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THE USE OF SAIL POWER IN FISHING VESSELS

by

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SUMMARY

This paper discusses briefly the theory of sail power and its application to fishing vessels, looks at the operational requirements of a variety of fishing methods and the conditions under which sail power can be used in each method to reduce energy consumption. Fishing methods are listed in descending order of utilisation of sail in the operation.

Traditional working sail configurations and the development of newer systems are examined in detail and their applicability to present day fishing vessels discussed. Explanations are included of practical details of rig and sail handling for large and small inshore and coastal fishing vessels. Design considerations for the application of sail in displacement fishing craft and multihulls are discussed and the economics of sail power are examined and costs and maintenance balanced against expected savings in operational expenditure for fossil fuels.

1. INTRODUCTION

Vessels using sail as a method of propulsion can be arbitrarily divided into five categories:

1) Light flat bottom forms designed to skim over the water surface (e.g. light sailing dinghies used for racing);

2) heavy displacement hull forms (which include most, if not all of the traditional working craft using sail);

3) multihulls (catamarans, trimarans and other craft using multiple hulls or outriggers);

4) sailing hydrofoils;

5) miscellaneous craft using sail, such as sailboards, land and ice yachts, etc.

Given the nature of fishing vessels as load carrying craft categories two and three are the ones which most concern us in work boats in general and fishing vessels in particular, although some of the principles evolved by the other forms of craft could have application in fishing vessels (e.g. the rig of the sail board).

The wind which provides the fuel for propulsion varies in strength and direction both on a daily basis for each infividual location and from one geographical area to another according to topography and global wind patterns. Mean wind speeds can however, be in quite close agreement from year to year, particularly in certain areas of regular wind speed and direction over a period, due to specific climatic factors, e.g. monsoon or trade winds. Where local knowledge is not available the Admiralty pilots or the U.S. Navy pilot charts or the Marine Climatic Atlas of the World will give an indication of mean wind speeds and direction at various times of the year. On the basis of this, it is possible to make a preliminary selection of areas particularly favourable to the utilisation of wind energy either as a primary power source or in combination with fossil fuel engines.

An examination of the fishing methods appropriate to a particular location and the operational characteristics suitable to the adoption of sail power, as discussed in Section 2 will also assist in making an evaluation of the potential of sail power for the area while an analysis of the economic advantages to be derived as outlined in Section 5 should permit a decision to be made.

2. OPERATIONAL REQUIREMENTS FOR THE UTILISATION OF SAIL IN FISHING VESSELS

Before proceeding too far with the design of sailing fishing craft, thought must be given to a marriage of the sail system to be adopted with the operational conditions under which the vessel will be working.

Even a superficial examination of the evolution of a working sail powered fishing boat in any part of the world will show that the rig, while partly owing its form to traditions, has always evolved in a manner to suit the climatic conditions and the fishing methods practised in the area. A change in fishing method or extension to new areas has frequently resulted in the modification or abandonment of an older rig where the operational conditions favour change.

The following list, while perhaps not exhaustive, shows factors which require consideration during the preliminary design stage:

(i) fishing method (or methods) to be used;

(ii) working deck space required and the location of the principal operating areas;

(iii) amount of time spent travelling to the fishing grounds;

(iv) climatic conditions likely to be encountered and their probable variation through the yearly cycle;

(v) power requirements for propulsion during the fishing operation;

(vi) expected catch and the method of bringing it aboard;

(vii) auxiliary sources of power necessary to:

- (a) the fishing operation, e.g. winches, net and line haulers, etc.
- (b) navigation and detection of fish, e.g. radar, echo sounders, sonar, etc.
- (c) conservation of catch, e.g. power requirement for refrigeration in one of its several forms
- (d) life on board, e.g. cooking, lighting, heating or cooling of living spaces, etc.

As we are considering wind power as a primary source of propulsion, the ease with which a partidular type of fishing can be adapted (or readapted) to sail power will depend on the power needed for auxiliary operations during fishing, speed requirements for fish capture, and the relationship between travel to the grounds and the intensity and duration of fishing operations. Obviously certain fishing methods - those requiring long periods of free running at less than full speed, with minimum use of auxiliary power for the operation of gear will lend themselves most readily to an investment in the gear and skill needed to operate a sailing fishing boat, the advantages to be derived decreasing in proportion as the power output for gear operation and/or speed requirements for fish capture increase.

A few examples should be sufficient to emphasise the point. In descending order of advantage we might list:

(i) trolling for surface and near surface pelagics (with the exception of certain species, such as skipjack tuna which travel fast and require a speed and manoeuvrability for maximum catches which is beyond that to be expected from a working sail boat

(ii) long lining

(iii) pot and trap fishing

(iv) gillnetting

(v) seining and lift netting with lights.

At the other end of the scale, we would expect to find modern day purse seining and deep bottom and mid-water trawling. In these cases any advantages to be derived from sail power would be excusively in free running between port and fishing grounds. The high towing power needed for a trawl or the speed for setting a seine, together with the considerable auxiliary power requirement of winches and power blocks, demand considerable alternative energy sources for the large amounts of mechanical power needed, with a consequent reduction in the economic importance of the proportion of energy input which can be provided by sail power.

3. SAIL SYSTEMS

With due consideration being given to the operation requirements of Section 2, let us now look at different sail systems to see what characteristics of the different rigs are favourable for adoption by fishing vessels.

3.1 Traditional working sail rigs

3.1.1 Spritsails and their rig

The spritsail is a quadrilateral or triangular sail extended from a comparatively short mast by the use of a spar which braces the sail at single point either at the head or the clew.

Perhaps the most well known large example of a working spritsail in commercial use until our own time was (or rather is) the Thames barge (see Fig. 1). Smaller craft around 20-30 feet using this rig were and are numerous, ranging from the sailing dory and wherries of the United States, to the still to be seen sailing fishing canoes of Senegal and the larger transport boats working the estuarine ports and lower reaches of the river Gambia (see Figs. 3 and 4).

Another version, most commonly known in the New Haven Sharpie, uses a horizontal sprit to the clew of the sail but the principle is the same (see Figs. 12, 13 and 14). The prime advantage of the spritsail is in its ease of handling and, especially in the smaller sizes, the simple rig, (see Figs. 7 and 8). The Thames barges were renowned for their crew of two, confidently handling a total sail area of more than 4,000 sq. ft. with 15-1600 sq. ft. in the main sail alone.

Additional advantages of the rig are in the possiblity of brailing the sail up to the mast for quick sail reduction or to leave the deck free for working, (see Fig.2). On the smaller sizes another quick reefing technique is to "scandalize" the sail, by which the sprit is removed from the peak and the upper part of the sail allowed to drop down to leeward, thus effectively reducing the sail area to that of a triangle with corners at masthead, tack and clew, (see Fig. 9). Smaller reductions can also be made by easing off the heel of the sprit and taking in a reef in the conventional way (see Fig.10) or by removing a "bonnet" or separate section of the sail as seen in the illustration of a Chinese spritsail in Fig. 5.

The spritsail is capable of some variation in draft according to wind strength. In moderate to strong winds the lower end of the sprit is hoisted higher by means of a single purchase in smaller boats and with the use of tackles in the larger vessels - as can be seen in Figs. 1 and 2. The peak of the sail is thus pushed out and higher, flattening the sail, bringing the draft forward and improving performance to windward. In light airs the heel of the sprit is moved forward and lower by easing the tackles, giving the sail a further curved shape.

The simplicity of the sail and its fabrication has much to recommend it for small craft particularly where fishermen are not accustomed to sail or do not have a previous tradition in another rig.

3.1.2 The lateen rig

The principal advantage of the lateen rig is the large area of sail that can be set on a short, unstayed (or lightly stayed) mast, (see Fig.17). The gear is simple and, in small sizes, relatively light and easily handled. A major inconvenience compared to other sailing rigs is the comparatively unhandy performance beating to windward. In the raft kattumaran of Fig. 18 for example, the sail is usually furled, the simple shrouds loosed and the mast shifted from one side of the hull to the other as the kattumaran passes or is paddled through the eye of the wind.

In the case of a constant wind system of the monsoon or trade wind type, which provides a comparatively stable wind direction parallel to or at more than 45 degrees to the trend of the coastline, this is not such a great disadvantage and it is usually under these conditions that the rig has developed as a means of propulsion for small craft carrying out a day operation from the beach. Larger craft have traditionally followed the monsoon systems and their seasonal changes to avoid the need for periods of beating into head winds.

The lateen rig has probably evolved from the square sail to provide improved performance when sailing against the wind. On this point of sailing, the leading edge of the sail should be kept taut and a square sail can only be set at a limited angle to the wind before the leading edge is taken aback. If a sail attached to something solid such as a mast, a spar or a stay or the leading edge is kept taut by battens and downhauls (or Chinese rig), the sail can be set much closer to the wind to give improved windward performance.

In the case of the lateen sail we can envisage the original yard of the square sail tilted down to form a solid leading edge. There are two forms of the lateen sail, one forms a complete triangular sail such as that seen in the Mediterranean type shown in Fig. 15 of a Venetian galley. This type is also seen in some small craft in S.E. Asia. In the second, which might be called the Arab rig as it is most commonly seen in the vessels described as Dhows, the forward corner is cut off, leaving a short unsupported edge, properly called the luff. The advantage of this sail shape is that a bigger area of sail can be set on the same length of mast. With a fixed pole mast of the Arab type the portion of the yard forward of the mast cannot be longer than the mast itself as the whole yard has to be swung up vertically when the vessel goes about. In a triangular sail the forward end of the yard carried a relatively small amount of canvas if the mast height is kept small. But by cutting off the corner, the amount of sail that can be carried is increased without increasing the yard length. For example, a traditional Dhow with a mast of 65 feet in height can set over 7,000 ft^2 of canvas in a single sail which is more than any other working rig.

The luff of the sail is heavily roped and is kept taut by a downhaul lashing, and the weight of the yard.

As the rig is still commonly used in many small traditional crafts in Asia (e.g. the raft and boat kattumarans of India), the method of setting and manoeuvring the sail is described for two typical crafts, (see Figs. 18 and 19).

The raft kattumarans of Tamil Nadu, Fig. 18, and the boat kattumarans of both Tamil Nadu and Andra Pradesh all use the lateen sailing rig as their principal means of propulsion other than the paddles and oars used to propel the craft through the surf.

When crossing the surf line the mast sail, yard and boom are lashed to the craft. Once through the breaking surf the sail and its rig are unlashed, forward and aft shrouds loosely attached on the windward side and the heel of the mast placed in the hollow of the leeward kombu. One of the crew members balances the sail (already attached to the yard and boom) on his shoulder while standing close to the mast position. The grommet on the yard (see (4) and the enlarged detail at A) is lifted over the mast head and settles into the top knotch over the top of the shroud.lashing. The sail and boom are then unfurled, and while another crew member tightens up the shrouds, at the points shown, to held the mast in position against the weight, the first crew member pushes the boom aft, far enough to allow the outer of the two rope loops on the boom to be passed around the mast and over the boom end (see (11) and enlarged detail at B). When the boom moves forward under its own weight and that of the sail, it is effectively held against the mast, and yet can be quickly released when desired. Either the helmsman or one of the crew members than hardens in on the main sheet until the correct sail angle is reached for the desired point of sailing and the kattumaran begins to move forward under the pressure of the wind in the sail. For longer yards an after guy (17) is also used to control the angle of the yard to the wind.

When sailing close hauled the mast is angled well forward and with the head slightly to windward by the adjustment of the two shrouds. The lashing on the heel of the yard is taken around the forward shroud and the yard heel is triced well up to windward. At the same time the main sheet is hauled in and the after guy tightened to reduce the tendency of the yard to, sag away to leeward. In this way the sail can be set quite flat and is an effective driving sail up to about 50 degrees from the wind. On this point of sailing the leeboard is necessary to reduce the tendency of the raft to slide away to leeward. The head of the board is lashed to the mast and the board held in place by water pressure. According to the wind strength and degree of leeway the board can be raised or lowered and lashed in a new position as desired. When sailing close hauled, the kattumaran, as any other unballasted small sailing craft, will heel to leeward and the crew sit out to windward using their weight to counterbalance the wind pressure. In stronger breezes a log is used as a "hiking board". One end of this log is forced under the after lashing with the other end outboard to windward. One crew member then sits on the log, moving further outboard on the log as the craft heels to increased wind pressure.

To tack through the eye of the wind requires the lowering of the sail, shifting of the mast to the other side of the craft and resetting of the sail. As in a wind of any strength, ground is often lost to windward during this manoeuvre. Close tacking to reach a position directly to windward is not usually attempted; instead the sail is taken down and the craft rowed or paddled.

The manoeuvre is accomplished as follows: the helmsman hauls in the main sheet and steers the craft in a curving track towards the eye of the wind. The boom to mast lashing (11) and the yard heel rope (9) are cast off, the main sheet and aft guy slackened and the yard swung to a horizontal position. A crew member grasps the boom and furls the sail around it up to the yard.

Yard, sail and boom are supported on a shoulder and the strop holding the yard to the mast lifted off. The shrouds are released and the heel of the mast is lifted out of its positioning hole on the leeward side log. If the raft carrie its way through the eye of the wind, the head of the mast is then dipped under the yard to the new windward side and the heel placed in the depression in the other (leeward) kombu. As the shrouds are set up to windward, the crew member supporting the sail drops the yard grommet over the mast head and the sail is allowed to unfurl to leeward. The same procedure is then followed as for setting the sail, as described above. If the raft does not carry her way through the wind, the mast sail and yard are dropped on to the logs and the crew members paddle the craft through the wind to the new point of sailing, the mast and sail are set up as before and the kattumaran takes off on the new tack.

As the kattumaran bears away from the wind the main sheet and guy are slacked off and the yard heel lashing released to allow the sail to swing forward progressively as the wind moves aft. The leeboard is not required as the wind moves aft of beam and it is unshipped. In order to bring the centre of effort as near as possible to the centre line of the craft, the shrouds are tightened to pull the head of the mast as far as possible towards what was the windward side, also moving the sail and its centre more towards the centre line. The effect of this movement reduces the couple between the centre of lateral resistance of the hull and the centre of effort of the sail, thus making for easier down wind steering, such as is done in a windsurfer where the mast is also centred well to windward when sailing down wind.

The nava of Andra Pradesh (see Fig. 19) is a planked craft with a flat bottom and considerable rocker in the ends. This is a heavier open craft capable of carrying considerable loads and is used for gill netting and beach seining.

The sail plan differs from the kattumarans principally in having a heavier and longer mast without stays or shrouds. The halyard used for hoisting the yard runs through a hole in the head of the mast and is then taken across the windward and set up tight, thus acting as a form of shroud support for the mast. The mast itself is lashed to a heavy thwart at a position a little more than 1/3 of the hull length aft of the bow. The heel of the mast is tapered and rests in a hollowed out mast step which permits the mast to be swivelled in place when the thwart lashing is slackened off.

The sail is set loose footed and the heel of the yard is set on the fore deck with the tack of the sail lashed down to a crossbrace in the bottom of the boat under the foredeck. When tacking, the tack lashing is released, the yard swung up vertical and carried back aft of the mast and then forward on the new leeward side. At the same time, the halyard is cast off and carried to the new windward side and set up. While this is being done, the mast thwart lashing is slackened and the mast rotated in the step so that the halyard leads correctly from the yard through the sheave hole in the mast head and down to the new windward side.

When jibbing the sail is allowed to fly forward, the main sheet is carried around the yard and the sail set up on the new leeward side. As the sail is carried forward the mast is rotated so that the yard moves around its forward face to take up its new position. The halyard and guy are set up again and the mainsheet hauled in to set the sail for the new course.

These two examples of the lateen rig have been described in some deatil as they illustrate the basic principles of a rig which is still commonly used in the Asian region in small traditional craft.

When proposing to increase the use of sail to reduce energy consumption in fishing craft it is suggested that if a traditional rig has been used for a long period in the area and knowledge of its operation is still available then at least in initial stages of reintroduction of sail the traditional rig should if possible be retained and modified where necessary to fit new circumstances such as the use of combined sail/power as described in Section 1.4.

3.1.3 The Chinese lug sail

Figs. 23-32 show various forms of the traditional Chinese sail. Referring to Fig.24 we can see the components of a typical Chinese sea-going sail. The mast is frequently a single pole without stays in the smaller types, although stays are used in larger craft. However, the fully battened sail and sheeting arrangement of the Chinese rig enables the forces exerted by the sail on the mast to be fairly evenly distributed over the entire length rather than concentrated in one or two points as is typical of Occidental sailing rigs. Because of this fact a fairly heavy pole mast can resist the forces applied to it without the complicated rigging employed by Western craft.

The sail is a fully battened balanced lug and its shape and cut depend very much on the region of China in which the craft operates. In general, Southern sea-going rigs have fairly highly peaked sails, while those of the more Northern provinces and inland lakes and rivers use a more flat headed, narrow and taller sail (see Fig.25). The sail is stiffened and controlled by full length bamboo battens and a seemingly complex system of multiple sheets. Principle advantages of the system are the control over the sail that can be exerted by the multiple sheeting system and the flatness of the sail given by the multiple full length battens.

Because of this control the Chinese sail is very well suited to the combined use of power and sail. See Fig.38 in which an examination of the wave form will show that the hull is being driven at, or just above, full speed by the use of an improvised belt-driven engine of 10 hp and a single sail.

The Chinese lug sail rig carries only one fully battened sail on each mast. In larger sizes, sail, yard, battens and boom can be very heavy - whole weight carried by one or more halyards from the top of the mast. Therefore sail size is limited, the largest practical being probably about 185 m^2 (2000 ft^2).

In experienced hands the Chinese sailing vessel is easily manoeuvrable. Turning circles are small and the vessels sail well into the wind as the fully battened sails can be sheeted hard in and still draw well.

The Chinese lug sail rig can be designed to use battens of equal length and the rig is easy to reef, unreef and fuel from one location without touching the sail. The rig is inexpensive, provided a solid wood spar is available. The complete rig consists of mast, sail, battens (bamboo where available otherwise aluminium tubing), blocks and running rigging. There is no need in the smaller sizes for winches (see Figs. 32 and 33 for details of simple hard winches), and no stainless steel rigging, rigging screws, chain plates, crosstrees and their fittings, fore and back stays etc.

The sail is cut flat getting its shape from the battens and the sheets. A vessel of 15 m with a sail area of 138-140 m^2 (1500 ft^2) does not require more than one or at most two crew for any sailing manoeuvre including tacking, gybing, reefing, furling and making sail, the sails being controlled by hailing in or slackening ropes which can if required be brought to a central point so that there is no need to move around the deck.

Reefing is accomplished by letting the halyard run, the weight of the sail and battens causing it to fall the desired distance to be gathered by the topping lifts (see Fig.35). The multiple main sheet is hauled in to achieve the desirable trim of the sail and shortening sail is complete. An additional refinement is in the adjustment of the mast inhaul (see Fig.24) to move the centre of effort of the sail to the most desirable point for balance of the new sail area to the centre of lateral resistance, reducing the amount of helm required and making the craft easier to steer.

When tacking or gybing there is little to do except steer as the sails look after themselves. When head to wind the sail does not flog but just waves backwards and forwards quietly. The sheet can be let go and the sail allowed to swing to the wind at any time when weight is to be taken off the vessel. When gybing, particularly with larger sails, it is common practice for a crew member to slacken off the halyard reducing the sail area by 1/3 to 1/2 of its area at the moment when the sail swings across the wind, thus reducing the shock loading on sheet battens and mast as the sail is brought up at the end of the gybe. The rig is at its best in heavy weather when it performs better to windward than a gaff sail and is much more efficient off the wind.

The Chinese lug sail does not perform well to windward in light airs with sea running and in this situation the use of engine power would be advisable. Addition jibs, light weight genoas or staysail between the masts could be set in these circumstances but the requirement for additional staying of the masts and the added complexity of sail wardrobe and handling would probably not justify the effort when auxiliary power is available. See Fig.29 for an example of a flying staysail set on a Chinese lake fishing boat engaged in pair trawling (photographs taken by the author in September 1980).

3.1.4 The gaff sail

Due to the widespread use of the triangular sail and its tall mast which has been developed for the requirements of racing yachts, where close hauled performance is of primary importance, the gaff sail has tended to fall into disrepute. For fishing boats, where performance to windward is not necessarily the major consideration, the rig has very much to offer and Figs. 39 to 49 show the extensive use made of the rig in Europe and America in the 1800s and early 1900s.

The gaff mainsail is a quadrilateral shaped sail with its luff fastened to the mast traditionally by wooden hoops or a lacing in smaller craft. The gaff which is laced to the head of the sail is hoisted by two halyards - a main or throat halyard and a peak halyard, see Fig.41 for details of the hoisting arrangement aboard a typical British trawler of the 1920s, with a rig that had changed little from the previous century. The foot of the sail was not laced to the boom as it was considered that the shape of the sail was more efficient if it kept its curved shape throughout.

Light weather top sails could be set above the main sail on a sliding top mast which could be run down in bad weather to reduce the weight aloft. Earlier fishing vessels usually had one mast, but as the size of the vessels increased the increase in sail area resulted in inordinately long booms which became difficult to handle so that in European waters the ketch rig developed with the larger or main mast foward and the smaller or mizzen mast aft. One of the principal fishing methods of these vessels in the mid 1800s to the early 1900s was beam trawling and Fig.42 shows the method of setting the beam trawl. The rig was ideally suited for the arduous conditions to be found in winter trawling in the English Channel and the North Sea.

In the United States and Canada, with different weather conditions and different fishing methods, another double masted rig developed, that of the schooner with its longer or main mast aft.

These vessels were designed to sail fast to the fishing banks off the North Eastern coast of the United States and Canada and line fishing was the principal method employed. Figs.45 and 46 show schooners under full and reduced sail. Fig.47 shows rigging details for a 32.60 m (107 ft) schooner.

In Fig.48 we see the flexibility of the rig with changing weather conditions. A choice of sail could be made for any condition with sail set remaining balanced to give an easily steered and seakindly craft.

Many western seamen consider the schooner the best and most versatile rig of all; for the larger fishing vessel and in areas where primary experience is with western type rigs this is probably that which will be adopted. The modern sailing fishing vessel of Fig.51 uses the same mast configuration but with high aspect masts and sails - in this case made easier for handling with roller furling and reefing sails. Time will tell whether the lower masts and simpler rig of the gaff schooner will prevail. Certainly, for simplicity of rig it has many advantages for a developing country.

3.2 Rigs derived from pleasure craft

Thanks to the rapid growth of pleasure boat sailing and the experimentation in materials, rig and hull form which has taken place in recent years, there is a considerable body of experience on which a designer can draw when proposing new rigs and sail systems for fishing vessels. Even if a decision is taken to revive a traditional rig, the use of modern synthetic sails and running rigging aluminium mast and boom extrustions etc. can increase efficiency, decrease weight aloft and reduce the maintenance required. Fig.49 shows a pleasure craft design by the author for a 23 m (75 ft) schooner using modern materials for a traditional rig.

The convential Bermudian rig of pleasure craft, while more efficient to windward is at a disadvantage compared to some traditional working rigs off the wind. This is overcome by the use of large, lightweight spinakers, "big boys","tall boys", etc. as shown in Fig.50, which while suitable to the pleasure craft racing fraternity are unlikely to meet with much approval in working fishing craft due to the additional complexity of rig and handling requirements.

How then is the working fishing boat to utilize the Bermudian rig and recent advantages in technology without becoming involved in complex down wind sail handling?

One of the primary requirements for a working fishing craft is to be able to set sufficient sail to obtain the required drive under varying wind speeds and directions and at the same time be able to reduce sail area readily both when the wind increases and when it is necessary to clear the working deck for a fishing operation. As has been seen, successful traditional working rigs made provision for this requirement. Probably the most useful technical advance in this respect is the development of roller reefing and furling sail systems.

These enable the sail to be rolled up either around a wire stay or a tubular aluminium extrusion. Figs.51 and 52 show a proposal for a schooner rig using this principle for all of the working sails.

For down wind performance with this type of rig it is possible to set twin staysails.

In this method the luff of each sail is set on a taut wire stay and a pair of sails is set side by side on two parallel stays with one sail to port and one to starboard. The sails are boomed out with two spars, the inner end of each spar being attached to the mast and the outer end to the clew of the sail. The angle to the wind is controlled by a sheet led through a sheave block on the outer end of the spar. If two sails are carried in this way they can both be fitted with roller furling gear so that sail areas can be reduced according to wind strength.

A further development of this type is seen in the Ljungstrom rig of Figs.55 and 56. In this case the sail is double sided. When going to windward one sail lies flat against the other. With the wind free the two sides are used in a similar manner to twin staysails. The operation is explained in Fig.56.

Use of the "wishbone" boom from sailboards (e.g. the windsurfer) is an interesting possibility for easily handled sails, see Fig.57, and the shape of the "wishbone" boom does not disturb the aerofoil shape of the sail as much as a single pole sprit may do on one of the two tacks.

3.3 Experimental sail systems

Of the experimental rigs for wind powered propulsion we can list four which could conceivably be of interest in fishing vessels large or small, these are:

1) Fixed aerofoils - which include both rigid and fabric aerofoils, amongst which are also included conventional square and fore and aft sails. Aerofoils of this nature convert wind power into a thrust which can be directly applied to moving the vessel through the water;

2) Magnus Effect Devices - of which the best known is the Flettner rotor which uses power rotated cylinders to produce an aerodynamic thrust;

3) Wind Turbines - in which wind power is converted into mechanical power by a wind driven rotor either on a horizontal axis similar to land based windmills or a vertical axis turbine either of which can be used to drive a shaft and conventional propeller;

4) Airborne kites - which can be set and retrieved from the deck of the vessel and produce traction forces which can be used to propel the ship.

3.3.1 Fixed aerofoils

Aerofoils of the rigid type may be compared with an aircraft wind standing vertically and in theory this type is one of the most aerodynamically efficient rigs. Its other advantage is in the purely mechanized operation which means minimum manpower in handling. Solutions to one of the major problems of stalling of the symmetrical aerofoil which is needed to enable the boat to sail on both tacks have been proposed. See Figs.60 and 61 for designs utilizing symmetrical aerofoils in which the slots between the aerofoils can be used to prevent stalling and obtain high lift values. Other solutions to the problems of rigid aerofoils seem to be solvable, the practical problems of where on a fishing vessel to site foils of sufficient size to generate the required power without interfering with the fishing operations still remain. Cargo ships might well use rigid aerofoils which can be folded up in part to give access to cargo holds but a fishing vessel needs clear access on deck while working her gear and under way at sea.

A purpose design of rigid foils of a size and efficiency appropriate to fishing vessel operation needs to be prepared and analysed both in relation to speed generated by the foils and in the reaction of foils and operational requirements as discussed in Section 2.

3.3.2 Magnus effect devices

So called from H.G. Magnus who developed a theory of the generation of lift on a rotating cylinder lying crosswise in a stream of fluid. The effect was applied to ballistics and the explanation of the flights of such objects as tennis, golf and baseballs. From a sailing point of view the main interest in such rotating cylinders is that the flow of air around such a cylinder is similar to the flow around an aerofoil or sail. It can then be shown that such a rotating cylinder can generate lift and be used as a device for propelling a vessel in the same way as an aerofoil. The major difference being that the cylinder requires a power input to allow it to rotate before lift can be generated.

The best known example of the use of the Magnus effect was Flettner's rotorship. A schooner of 680 GT was converted in the 1920s and with two cylinders 18.30 m (60 ft) in height and diameter of 2.74 m (9 ft), rotated by 45 hp engines, the ship achieved speeds of 5.6 knots in a 10 knot wind. An advantage of the rotorship is that an increase in wind strength beyond about 12 m/sec does not result in an increase in the forces on the cylinders - the lift generated being dependent on the speed of rotation of the cylinders. This means that the ship is not greatly affected stability-wise by squalls and large increases in wind strength, with obvious advantages.

It is possible to calculate the drawing force on a vessel hull fitted with two rotors of 9.15 m (30 ft) in height and diameter 1.54 m (5 ft) at an apparent wind velocity of 40ft/sec and cylinder rpm of 360, as 948 kg (2090 lb) in the direction of rotation.

From our resistance curve of Fig.63 this would result in a speed of 8.9 knots at 60 t displacement.

The original experiment failed economically because of the relatively low cost of fuel at the time. With present day fuel prices the Flettner rotor deserves arevival with a close look at operational characteristics and economic viability.

3.3.3 Wind turbines

In this system wind power is converted into mechanical power by a set of turbine blades either on a horizontal axis, as in the familiar windmill seen in rural areas of many countries or by turbine blades which rotate on a vertical axis.

The mechanical power from the turbine blades in either system is then used to drive the vessel through a conventional propeller arrangement See Fig.62 for a design idea of how this might be done.

Practical windmills achieve at best efficiencies of about 35% but their most interesting potential lies in the fact that, in theory, a wind turbine powered ship can be driven in any direction, including directly into the wind.

There are, however, practical problems. Performance in a 15 knot wind gives only about 1 hp for ever 9.29 m^2 (100 ft2) of projected area, which suggests that in any but strong winds the size of the windmill required would be larger than could be made available on the average fishing vessel. Other practical problems concern the difficulty of reducing blade area in strong winds and the risk of damage to the structure.

3.3.4 Airborne kites

The first impression one tends to get from the idea of kites being used as a towing force for the propulsion of ships is that it could not possibly work. However, small craft have been towed some distance by specially designed kites and there is some experimental work being carried out today.

Kites have been tried on displacement hulls with lengths of up to 10 m and kite areas up to 50 m^2 (538 ft^2).

Apparently a useful kite area is approximately equal to the hull wetted area, which is not beyond the bounds of possibility for fishing vessels.

Kites can be floatable and launched from the water and control is managed by 3-4 lines which apparently can be managed from a 3 drum winch, which is a piece of equipment frequently found on fishing vessels, e.g. shrimp trawlers. During launching of a kite from the water the winch pulling speed required is up to 5 m/sec.

The concept is still very much in the experimental stage and at this stage it remains an interesting idea which should be kept in mind as a future possibility when the experimental phase has produced results which can be translated into quantifiable fishing vessel terms.

4. DESIGN CONSIDERATIONS

4.1 Displacement Mono Hulls

4.1.1 Hull design

The hull of the vessel must be able to resist the sideways force of the sailing rig to a sufficient extent to avoid excessive amounts of leeway and it must hold the rig up against the wind pressure.

The shape should be of a sufficiently balanced form that heeling under sail will not result in an immoderate increase in immersed volume either fore or aft of the centre line. For example, beamy hard chine fishing vessels with wide transoms with maximum transom beam carried well out to the immersed waterline are not likely to produce a happy result under sail, unless the amount of sail carried is so small as not to result in appreciable heeling moment. In this case sail could only be considered as an auxiliary to a powerful engine and while some benefit in fuel economy may be derived this will not be as significant as in a craft which is purpose designed to carry sufficient sail to operate under sail alone, when the wind is favourable, or with only minor assistance from an engine at reduced power.

The hull should have fairly well rounded sections with a moderate deadrise and a smooth run to its longitudinals. A transom stern is not disadvatageous, provided its shape and that of the after body are designed so as not to immerse larger volumes aft when the craft heels.

In materials such as steel, ferrocement or FRP a box keel section is useful to provide space low down for the ballast which will be needed for stability. Double bottom fuel tanks are also useful for this purpose provided that stability is sufficient when fuel is carried or they can be arranged to be filled with ballast water in the exceptional case where no fuel is carried and no fish have been caught to add the necessary weight. Any changes of weight distribution due to fuel consumption and the taking on of fish must be carefully planned to avoid trim changes to which a sailing vessel is much more sensitive than a wide beamed full powered motor vessel.

4.1.2 Speed under sail

Calculation of maximum sail areas to be used and accurate speed estimates of a sailing fishing boat are a matter for the designer, however, some idea of the likely speed that can be achieved is important in order to estimate the saving of energy that can be achieved by the use of sail.

When normal displacement vessels (non planing), which include most sail-carrying fishing vessels, are considered speed is a function of the waterline length of the immersed hull (not necessarily the static waterline length). From this fact can be derived what is known as the speed length ratio which permits speed comparisons of vessels of different sizes. This ratio is commonly expressed as the speed of the vessel in knots divided by the square root of the waterline length in feet.

The best average speeds achieved by yachts (less can be expected for fishing craft) when sailing to windward in smooth water is rarely more than $V/\sqrt{L} = 1$, while in any sort of a sea a figure of 0.8 is more likely. In lighter winds of say 6-10 mph $V/\sqrt{L}$ value will be 0.6 or less.

Highest speeds are achieved with beam winds but, even in ideal conditions and smooth water, speeds will rarely exceed $V/\sqrt{L} = 1.4$. In average winds speed with the wind from aft will be about 2/3 of that on the beam with the values approaching parity with increasing wind strength.

If the speed under sail of one vessel is known at a particular wind velocity then the speed of another vessel of similar hull form but of differing displacement and sail area can be estimated from the formula:

$$\frac{SA_1}{SA_2} = \frac{\Delta_1^{2/3}}{\Delta_2^{2/3}} \times \frac{V_1^2}{V_2^2}$$

where SA_1 and SA_2 are the respective sail areas Δ_1 and Δ_2 are the displacements of the two vessels and V_1 and V_2 will be the speeds achieved.

These speeds do not take account of light displacement vessels, multi-hulled craft, including catamarans, trimarans, outriggers and proas where greater speeds can be achieved because of the light displacement or a combination of this with the increased initial stability and greater sail carrying ability of the multihull as discussed in section 4.2.

4.1.3 Calculation of sail area and stability

While calculation of sail area, balance and stability of a sailing fishing vessel requires a complete design study, it is possible to make a preliminary estimation of the sail area required to propel such a fishing vessel at a reasonable speed. A provisional figure can be obtained for load carrying fishing vessels in the size range 12-22 m LOA from the equation:

$$\frac{\text{Sail Area in m}^2}{\text{Loaded displacement in tons (m}^3\text{)}} = \text{Coefficient of 1.5 to 2.}$$

Table I gives a list of dimensions of sailing fishing vessels in this size range with the appropriate coefficient. An additional check on suitable sail areas in relation to wind strength can be derived from the calculation of air pressure on the sail surface. From reference 1, the driving force of the sails can be calculated according to the sail area SA, the wind velocity VA, the mass density of air ρ and a driving force coefficient C_R.

In Imperial units the driving force $F_R = 3.394 \times 10^{-3} \times SA \times VA^2 \times C_R$. From reference 1, C_R for a beam wind is approximately 1.2. Given the sail area and the desired wind velocity, the driving force F_R can be calculated. Alternatively, with a knowledge of the driving force required to achieve a certain speed the desired sail area for a particular wind velocity can be found.

Let us assume that we wish to calculate the sail area necessary to propel a sailing vessel at a speed length ratio of 1 in a favourable beam wind of 15 knots (the upper range of Force 4 on the Beaufort scale). If a resistance curve plotting resistance against speed similar to that shown in Fig.63 is available it is a simple matter to calculate the driving force required at a particular displacement to overcome the resistance of the hull and propel the vessel at the desired speed length ratio.

