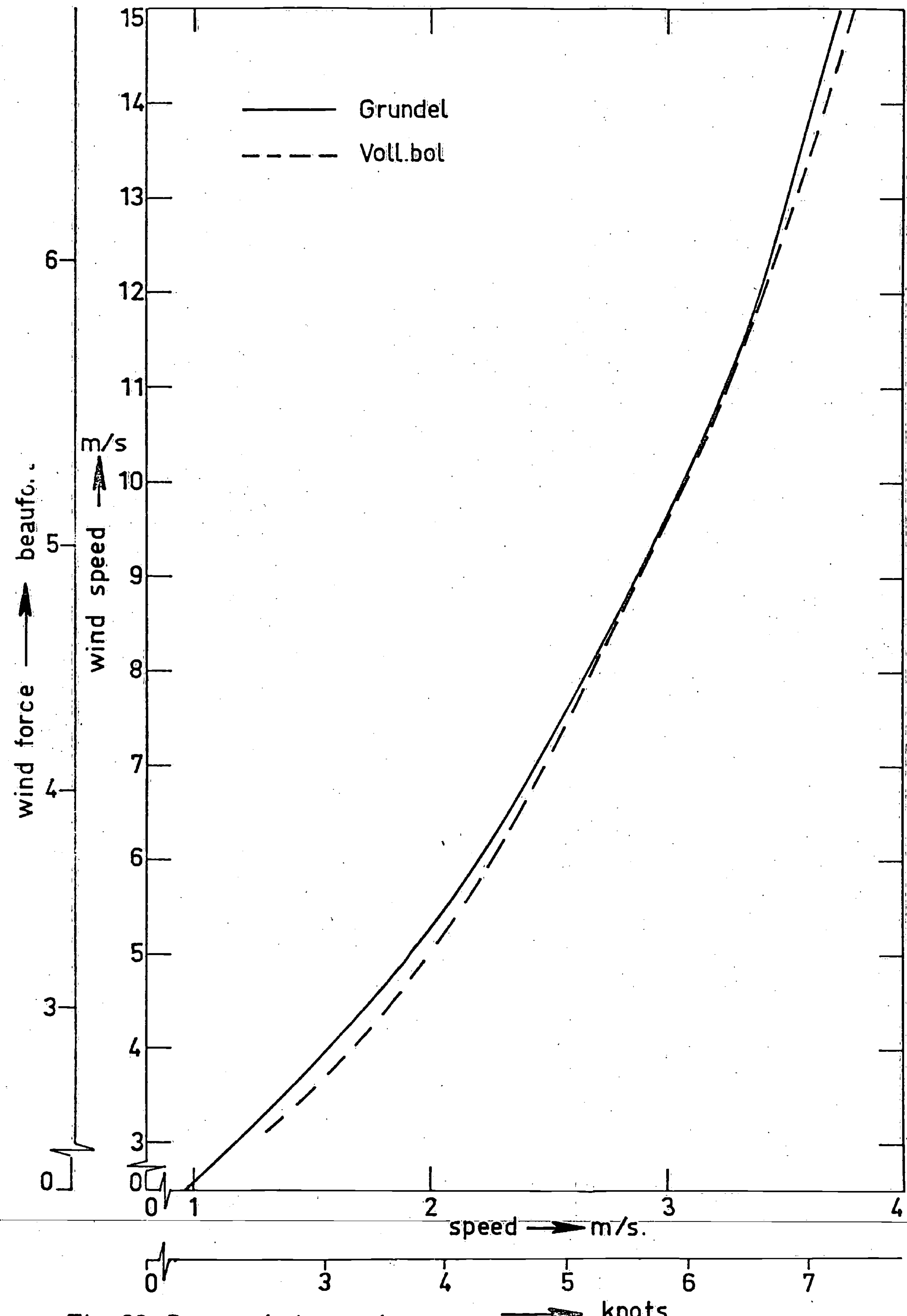


Fig. 20: Down wind speed

