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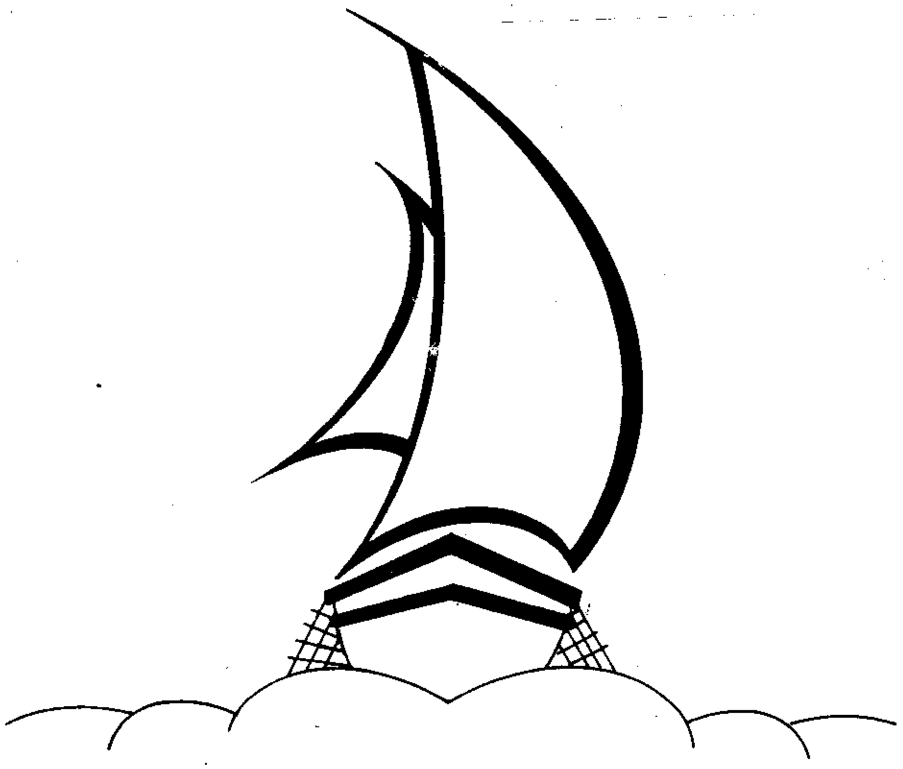

International Conference on Sail-Assisted Commercial Fishing Vessels: Proceedings

John W. Shortall III
and
Billie H. Lowry

FLORIDA SEA GRANT COLLEGE MAY 1983

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INTERNATIONAL CONFERENCE
ON
SAIL-ASSISTED COMMERCIAL FISHING VESSELS

Proceedings of a Conference
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at Tarpon Springs, Florida

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FOREWORD

This publication is a collection of papers accepted for presentation at the International Conference on Sail-Assisted Commercial Fishing Vessels. Four papers, missing from this publication will be published after the conference and mailed to the attendees. They rely on experimental data which is currently being collected. A few other papers were not received by the publication deadline and hence do not form part of these published proceedings.

In conjunction with this conference, a set of 331 abstracts has been published by Florida Sea Grant College from material assembled and edited by the College of Engineering of the University of South Florida. Copies of the publication, "Sail-Assisted Commercial Marine Vehicles -- Bibliography and Abstracts" (Technical paper 28), were given to conference participants and may be obtained by others for $2.00 from Florida Sea Grant College.

I want to thank all those who have made this conference possible including all of the authors here represented, the sponsoring organizations, members of the steering committee and the marine agents of the Florida Sea Grant Marine Advisory Program.

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PERFORMANCE PREDICTION, ROUTING, STABILITY, INSTRUMENTATION

ADVANCED WIND THRUSTERS AND SAILING RIGS FOR COMMERCIAL VESSELS

PAPERS FOR POST CONFERENCE PUBLICATION

REVIEW OF POTENTIAL SAIL-ASSIST APPLICATIONS TO FISHERIES AND INFLUENCE OF FISHERY OPERATIONS ON DESIGN

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ABSTRACT

The need to reduce fuel consumption of fishing vessels in order to work within economic boundaries of various fisheries has led to the introduction of sail assistance. Total power needs of fishing vessels are reviewed and the classification of fishing methods in terms of demands placed on the vessel is extended to a tentative ranking of fishing operations having potential for use of sail-assist and alternate source power generation. The need for basic data concerning power use by fishing vessels in order to permit development of power budgets, and matching needs with available sources and storage facilities, is considered, together with some of the developments necessary before alternate power can make an effective contribution towards the total energy needs of larger fishing vessels.

INTRODUCTION

Mechanically developed power was first applied to fishing vessels, as with most other commercial vessels, as a means of reducing manpower needed to operate various types of gear. As the use of auxiliary power grew, it became possible to handle bigger gear, and when steam propulsion was accepted, the ability to tow virtually without consideration of wind direction and force, led to the development of important new fishing methods, particularly in terms of towed and dragged gear.

The modern fishing vessel has developed, therefore, around the availability of almost unlimited power, with the size, gear and operating techniques optimized within the social and economic boundaries of an individual fishery, its markets, and people involved. Typically, fishing vessels applicable in the more commercialized and developed fisheries involve high levels of investment and are relatively complex and sophisticated. Fishing craft used in the small scale and artisanal fisheries are normally smaller and likely to use manpower or only the simplest of low powered equipment to handle the gear.

At all levels of operation, however, the rise in fuel prices has caused the economics of the fishing operations to become out of line with the economics of the market place. This has resulted in an urgent need to reduce fuel consumption and hence costs; most larger vessels are operating at reduced speed and artisanal fishermen in the developing countries are putting aside their outboard motors and seeking assistance in the use of sail power for propulsion.

The application of sail power to small scale fishing craft such as canoes, is a specialized topic which is the subject of later papers.This paper will therefore consider the power needs of fishing vessels at the more developed levels and attempt to provide in a general manner, some useful ways in which wind and other natural power might be utilized during operations.

TOTAL POWER REQUIREMENT OF FISHING VESSELS

A modern fishing vessel uses power for a number of functions in addition to propulsion, and all of the power is produced by the main and auxiliary engines, which normally rely on diesel fuel for their operation.

The following represents an initial attempt to provide a generalized summary of power uses aboard a fishing vessel:

1. Propulsion on passage to and from the fishing grounds, and while changing fishing locations.
2. Maneuvering the vessel during fishing operations, including setting and hauling the gear, and towing or other movement needed while working the gear.
3. Winches and other powered deck machinery used to handle the gear while setting, hauling, bringing the catch aboard, handling and offloading.
4. Deck equipment used for anchoring and operating the vessel.
5. Storage of the catch: depending on the storage method, this may involve pumps, refrigeration, icemaking.
6. Processing the Catch: depending on requirements for processing at sea, may involve machinery for gutting, filleting, freezing, etc.
7. Ships Systems: pumps, electrical, electronics, heating, air conditioning, cooling and cleaning, fresh water, fuel, salt water etc.

The levels of power use required by a particular vessel will, naturally, be dependent upon its size, type of fishing operation and complexity in terms of equipment for handling the gear, handling, processing and storing the catch, and crew living conditions.

For the most part, the application of sails to fishing vessels has focussed on use during passage in order to reduce or replace mechanical power requirements. It is important to note however, that a number of useful fishing methods either do not require the use of power while fishing, or may benefit from an absence of engine or propeller noise.

In other cases it may be possible to use previously generated and stored power (e.g. batteries) in order to meet the power needs for gear operation, if the vessel does not require power to maneuver during fishing.

In terms of more general vessel system needs, there is potential for the use of wind, water or solar generated power.

FISHING METHODS AND GEAR

Traditionally, fishing operations and gear have been classified in terms of the manner in which the gear is worked to capture the fish (refs. 1 & 2). Design criteria placed on fishing vessels have been concerned primarily with meeting the requirements of fishing gear operation while allowing for a viable profit making enterprise.

Some types of gear have been developed to be effective on species living near or on the sea bed, commonly termed demersal fish, groundfish or bottom fish (e.g. cod, haddock, flounder); other gear is designed to scrape or dig into the sea bed to gather clams and other shellfish. Operations with these types of gear use the sea bed as a reference.

Where the fish being sought are found in the water column or near the surface in the deep ocean (pelagic species such as tuna and sardine),operations and gear may be designed to use the sea surface as a reference. Fig. 1 shows typical species within these general groups.

Depending, in most cases, on the individual size and value of the species being sought, a fishing method may be designed for capture in bulk (e.g. menhaden for reduction to fish meal), in relatively smaller quantities, or by the individual (e.g. swordfish). In some cases, such as with tuna, the characteristics and economic value of the fish may permit profitable operations both at the bulk catching (large scale) and at the individual (small scale) levels.

At the same time, characteristics of a species will control whether bulk catching techniques are practicable, i.e. if the fish school together, are spread less densely, or are scattered. Habits and patterns of movement will be important and govern whether and in what manner gear must be placed or moved to effect capture.