Using this figure we can calculate the sail area required from the equation:

$$SA = \frac{F_R}{3.394 \times 10^{-3} \times VA^2 \times C_R}$$

If a resistance curve is not available an approximation for the driving force can be estimated from the data available for engine driven vessels. Assuming that to drive a well designed vessel at a speed length ratio of 1 will require approximately 1 hp/ton of displacement and assuming that for the free running condition one hp will provide a thrust of approximately 10 kg (22lb), the driving force in kilos (pounds) will be approximately 10X (22X) the displacement in tons. Using half load displacements (as an average figure) of several of the vessels listed in Table we can calculate the possible sail area.

1. 21.34 m (70 ft) staysail schooner (US) 1/2 load displacement 84 t (est) SA = 187 m^2 (2008 ft^2) which agrees with the designed sail area of 187 m^2 (2012 ft^2)

2. 19 m (62 ft 4 in) staysail schooner (Fr) 1/2 load displacement 78 t SA = 167 m^2 (1793 ft^2) which is higher than the designed sail area of 150 m^2 (1620 ft^2)

3. 16.15 m (53 ft) gaff schooner (US) 1/2 load displacement 55 t (est) SA = 122 m^2 (1315 ft^2) which is lower than the designed area of 139 m^2 (1500 ft^2)

4. 16.15 m (53 ft) Bermudian ketch (US) 1/2 load displacement 51 t (est) SA = 113 m^2 (1220 ft^2) which is in close agreement with the designed area of 117 m^2 (1260 ft)

5. 14.33 m (47 ft) Bermudian ketch (US) 1/2 load displacement 45 t (est) SA = 100 m^2 (1076 ft^2) which is in fairly close agreement with the designed area of 89 m^2 (960 ft^2).

This calculation which, as can be seen, gives a reasonably close result when compared with actual designed sail areas, does not take into account the hull stability required to carry this amount of sail. It is the job of the designer to calculate the stability of the vessel and equate this to the heeling moment which will be caused by wind pressure on the sails in order to be sure that the vessel will not capsize or heel to an unacceptable angle in the wind speeds likely to be encountered. It is however possible to make some basic assumptions which will indicate whether a particular sail area and sail plan are acceptable on a properly designed hull. The stability of a sailing craft can be shown to be dependent on the sail area SA, the heeling arm H (which is approximately the height of the centre of effort of the sail area above the mid draught of the hull) and the wind pressure P to which the sails are subjected. The forces generated by these three components tending to heel the vessel to an angle of X degrees will be opposed by the righting arm GZ of the hull multiplied by the displacement. For small angles of heel the righting arm GZ can be taken as equal to GM sin θ where GM is the transverse metacentre height and θ the angle of heel. Therefore the sine of the angle of heel will be equal to

$$\text{Sin } \theta = \frac{SA \times P \times H}{\Delta \times GM}$$

As a first approximation we cann assume that for small sailing craft in the size range we are considering a properly designed hull will have a GM of approximately 1 m (3.28 ft). This figure will be somewhat high for the larger craft but is a good approximation in the 12-16 m range.

If we have a sail plan for a proposed vessel and know the displacement it is possible to calculate the heel angle for a given sail area, heeling arm and displacement at a given wind pressure. If we assume that full sail is carried up to a wind force of 20 knots and that wind pressure at this speed will be approximately 9.8 kg/m^2 (2lb/ft^2) then we can calculate the heeling angle produced by a particular sail area and heeling arm. If we assume that for a working fishing boat operating under sail, stability should be such that under these conditions the heeling angle should not exceed 20°, we can then determine whether a particular sail area can be carried at a proposed heeling arm. Taking the 19 m staysail schooner of fig.51 as an example, the 1/2 load displacement is 78 t, the SA 150 m^2 and the heeling arm as measured is 10.25 m

$$\text{i.e. } \quad \text{Sin } \theta = \frac{150 \times 9.8 \times 10.25}{78 \times 1000\text{kg} \times GM{=}1} = 0.19$$

which is equal to a heeling angle θ of 11° which indicates that the proposed sail area and heeling arm are acceptable.

It should be emphasized that the preliminary calculations given above are intended to provide a first approximation of likely sail areas and speed that can be safely achieved under sail. For example while the use of the stability formula with an assumed metacentric height GM will tell us approximately what is possible, a complete design calculation must also take into account the range of stability and therefore what value of wind pressure will cause the vessel to heel to an angle at which it will capsize. Factors such as the free-board and the vertical position of the centre of gravity of the boat in relation to its centre of buoyancy at different heel angles must be taken into account and a full stability calculation made.

As has already been mentioned in Section 4.1.1, conventional diesel powered fishing vessels are not suited to the carrying of sufficient sail area to make efficient use of sail, due not only to the balance of the hull under sail but also to the reduced wetted surface and the absence of ballast.

Small modern combination trawlers/purse seiners, for example, have increased superstructure height to retain maximum deck length for working purposes. Attempts to put sail on this type of vessel will result in a greatly increased heeling arm due to the centre of effort of the sails being very high over the centre of lateral plane. The heeling arm will become larger and stability will suffer. Acceptable heeling arms for sailing fishing craft of 50-100 t displacement range from 7.8 m for 50 t displacement to 10.5 m at 100 t. And superstructure heights must be modified to remain close to these values if a reasonable amount of sail is to be carried.

4.1.4 Combination of engine power with sail

In its simplest form, speed estimation under power can be related to displacement which in the lower speed ranges most affects the resistance to forward motion. Where speed/length ratios are to be kept to or below unity an approximation of 1 hp per t of displacement is sufficient in calm water whereas to achieve a V/ L of 1.3 where wave making resistance becomes more important, requires 3-4 hp/t. A $V/\sqrt{L}$ of unity will give speeds of 5.5 knots for 30 ft LWL, 5.9 for 35, 6.35 for 40. 6.7 for 45, 7.1 for 50, 7.5 for 56 ft.

Therefore the combination of enough hp to achieve a $V/\sqrt{L}$ ratio of 1 plus sail power can result in a significant increase in speed while utilizing power from diesel fuel at a most economical level.

Let us look at the resistance curve of a sail powered fishing vessel of 19 m (60 ft) LOA and 17 m (56 ft) LWL as seen in Fig.63. If with 1 hp/t of displacement we can obtain a speed length ratio of unity this would be approximately 7.5 knots for a 17 m (56 ft) LWL. At a displacement of 60 t from the curve of Fig.63 we can see that the thrust required to achieve this speed is 540 kg (1189 lb). If the total sail area of the vessel is 150 m^2 (1400 ft^2) in a true beam wind of 15 knots we may achieve a drive component of around 2.9 kg/m^2 (0.6 lb/ft^2) of sail, this means that with 150 m^2 (1400 ft^2) we can obtain 381 kg (840 lb) of thrust.

If we sum the thrusts from engine and sail, divide by the displacement and compare the resulting figure with the resistance curve, we will find that with sail and economical engine power we can achieve a speed of 8.9 knots or a speed length ratio of 1.2 which under power alone would require more than twice the horsepower.

This is a very simplified way of looking at the potential speed under sail and power and does not take account of increased resistance due to waves or leeway in winds forward of the beams. Balancing these losses to some extent is the fact that the speed obtained from the use of engine power will result in an increase in apparent wind speed. As the effect of wind speed on the propulsive force from a sailing rig varies as its square, the power output from the rig will be appreciably increased with a more favourable result on total speed.

A combination of engine and sail power at these speeds will mean a decrease in the apparent wind angle compared to that of the true wind so that the proportion of close hauled conditions will increase. Therefore a sail which produces good driving qualities when sheeted in hard at low wind angles will be advantageous. For the reasons discussed in Section 3.1.3, the Chinese lug sail makes a very good sail in these conditions, see Fig.38.

4.2 Multi hulls

Provided the basic principles of sucessful multi hull design are followed, these craft can have advantages over sailing mono hulls in certain well defined conditions. These advantages are: greatly increased working deck space for a given length, higher speed for the appropriate sail area and reduced angle of heel under comparable operating conditions.

In order to achieve the performance advantage, hull length to beam ratios of individual hulls are kept high giving long slim hulls with greatly reduced wave making resistance. Because of their form, load carrying ability is limited. While some racing catamarans may have hull length to beam ratios of 20:1, for practical workboat purposes the limit is about 14:1 for larger boats, reducing to 12:1 on smaller craft. Such hulls are very sensitive to weight additions and if improved performance over an equivalent mono hull is required the load carrying ability of the multi hull will be sensibly less than that of an equivalent length mono hull. This factor must be carefully considered when operating requirements of a design are evaluated.

Multi hulls do not depend on relatively deep draft and high displacement to achieve their power to carry sail but rather to the greatly increased initial stability due to their large overall beam compared to mono hulls.

In a double-hulled catamaran for example the overall beam may be close to half the length over all and as the shift of the centre of buoyancy on heeling will be half the overall beam less half the beam of the lee hull, for small heel angles there is a large increase in GM. Maximum righting moment occurs as the windward hull is just leaving the water and from this point, which may occur at heel angles of 10-15 degrees, the righting moment falls off rapidly. Catamarans therefore, because of this high initial stability, can carry larger sail areas than the equivalent mono hull and will sail more upright. Values of sail area to displacement for fishing craft will be of the order of 10 for light weights to 6 at full load, compared to the 1.5-2 of single hulls.

As the catamaran does not use ballast for stability the total light weight of the two hulls and the connecting structure will normally be less than or at most equal to that of an equivalent mono hull. At slow speeds the resistance will be greater than an equivalent weight mono hull since the wetted surface will probably be greater but with a larger sail area the catamaran should be faster. The maximum speed length ratio for a high speed racing catamaran is around 4.5. Working double hulled catamarans of 15 m length have been reported to achieve cruising speeds of 12 knots which is an S/L ratio of 1.7 which is faster than an equivalent length displacement mono hull can achieve under power.

A trimaran with floats on either side of a central hull will not achieve the same high initial righting moment as a catamaran and will therefore carry less sail. For equivalent windward performance to that of a deep draught mono hull, the multi hull will require some means of increasing lateral resistance and, where windward performance under sail is important, some form of centre board is desirable.

As has already been mentioned, successful operation of a multi hull presupposes relatively light displacement and hence reduced carrying capacity. In operational fishing conditions, where speed under sail is important, where the catch is of relatively high value for low total weight and where large deck area for handling gear is advantageous, the multi hull may well prove to be a very good solution.

5. THE ECONOMICS OF SAILING FISHING VESSELS

The economic viability of substituting a renewable energy source, wind, for non renewable fossil fuels in the powering of fishing vessels rests on an analysis of the costs of investing capital in the proposed energy source, compared to the monetary worth of the fossil fuel saved.

As has already been suggested, a return to sail as a sole energy provider is unlikely at least in the present and immediate future of fossil fuel availability and price. Sail power will therefore be considered as an auxiliary power source which can, under favourable operational conditions of fishing method, wind force and direction, also be used as the sole driving force for a fixed period of time.

On page 16, for a fishing vessel of 60 t displacement and waterline length of 17 m (56 ft^2)we assumed a speed of approximately 7.5 K using 1hp/ton of displacement, i.e. 60 hp delivered to the propeller.

In a favourable wind of 10 knots (5.1 m/s)the increase in thrust obtained with 150 m^2 (1400 ft^2)of sail was estimated as producing a speed increase of approximately 1.5 knots to give a vessel speed of 9 knots.

Using these somewhat oversimplified figures, let us first look at a typical fuel saving calculation. In a favourable beam wind using a combination of sail and power we can achieve a respectable speed of 9 K or SL of 1.2 utilizing some 60 hp. Under power alone we would expect to need 120 hp to achieve the same speed. To reach 10 K would require 234 hp or almost 4 x the hp for 7.5 K.

We cannot expect to always have either sufficient wind or to have that wind blowing from the most desirable direction. Let us for the purposes of calculation assume that we can average 70% of the thrust achieved under most favourable conditions. (This assumption should not be taken as typical of all cases and reasonable estimates of likely wind assistance should take careful account of local climatic conditions using meteorological information on average wind strength and direction, month by month.)

Average speed using an engine hp of 60 with wind assistance could then be estimated as approximately 8.5 knots.

Fuel consumption in litres/hour (Imp gals/hr) can be derived from a typical consumption curve which might give a consumption at operating RPM of 180 g/hp/hr (0.41b/hp/hr).

For 60 hp this would give an average consumption of 10.8 kg/hr
" 120 hp " " " " " " " 21.6 kg/hr
" 235 hp " " " " " " " 42.4 kg/hr

or 13 l/hr, 26 l/hr, 52 l/hr respectively (rounded to nearest litre). With a knowledge of trip times, distances to the grounds, time spent on actual fishing operations and typical power requirements during fishing it is possible to make an estimate of average fuel consumption per trip. With longer trips with considerable free running to and from the grounds the extra trip time to achieve equal fishing time must also be taken into account as crew costs will be higher in this case.

Let us now examine a hypothetical operational case in order to see how an estimation of potential saving can be made using a sail/engine power combination.

A breakdown of costs for a 19 m (62 ft) sailing fishing vessel could be of the following order of magnitude.

	US$	
Hull cost	180,000	
Machinery and Installation	40,000	
Hull Fittings and Equipment	34,000	
Sub total (i) - Hull, Equipment & Machinery		254,000
Fishing Gear	15,000	
Sub total (ii) - Complete vessel ex sailing rig		269,000
Masts and rigging	16,500	
Sail	6,000	
Steel ballast	8,500	
Sub total (iii) - Sailing rig		31,000
Total Investment		300,000

As we can see from this breakdown the cost of the sailing rig is of the order of 10% of the total investment although this cost is offset to some extent by the reduced cost of the engine installation - 100 to 120 HP compared to the 200 to 250 HP which would be normal for a fully powered vessel.

Assuming that the vessel has been equipped for trolling and deep reel handlining the total annual mileage covered in travelling to the fishing grounds and in the fishing operation could be of the order of 24,000 miles or a daily average of 120 miles for 200 days/year.

Our original estimates of speed did not take account of weather effects on speed. Wind speed varies in direction and force and this in turn affects the sea state. Both daily and seasonal variations occur and average wind speeds vary in different geographical areas. This is why it is difficult to quantify the input of wind power to a sailing fishing vessel operation in a particular locality without a good knowledge of average wind strengths and directions on an annual basis.

For our calculation let us assume that a combination of varying wind strengths and sea conditions will reduce the average speed maintained by the sail and 60 HP engine input of our vessel to 8 knots. At the same time, in order to maintain an average speed of 9 knots in all wind and sea states encountered a fully powered vessel will require an input of 160-180 HP.

If annual operational mileage is 24,000 nautical miles and average daily mileage 120 miles for 200 days the use of sail and engine input of 60 HP for a speed of 8 knots will give an average daily operational time of 15 hours while the use of full power of 160 HP to give 8 knots will require 13.3 hours. Daily fuel consumption for an input of 60 HP will be 195 l while 160 HP will require 465 l. At an average fuel price of $0.40/l daily fuel costs will be $78 and $186 respectively with yearly fuel bill of $15,000 and $37,200.

In this case annual fuel savings could then be of the order of $21,000. At this rate an initial investment of $31,000 in sails and rig could be recovered in approximately one and a half years.

These figures are given as an example of what might be possible in a particular case. For a full comparative economic evaluation of a potential design and sail power application more detailed information is required on the resources and fishing methods appropriate to its catch, wind and sea conditions in the area, time costs for crew and vessel operation, maintenance of sailing rig and gear, estimated catch rates and ex vessel prices for the fish landed.

For methods of calculation in more detail see chapters 6 and 7 on Construction Cost Estimation and Comparative Economic Evaluation in FAO Fisheries Technical Paper No. 188 Fishing Boat Designs : 3 which is available on request from the Fisheries Technology Service of FAO.

CONCLUSIONS

For fishing vessels the traditional working sail rigs still have much to offer. In many cases the simplicity of the gear, the ease of sail reduction in increasing wind strength, the possibility of readily clearing the working deck for fishing operations and good off wind performance make their use attractive in developing countries. The use of new materials developed for pleasure craft can increase efficiency and/or decrease weight aloft.

Modern Bermudian sail rigs developed for pleasure craft tend to require more complex staying systems and sophisticated sail handling to achieve best results, however developments in this field, notably in sail systems used in short handed long distance voyages are applicable to fishing vessel rigs.

None of the experimental rigs discussed have yet provided outstanding advantages which would warrant their immediate adoption for sailing fishing vessels. However, continued experimentation may well produce a rig with advantages in drive, simplicity and ease of operation, either for use as the principal power source or in combination with engine power.

Examination of the economics of the use of sail in fishing vessels indicates that in the present day climate of increasing fuel prices, combined sail and engine power operations are very definitely viable, particularly in fishing methods that require a large amount of free running time, either to the fishing grounds or in a searching operation for fish.

TABLE I DIMENSIONS AND COEFFICIENTS OF AUXILIARY/SAIL POWERED FISHING VESSELS

VESSEL DESCRIPTION	LOWESTOFT TRAWLER (KETCH) (UK)	LOTTIE S. HASKINS (SCHOONER) (US)	STAYSAIL SCHOONER (US)	STAYSAIL SCHOONER (FR)	RYE SMACK (KETCH) (UK)	GAFF SCHOONER (US)	BERMUDIAN KETCH (US)	BERMUDIAN KETCH (US)	FRIENDSHIP SCHOONER (US)
LOA m (ft)	23.9 (78'9")	23.64 (77'6")	21.34 (70)	19 (62'4")	17.8 (58'9")	16.15 (53)	16.15 (53)	14.33 (47)	7.31 (24')
LWL	21.35 (70')	19.83 (65')	17.83 (58'6")	17 (55'9")	15.66 (51'5")	14 (46)	13.1 (43)	11.58 (38)	6.2 (20'2")
B max	5.85 (18'6")	6.05 (19'10")	5.49 (18)	6 (29'8")	4.51 (15')	5.03 (16'6")	4.57 (15)	4.06 (13'4)	2.23 (8'7")
DEPTH	2.78 (9'2")	2.72 (8'11")	2.74 (9)	2.8 (9'2")	2.36 (7'9")	2.25 (7'4")	2.44 (8)	2.17 (7'2")	1.30 (4'3")
DRAFT (LWL)	2.90 (9'6")	3.20(10'6")	2.44 (8)	3.2 (10'6")	2.44 (8')	2.13 (7)	1.98 (6'6")	1.75 (5'9")	1.30 (4'3")
LIGHT SHIP/FULL LOAD t	-- (187)	-- (100)	60(107)	60 (95)	-- (88.4)	40 (69)	40 (62)	35 (55)	14.3 (19')
F-H CAPACITY m^3 (ft^3)	39.8 (1406)		68 m^3 (2350)	50 (1765)	25	22.6 (800)	19.8 (700)	17.6 (620)	-- (50)
FUEL CAPACITY l	--	--	15000	8000	--	7500	4875	2810	--
FW CAPACITY l				2000		2250	2810		--
INSTALLED BHP	--	--	150-180	160	--	150	90	60.8	--
SAIL AREA m^2 (ft^2)	288 (3117)	347 (3734)	187 (2012)	150 (1620)	149 (1605)	140 (1500)	117 (1260)	89 (960)	39 (423)
TOTAL LENGTH OF MASTS	33 (108')	49 (160')	45.11 (148')		30 (98')	29.6 (97)			6.9(22'6")
<u>RATIOS</u>									
CUNO m^3	375	389	321	319	197	183	180	160	26
BHP/ t(light)(loaded)	--	--	3 (1.68)	2.66 (1.68)	--	3.75 (2.17)	2.25 (1.45)	2.28 (1.45)	
V at V/ L = 1	8.4	8.1	7.65	7.46	7.1	6.78	6.55	6.16	4.6
V at V/ L = 1.3	10.9	10.5	9.94	9.7	9.3	8.8	8.5	8.0	6
SA in m^2/ t LIGHT SHIP	--	--	3.1	2.5		3.5	2.93 (31.5)	2.54	
SA in m^2 t FULL LOAD	1.5	3.47	1.75	1.58	1.68	2.03	1.89	1.62	2.05
SA/ 2/3	8.5	--	8.32	7.21	7.49	8.32	7.47	6.16	6.7

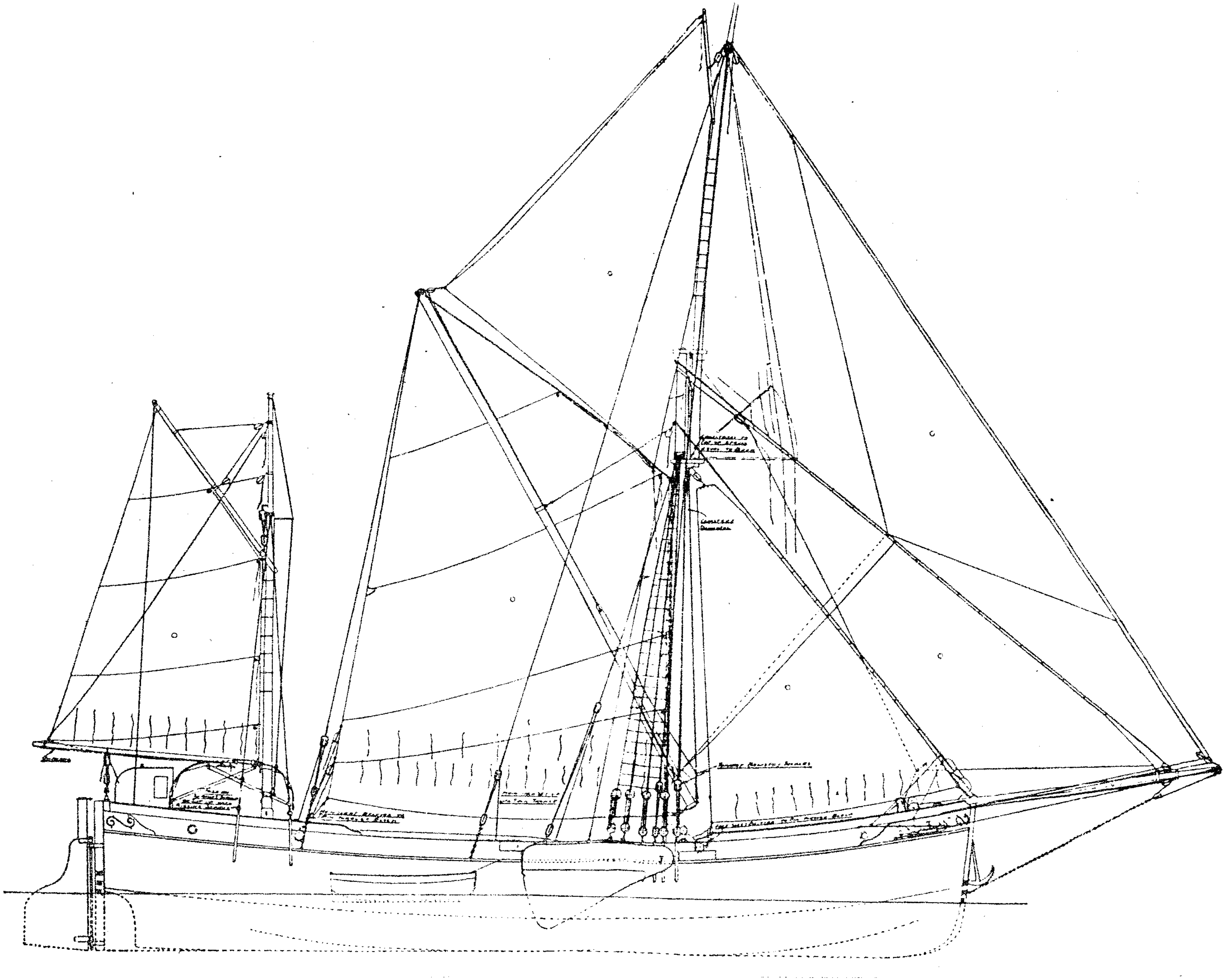


Fig. 1 Thames Barge with sprit rigged mainsail

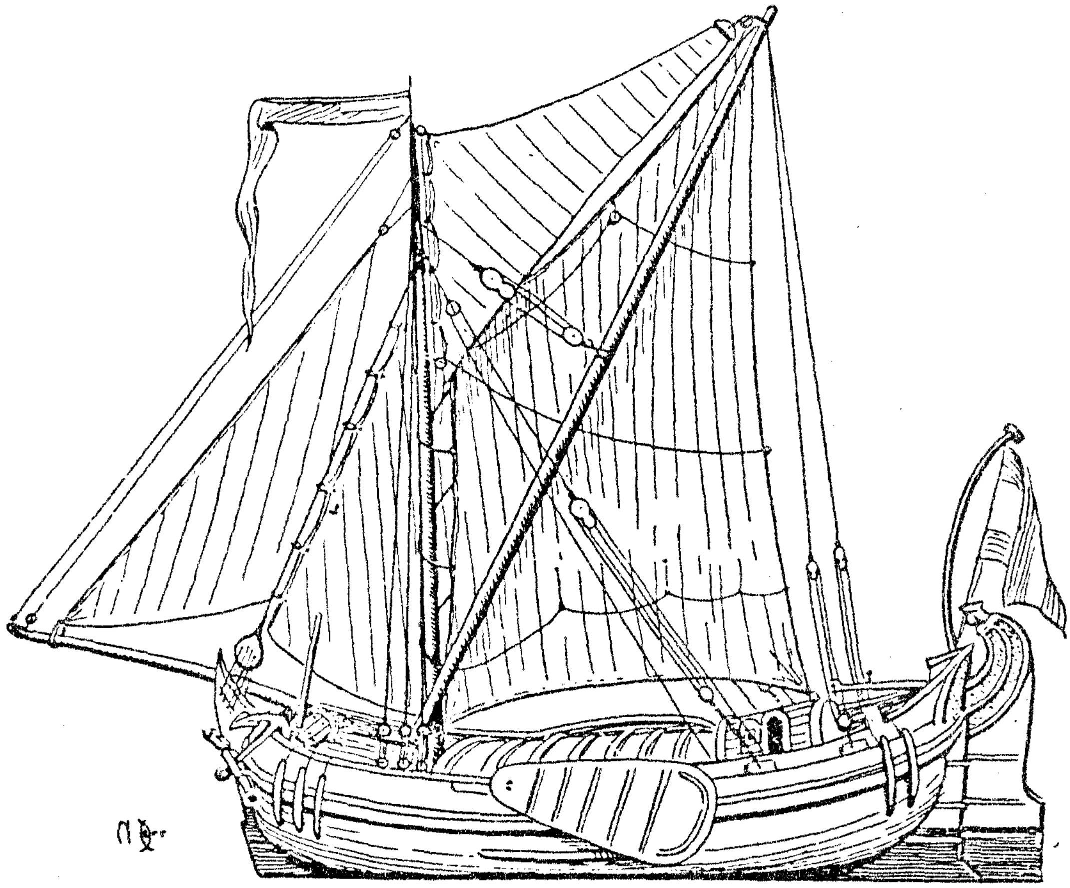


Fig. 2   Spritsail rig of a Zuider Zee cargo carrier showing the lines used for brailing up the mainsail

Fig. 3 25 m (82 ft 3 in) Senegalese cargo carrying canoe using a sprit sail

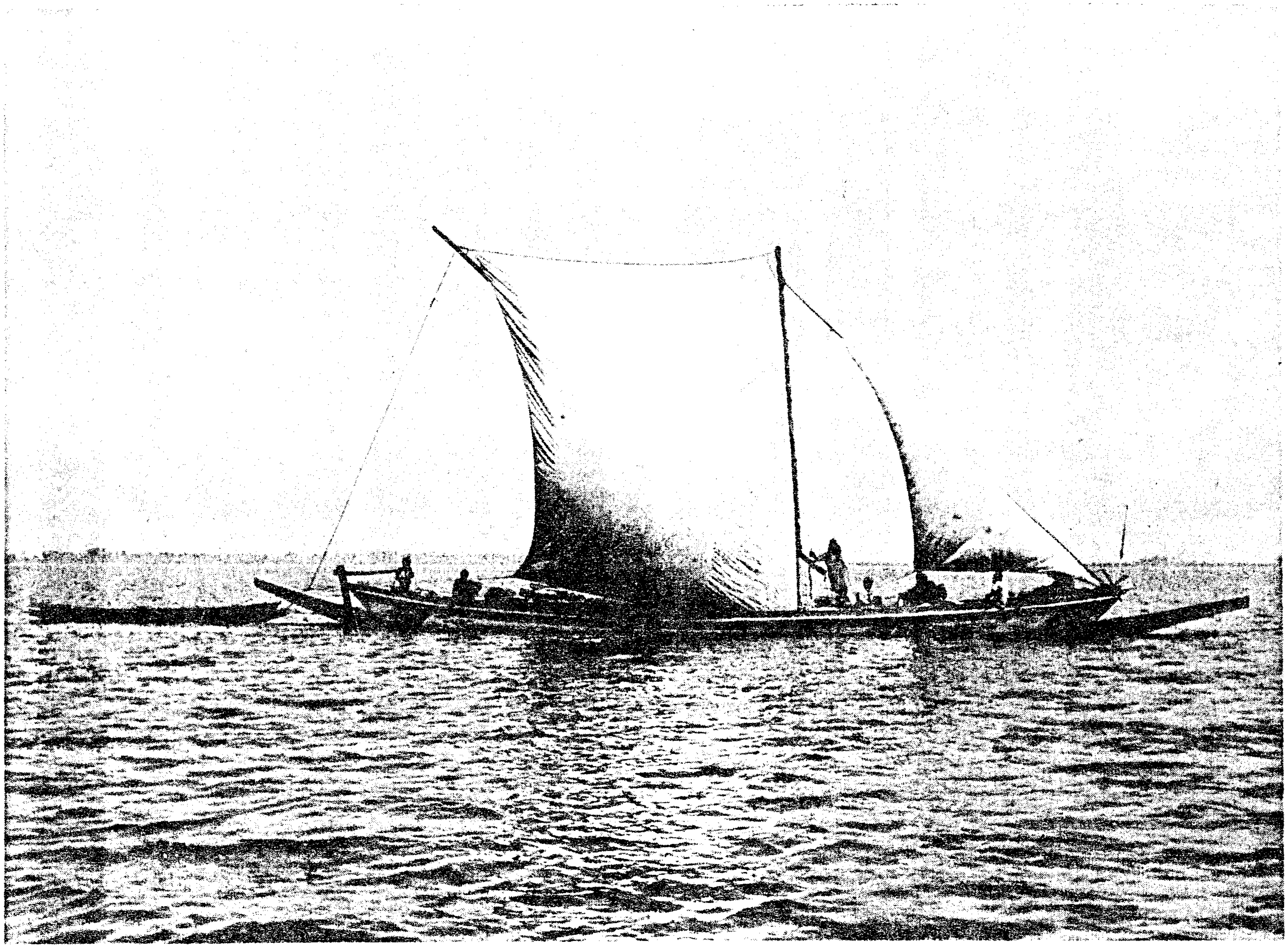


Fig. 4 Senegalese cargo carrying canoe with spritsail and jib

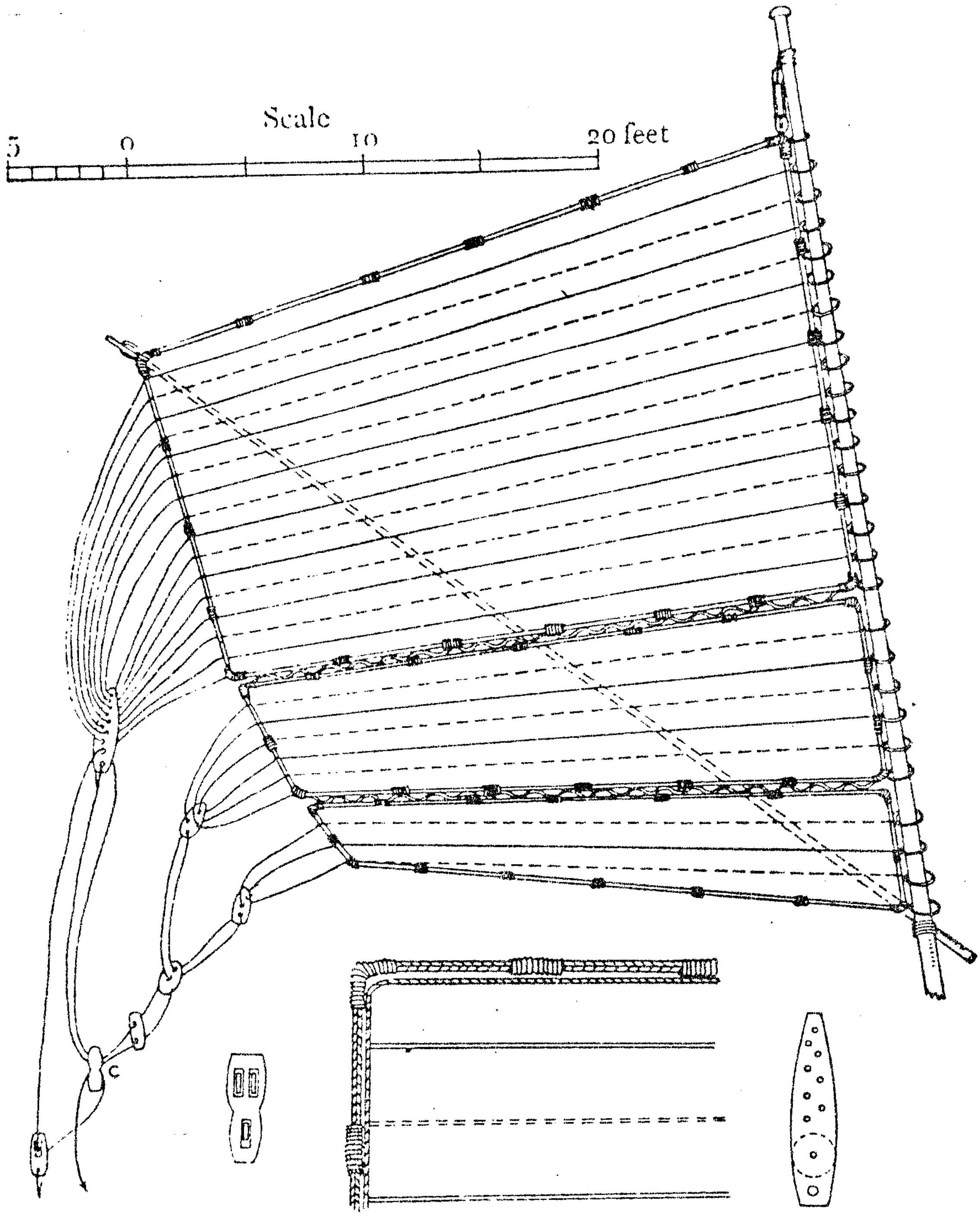


Fig. 5 Chinese spritsail showing the possibility of sail reduction by unlacing of sail sections