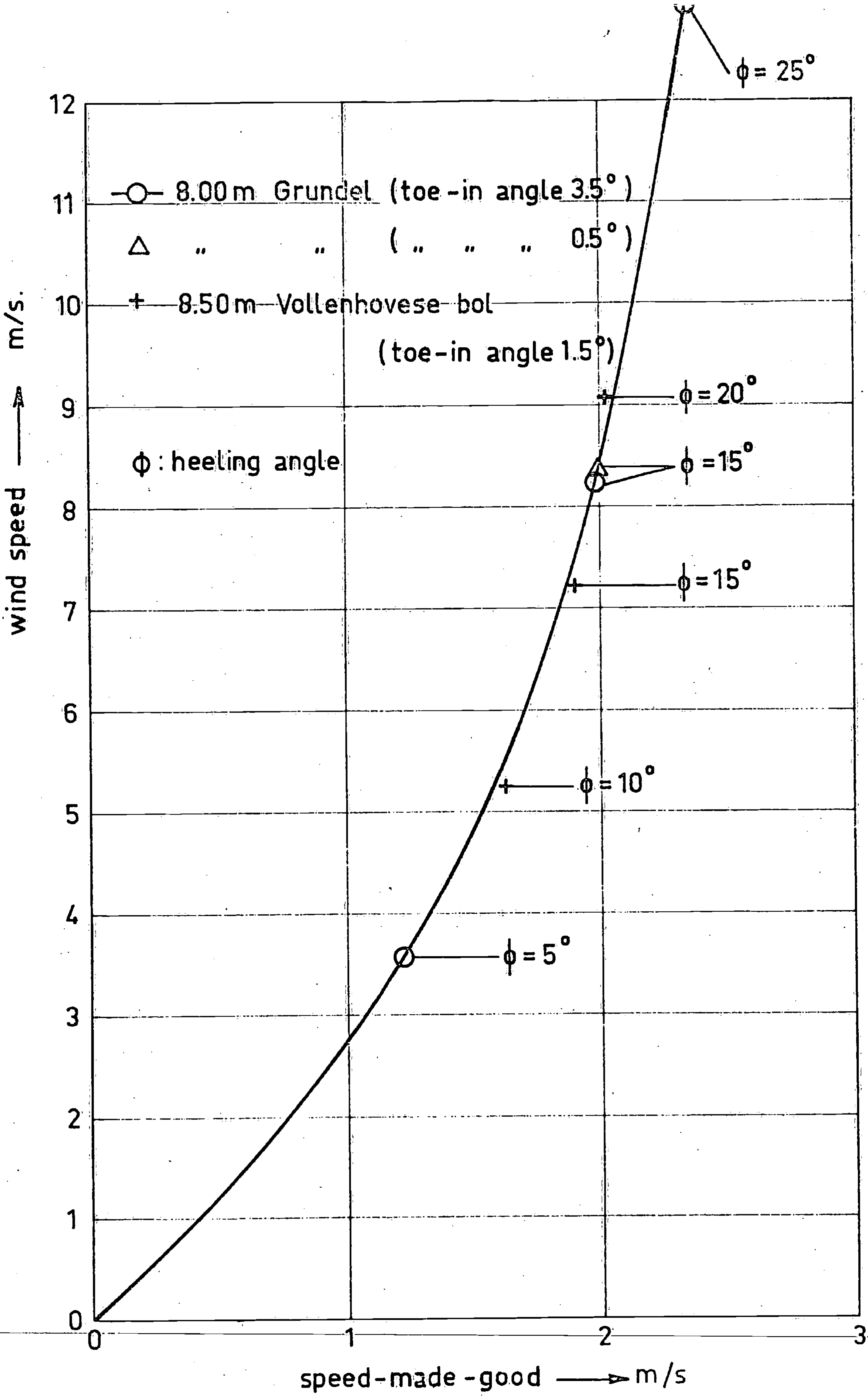


Fig. 21: Speed-made-good to windward.