In order to discuss the applicability of sail assist to the operation of fishing vessels, it appears necessary to classify the fishing methods in terms of demands placed on the vessel:

1. Methods requiring considerable power inputs, or the vessel to perform closely defined maneuvers, during the fishing operation

   a) Trawling
   The bottom trawl (Fig. 2) is towed along the sea bed to cover large areas in order to bulk-capture species which are loosely distributed.

b) Dredging
Dredges (Fig. 3) are dragged so that they scrape or dig into the sea bed to gather scallops, clams, etc.

c) Midwater Trawling
The midwater trawl (Fig. 4) is utilized to capture fairly densely congregated fish between the bottom and the surface.

d) Purse Seining
The purse seine (Fig. 5) is used to bulk capture pelagic species which school at or near the surface. The net is very large and heavy, and may require considerable power to operate.

e) Seine Netting
This method (Fig. 6) is used to catch high quality bottom fish and involves the vessel maneuvering to set out long warps in a triangular fashion with a net similar to the trawl at the center of the base. Depending on the technique, the vessel may tow the gear or may lie at anchor while hauling.

2. Methods which utilize static gear, the vessel being used only to set and retrieve the gear

This category includes gillnets, traps, longlines and pots. The gear is placed in position, left to "soak" for a suitable period and then retrieved. It relies either on bait to attract the fish or on the fish being trapped in nets. Involvement of the vessel is restricted to setting and hauling the gear, and retrieving the catch. It is not necessary for the vessel to be present while the gear is fishing, and power requirements are relatively low.

3. Methods in which the vessel is actively involved during the fishing operation, while power requirements are relatively low

a) Methods in which the vessel is a stationary platform from which the gear is operated
Pole and line or "bait boat" fishing is used primarily for tuna and similar species which school in the surface. When a school of fish is sighted, live bait carried aboard is used to "chum" the fish into a feeding frenzy. Hand operated bamboo fishing poles with barbless lures are then used to hook the fish and bring them aboard. During the fishing operation, the vessel lies stationary or drifts at the particular location until all available fish have been taken aboard; it then moves in search of further schools and the operation is repeated.

Bottom line fishing is used principally on species such as snapper, grouper or tile fish which live at greater depths (up to 200 meters or more) or in coral reef areas. A vessel will fish a number of individual weighted lines each having several baited hooks and usually rigged on power operated reels. The vessel will either move among various locations, anchoring briefly at each while fishing, or will drift over a clear sea bed.

Lift nets suspended between booms over the vessel's side are used to scoop up pelagic fish which have been congregated at night using light attraction. The vessel drifts while operating.

b) Methods requiring the vessel to be mobile during operation

Trolling is used commercially to catch pelagic species including some tunas and salmon. During trolling operations a vessel will move at low speed, towing a number of lines each of which has several lures with hooks. The hooks can be set to fish at varying depths through the use of different weights and the piano wire lines are handled by power operated spools or "gurdies".

Harpooning is a method usually reserved for large species having high individual value but sparsely distributed, such as swordfish. When a fish is spotted as a result of a planned search operation, the vessel is maneuvered into a position where the fish can be harpooned from a "stand" extending forward from the bow. A buoy is usually attached to a line from the harpoon in order to mark the fish so that it may be located and brought aboard later.

APPLICATION OF SAIL POWER

Activities regarding the application of sail assistance have, for the most part, concentrated upon usefulness in:

a) reducing the power needed (and hence fuel consumption) on passage, or the time required for passage making.

b) providing an emergency means of propulsion should the principal power system fail, or a vessel run out of fuel, with the consequent savings of life and property and/or rescue costs.

When considering application to fishing vessels, other considerations may become important. In some fishing methods, e.g. trolling, it may be advantageous to conduct the fishing operation under sail alone. With other methods, e.g. bottom lining, the vessel remains anchored or drifts while fishing; power needs are restricted to operation of low powered fishing gear.

The more power intensive fishing methods require a vessel to maneuver and/or operate high powered equipment on a continuous basis.

At the maximum power need end of the spectrum, are trawling and dredging which require gear to be towed for lengthy periods and also use high power consumption when working the gear during setting and hauling operations.

The following is therefore an initial attempt, offered for discussion purposes, to classify fishing operations in terms of total power requirements during actual fishing operations.

1. Fishing operations in which it may be advantageous to avoid the use of engine operation

   a) Trolling: vessels move relatively slowly while towing the lines. Noise characteristics of engines and propeller have been shown as important in these operations, especially for Albacore Tuna. Vessels having particular noise profiles have been shown as relatively unsuccessful compared with other craft. A considerable number of sail assist vessels are operating successfully in this fishery. Power needed while fishing is limited to that for electronics equipment and for powering the trolling gurdies.

   b) Harpooning: during the search operation, sails appear to offer good potential. When a fish is sighted noise characteristics of the engine and propeller appear to be important in allowing the vessel to maneuver for harpooning without alarming the fish. No power is required during the actual harpooning operation, and minimum power may be used for winches to lift the fish aboard, although this may be done by hand tackles.

2. Fishing operations when the vessel is stationary and uses a relatively low level of power to operate fishing gear.

   a) Pole & Line Fishing: During the search operation, the vessel may operate under sail alone or in the sail assist mode. When the fish is sighted, the vessel stops and the only power need is for the circulating pumps for the live bait tanks and for refrigeration, if fitted. Traditionally, all fishing is undertaken by hand. Although powered rods have been introduced, they do not appear to be necessary for a successful operation.

   b) Bottom Line Fishing: The vessel proceeds to a number of potential locations in turn, and must maneuver (power? sail?) between locations. When on location the vessel drifts or anchors while operating the simple hook and line gear. Power is required for raising anchor as necessary, for electronic equipment, and for hauling back the reels as necessary to retrieve hooked fish.

   c) Traps: Once at the location, the vessel secures alongside the trap and commences to bring aboard the twine in order to "dry up" the fish so that they may be brought aboard. Power is often used for a simple winch which is used to lift aboard the twine by a fleeting operation; also power may be needed for using a bailer or pump for retrieval of fish.

3. Fishing operations when the vessel needs to maneuver but utilizes relatively low level of power while working gear

   a) Longlining: When setting, the vessel moves along desired course and gear is set out without the use of additional power; this operation was carried out in the past without power, and the possibility of using sail alone is high. When hauling the vessel lies to leeward and hauls back using relatively low winch power.

In heavier wind and sea conditions, the vessel may need to maneuver in order to reduce hauling loads. Again, this operation was carried out under sail alone. Most of the more mechanized longlining operations require little if any greater power for winches than the traditional manner of working. Power is needed while approaching the fishing grounds for operation of electronic equipment.

b) Gillnetting: As with longlining, the gear is set while the vessel moves along a desired course, often without the use of additional power. When hauling, the vessel lies to leeward and relatively low power is needed to operate the gurdy type of hauler. Power blocks require greater power and may need a mechanical power base during operation. Other than the more mechanized operations using drums and other heavy gear, the same comments apply regarding use of sail as for longlining.

c) Pots: Again, pots are normally set with the vessel moving ahead, and hauled using a relatively low powered hauler, with the vessel lying to leeward. The same general comments apply as with longlining.

3. Fishing operations in which the vessel must conduct closely defined maneuvers, and also require greater amounts of power while working the gear

a) Seine Netting:

(i) Anchor Dragging (Danish Seining): The vessel must steam in the required pattern to set gear, and in most cases this probably requires mechanical power to complete efficiently. The operation used to be accomplished under sail and/or oar power, but this probably would not be acceptable under modern conditions. No power is required for equipment during the setting out stage. When hauling the gear, the vessel lies at anchor, and power is needed only for the winch. Other power needs are for electronics and for handling the anchor.

(ii) Fly Dragging (Scottish seining): Vessel sets out gear in same manner as for anchor dragging and same constraints apply. When hauling, vessel requires power to tow ahead and for the winch. No power is used for anchor handling.

b) Purse Seining: When setting the gear, the vessel needs to move rapidly in a circular path to surround the fish. This is likely to be difficult to accomplish effectively without mechanical power. When working the gear, considerable power is supplied to the winch for pursing, the power block for net hauling and to pumps or deckwinches for bringing the catch aboard.

4. Fishing Operations which require considerable amounts of propeller power over lengthy periods for towing the gear, and for handling the gear and catch
   a) Dredging: Dredges are set out using winch power while the vessel moves ahead, and are towed for set periods depending on fishing conditions before being hauled back, with the vessel moving slowly or stationary, using considerable power for deck machinery.

   b) Bottom Trawling: The net and associated equipment is set out with the use of deck machinery while the vessel maneuvers. The gear is then towed for lengthy periods before being hauled back using considerable power to winches and other deck equipment. Power requirements are probably somewhat less in total with two boat bottom trawling as otter boards are not used.

   c) Midwater trawling: The same operation as for bottom trawling except that the gear is bigger, the doors likely to be heavier and catches are often considerably greater so that power requirements are increased over bottom trawling. Again, power requirements are probably somewhat less for pair midwater trawling.

It may not be considered surprising therefore that most emphasis on sail assistance has, so far, been placed upon those operations requiring least overall power consumption.

Perhaps the largest number of sail assisted fishing vessels presently working are in the trolling operations off the U.S. west coast; some reports indicate up to 160 such vessels in the tuna and salmon fishery there.

Considerable attention has also been placed upon the application of sail power to the bottom line fishery in the Gulf and southeast region of the U.S. for snapper and grouper; this is typified by the CSY vessels. Various other sail assisted craft are reported to be operating in this fishery, which is also one of the subjects for study of sail retrofit potential being undertaken at the University of South Florida.