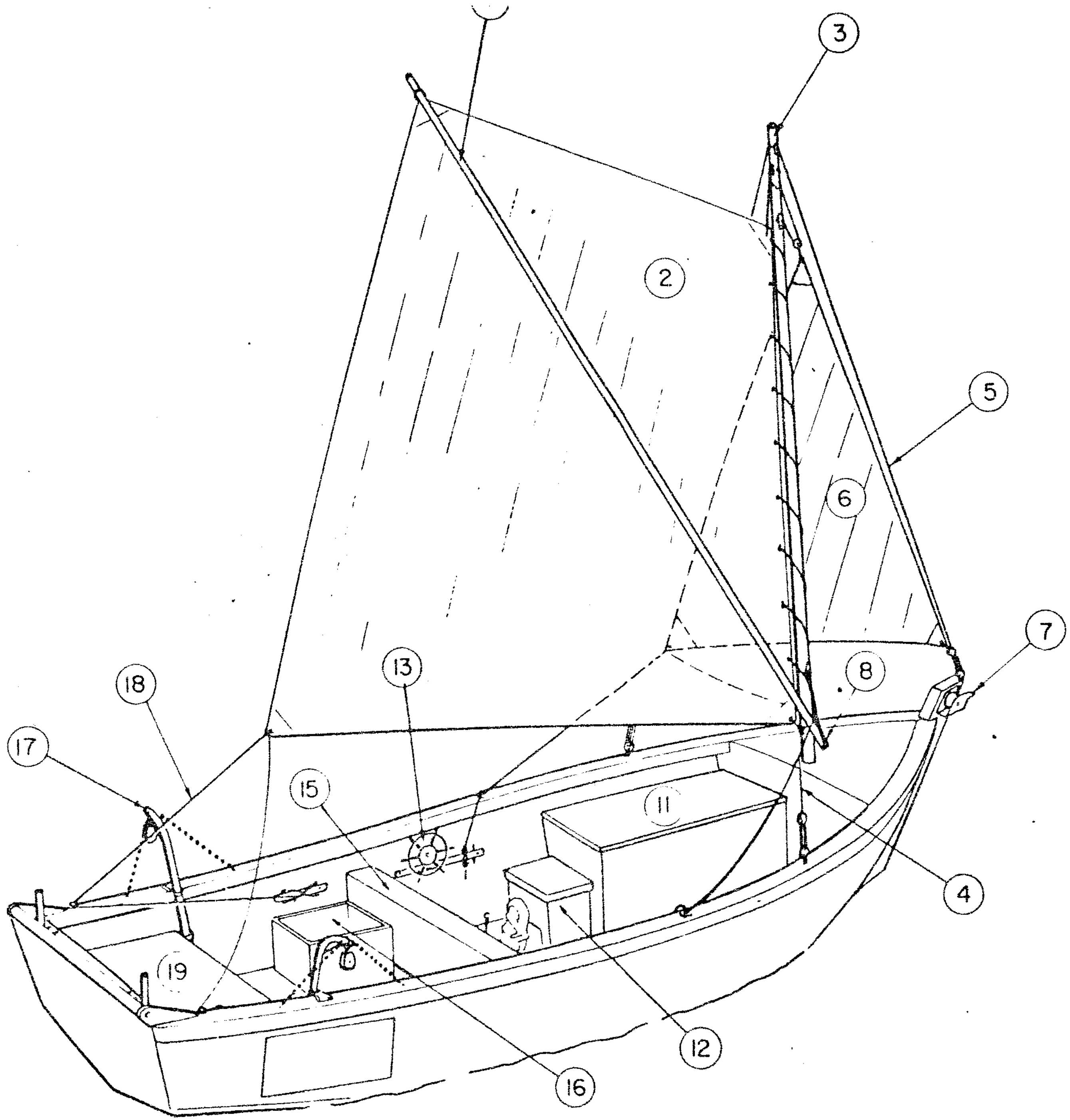


Fig. 6   7.5 m (24 ft 7 in) Small trawler with spritsail rig as auxiliary sail
(for explanation of numbers see Fig. 7)

1. Wooden sprit
2. Main sail, area 15.6 m^2 (168 ft^2)
3. Wooden mast maximum diameter 100 mm (4 in)
4. Standing rigging 8 mm (5/16 in) 1 x 19 wire
5. Fore stay 9 mm (3/8 in) 1 x 19 wire
6. Jib, area 3 m^2 (33 ft^2)
7. Stem head roller
8. Adjustable strap for support of sprit
9. Raised fore deck and fore peak
10. Cleats, fwd, midships and aft
11. Optional portable ice box for quality fish
12. Engine box and engine
13. Wheel steering
14. Fuel tank, capacity 80 l ($17\frac{1}{2}$ gall)
15. Thwart
16. Portable warp storage boxes
17. Optional removable trawl davits
18. Main sheet, 12 mm (1/2 in) synthetic cordage
19. Raised stern net platform
20. Lifting boom for handling large codends
21. Optional block and tackle for gear handling
22. Central towing bitt for pair trawling

OTTER BOARD TRAWLER

(with optional auxiliary sail)

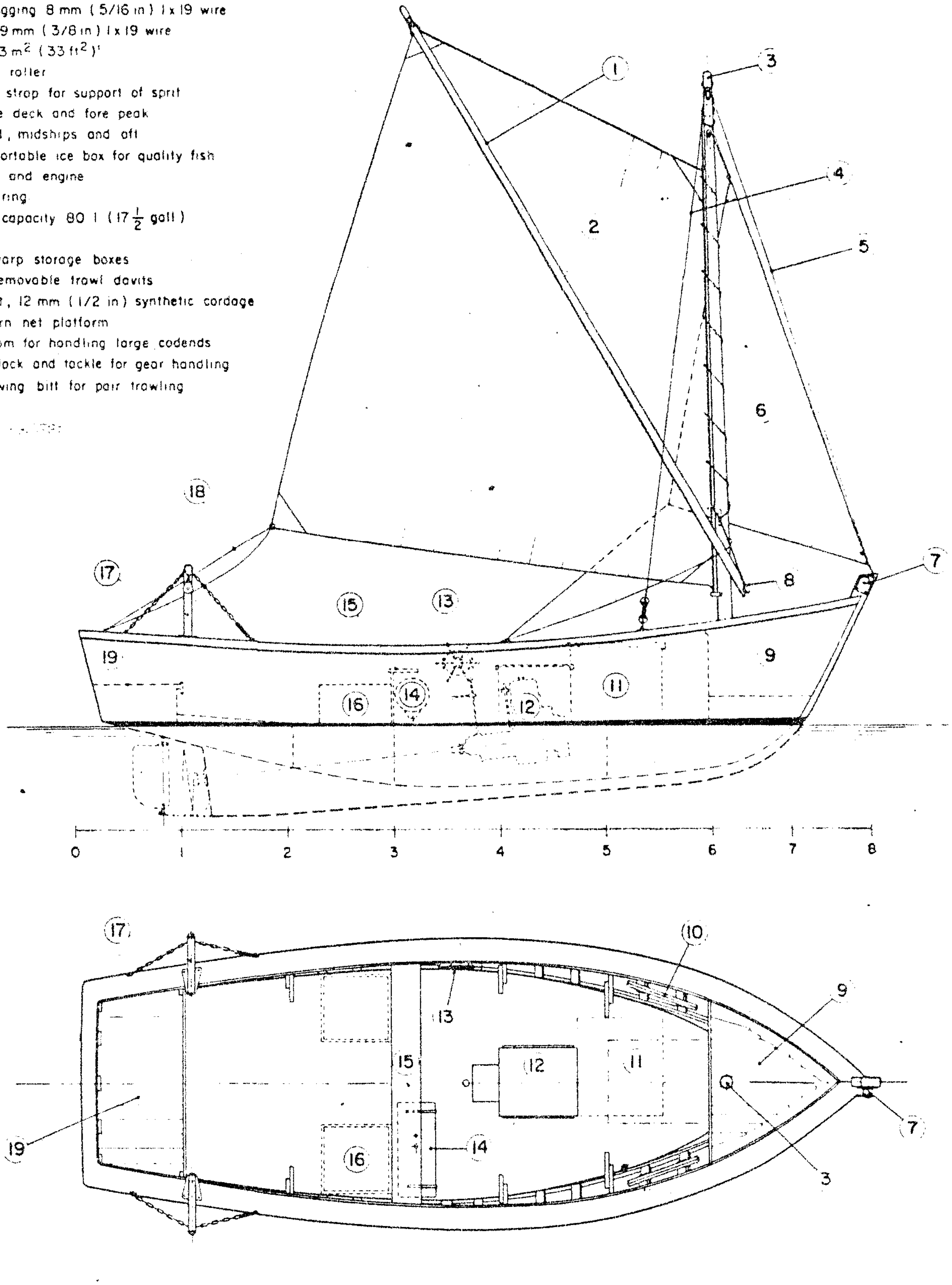


Fig. 7 7.5 m (24 ft 7 in) Small trawler with auxiliary sail profile and plan views

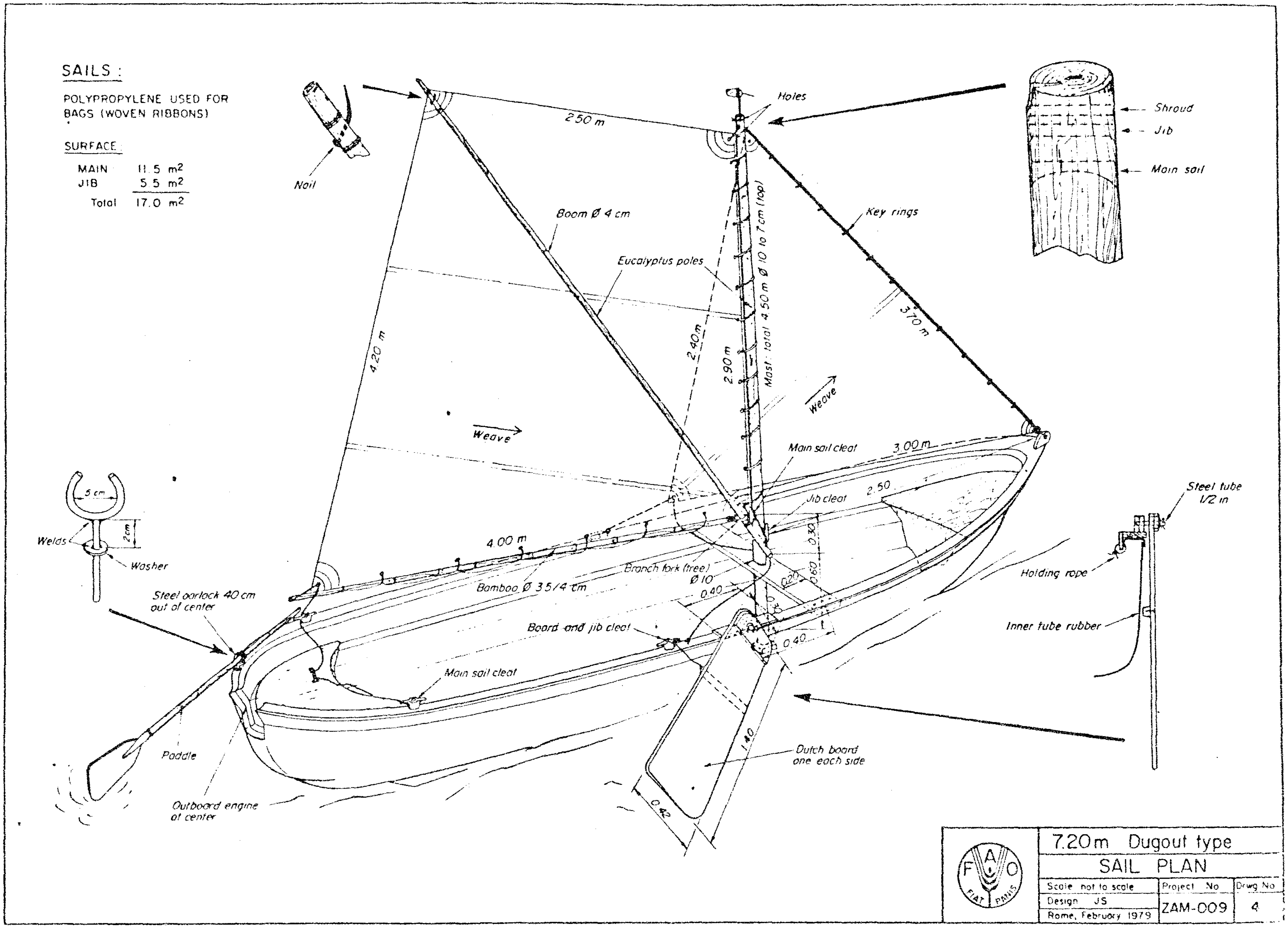


Fig. 8 7.20 m (23ft 8in) FRP canoe with spritsail rig and leeboard

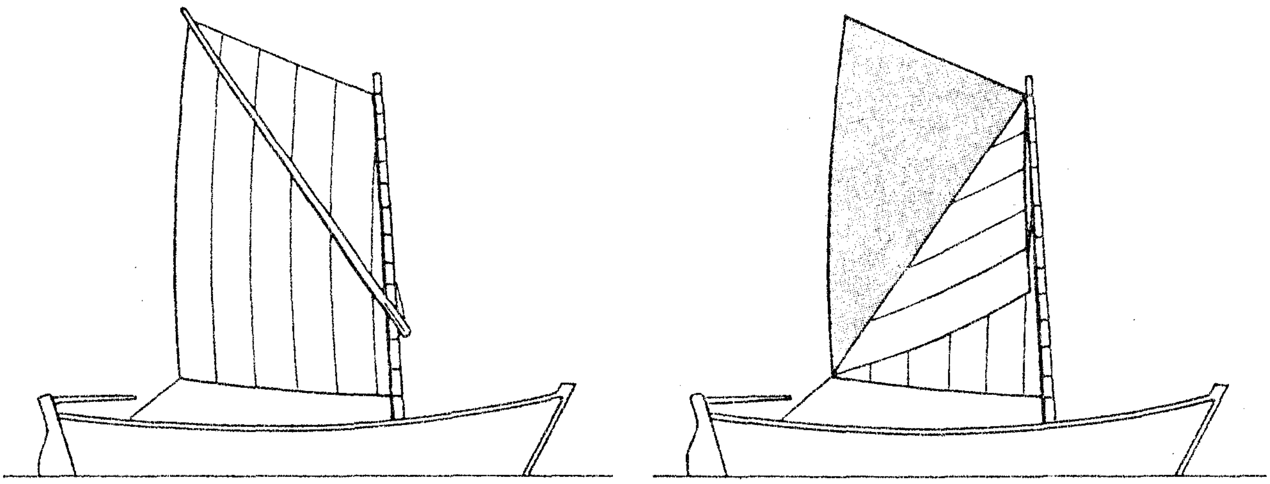


Fig. 9 Shortening sail of spritsail rig by scandalising

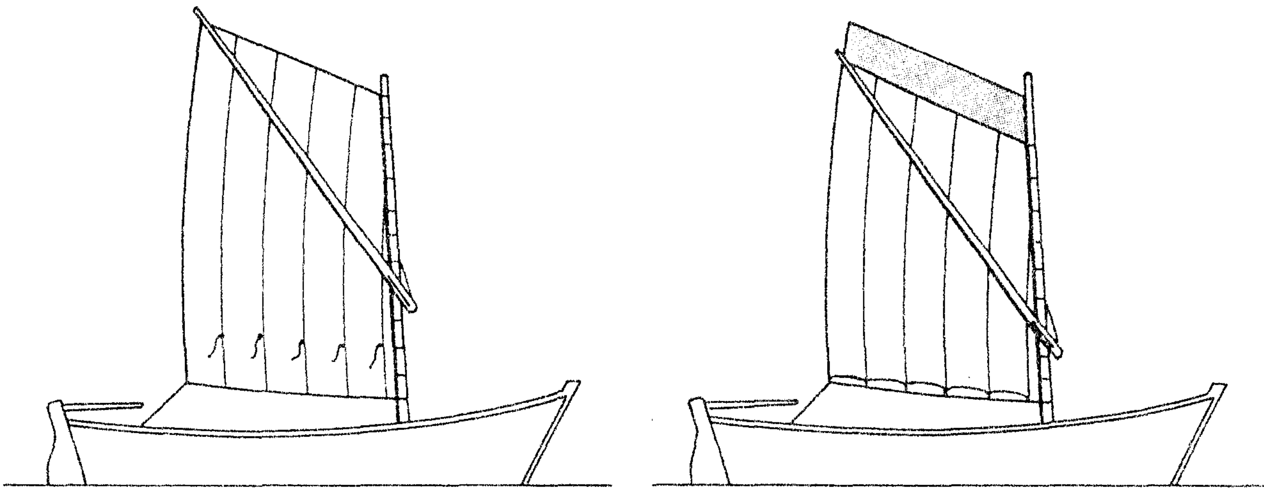


Fig.10 Shortening sail by point reefing

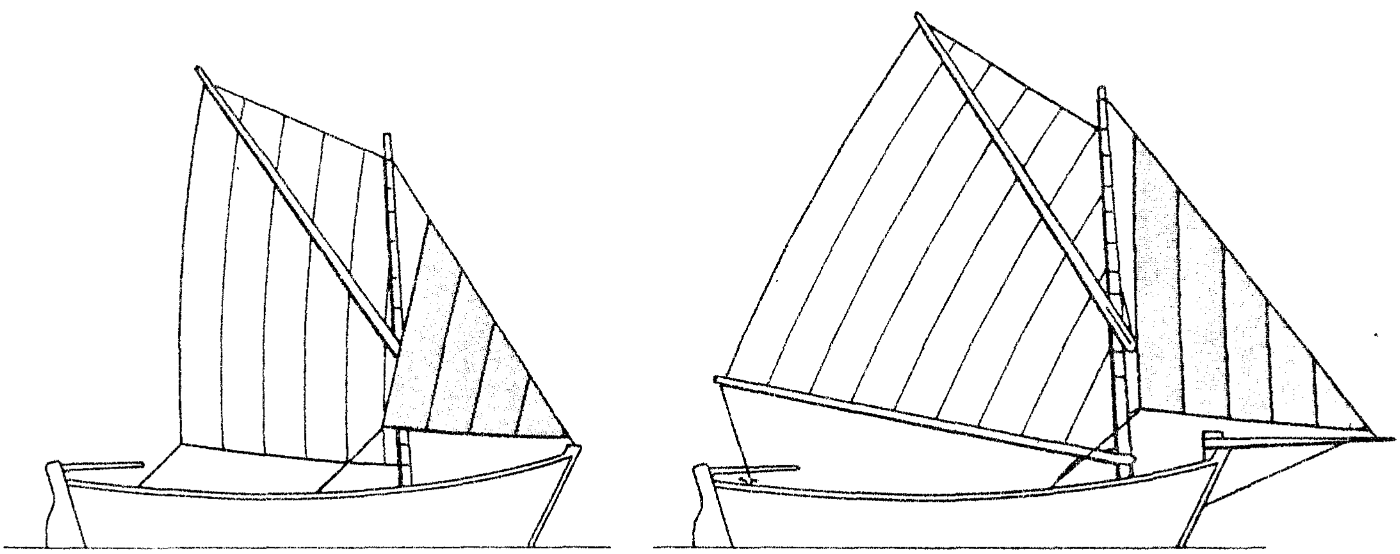


Fig.11 Increased sail area by adding jibs on stemhead or temporary bowsprit

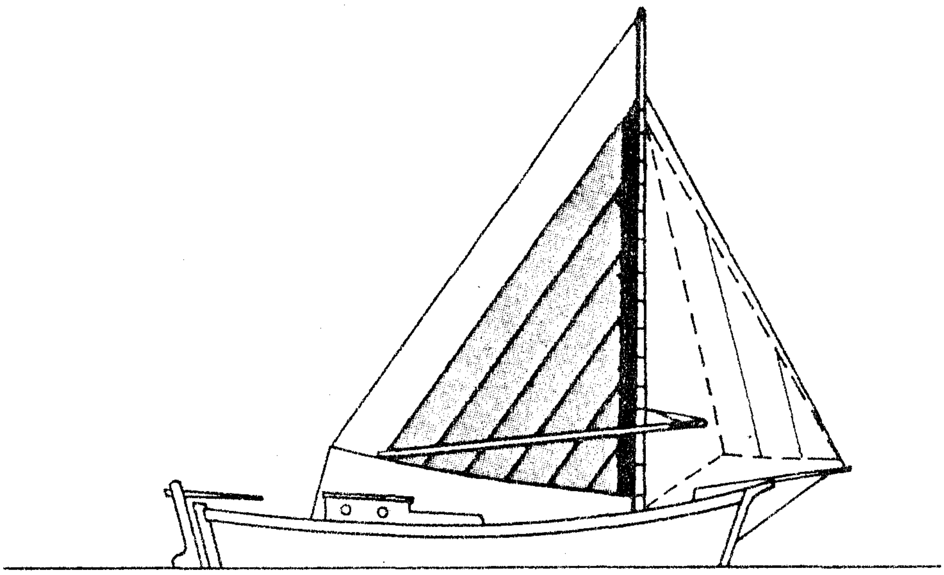


Fig.12 Triangular sail with horizontal sprit showing reefing method

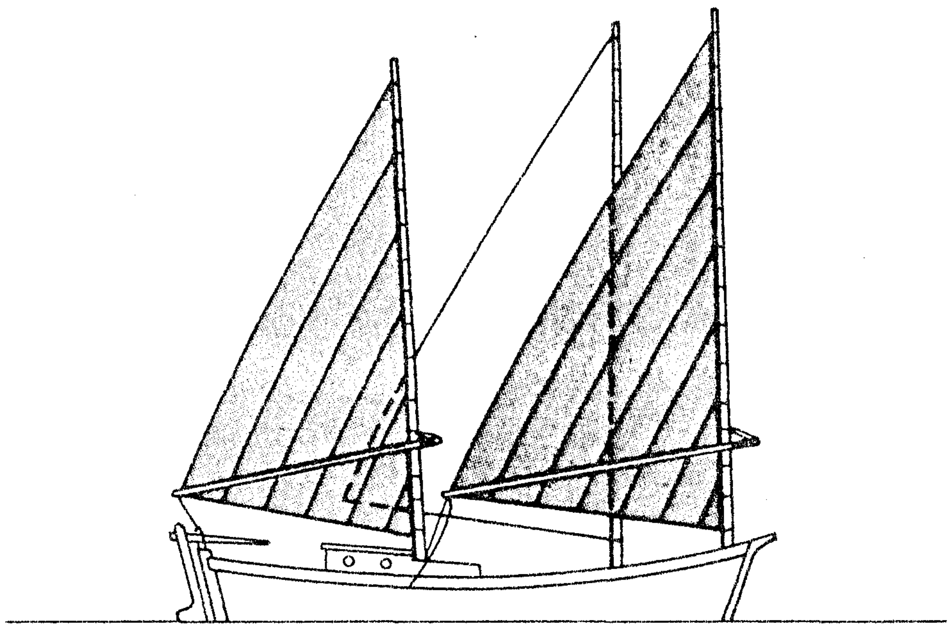


Fig.13 Increased sail area by adding masts

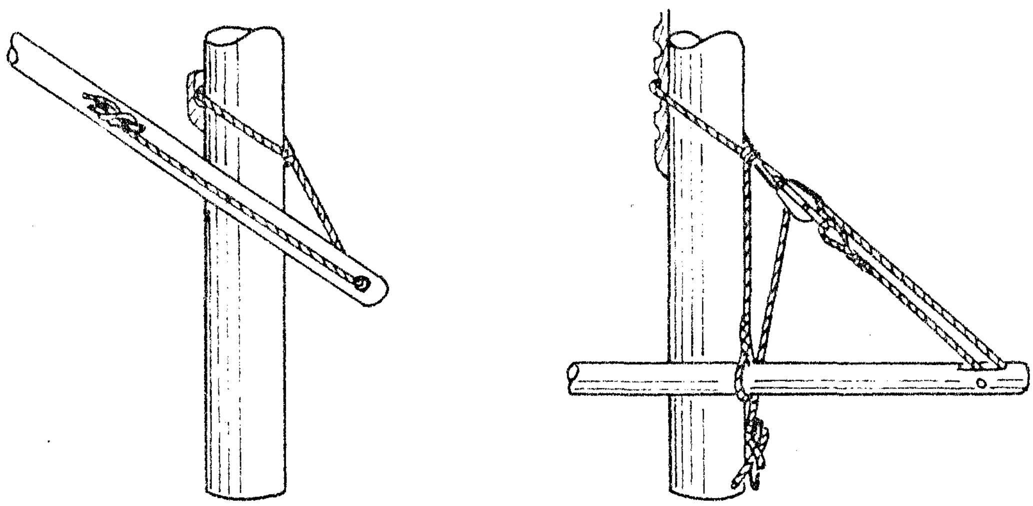


Fig.14 Methods of attaching sprit for light and heavy rigs

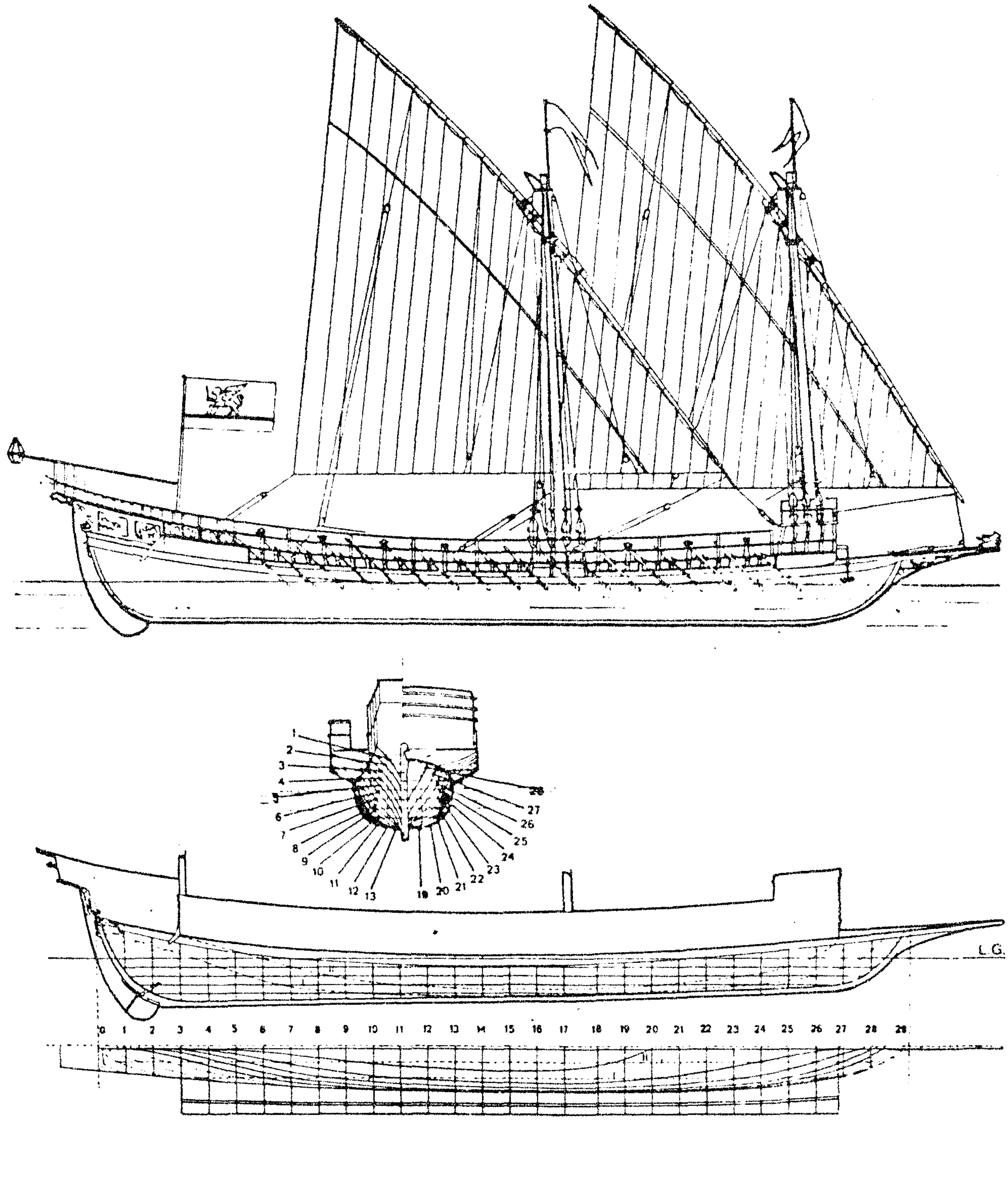


Fig. 15 Venetian galley (1300 AD) with Mediterranean type lateen sails

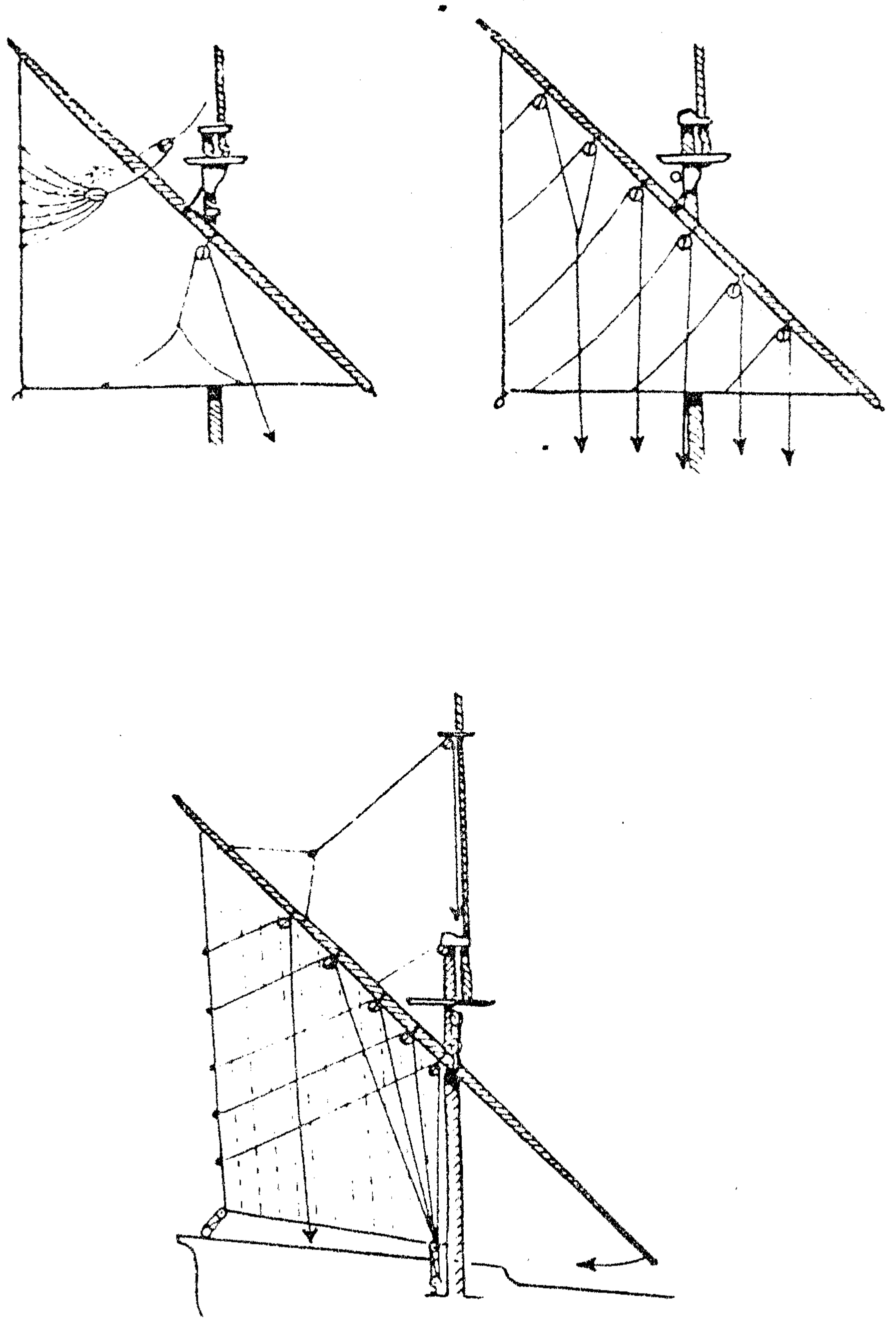


Fig. 16 Method of brailing up the lateen shaped mizzen sail of ships of 1500, 1600 and 1700 AD

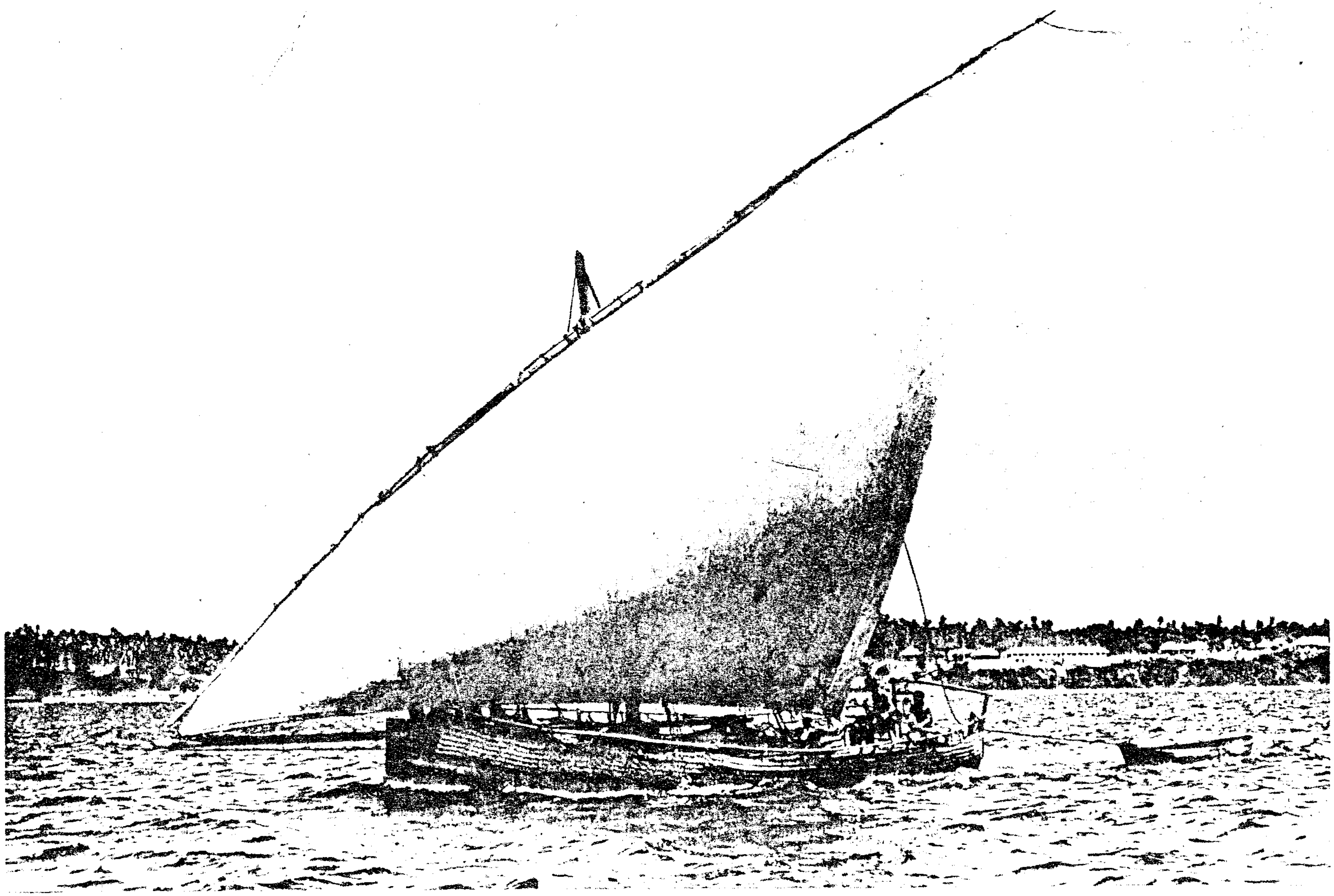


Fig.17 A Mombasa Dhow showing the large amount of sail that can be set on a short mast