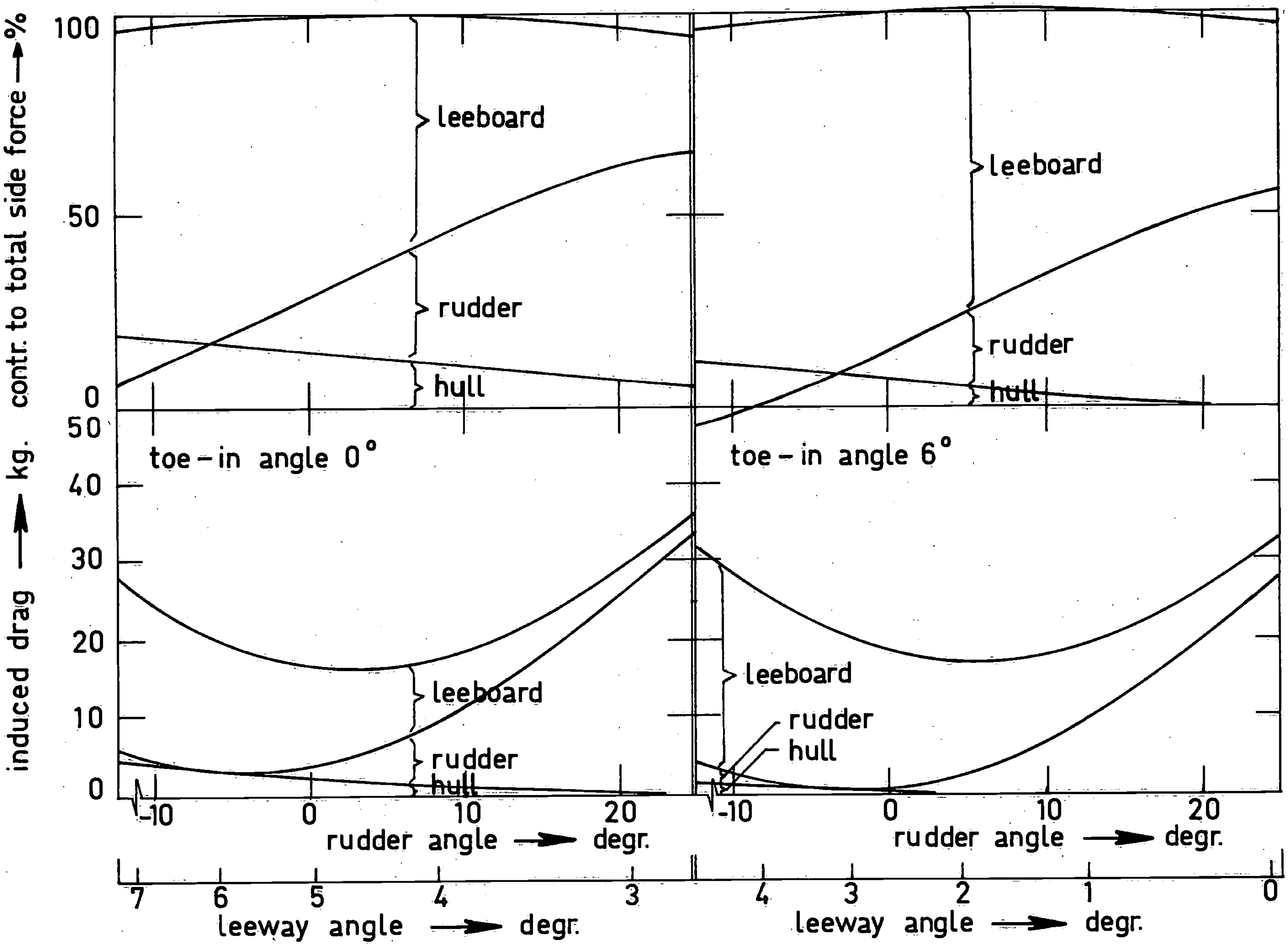


Fig.22: Contribution to side force and induced drag of hull, rudder and leeboard of a grundel in 7.0 m/s wind.