Sporadic reports of other sail assist operations have included long lining and gillnetting. It is surprising that other techniques which require low overall power consumption, such as pole and line, trapping or harpooning do not appear to have been attempted, or at least are not generally known.

Hopefully, later papers to be presented here, together with reports from participants will further define the range of fishing operations to which sail power has been applied, and also serve to catalog and provide a more definitive account of such applicability.

MEETING THE TOTAL POWER NEEDS

The relatively low amount of experience presently available indicates the importance of considering the total power needs of a fishery, if sail power is to be looked upon as more than a device to reduce power consumption when on passage. The snapper/grouper line fishery provides an example; although at first sight, total power needs appear to be relatively low, as the electric reels commonly used need to be operated only when bringing fish to the surface, in practice it is found necessary to keep the engine running at low speed while fishing in order to prevent excessive battery drain.

This low speed operation can present its own problems for small diesels in terms of maintenance (e.g., carbon build up, oil change intervals) and perhaps more importantly, reduction in time between overhauls; often small diesels within the power range suitable for sail assist applications require overhaul more frequently than do higher horsepower units (up to three times as often).

The problem therefore is more complex than may appear from initial consideration, especially as it is necessary to operate within the economic and physical realities of a particular fishery.

If the aim of reducing the use of mechanically generated power to a minimum is to be achieved, then not only must the direct application of sails to meet propulsion and maneuvering needs be considered, but also the generation and storage of power for operation of deck machinery while working fishing gear, and for the ship's systems.

If the direct application of mechaically developed power is to be avoided, then the commonly used direct engine driven or hydraulically driven deck machinery is not applicable. A number of power storage techniques may be suitable for consideration, including pneumatic, mechanical (e.g. flywheel), hydrostatic and electrical. Of these, low voltage D.C. electrical systems are in common use aboard fishing vessels below 100 ft in length, and appear to offer, at this time, perhaps the most directly acceptable means of power storage.

In addition to engine driven generators for battery charging, presently available technology permits consideration of photo-voltaic panels, wind driven generators and water driven power generation. These alternatives are now in use aboard sailing yachts to provide battery charging; although present outputs are relatively low, they represent a potential for development as individual or combined sources of power generation.

Unfortunately, very little definitive engineering information appears to be available concerning actual power use by fishing vessels during operations, and the manner in which use varies during a voyage cycle. This type of data must be considered essential if rational matching of available generation resources and storage facilities with power needs is to be achieved.

Particularly needed are audits of total energy use by various fishing vessel types throughout voyage cycles, broken down by category (e.g. propulsion, ship systems, fishing gear operation etc.). This would allow the preparation of energy budgets for power use throughout a voyage, and matching with available power resources. Perhaps it may be possible by means of changes in operating practices to provide for better matching.

Most, if not all, presently available alternate sources of power generation are able to provide only relatively low power outputs. At the same time, deck machinery and other equipment used aboard fishing vessels has been developed under conditions where the availablitiy of mechanically driven power was relatively unlimited.

If a realistic attempt is to be made to provide for a significant proportion of a vessel's power needs from alternate energy sources, then it appears necessary to narrow the gap between power requirements and availability. More efficient machinery and systems power units are needed together with more efficient generating systems and more "power efficient" operating procedures.

While there is a possibility of being able to provide for such matching in the case of the smaller, simpler craft, it appears that extension of meaningful fuel savings, other than when on passage, to the larger and more sophisticated vessels must await the development of the more efficient machinery and power sources.

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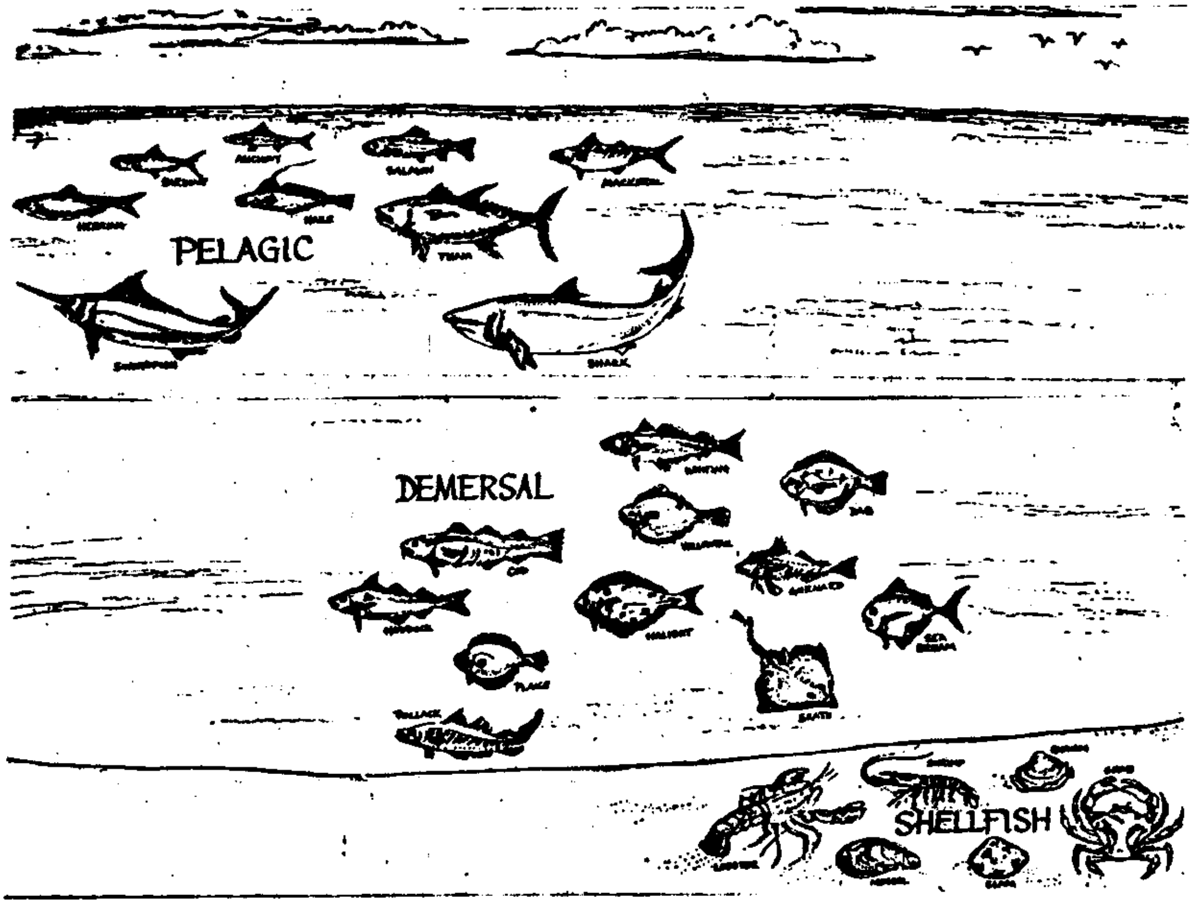


Fig. 1. Classification of Fish for Harvesting: The species here are only a selection of those important in each group as food or material.