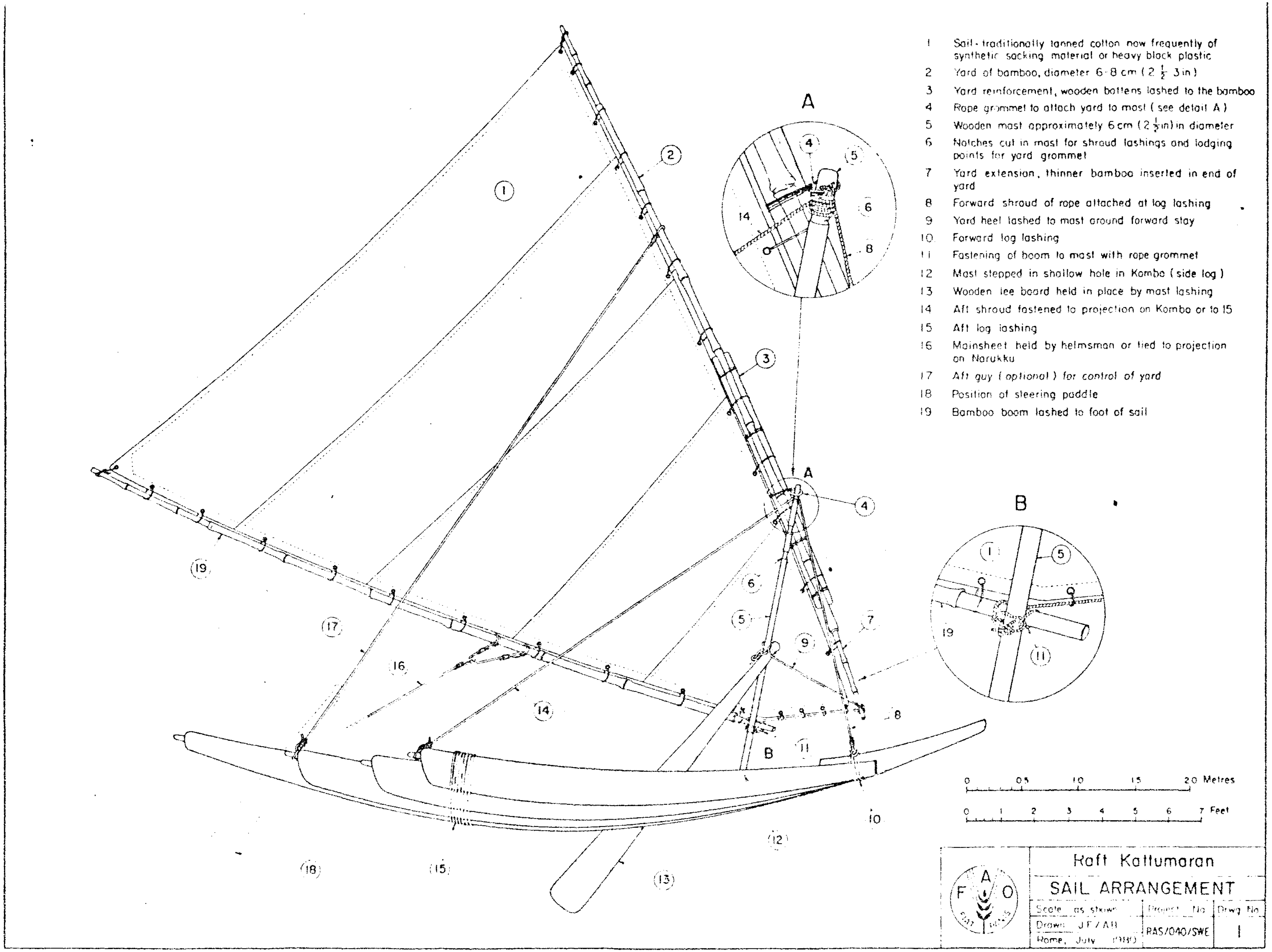


Fig. 18 Small lateen rig on an Indian log kattumaran

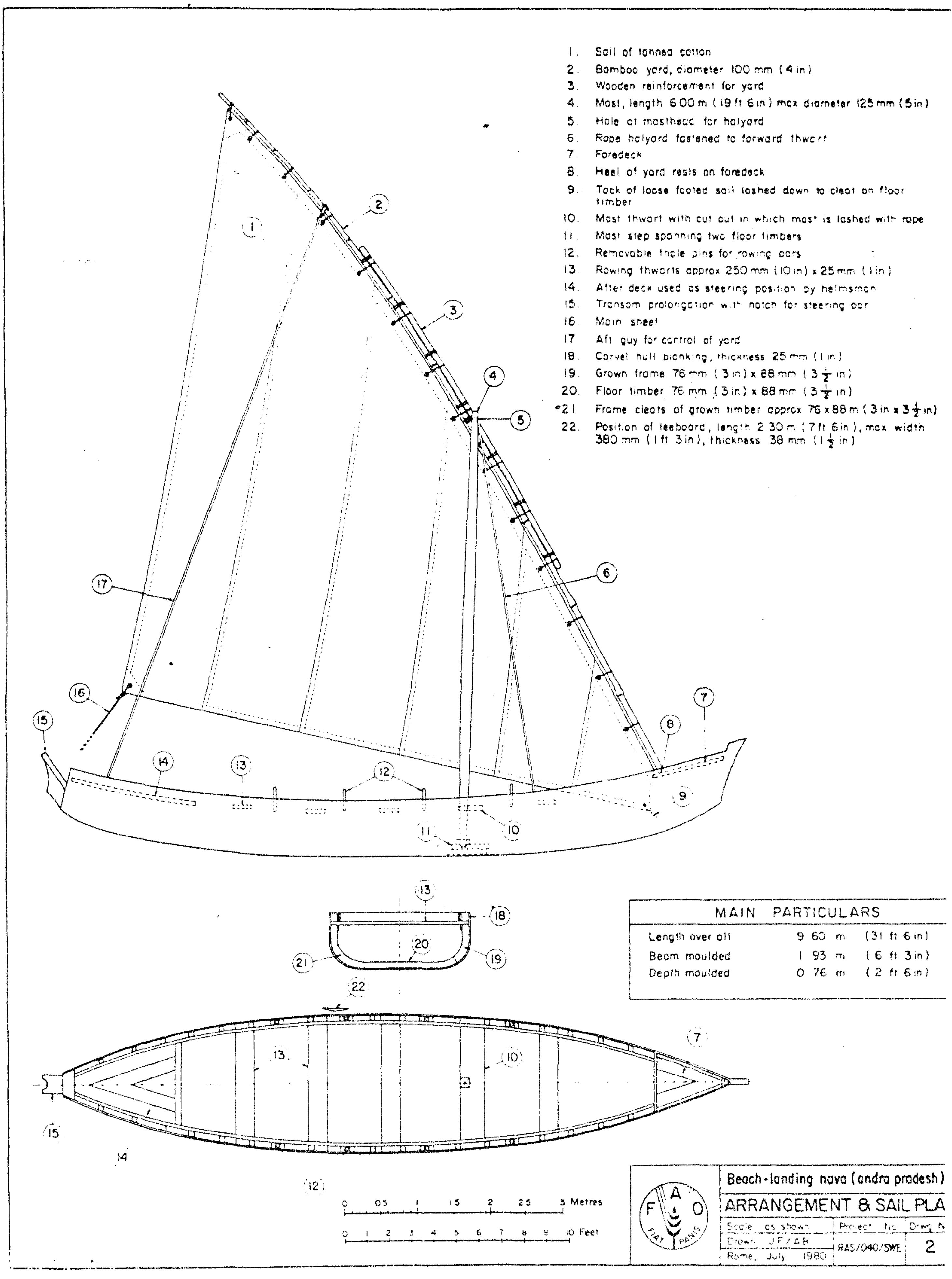


Fig. 19 Lateen rig on 9.60 m (31 ft 6 in) open boat showing simple pole mast revolvable in mast step with halyard set up as temporary shroud

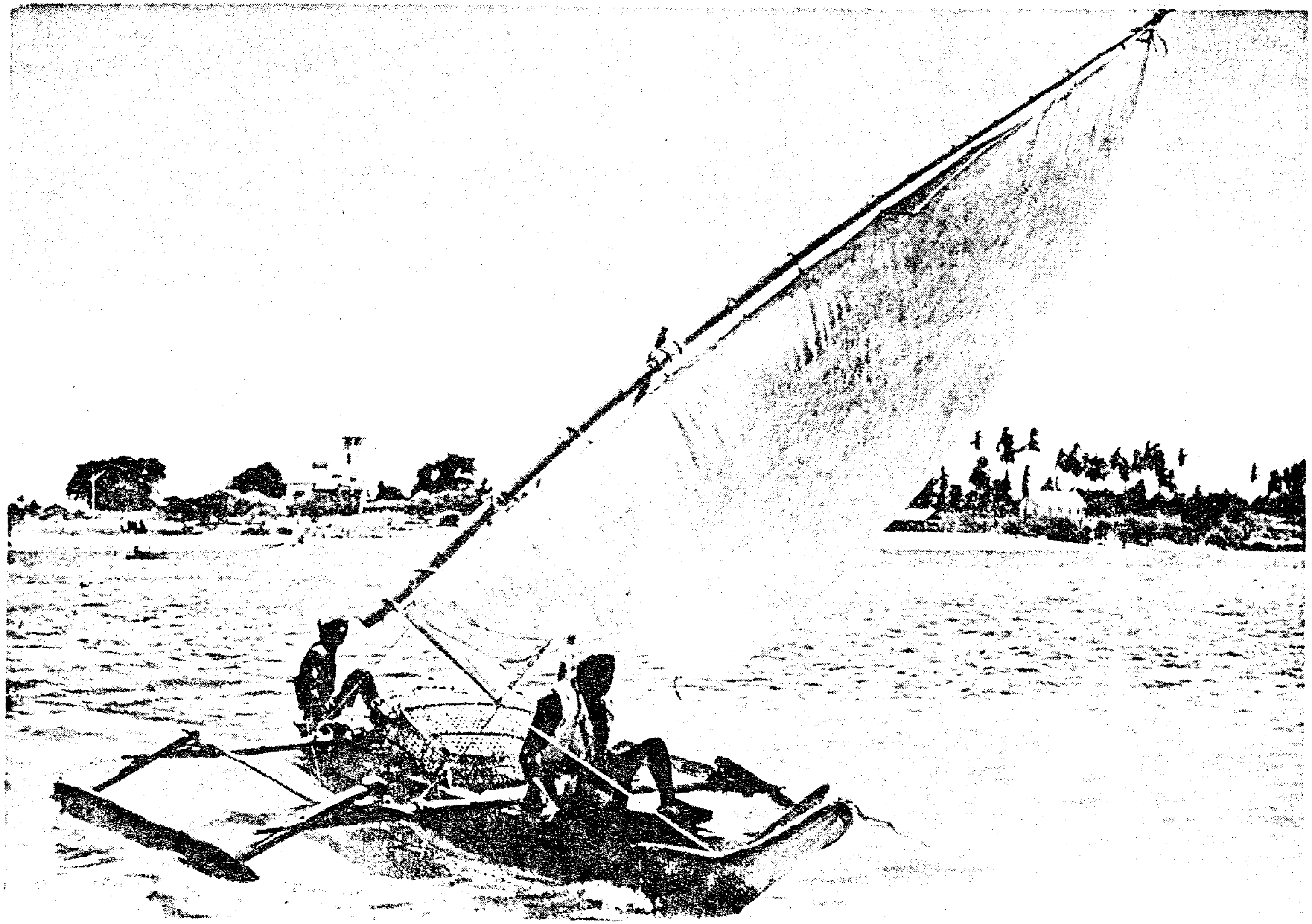


Fig.20 Running before the wind with a lateen sail on an outrigger canoe

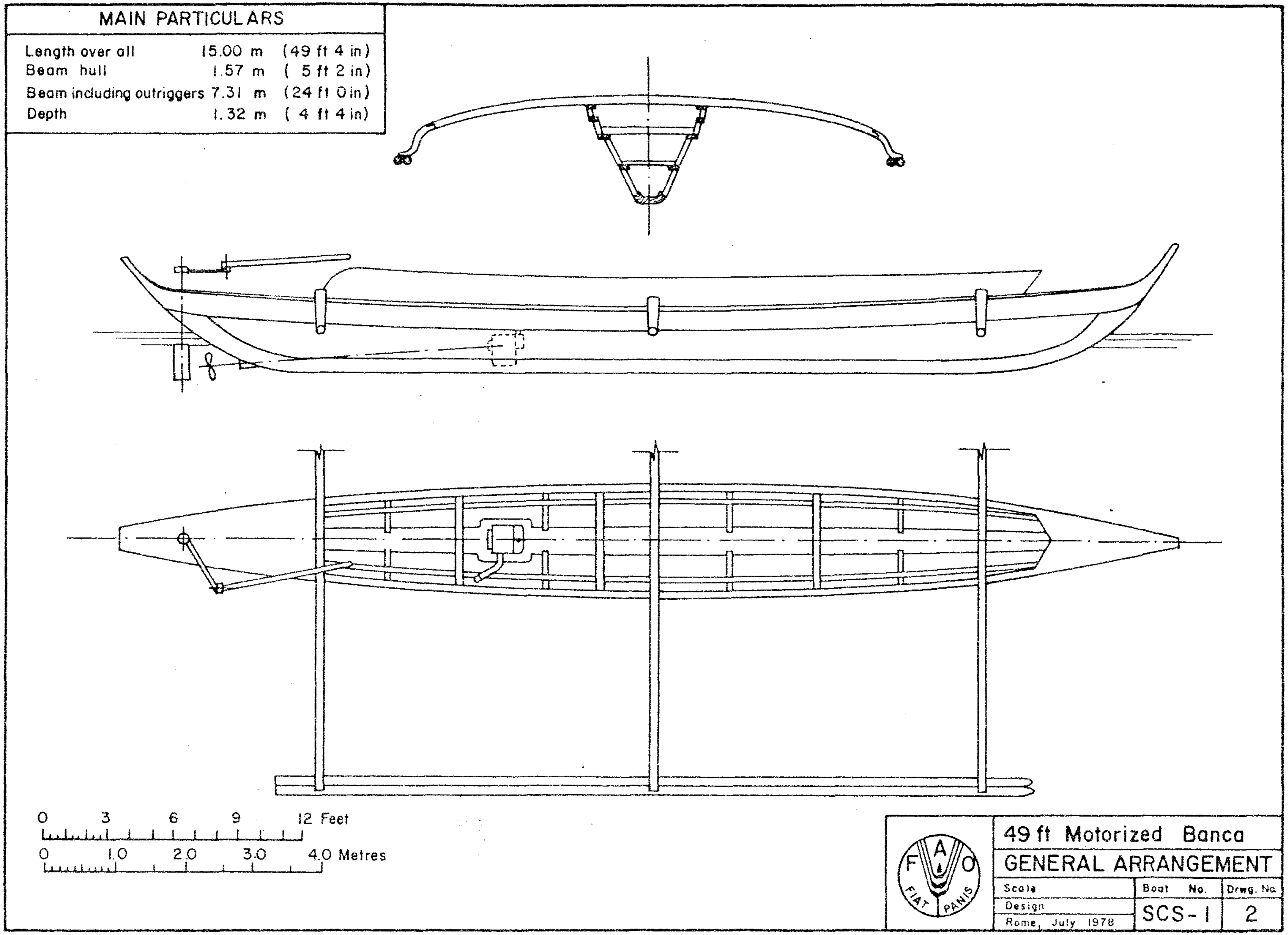
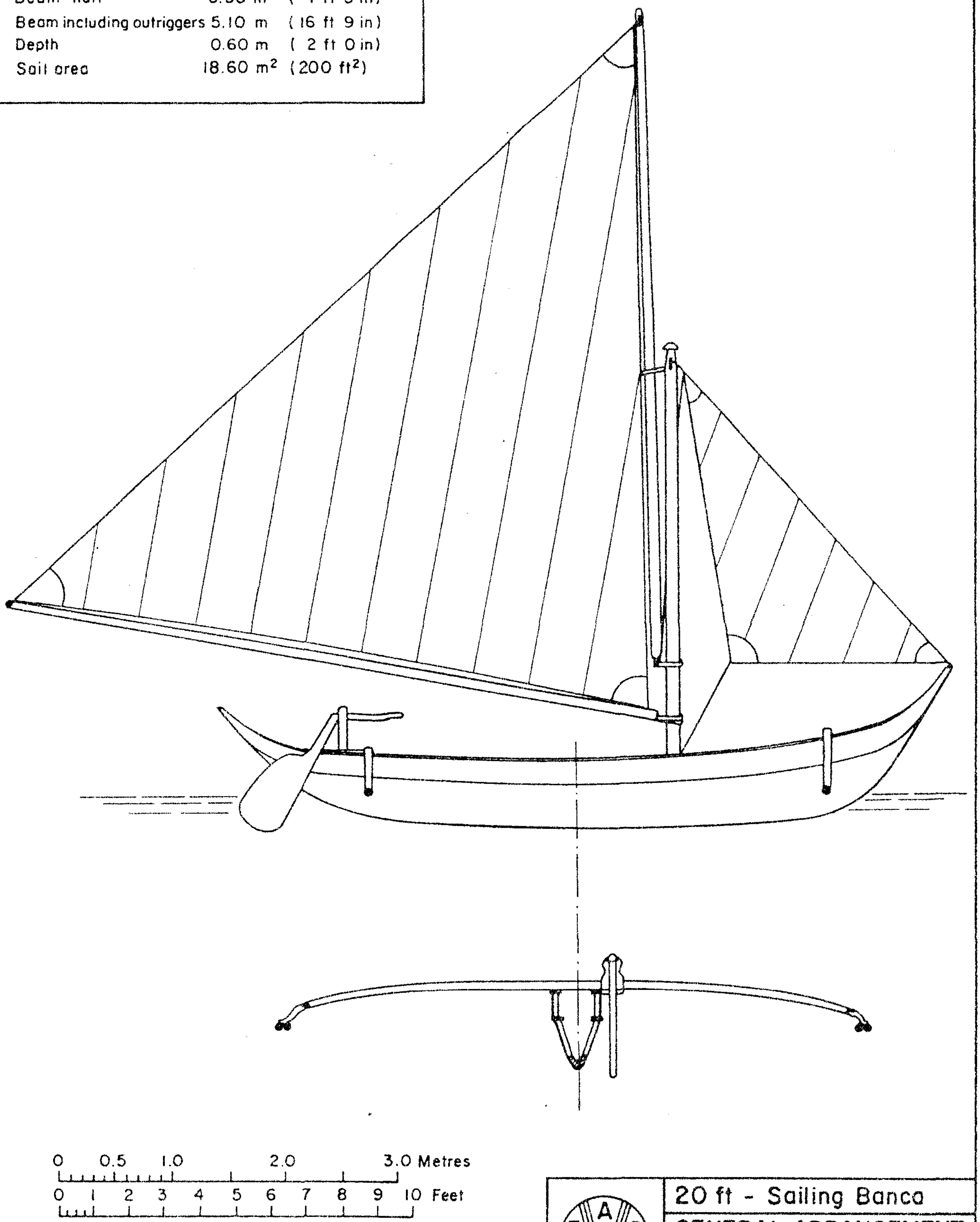


Fig. 21 An outrigger canoe from the Philippines

MAIN PARTICULARS

Length over all	6.10 m	(20 ft 0 in)
Beam hull	0.38 m	(1 ft 3 in)
Beam including outriggers	5.10 m	(16 ft 9 in)
Depth	0.60 m	(2 ft 0 in)
Sail area	18.60 m^2	(200 ft^2)



20 ft - Sailing Banca		
GENERAL ARRANGEMENT		
Scale	Boat No.	Drwg. No.
Design	SCS - 1	1
Rome, July 1978		

Fig. 22 Sail plan of an outrigger canoe

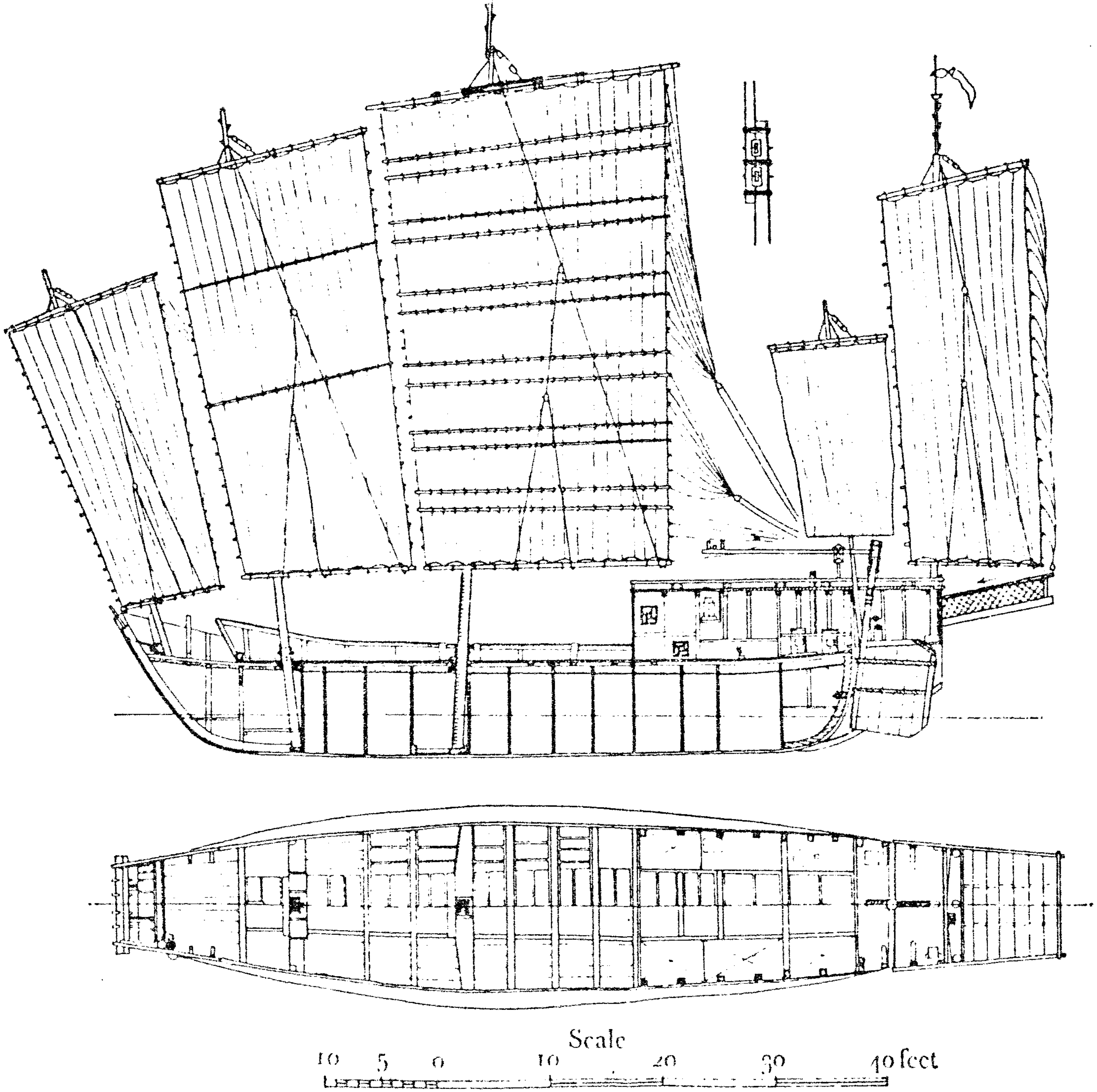


Fig. 23 Sail and construction plan of a typical Northern Chinese work boat

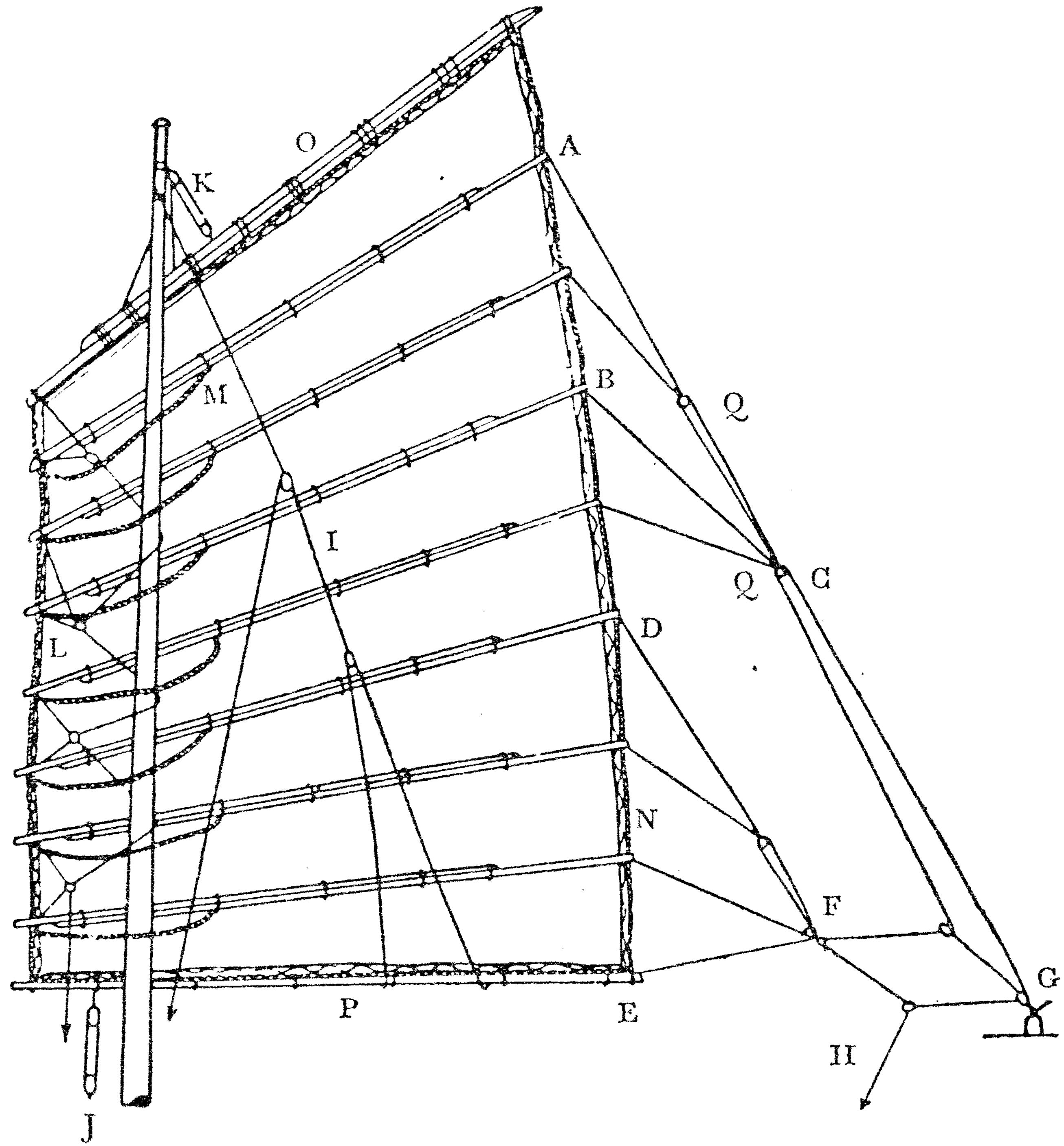


Fig. 24 Rigging of a Chinese lug sail

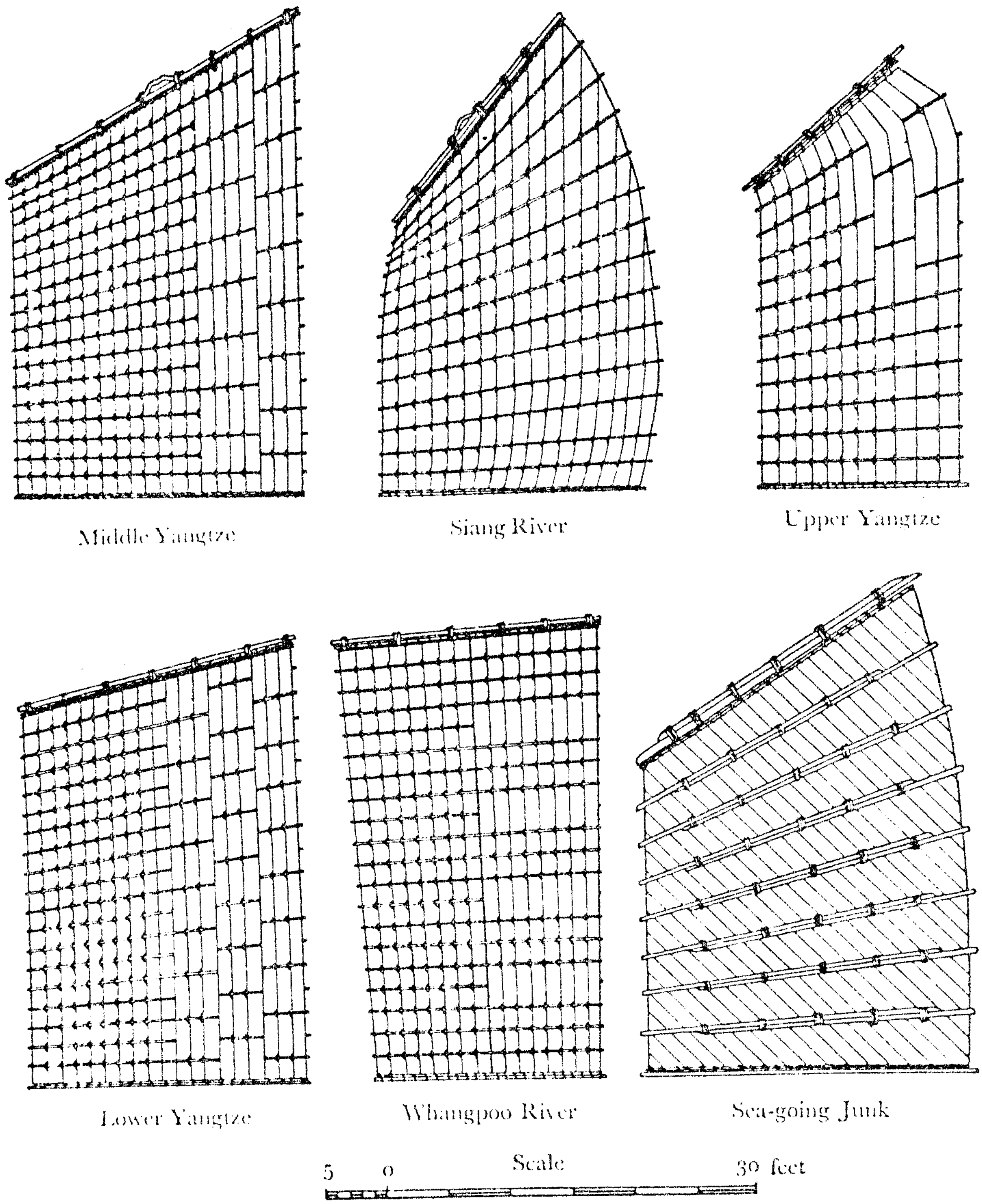


Fig. 25 Variations in shape of the traditional Chinese lug sail according to region

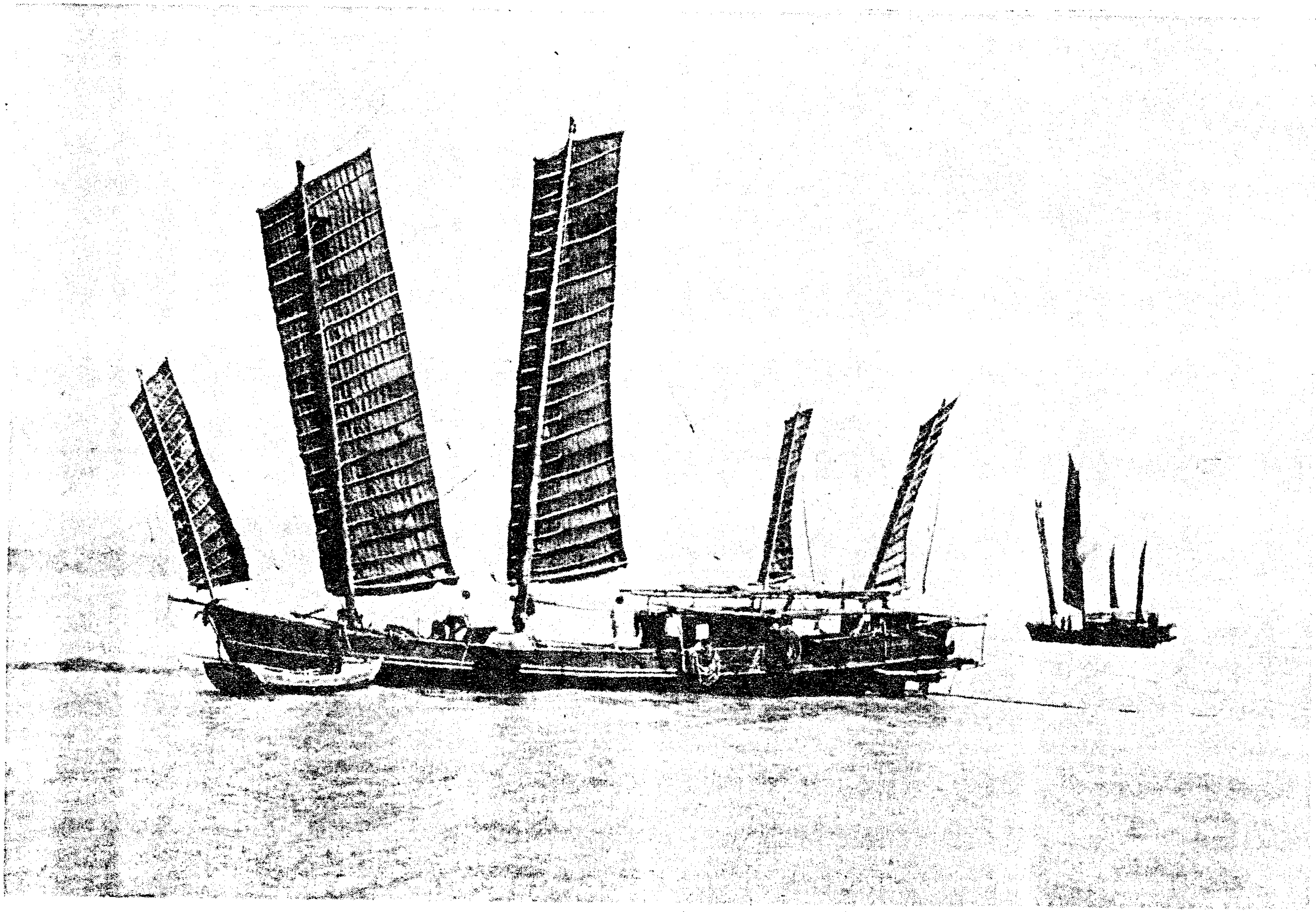


Fig. 26 20 m (65 ft 9 in) five-masted pair trawlers operating under sail in the lake fisheries of China