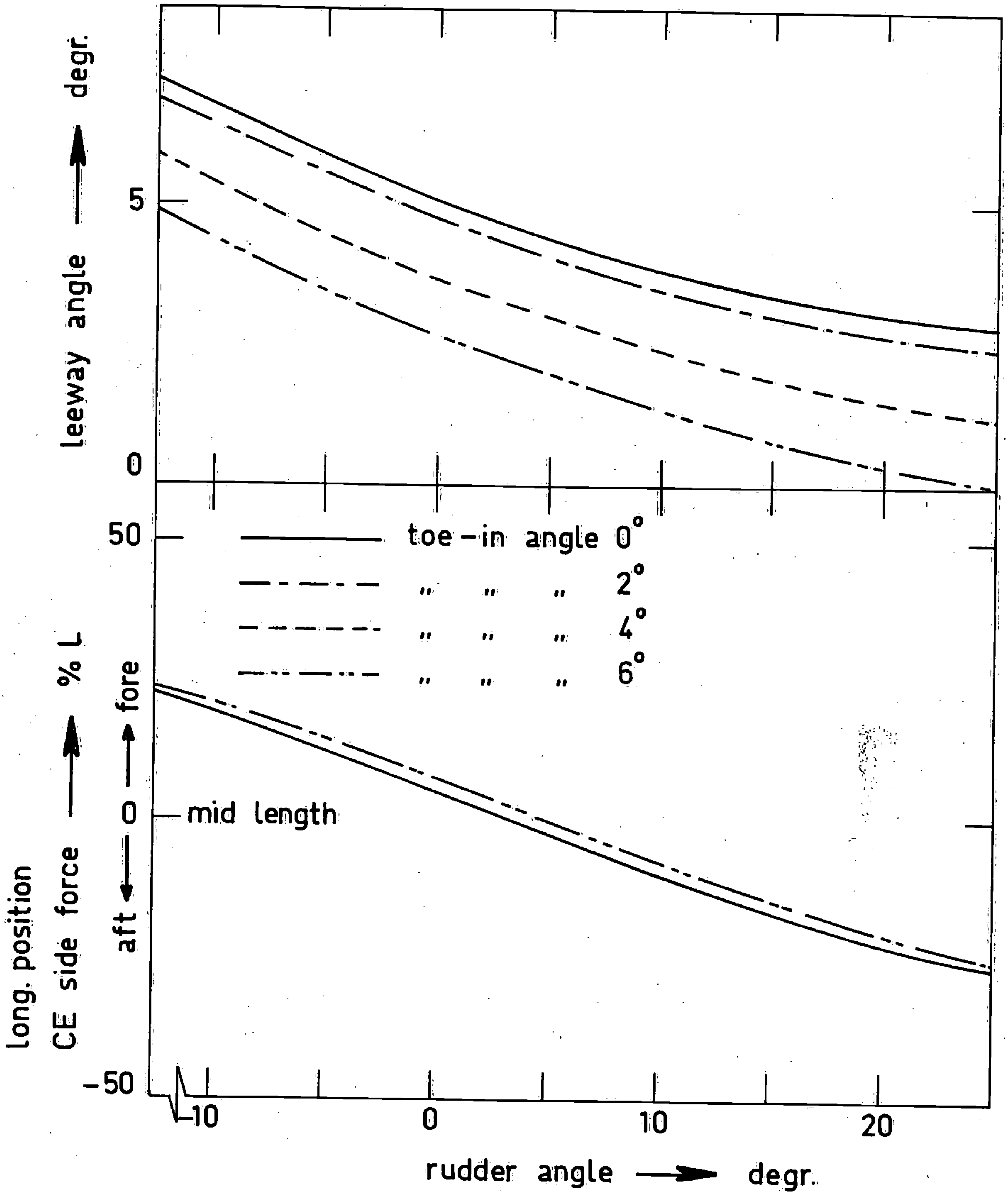


Fig. 23: Leeway angle and longitudinal position of centre of effort of side force for grundel in 7.0 m/s wind.