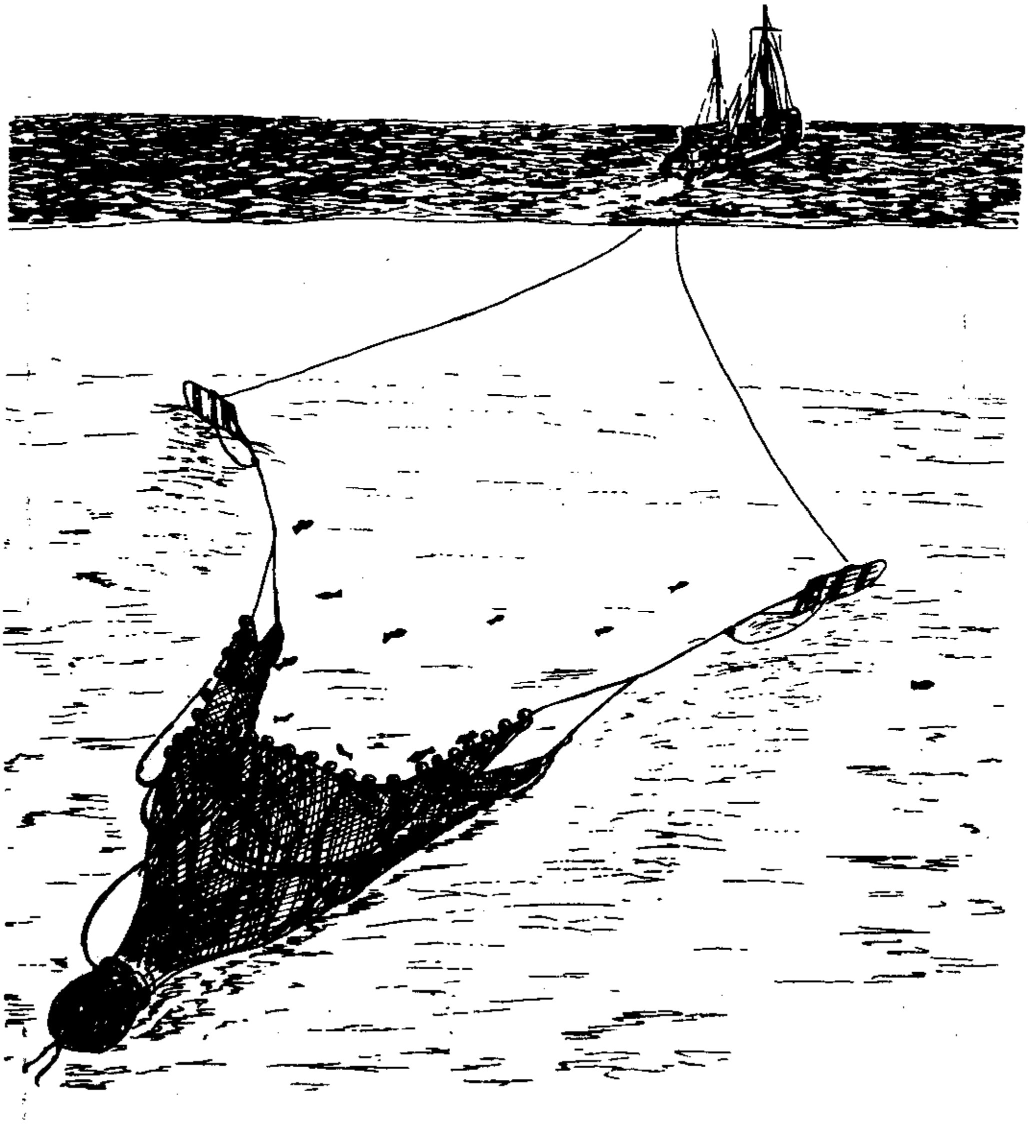
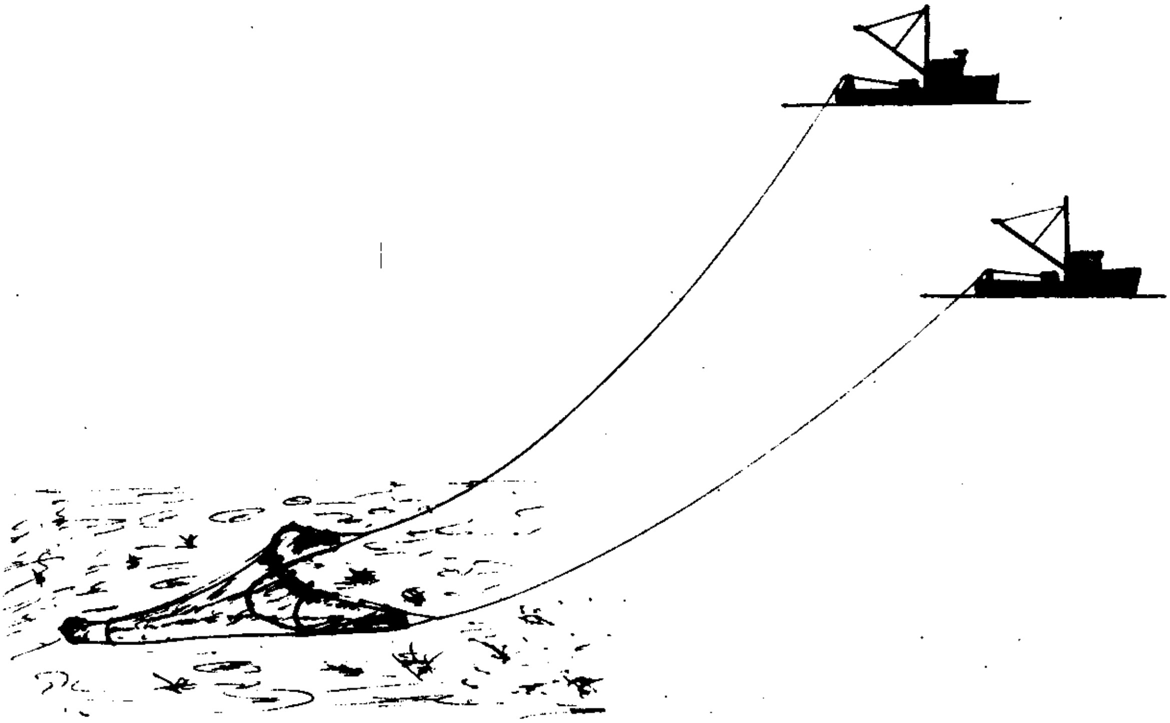


Fig. 2.: Bottom Trawling: a) In single vessel operations, the net is dragged along the sea bed at a speed of 1 to 4 knots. The mouth of the net is held open vertically by floats on the headrope and weights (often chain) on the footrope. Otter Boards, or "doors" are towed ahead of the net and use a combination of hydrodynamic lift and ground shear effect to spread the mouth horizontally. Fish pass down the net to become trapped in the cod end. A typical net may have a headrope length between 60 and 140 feet, and with the doors weight up to 2 tons or more. Considerable power is needed to tow a bottom trawl, about one third of the total power being used with the doors. Typically, winches need 50 h.p. or more to retrieve the gear.



b) In two boat bottom trawling, the net is held open by the separation between vessels, so that no doors are needed. This has proven to be an efficient method for low powered vessels. Winch power required is less than when doors need to be handled.

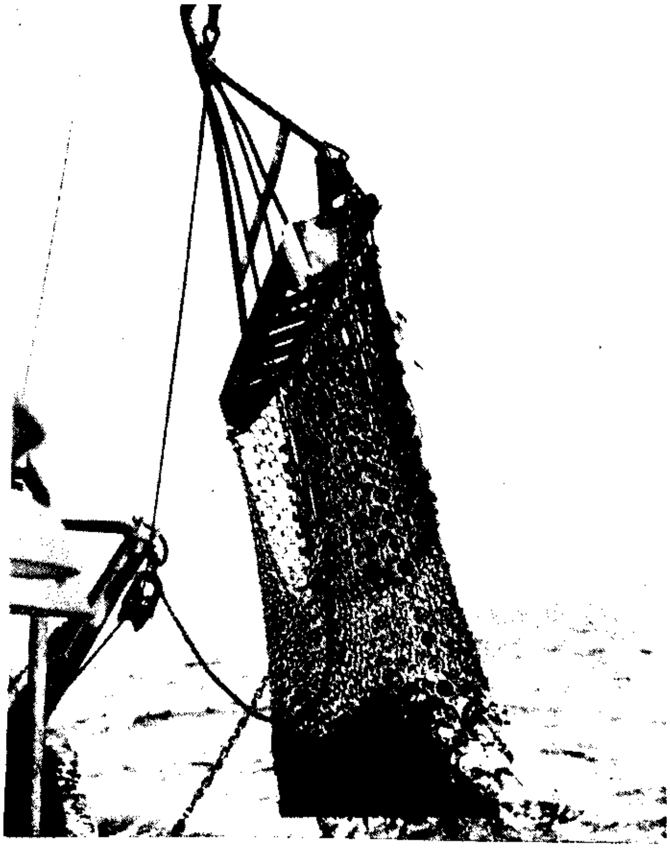
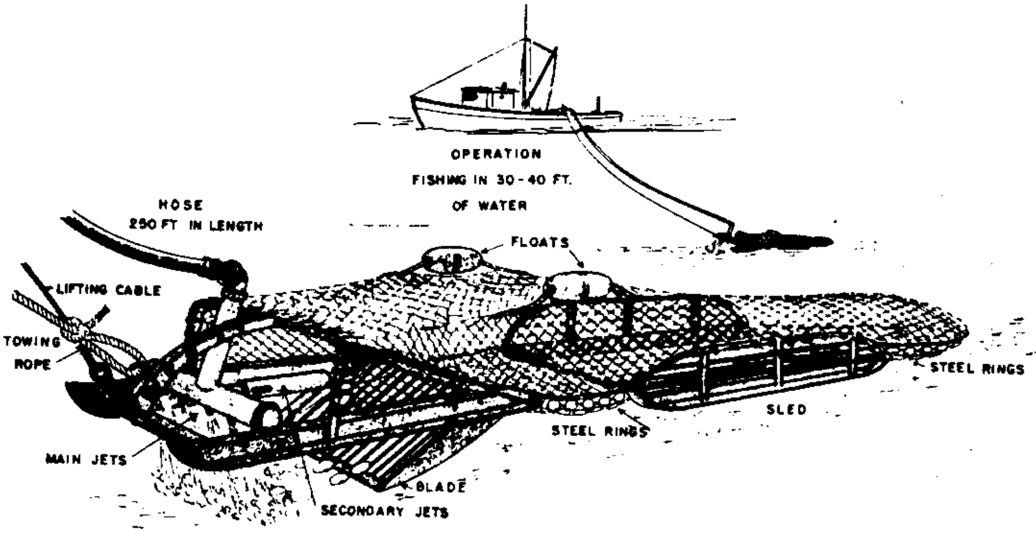
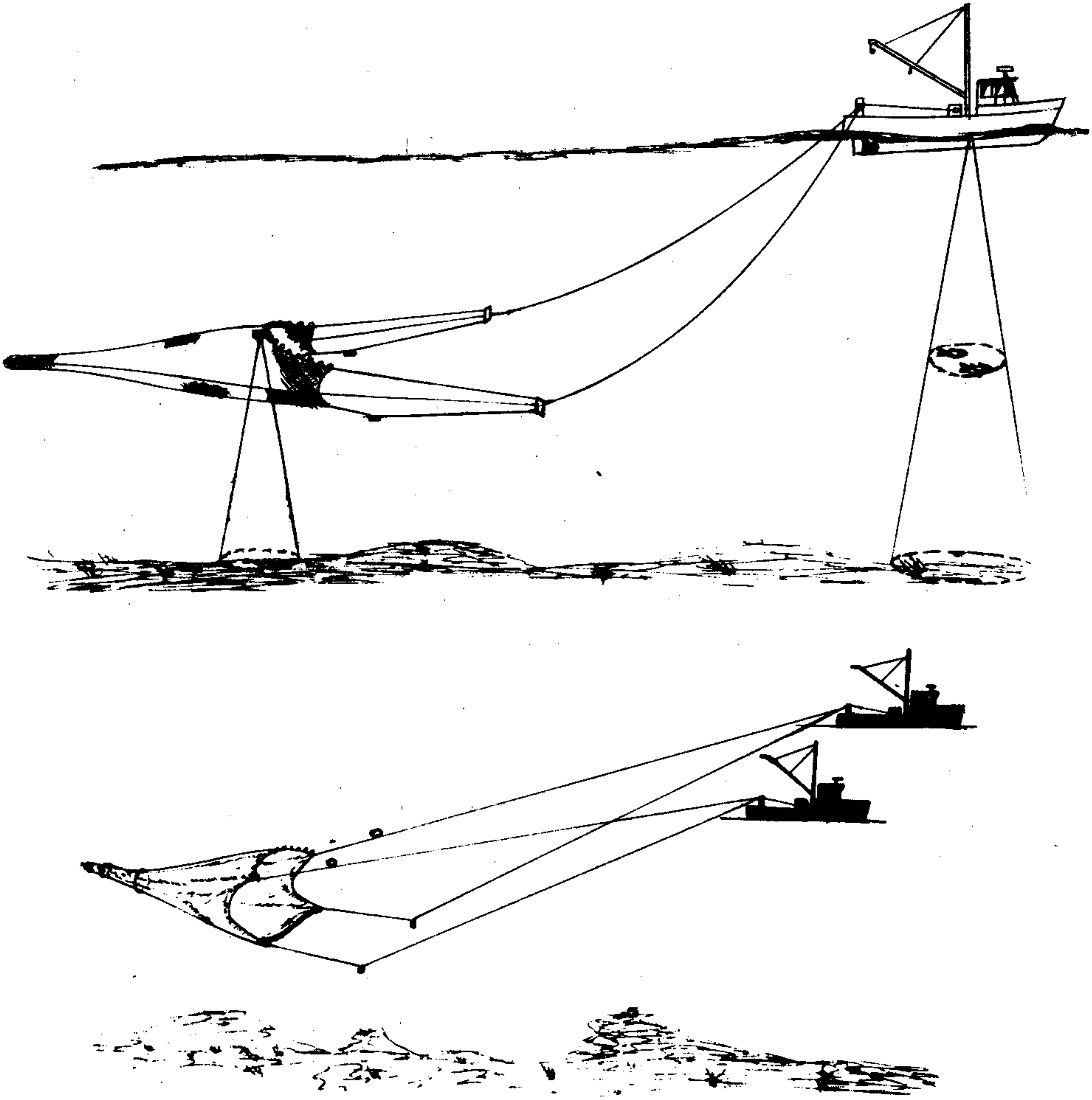