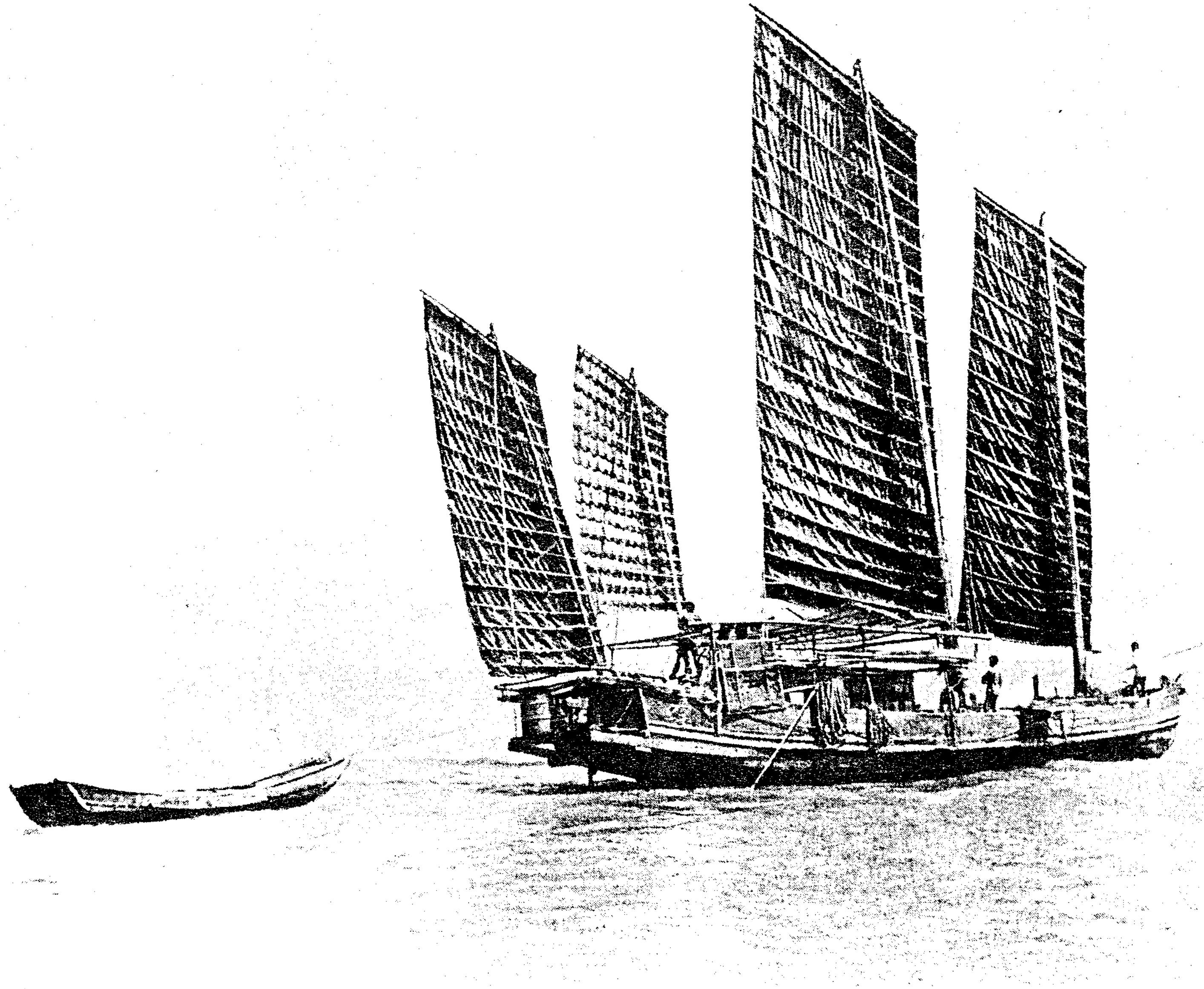


Fig.27 Four masted Chinese pair trawler while towing

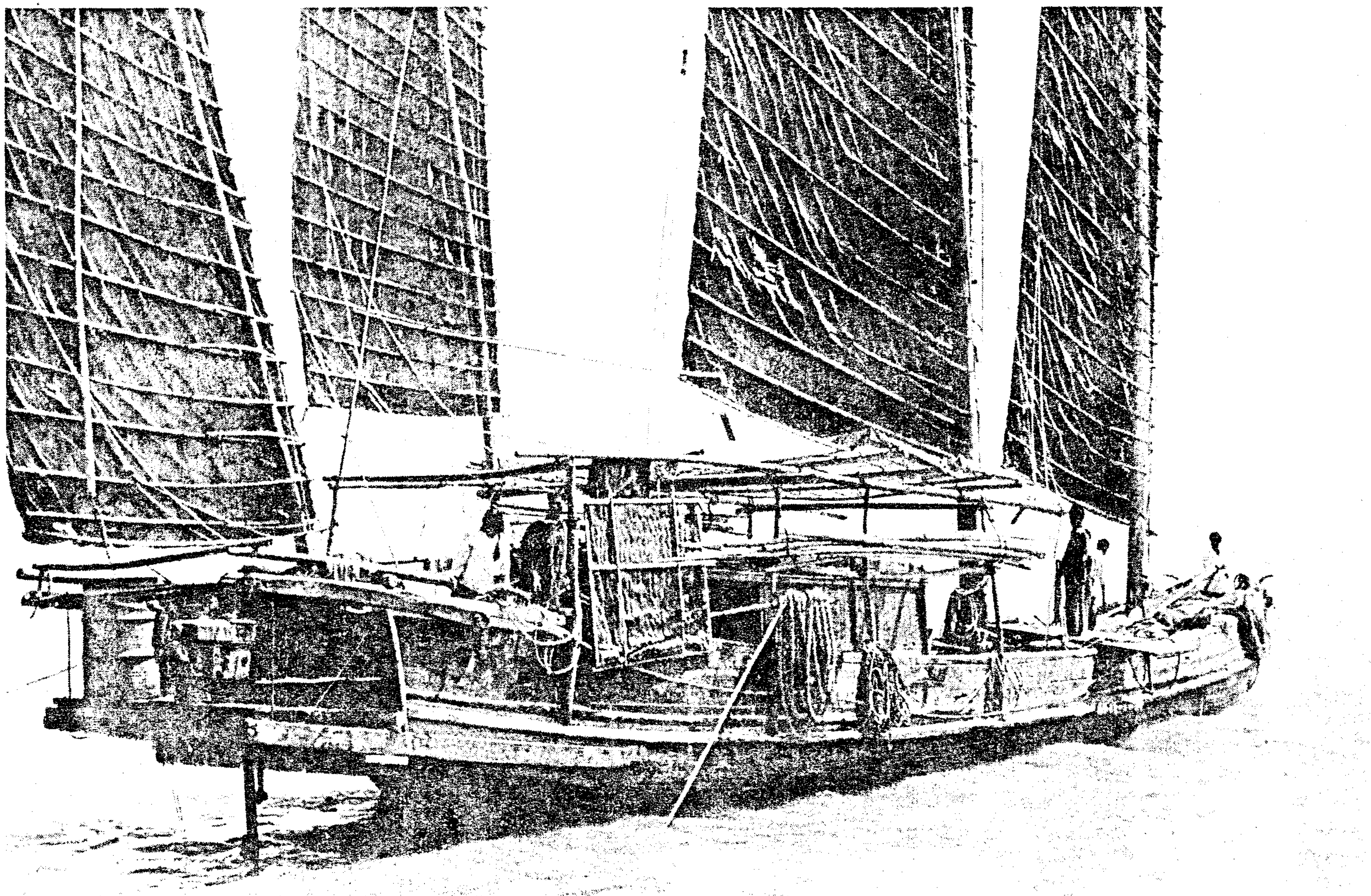


Fig.28 Close up of Chinese pair trawler while towing. Note the mast forward of the mizzen is stepped on the port side

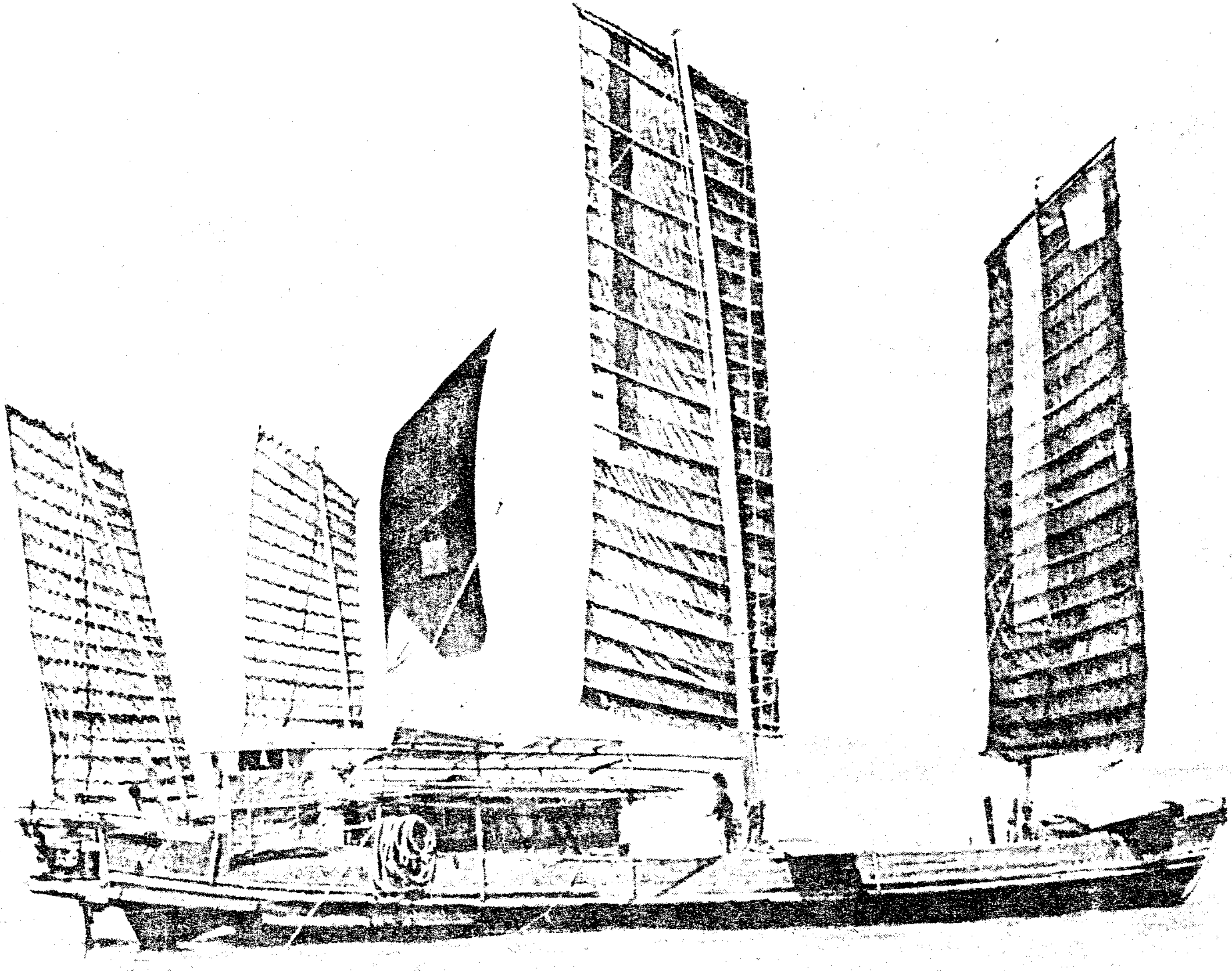


Fig.29 Chinese pair trawler with a staysail set for extra thrust while towing

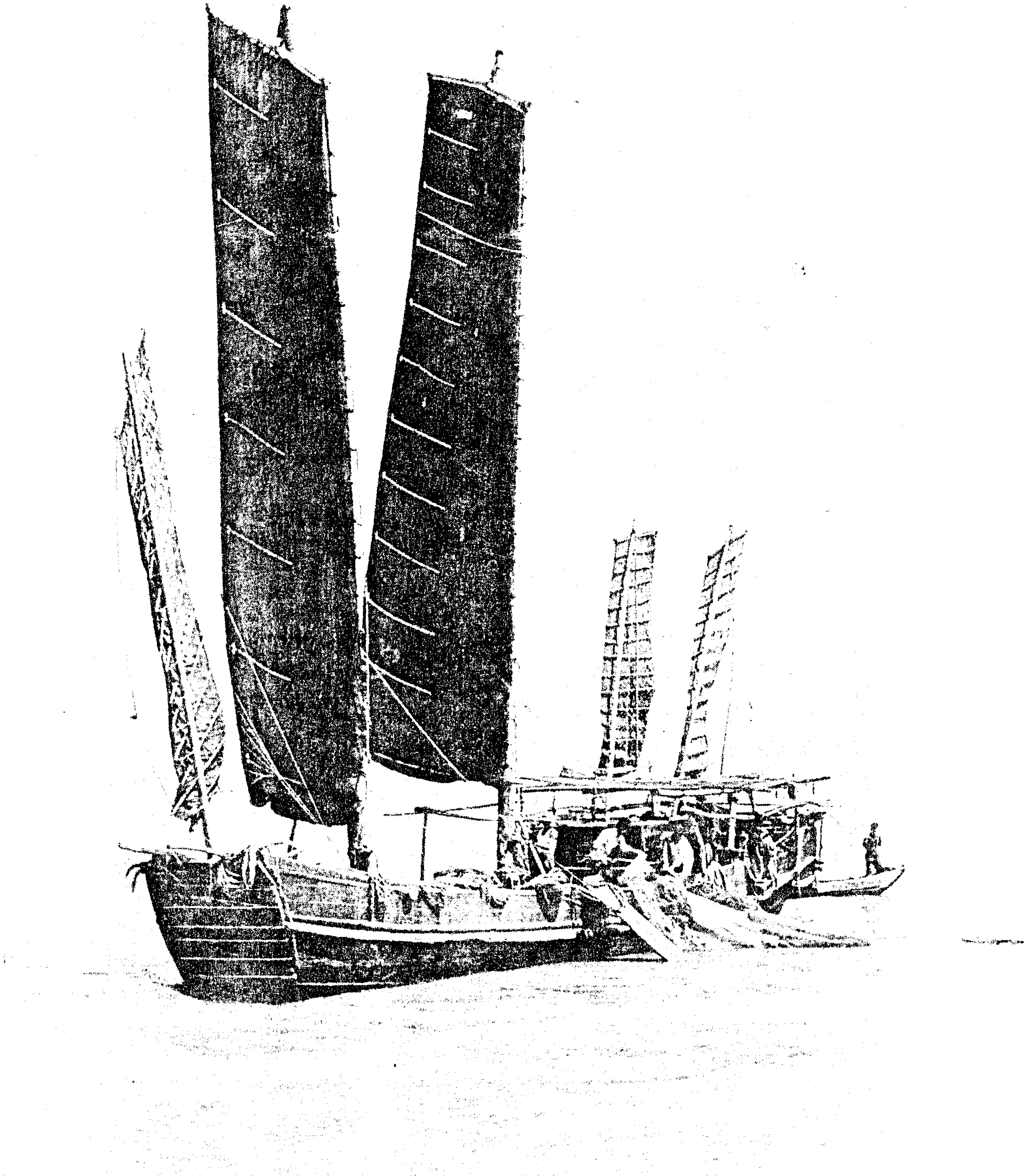


Fig. 30 Chinese pair trawler hauling the net. Note the main sails left to weather cock to reduce forward motion

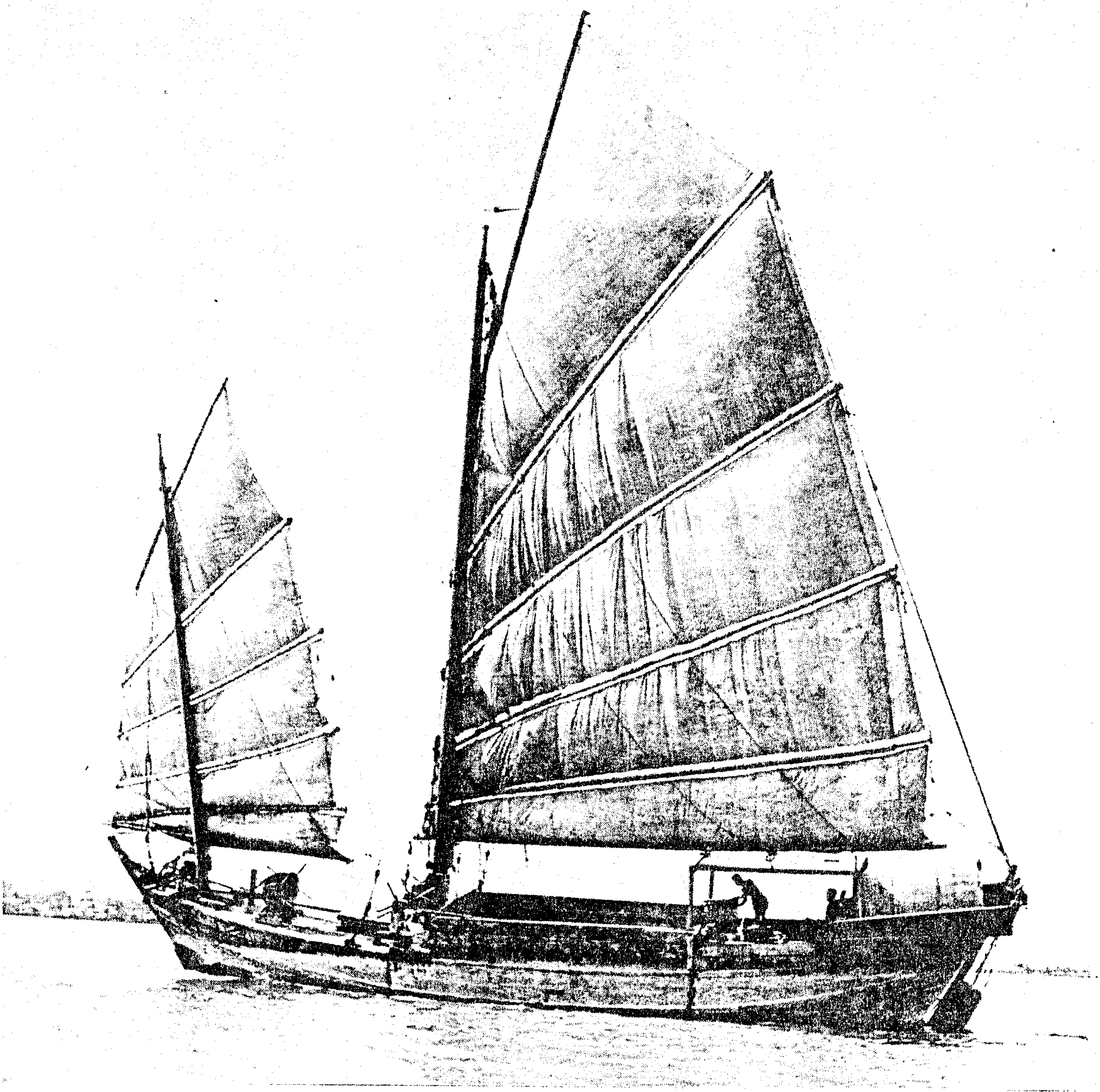


Fig. 31 Thai cargo vessel with Chinese lug rig. Note sails in separate sections between battens

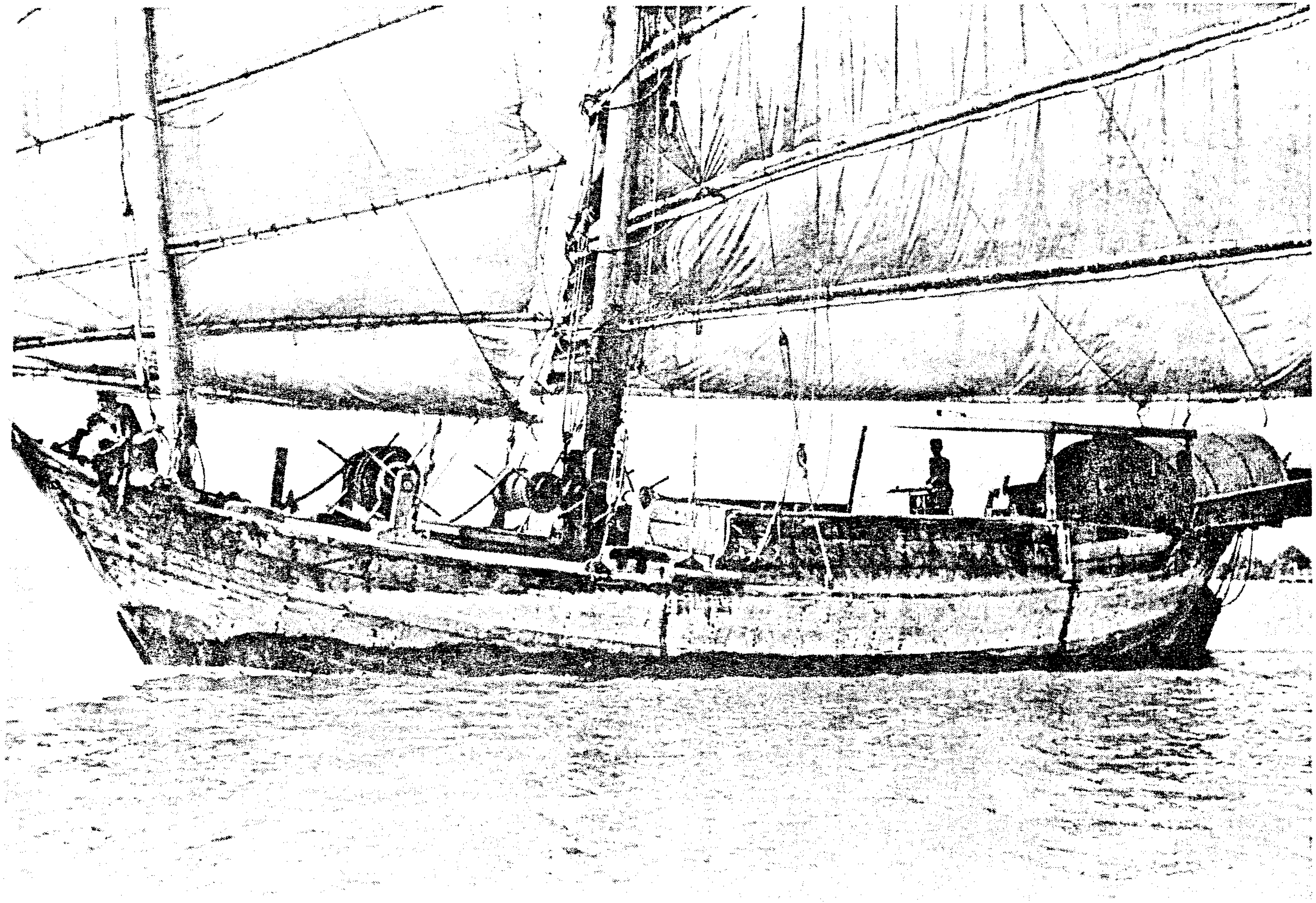


Fig. 32 Close up of Thai sailing cargo carrier. Note separate sail sections laced to battens and hand winches for sail and anchor hoisting

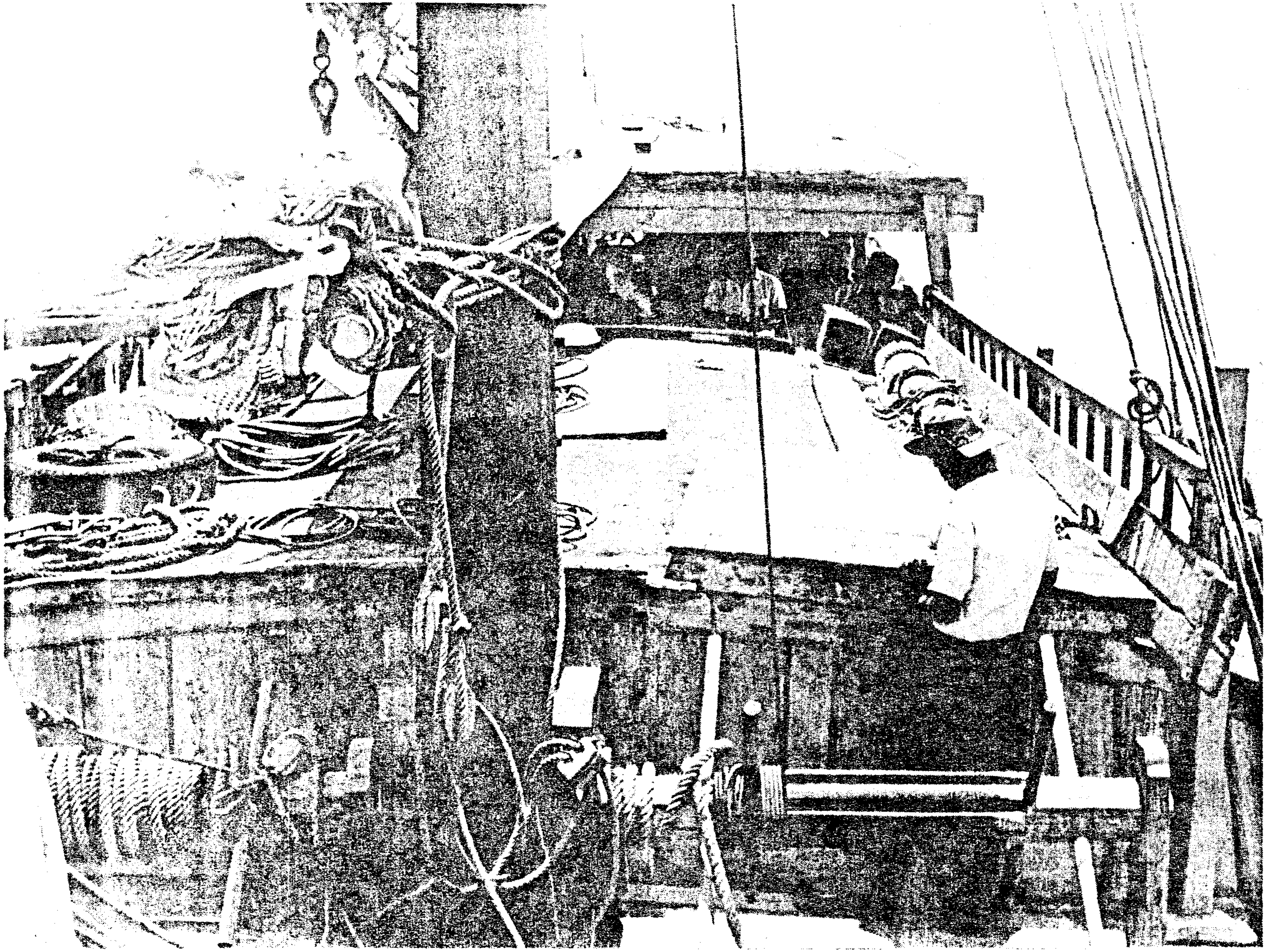


Fig. 33 Hand operated winches for sail hoisting on a Chinese sail boat

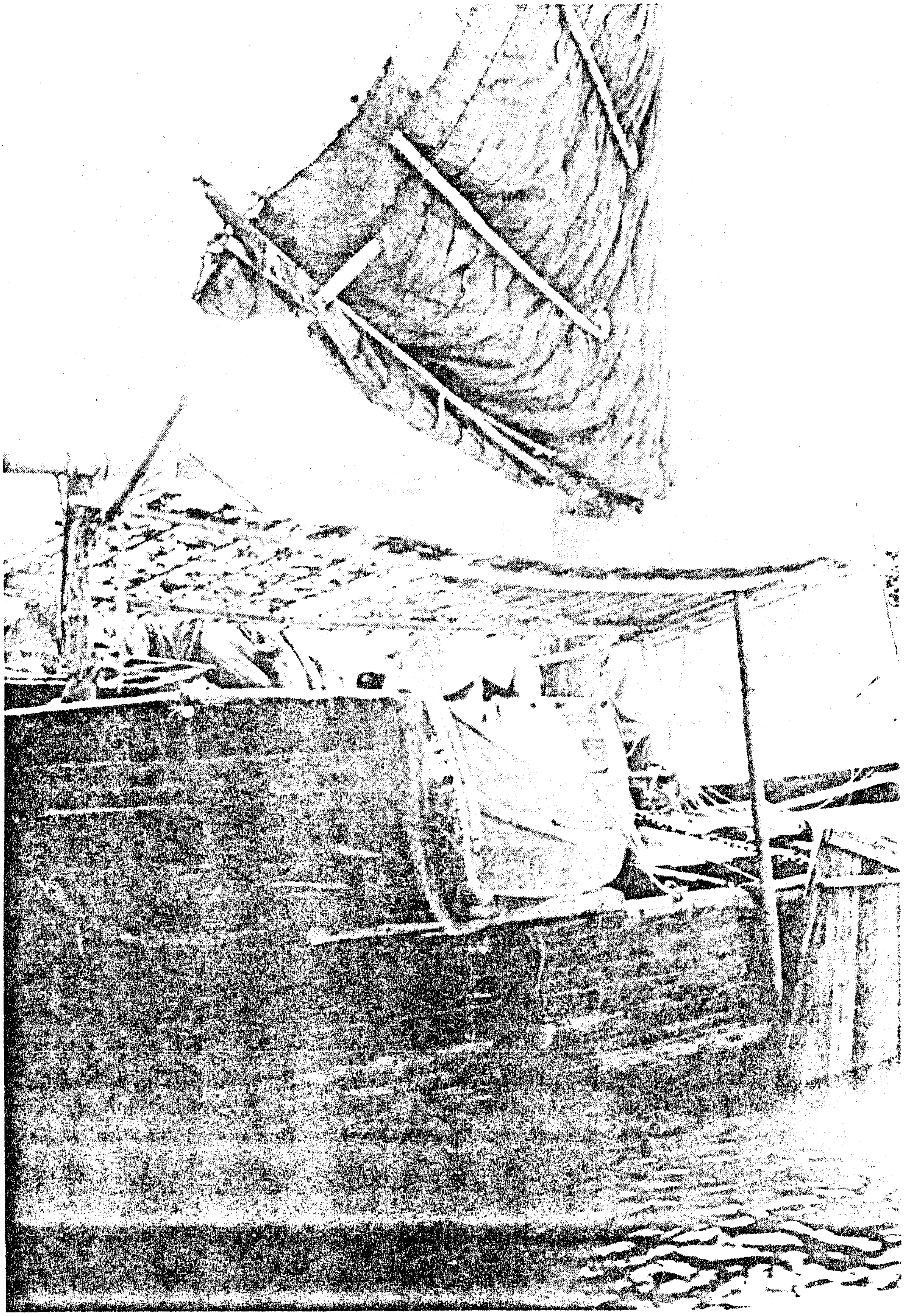


Fig. 34 Close up of Chinese lug sail. Note curvature of battens, vertical roping of sail and leeboard

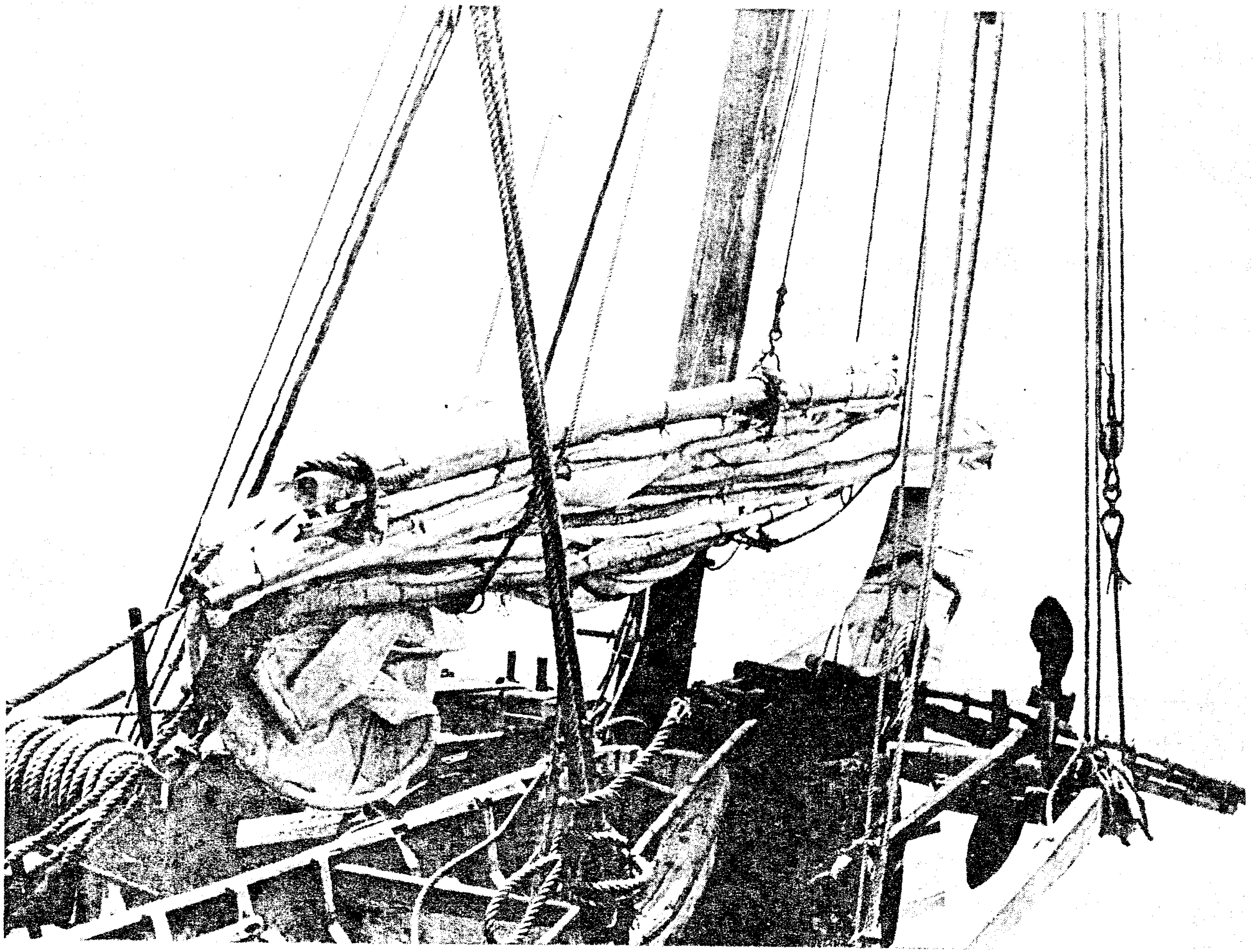


Fig. 35   Lowered fore sail supported by the multiple topping lifts of the Chinese rig

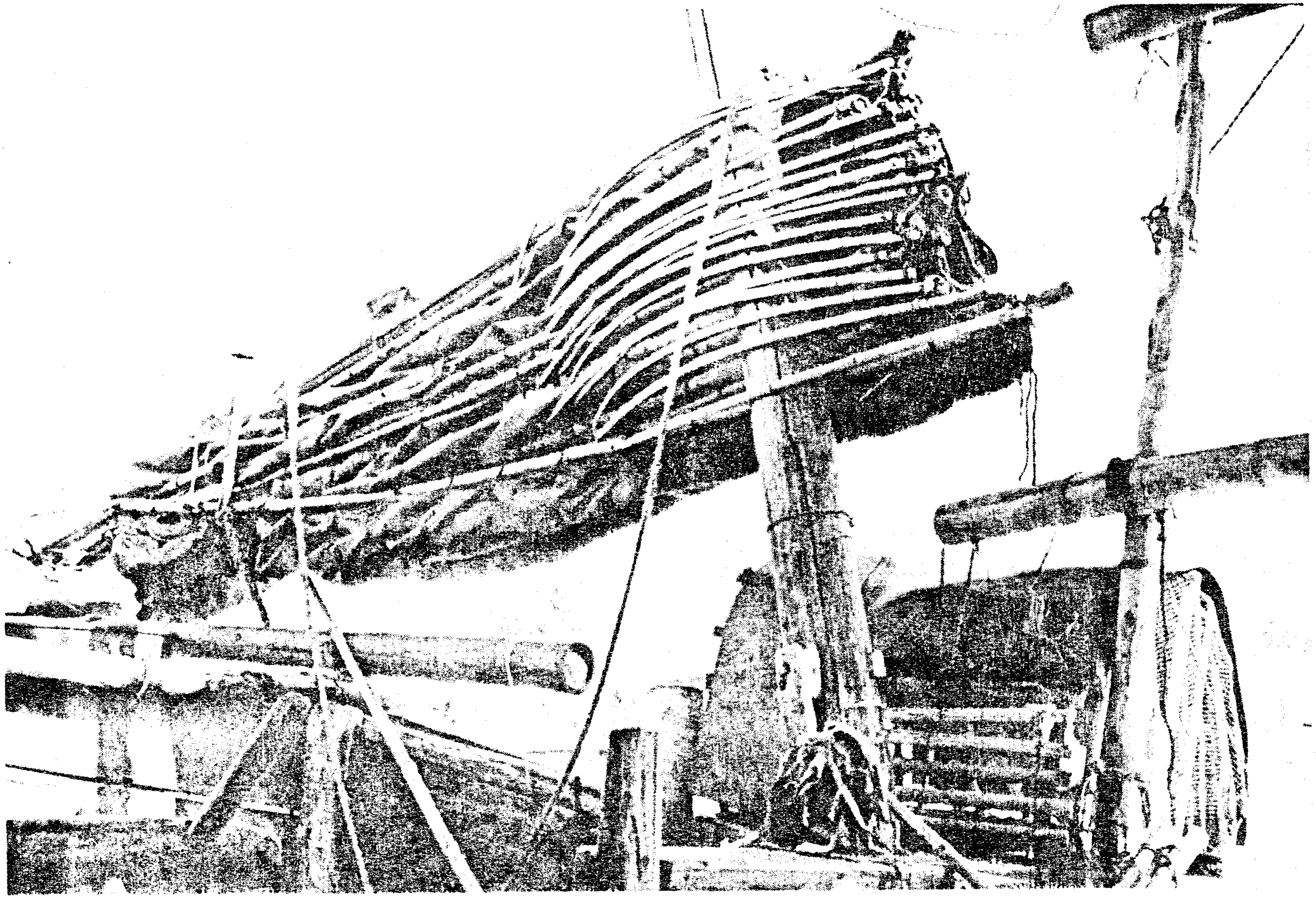


Fig. 36 Bamboo strips used as yard and batten parrels in a lake fishing boat instead of the sea going rope parrels of Fig 24

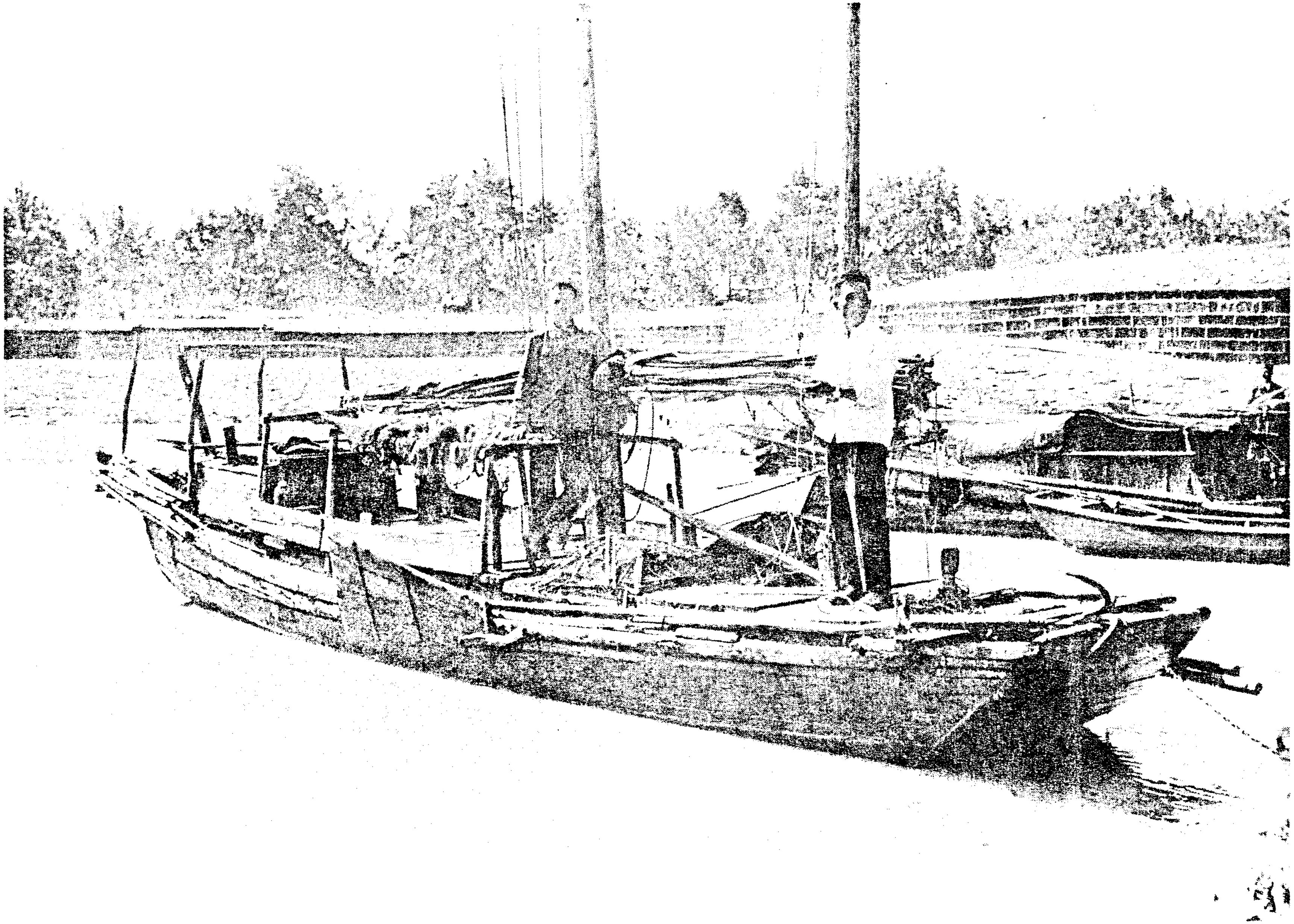


Fig. 37 9 m (29 ft 6 in) Chinese lake fishing boat with leeboard in the raised position

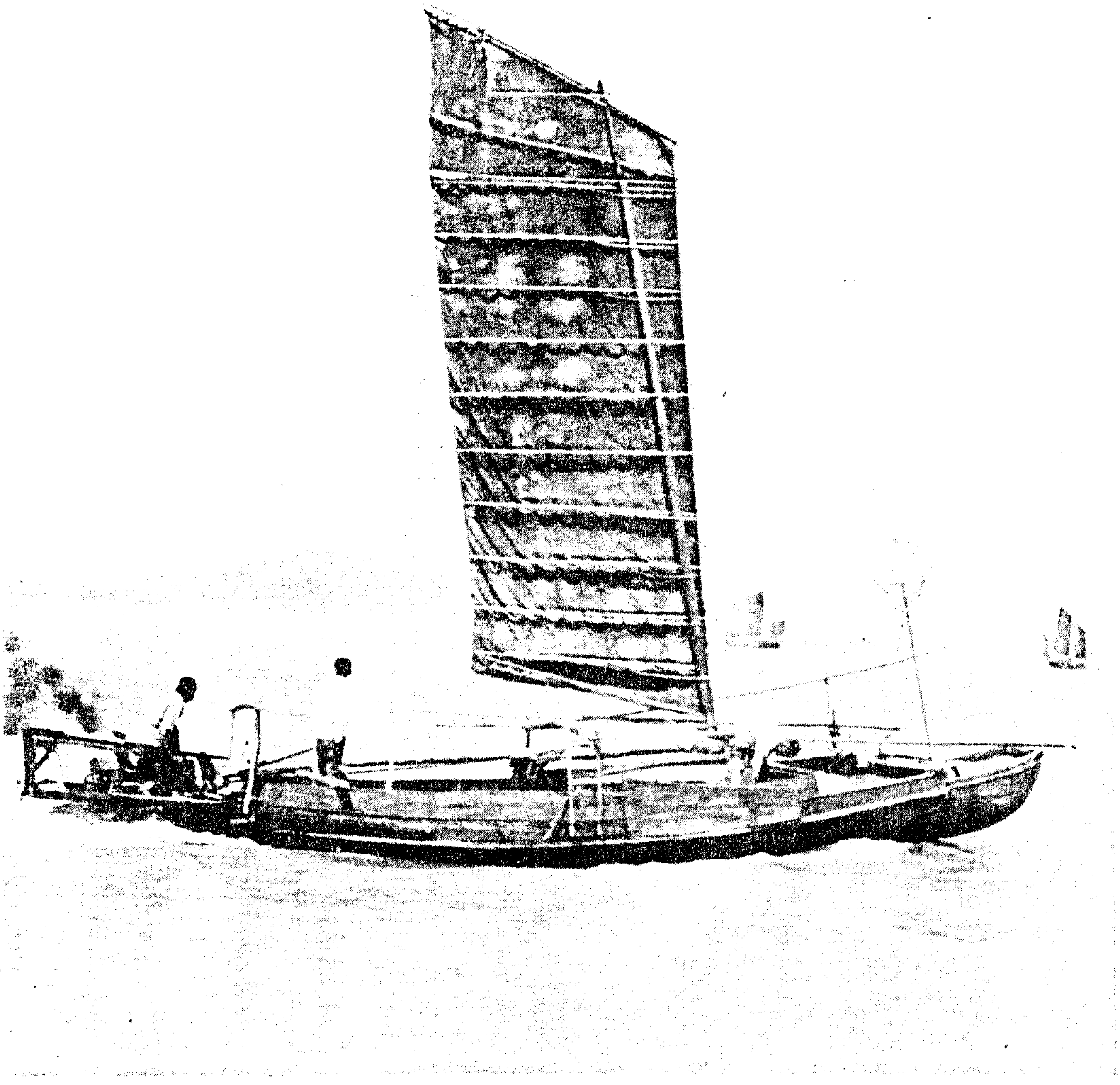


Fig. 38 9 m (29 ft 6 in) Motorized Chinese fishing boat travelling at hull speed (7.3 kn)
Note sail well hardened in and drawing effectively

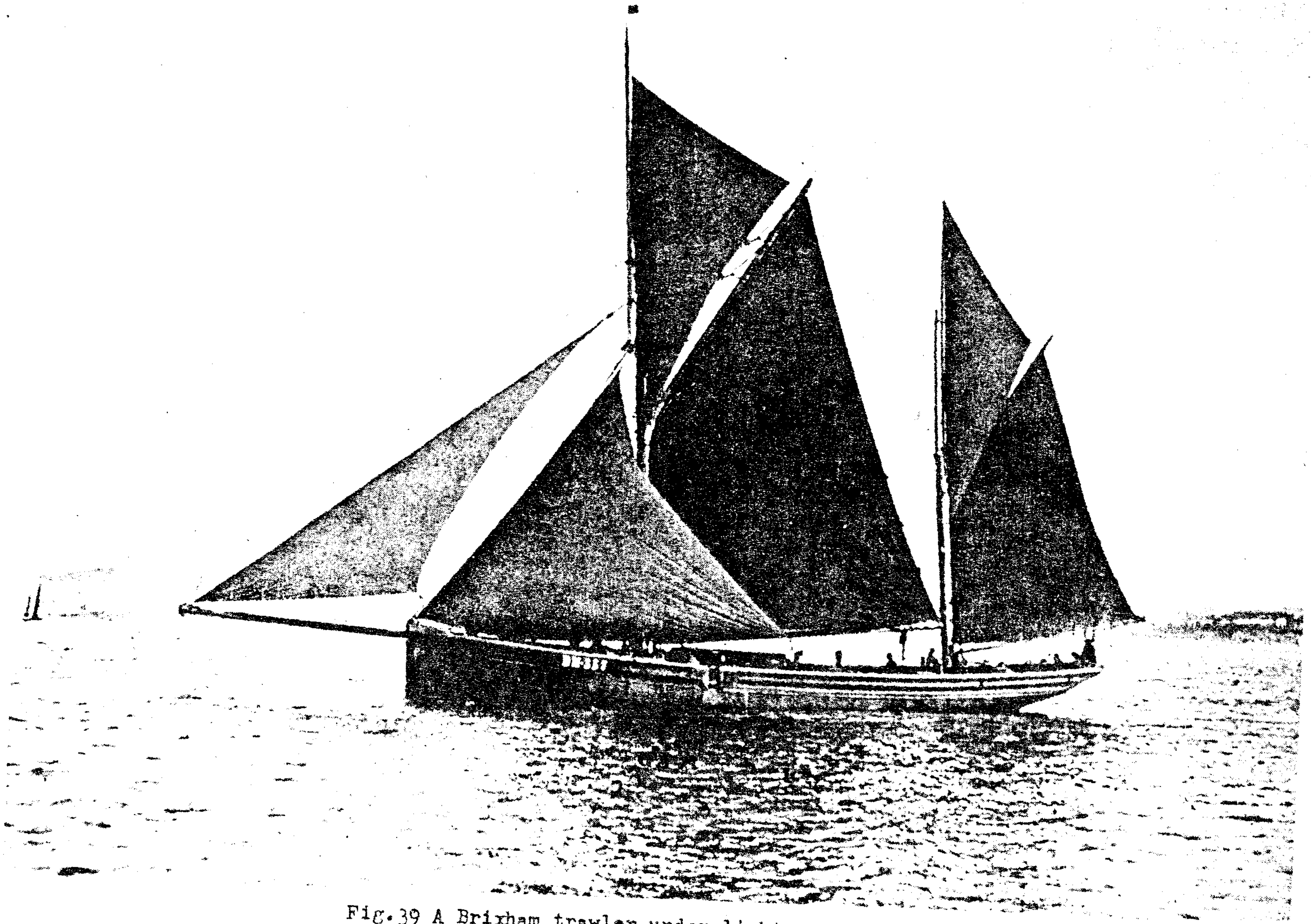


Fig.39 A Brixham trawler under light weather sail

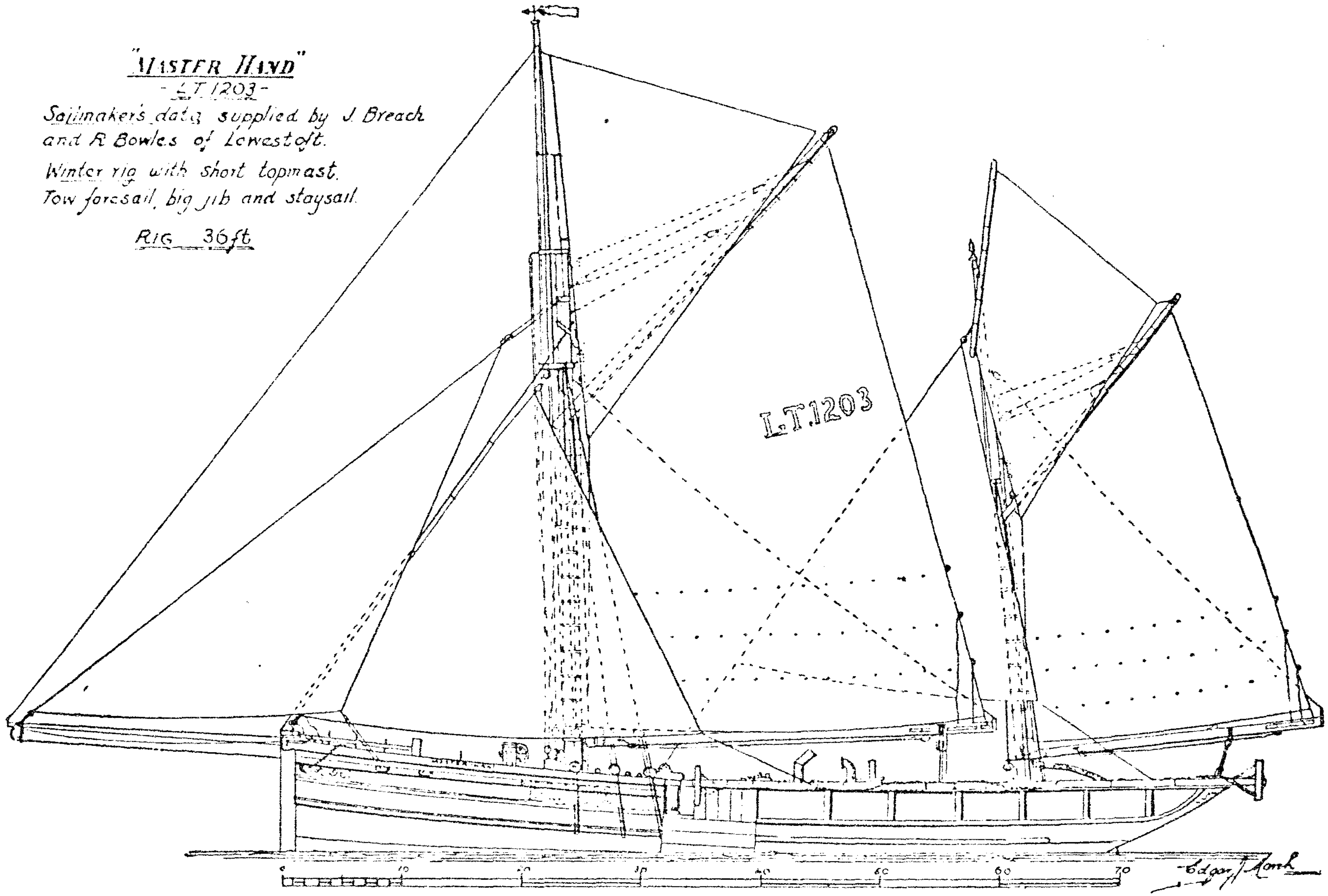


Fig.40 Rig of a typical British trawler of 1920

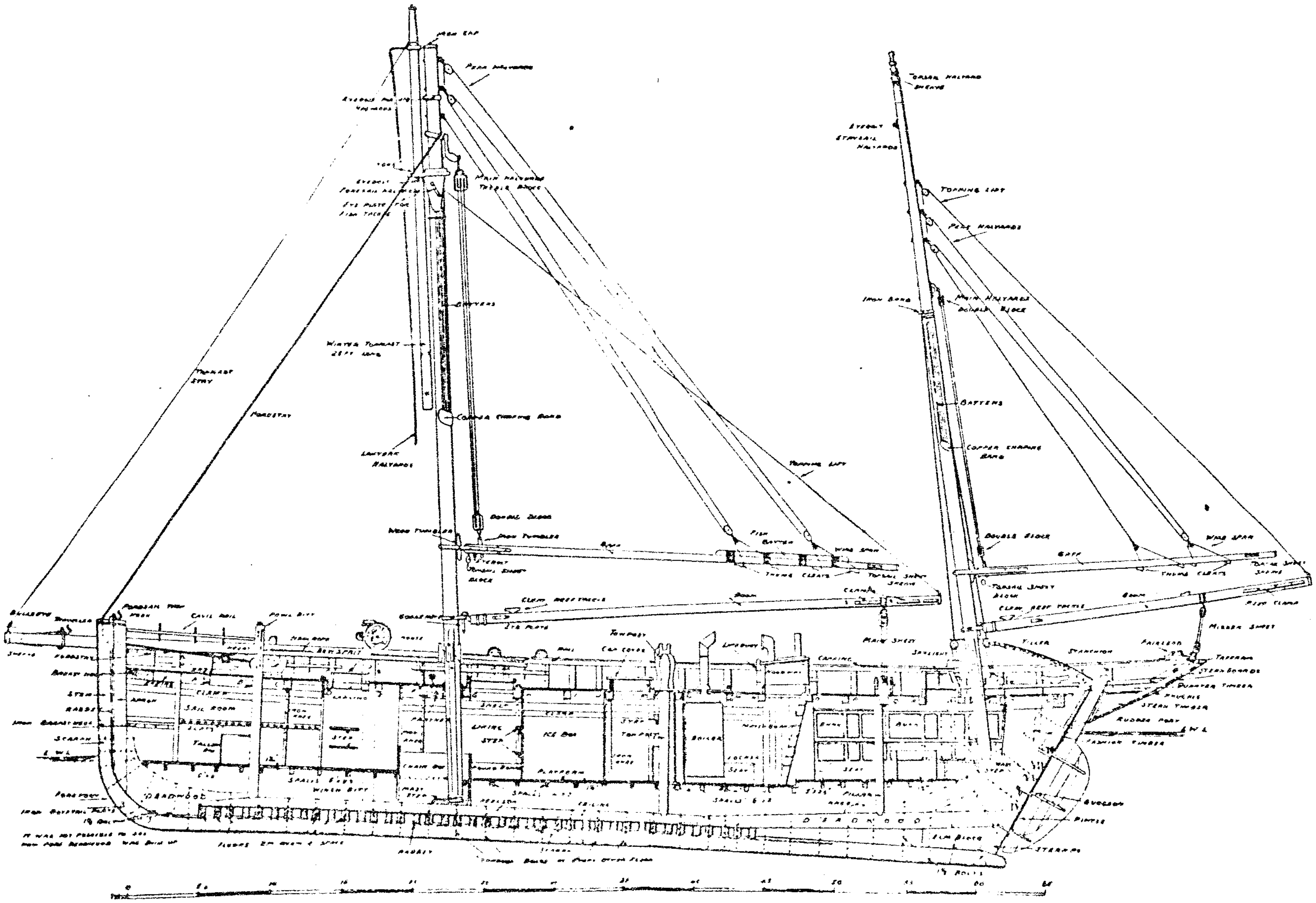


Fig. 41 Construction plan of the same trawler showing details of spars and running rigging

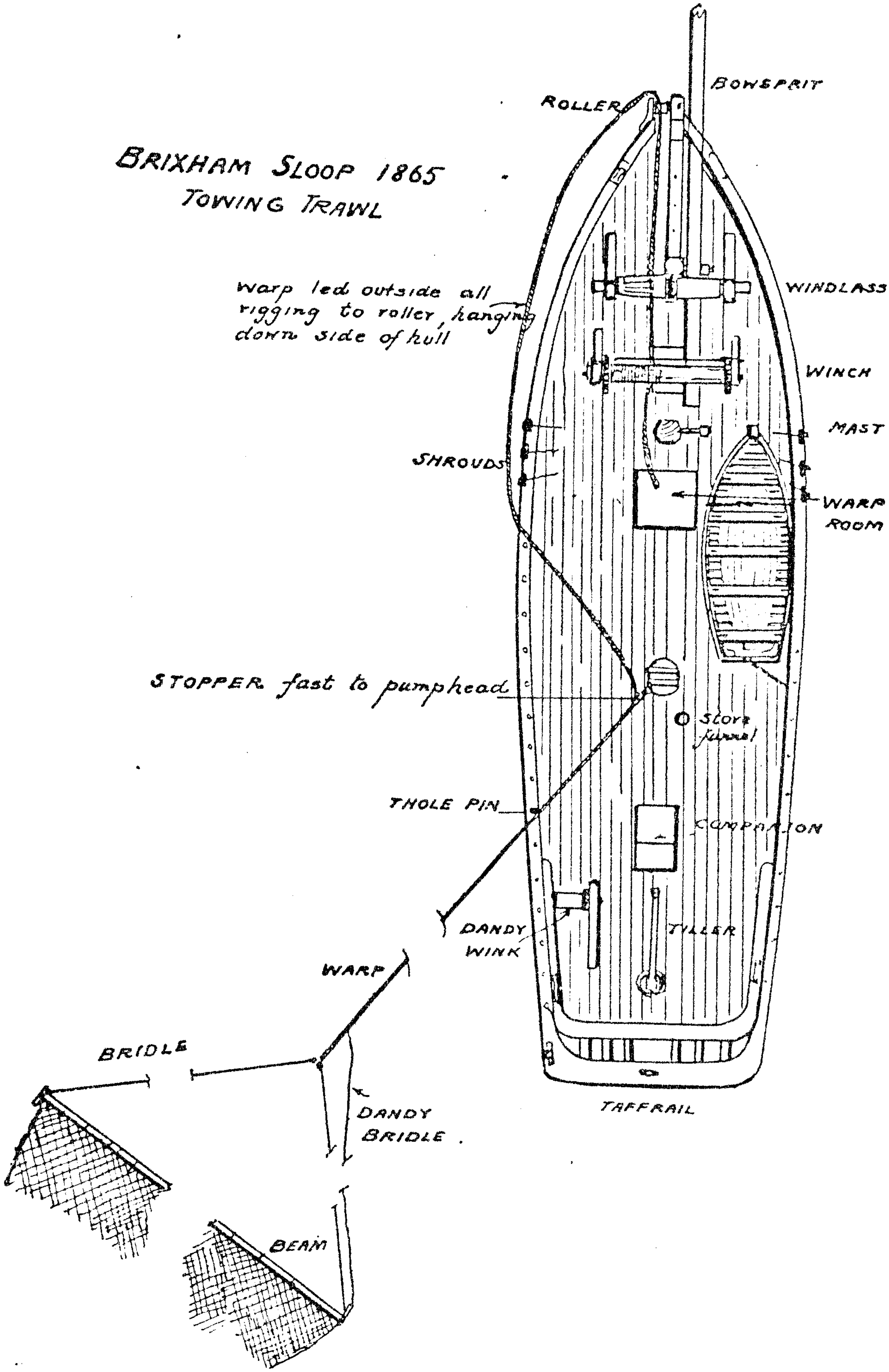


Fig.42 Showing details of the towing arrangement for the beam trawl of a sailing trawler

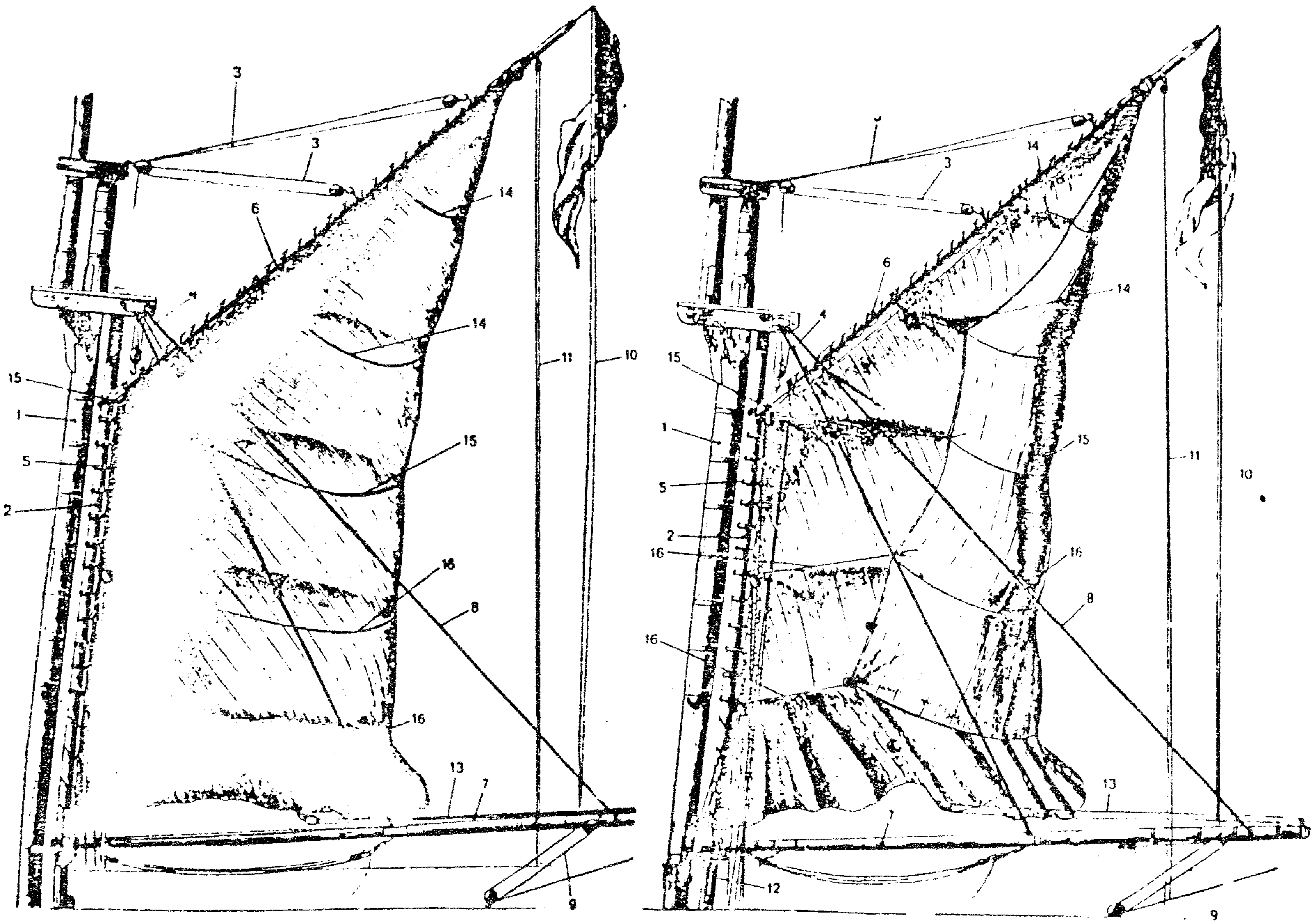


Fig. 43 Detail of gaff rig showing a method of shortening sail by brailing up the mainsail

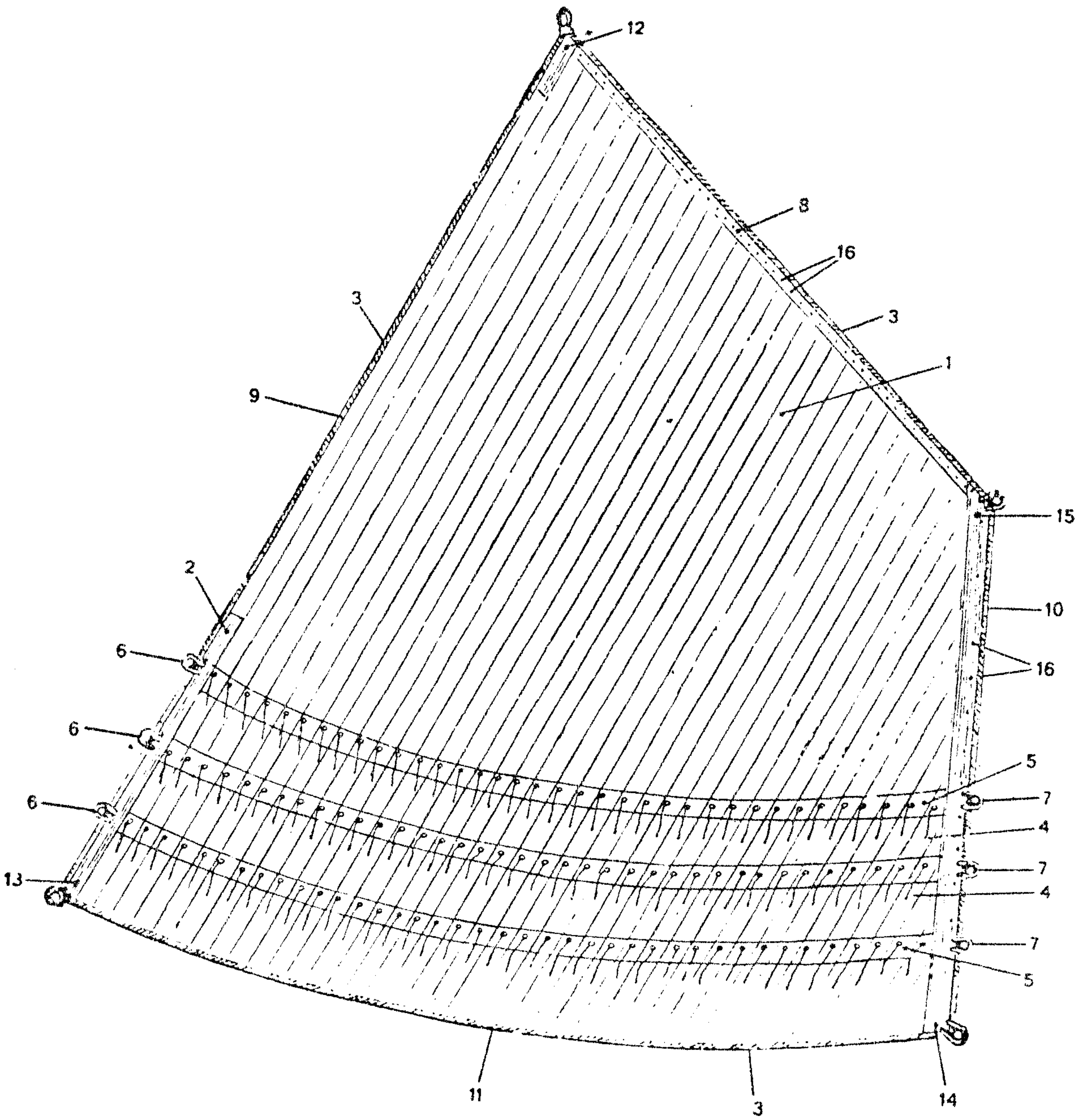


Fig. 44 A loose footed gaff sail showing vertical cloths and three rows of reef points for sail reduction in strong winds