Fig. 3: Dredging: a) Offshore, scallop dredges, up to 16 feet wide, scrape the sea bed and have a steel framework with the bag made of steel rings. Two or more may be towed at once; the vessels need to be rugged with powerful winches. Smaller dredges may be used for oysters and for scallops in semi-sheltered waters, some of which may be operated by hand from sailing vessels.



b) dredging for clams and other species which are found beneath the sea bed use dredges which use teeth to dig into the bottom sediment, or water jets to clear away the sediment and allow the teeth to scrape up the catch which then passes back into the bag.

Fig.4: Midwater Trawling: Midwater trawls are generally larger and built of lighter twine than bottom trawls and may be fished using either a single vessel or pair trawling arrangement. The depth of the net is adjusted by varying the length of the warps, the ratio of weight to buoyancy of the net system, and by the speed of the vessel(s), to that of the fish school, through the use of echo sounders aboard the vessel and at the net. The nets are usually towed at higher speeds than for bottom trawls and power requirements are considerably greater.



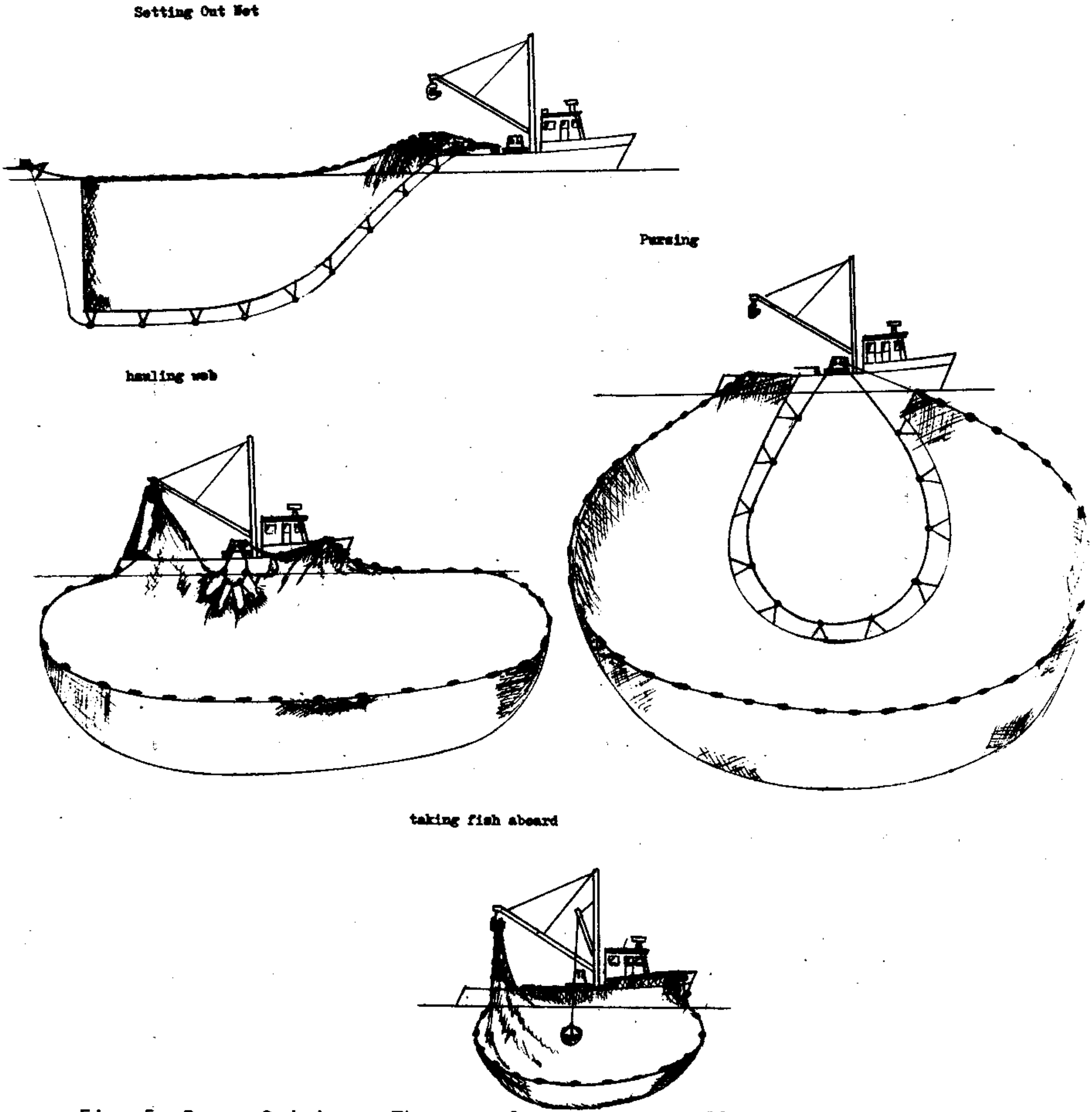
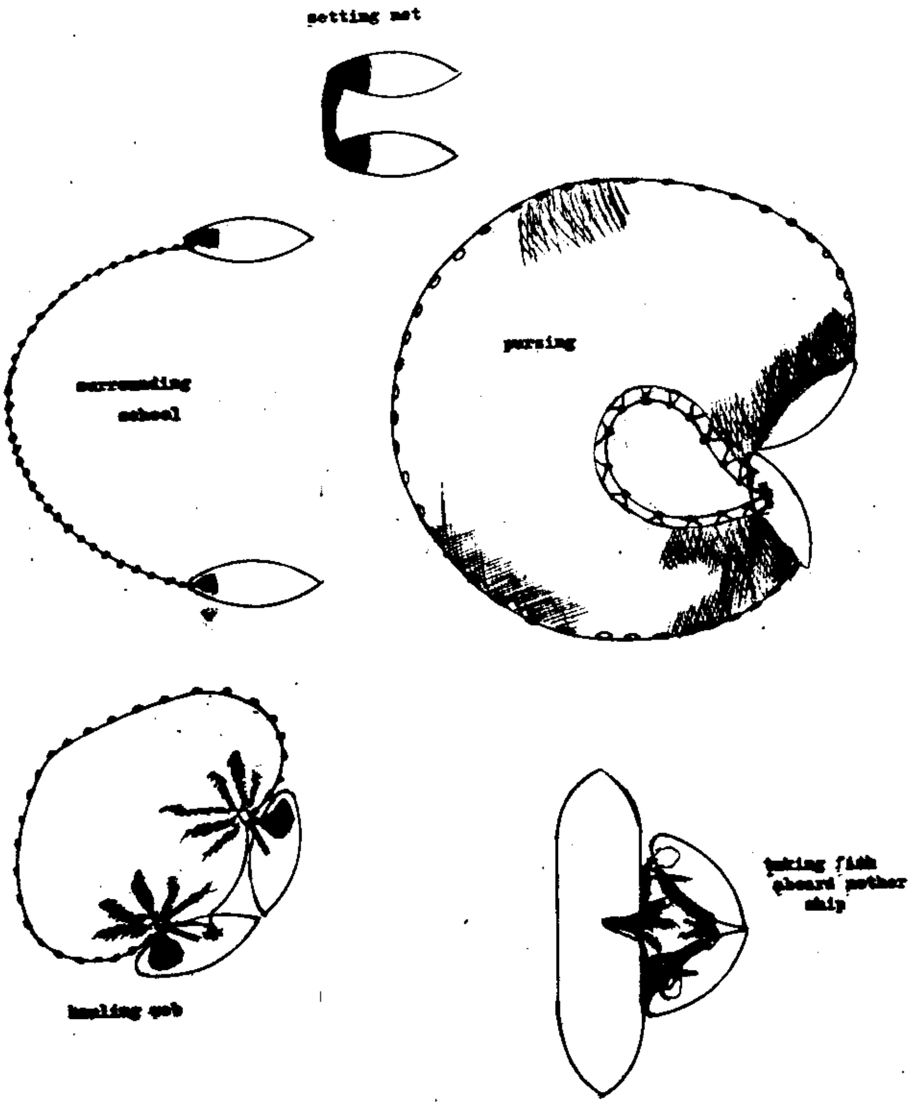