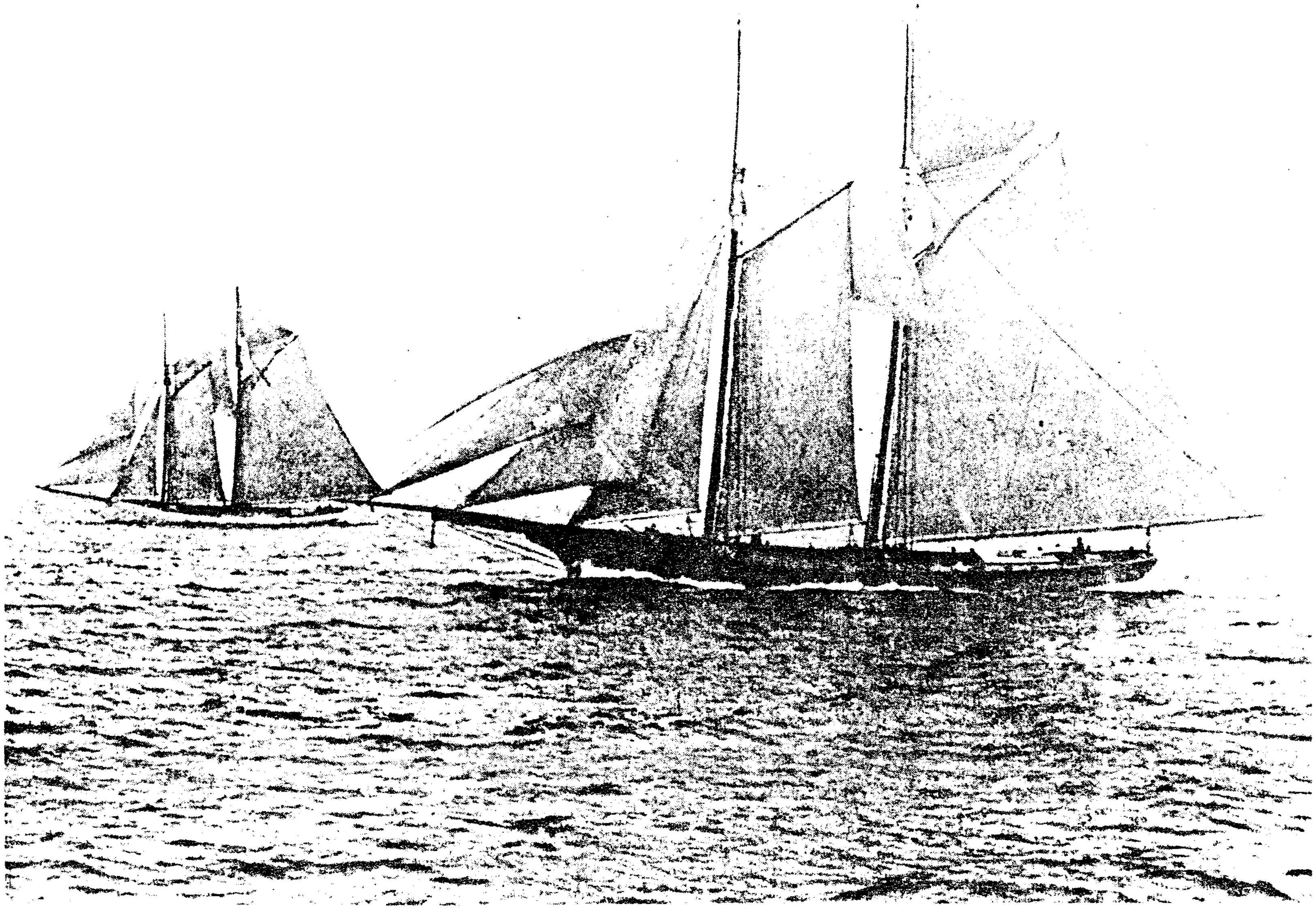


Fig.45 Two American fishing schooners under full sail

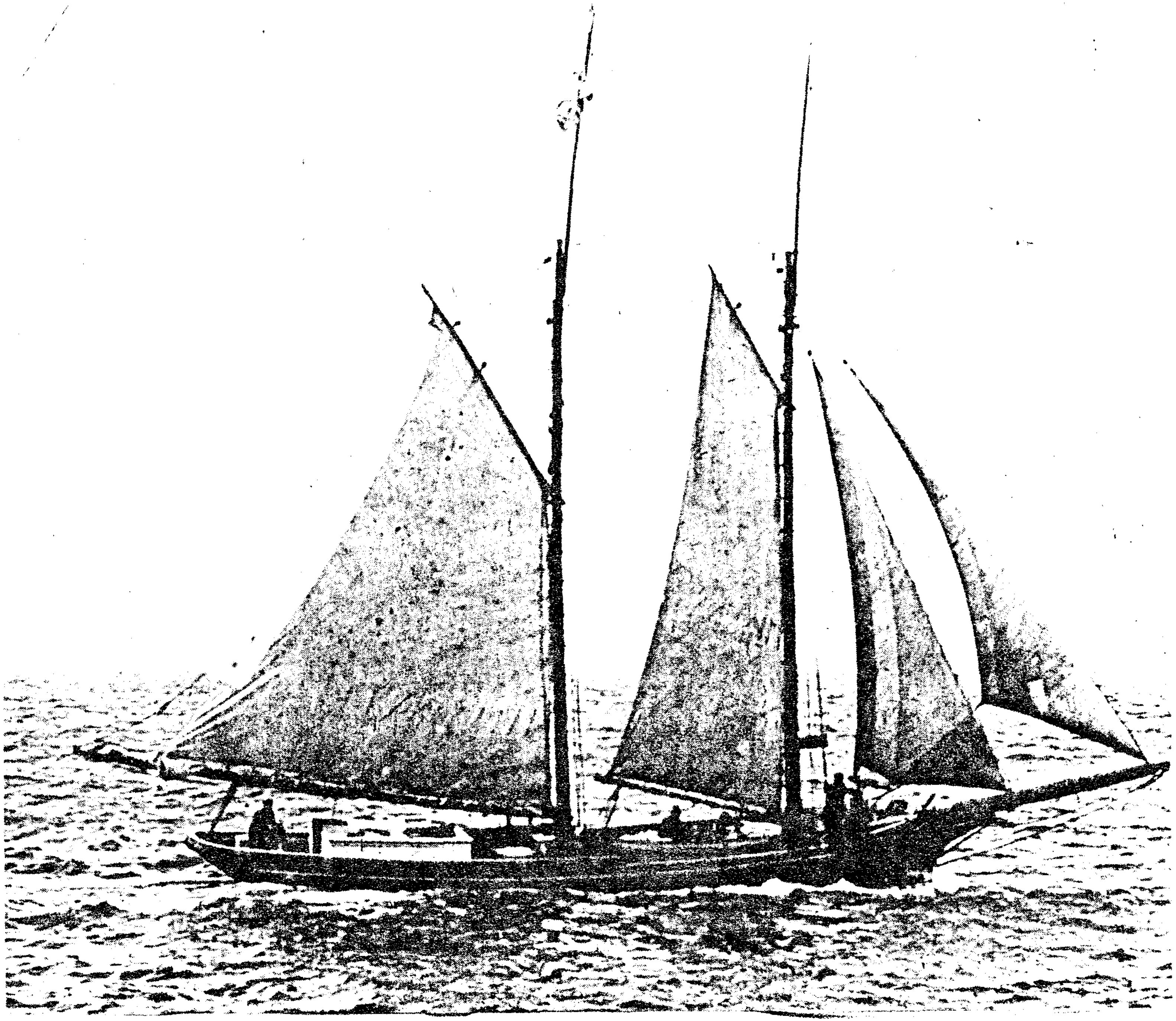


Fig.46 Under reduced sail with a reef in the mainsail. Note the topsail at the truck of the topmast

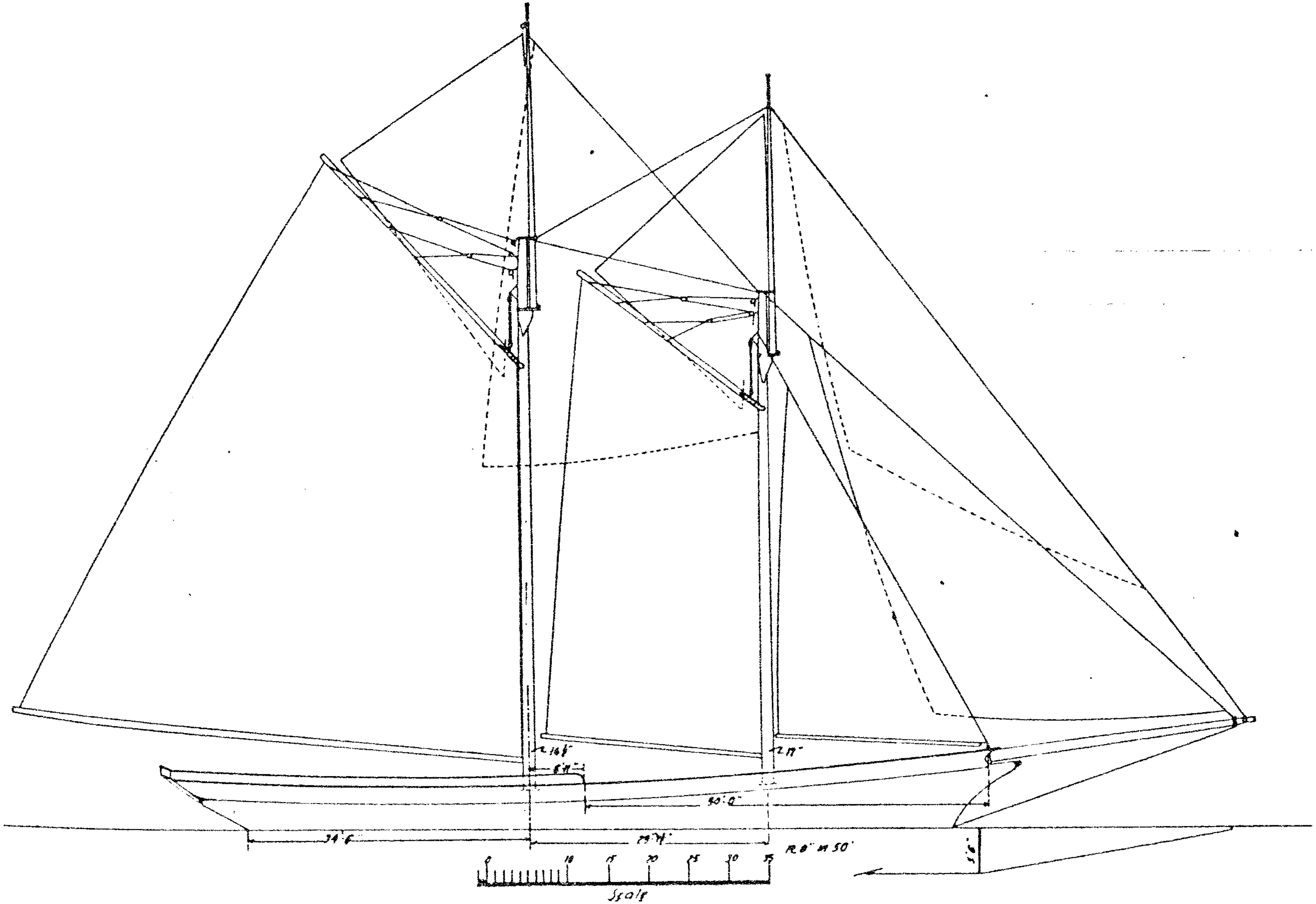


Fig. 47 Rig of a 32 m (105 ft) LOA fishing schooner

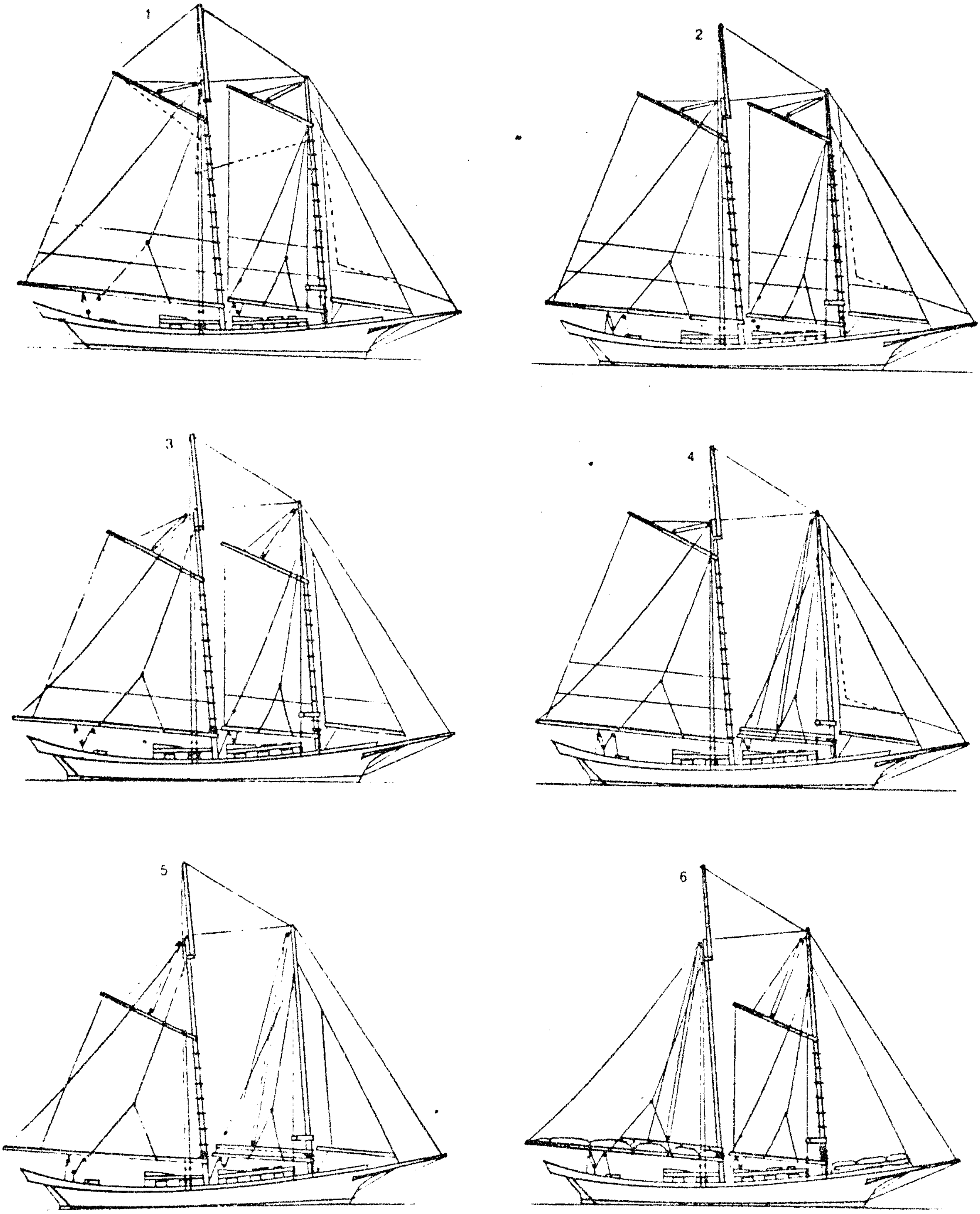


Fig. 48 Showing the progressive reduction of sail with increasing wind strength in a schooner with the sail area always in balance

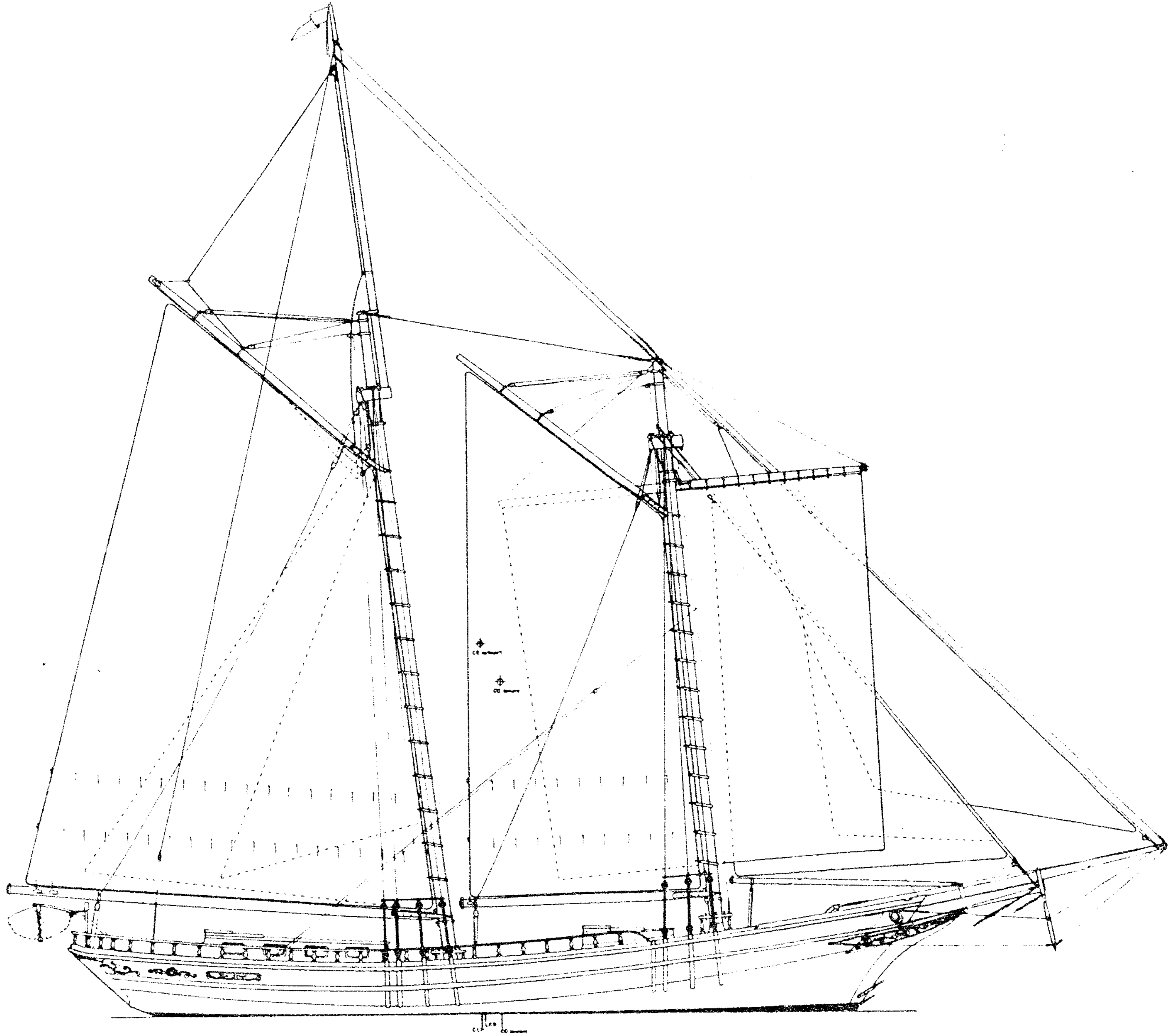


Fig.49 - 23 m (75 ft) sailing yacht derived from the American fishing schooner - design by the author.

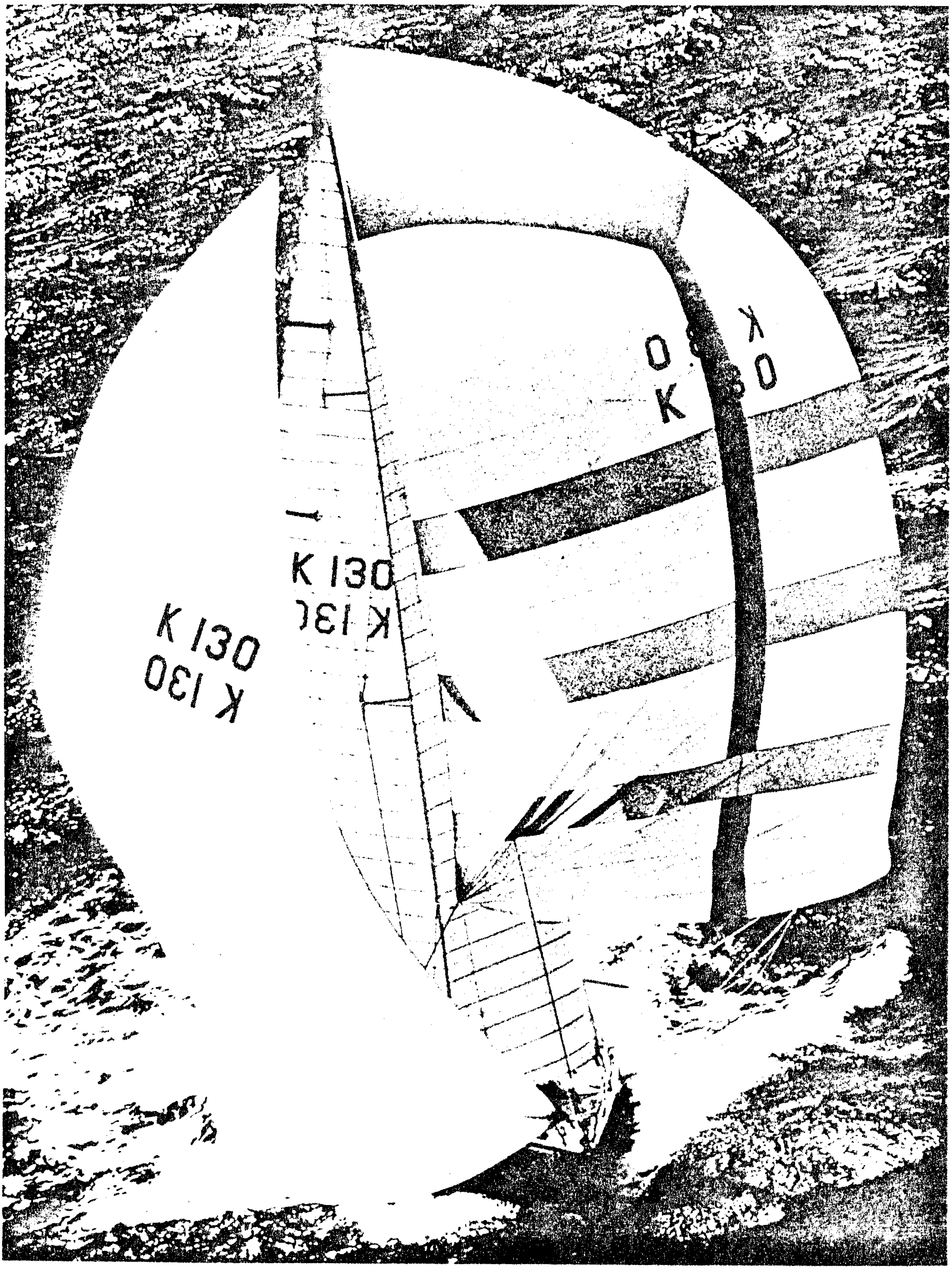


Fig.50 Example of a racing yacht and the large amount of down wind sail set with the Bermudian rig

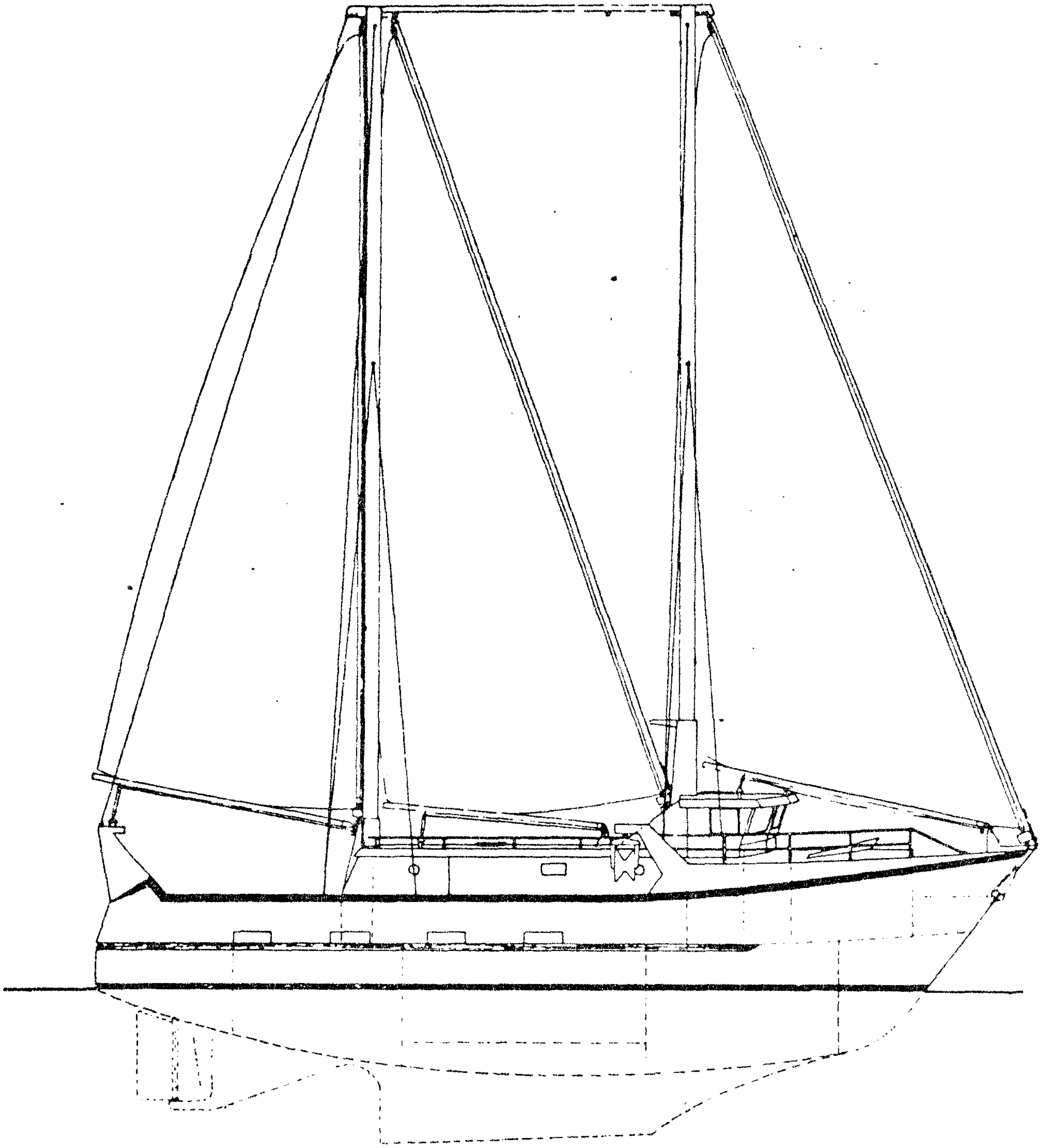


Fig.51 A 19 m (60 ft) LOA fishing vessel design. Sail area 150 m^2 (1400 ft^2) light displacement 60 t loaded 90 t

Fig.52 A model of the 19 m (60 ft) fishing vessel of Fig. 51 showing the use of trolling booms for tuna

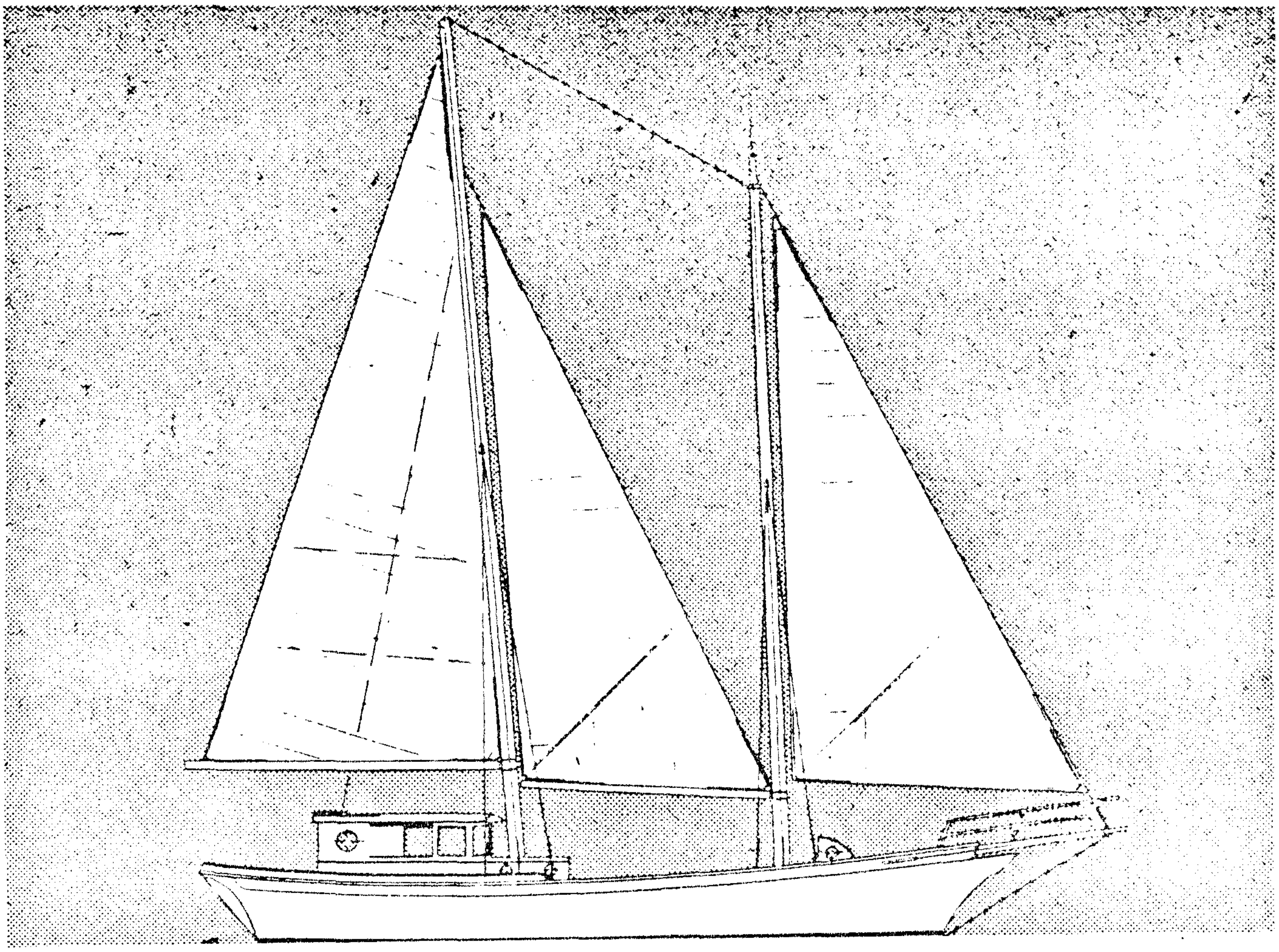


Fig. 53 A 14.30 m (47 ft) fishing schooner rig using roller reefing staysails

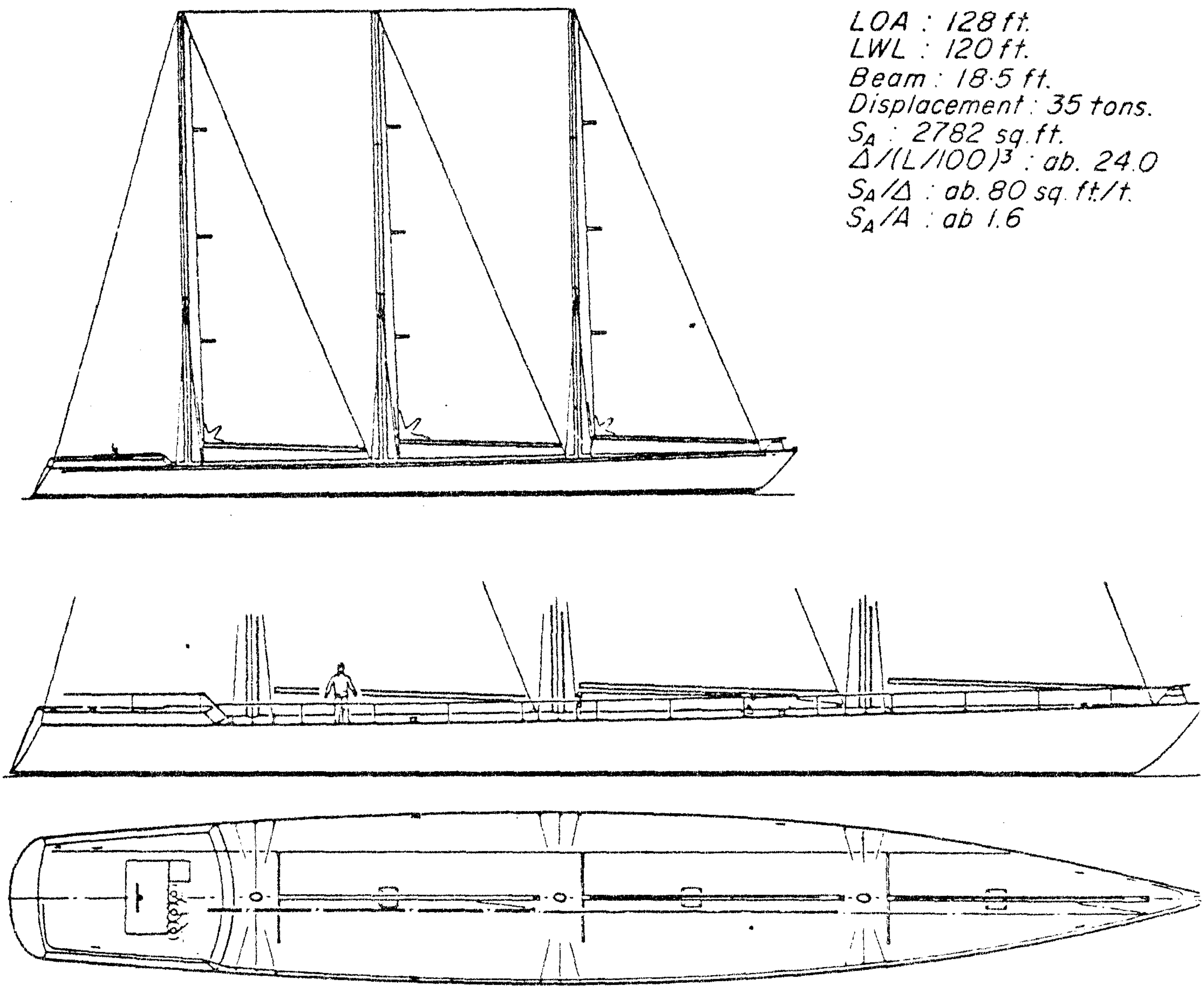


Fig. 54 An extreme example of a single handed racing yacht made possible by the ease of handling of the reefing staysails

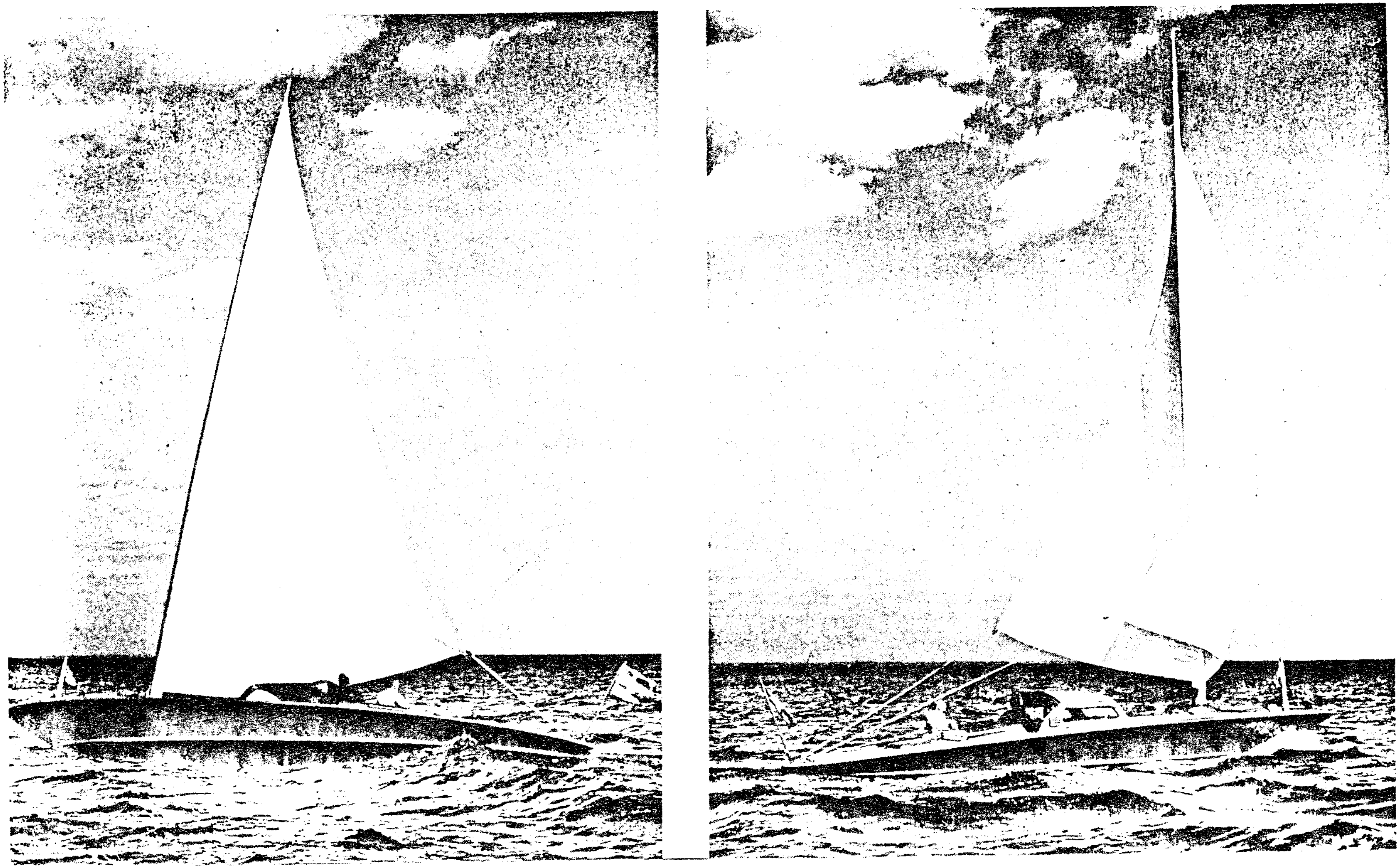


Fig. 55 Showing the double sided Ljungstrom rig on a 12.20 m (40 ft) yacht. For maximum efficiency the sails should be boomed out downwind

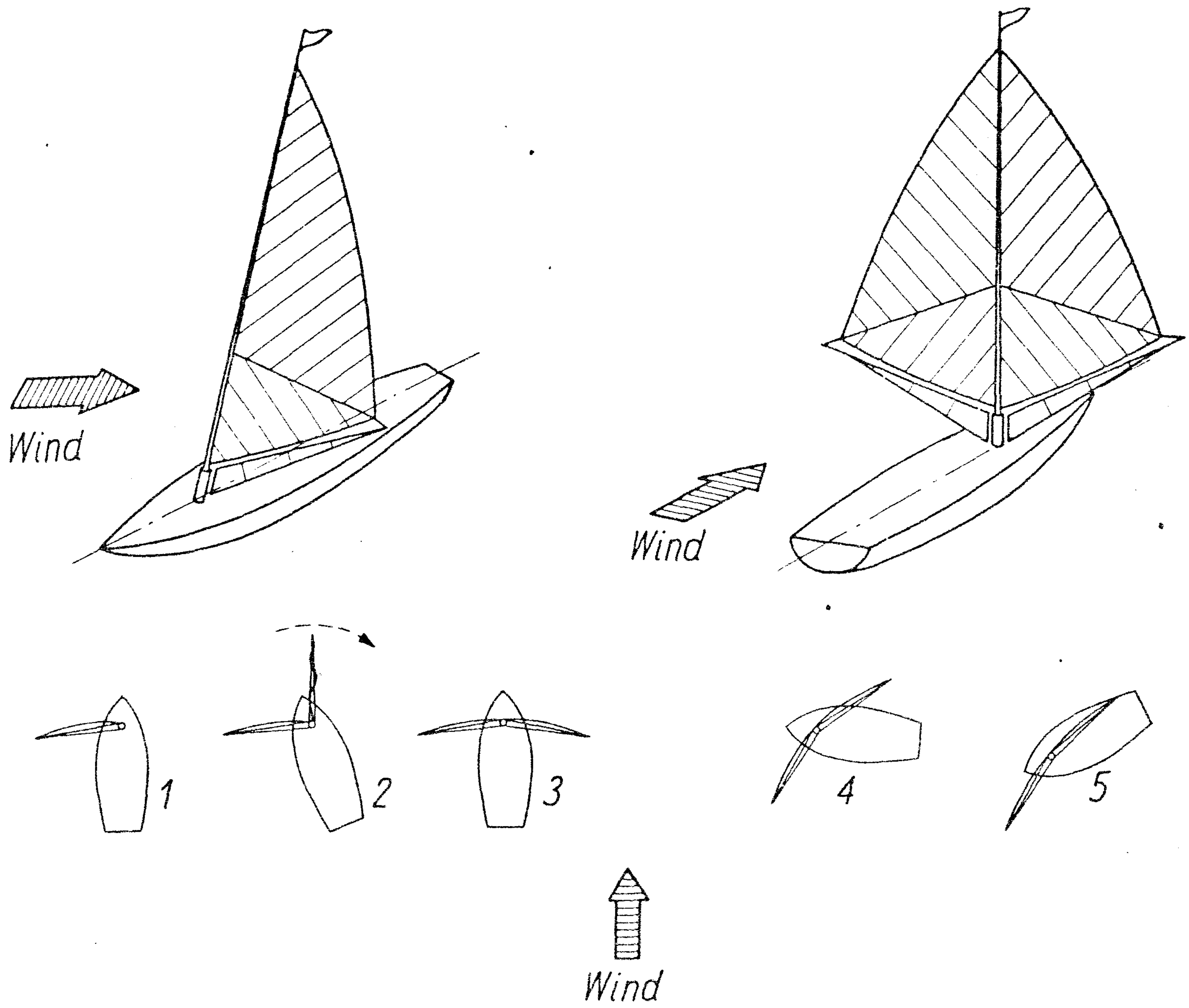


Fig. 56 Diagramatic explanation of the Ljungstrom rig of Fig.55

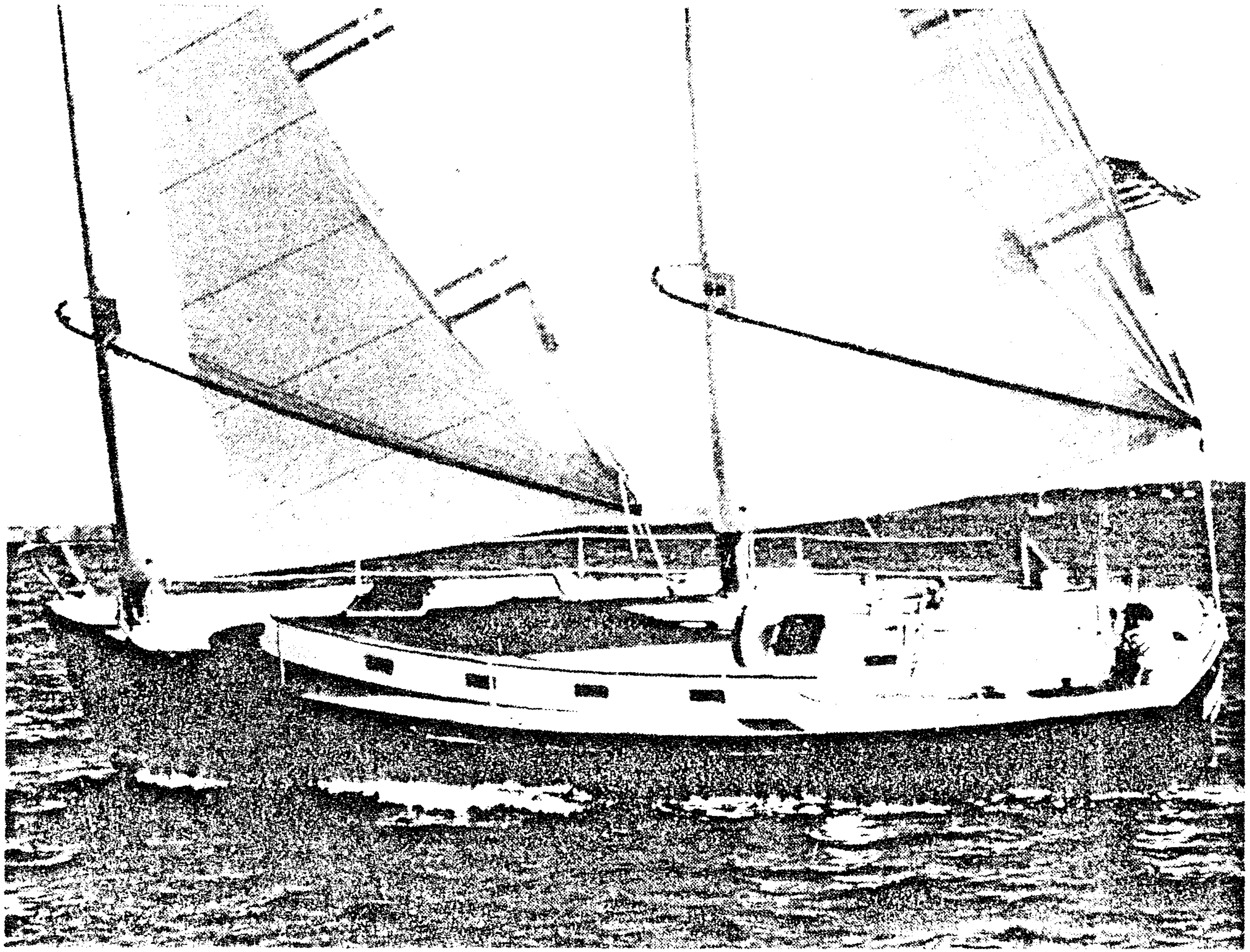


Fig. 57 Use of the wishbone type booms of the sailboard on a cruising yacht

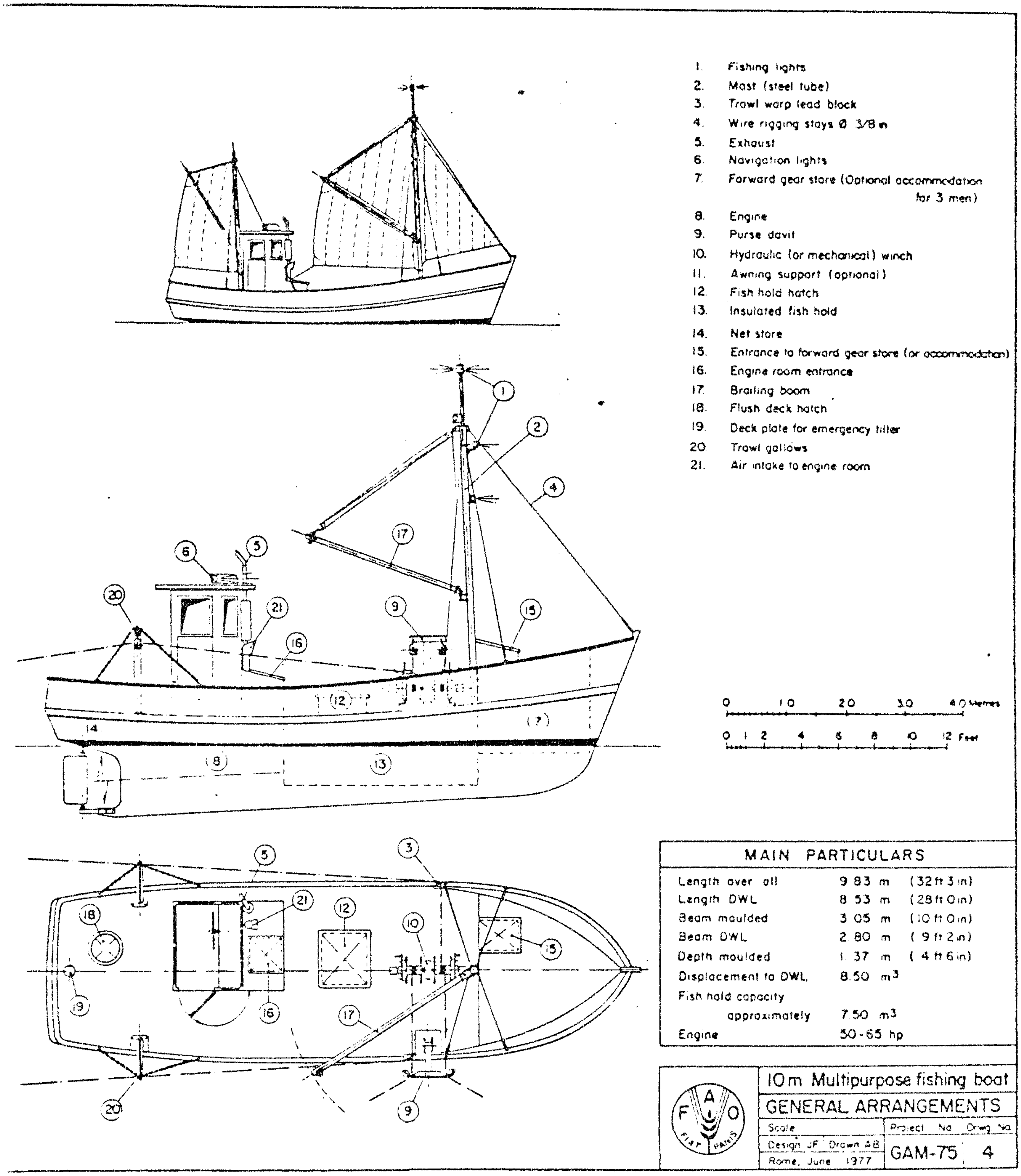


Fig. 58 Proposal for adding auxiliary sail to a small fishing boat

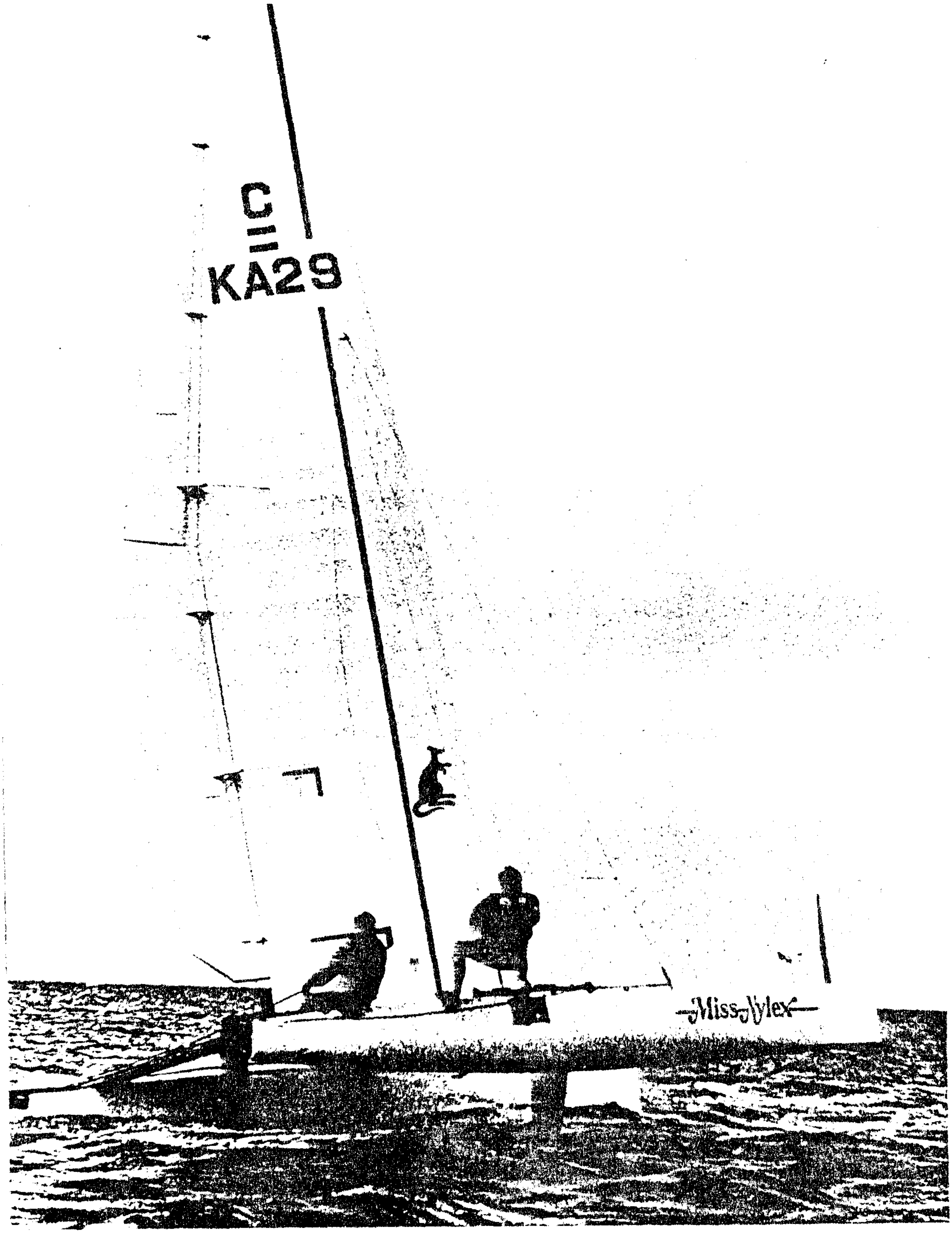


Fig.59 A rigid aerofoil in use on a racing catamaran

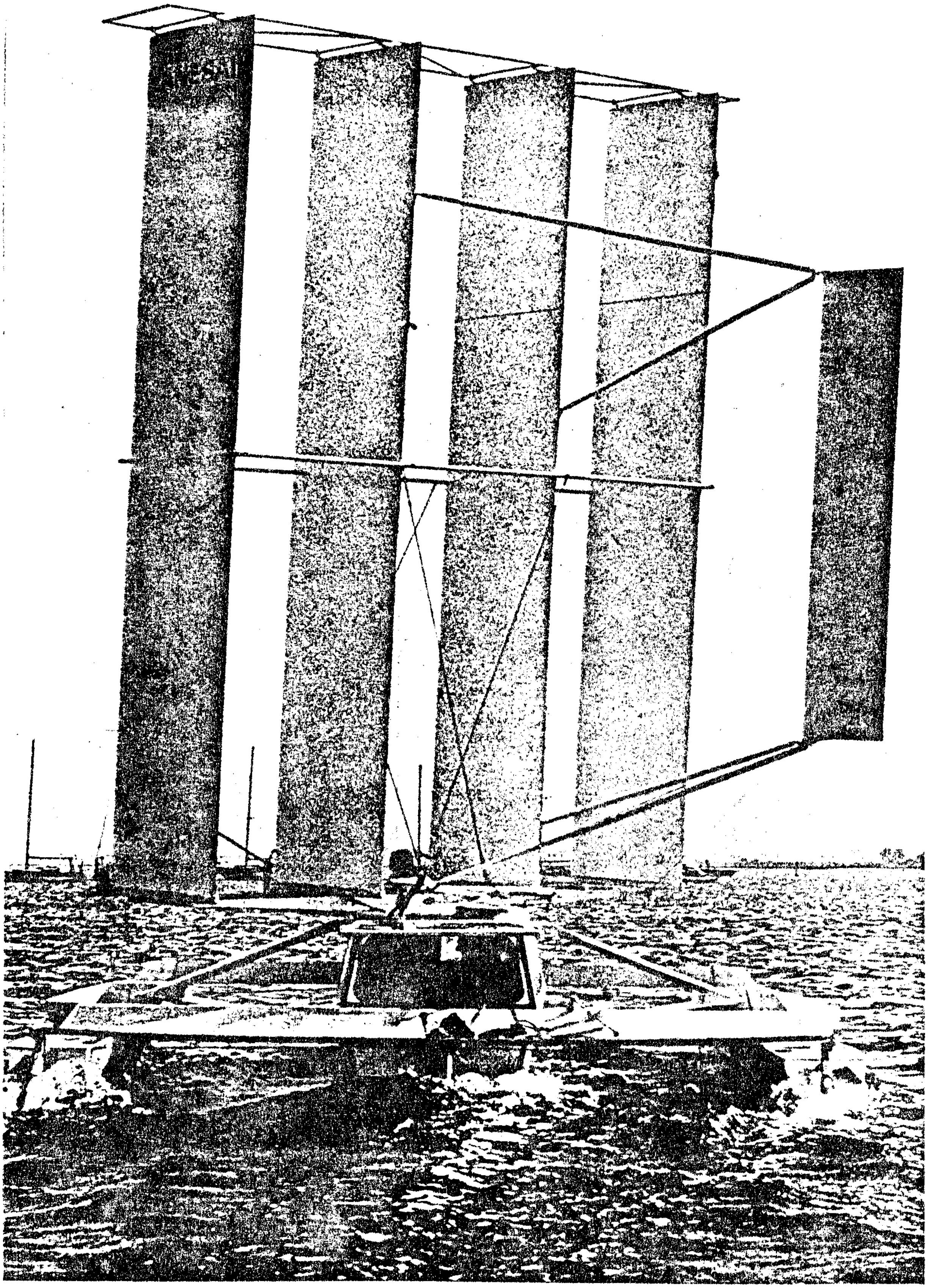


Fig.60 A fixed aerofoil sailing craft with four rigid foils (plus tacking foil)

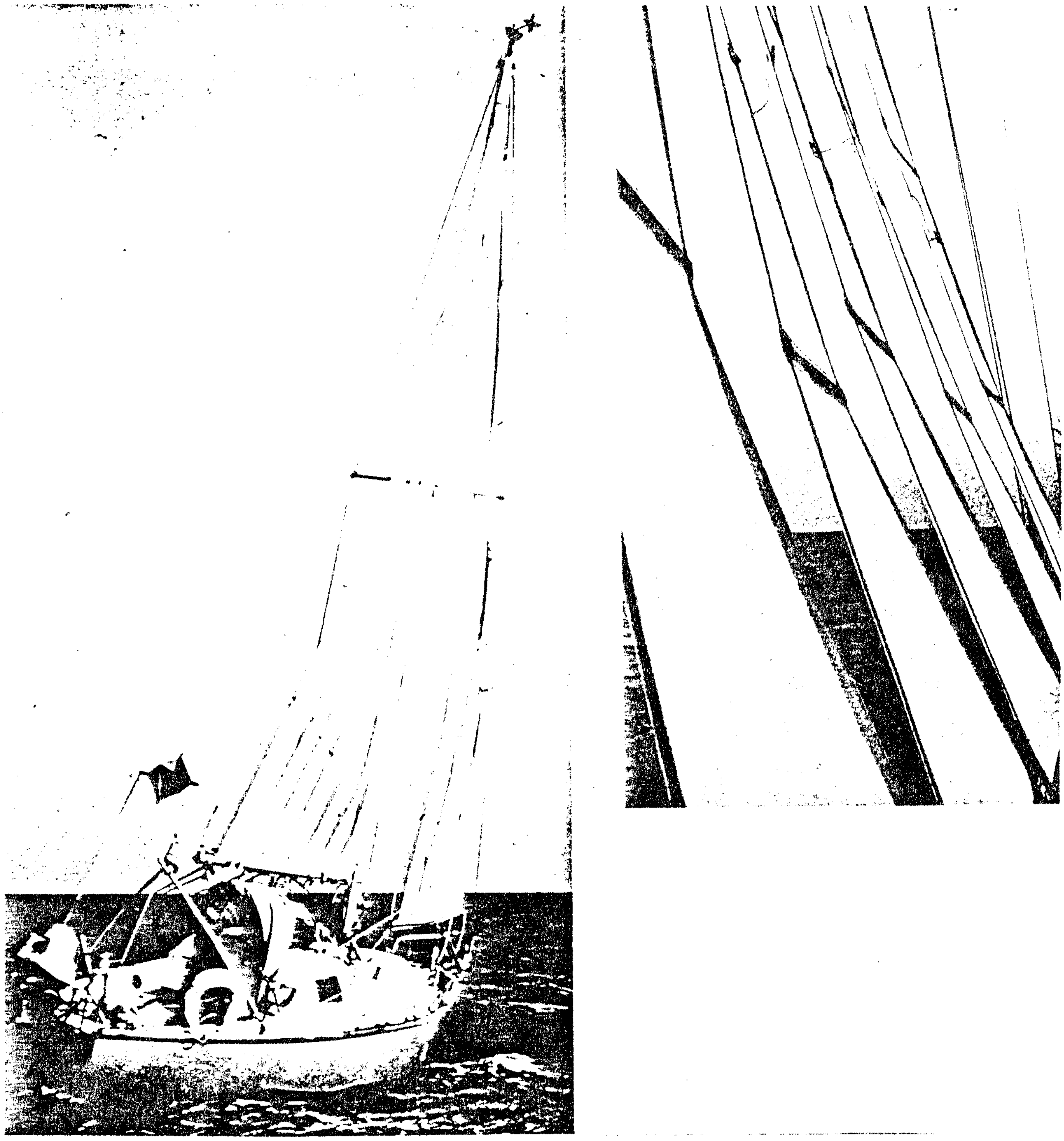


Fig. 61 Experimental slotted foil effect in sail fabric

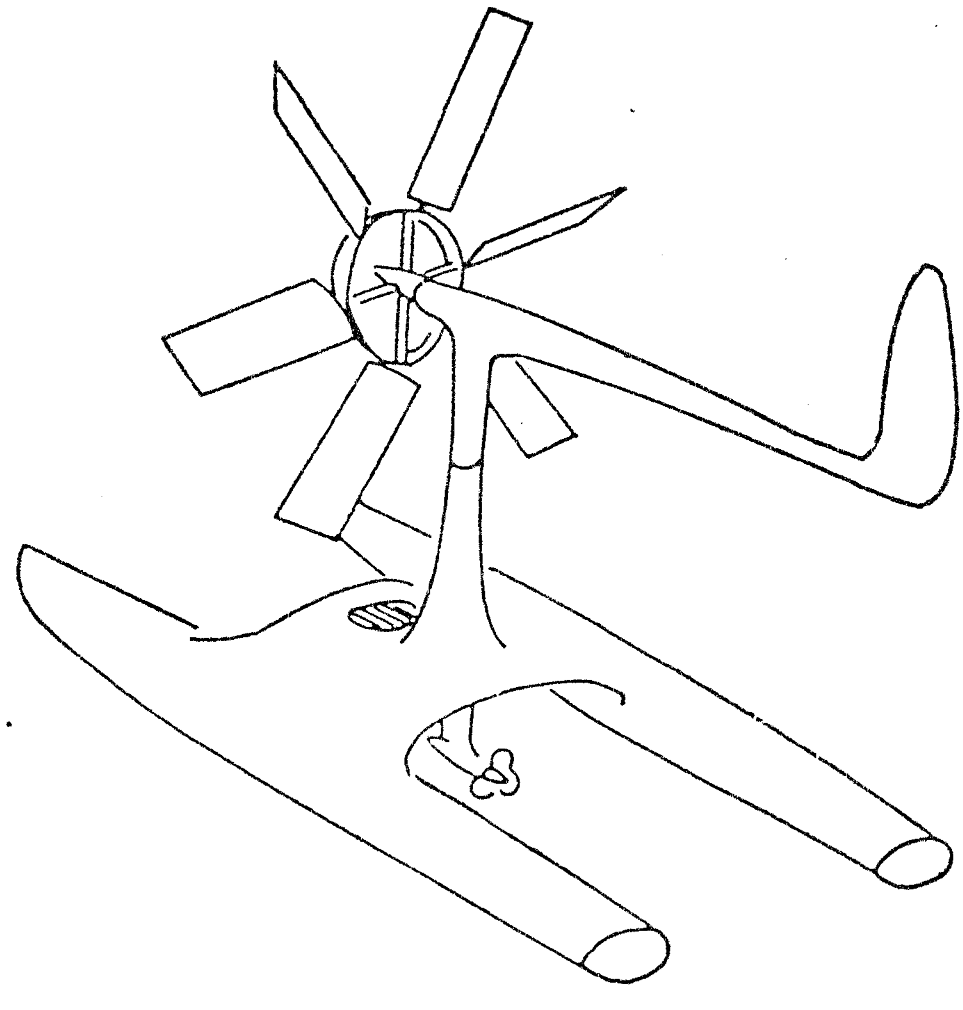


Fig. 62 A proposal for an experimental wind mill turbine

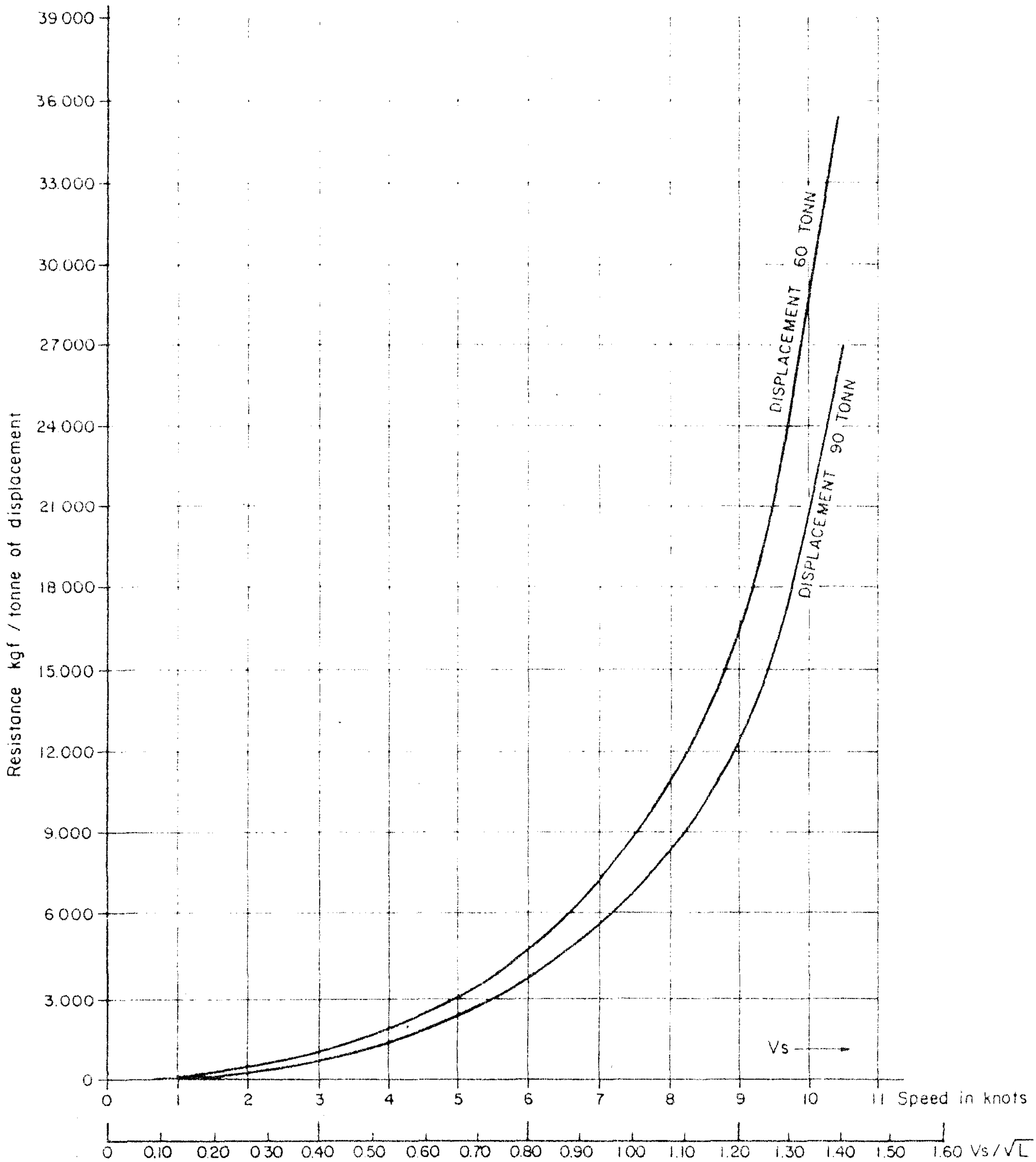


Fig. 63 Curve of resistance per ton on displacement against speed in knots and speed length ratio for a 19 m (60 ft) sailing fishing vessel