Fig. 5: Purse Seining: The vessel sets out a wall of netting around a school of fish. The bottom of the net is pursed, using a winch to pull a "purse line" through rings, and then one end of the net is pulled in over a hydraulically powered block to congregate the fish into a pond of netting from which they may be pumped or lifted out by a scoop type net. The ability of the vessel to maneuver precisely is important, and considerable power is needed for the winches when mechanized operations are used. As an alternative, hand power (needing a large crew) perhaps assisted by a small power winch may be used for smaller scale operations. The net may be handled from one or both ends with the fish being congregated in a strengthened section (the "bunt"). Various techniques involve the use of a single vessel or two smaller boats to operate the net, which commonly reaches up to 1000 feet or more in length. (See over)



Purse seining for Menhaden using two 30 ft boats to handle net.

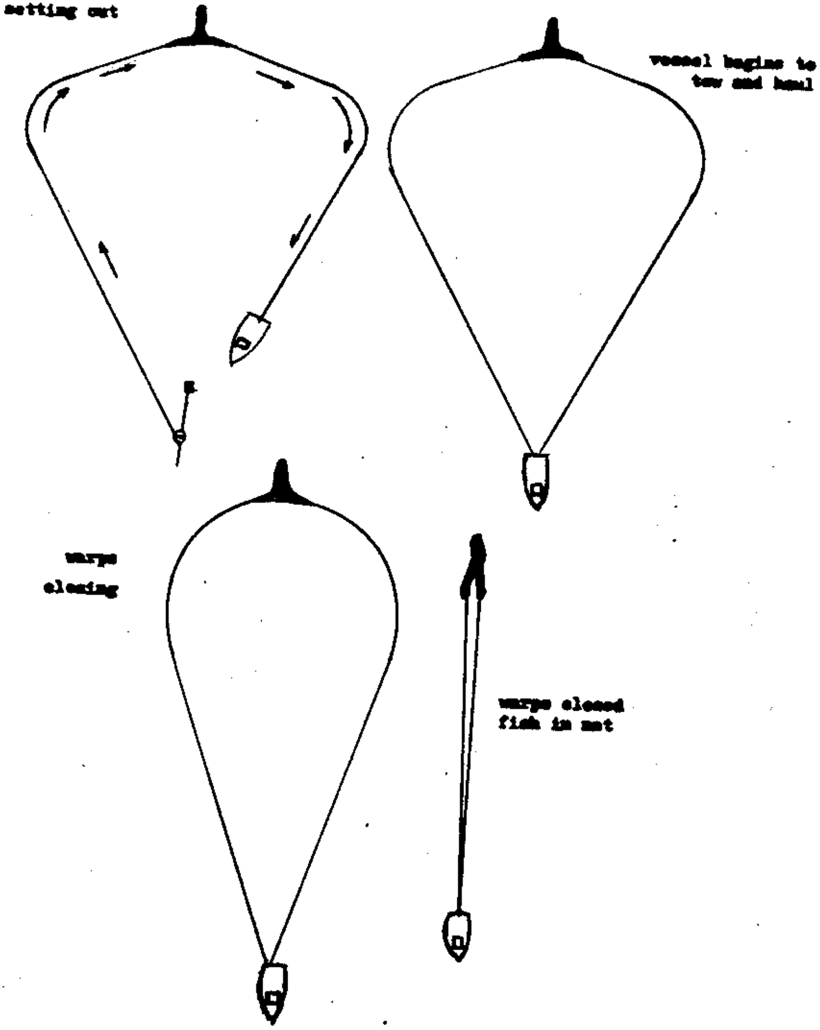


Fig. 6: Seine Netting: The vessel sets out a marker buoy attached to one end of a weighted warp, and then moves as shown setting out up to a mile of cable before putting out a net similar to a light trawl; then a further length of warp is set out while the vessel travels back to its starting point. In Scottish Seining or "fly dragging" the vessel then tows both warps while hauling them in by winch to produce the effect shown. Alternatively, during Danish Seining or "anchor dragging", the vessel lies at anchor while heaving in the warps. Power requirements are more reasonable in anchor dragging as power is only needed for the winch or to set out the gear at one particular time. Modern seine netters use large hydraulically powered reels to handle the warps.

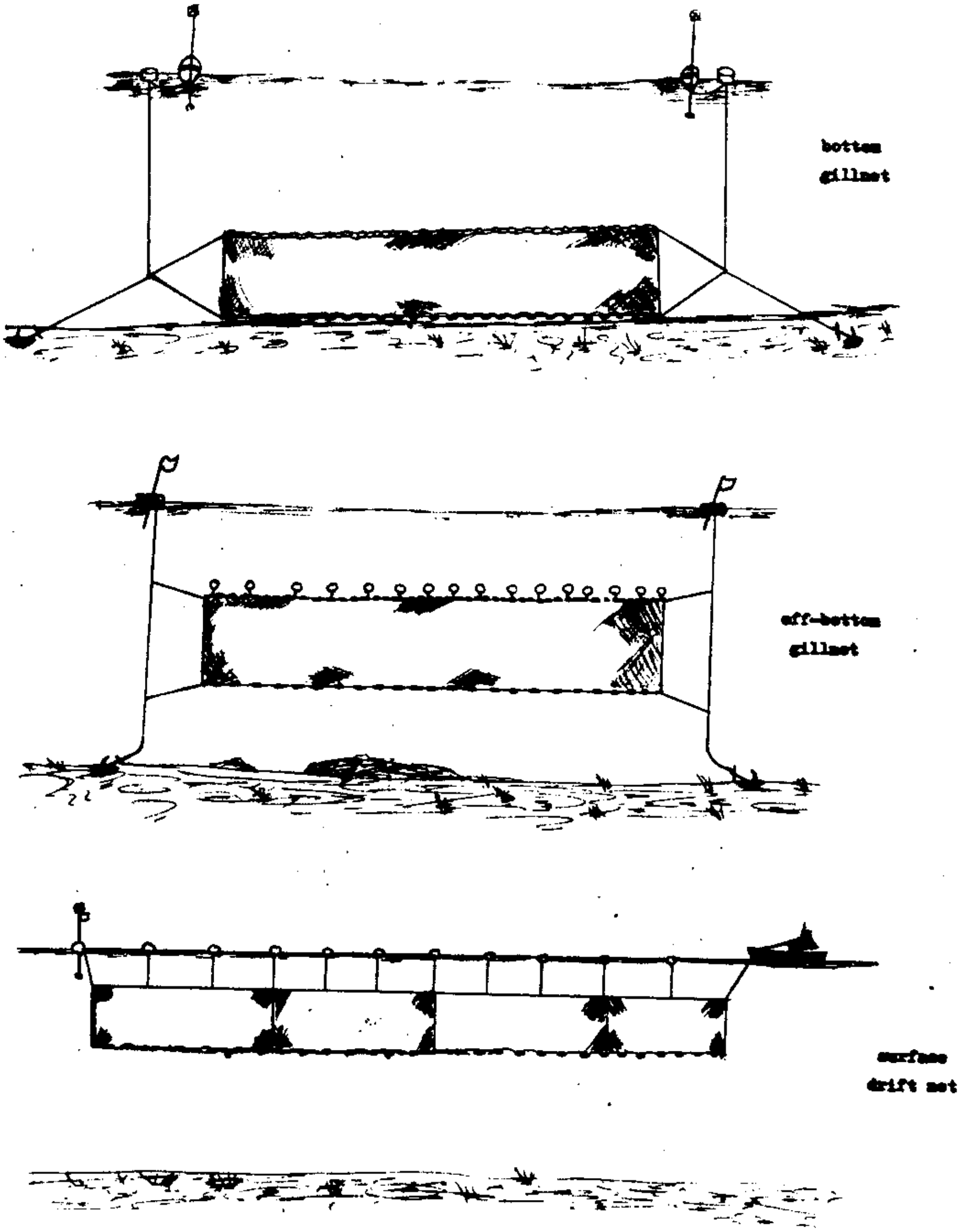
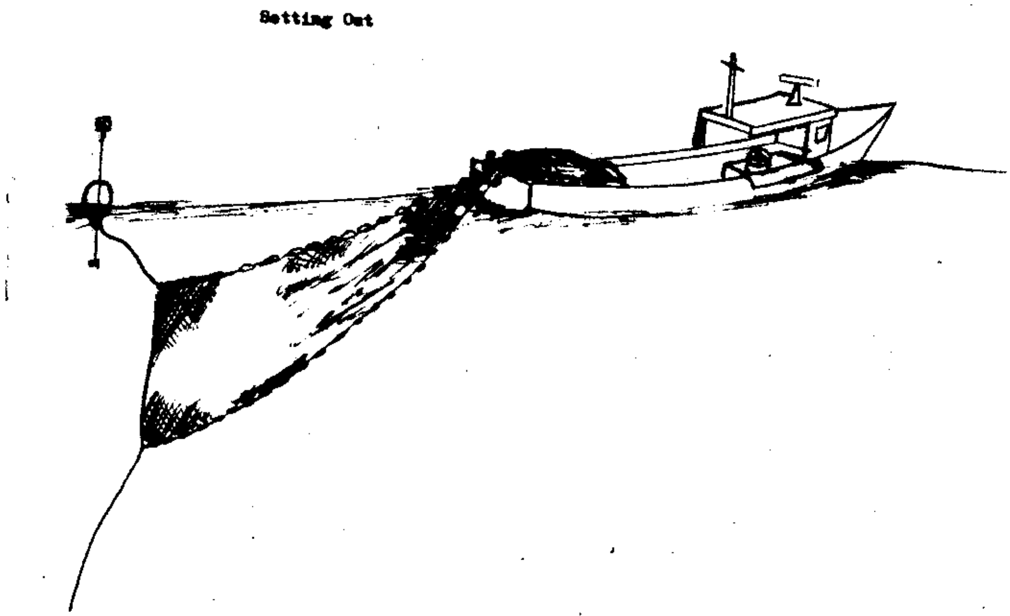
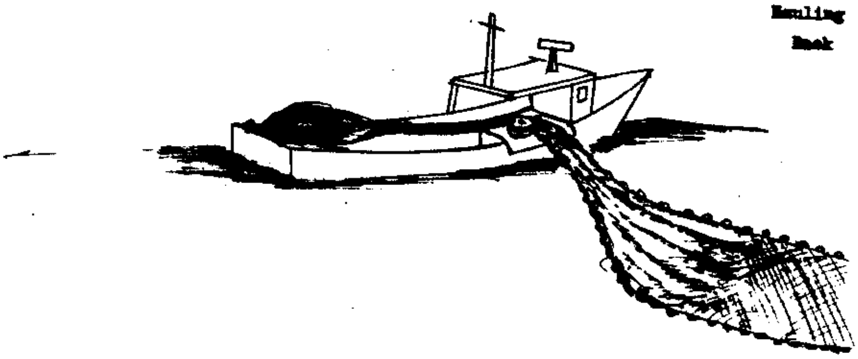


Fig. 7: Gill Netting: a) These may be set singly or in groups or "fleets", end to end, so that they extend up to a mile or more; by varying the ratio between buoyancy and weight, and by different rigging arrangements, they may be used as set nets or as drift nets, the latter normally used near the surface.





b) Traditionally, gillnets are set over the stern, being pulled out as the vessel moves ahead, and retrieved by a simple gurdy forward while the vessel lies sationary at the leeward end of the gear. Power reels, power blocks and other powered hauling arrangements may be used.

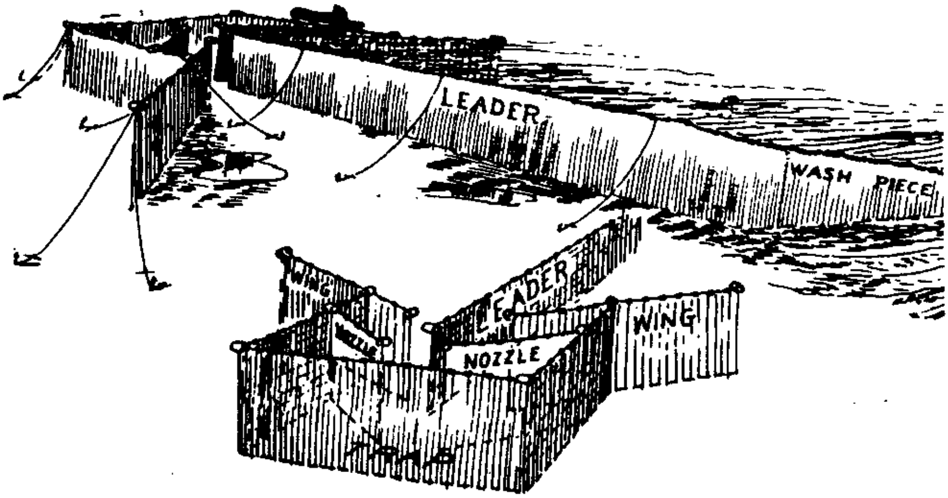


Fig. 8: Traps: Traps are set out in locations along the shore. Fish moving along the depth contours follow a leader net into the heart of the net and become trapped. The vessel's task is to haul in the trap part of the net and then transfer fish from the small remaining pond. Simple low power haulers are usually sufficient for the purpose, although the boats must be of a reasonable size to support the weight of net and fish while working the net.

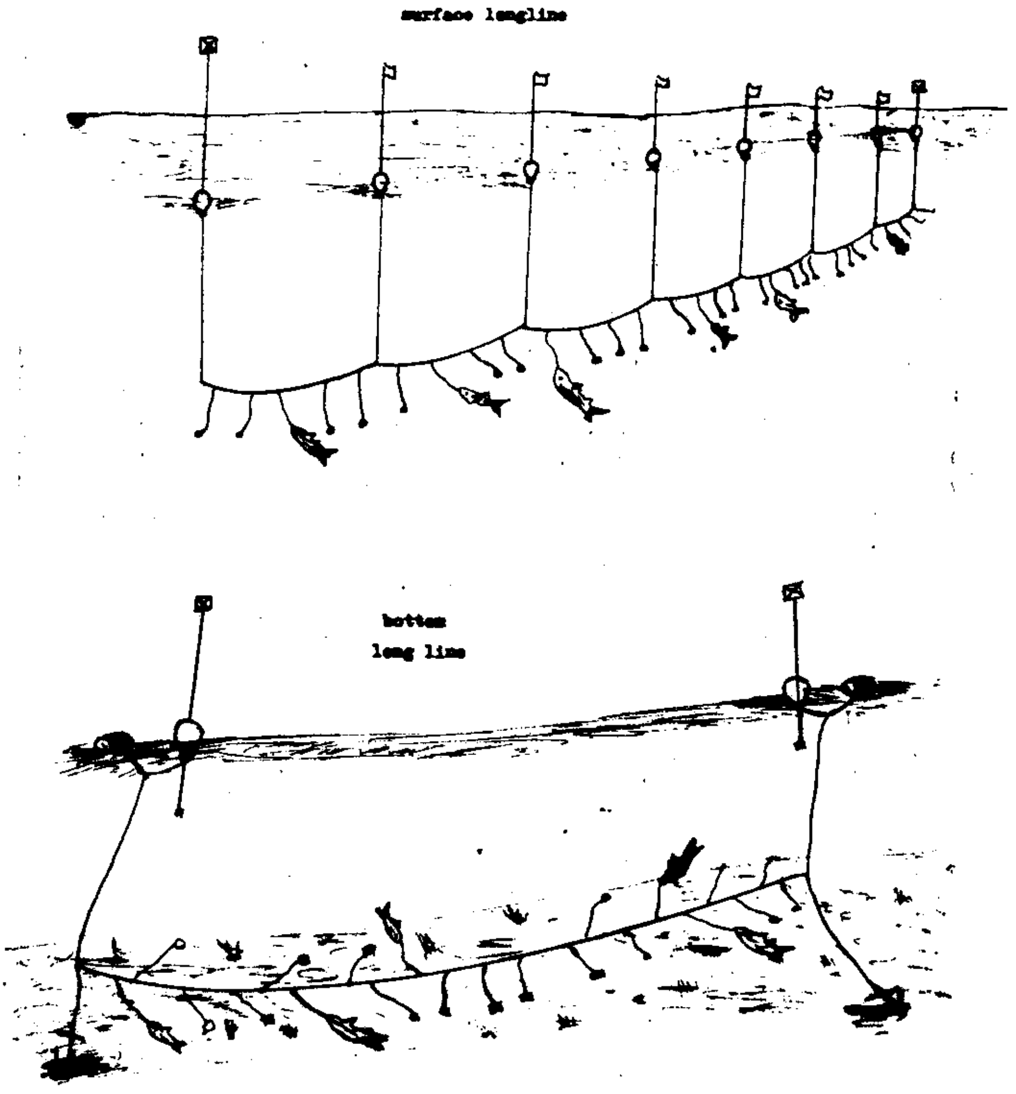
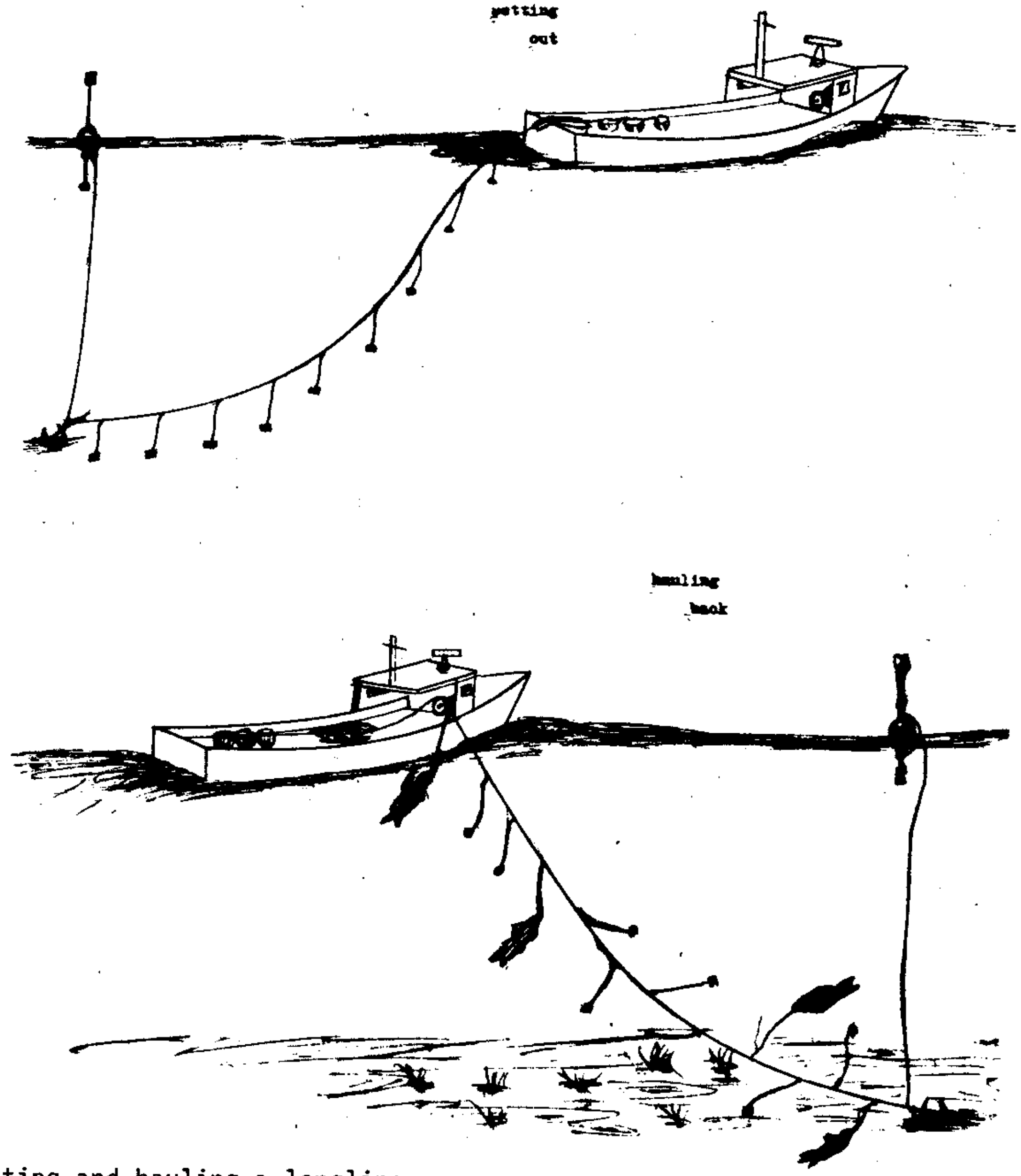
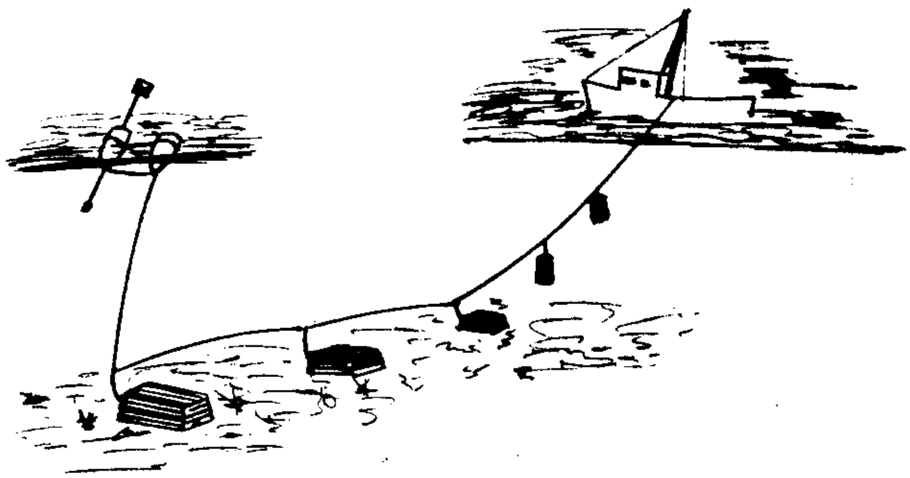


Fig. 9: Longlines: Longlines are set beneath the surface for pelagic species or on the bottom, in the configurations shown. Some surface longlines may be quite heavy with chain used together with wire, to prevent hooks being bitten off by sharks etc. Traditionally, longlines are set out over the stern after putting out a buoy, using the vessel's movement forward; hauling is by a simple line hauler mounted forward, while the vessel lies to leeward. Modern equipment and techniques use mechanized baiting and hook storage techniques, while requiring no increased winch power over the traditional work arrangements.



Setting and hauling a longline.

Hauling back a trawl of pots



A trawl of Pots fishing

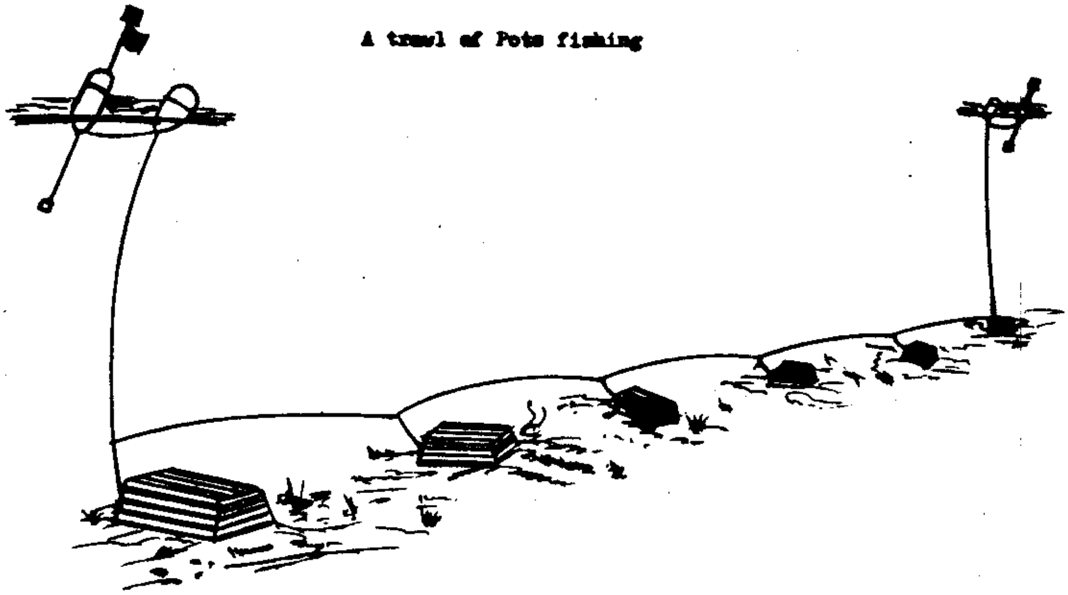


Fig. 10: Pots: Pots are used principally for the capture of crustaceans such as lobster and crab, although fish pots are in use particularly in tropical fisheries. The traps vary in size and type from 4' x 2' x 1' wooden slat construction up to 7' x 7' x 3' made of chicken wire over a steel frame. Traps may be set singly or in groups of six to twelve. The large deep sea pots (e.g. those for King Crab) are heavy, require large vessels to work the northern seas, and comparatively high powered haulers which ar used to handle as well as haul the pots. Inshore and reef pots are generally worked by smaller vessels which set the gear over the stern and haul back from forward using a fairly low powered winch.

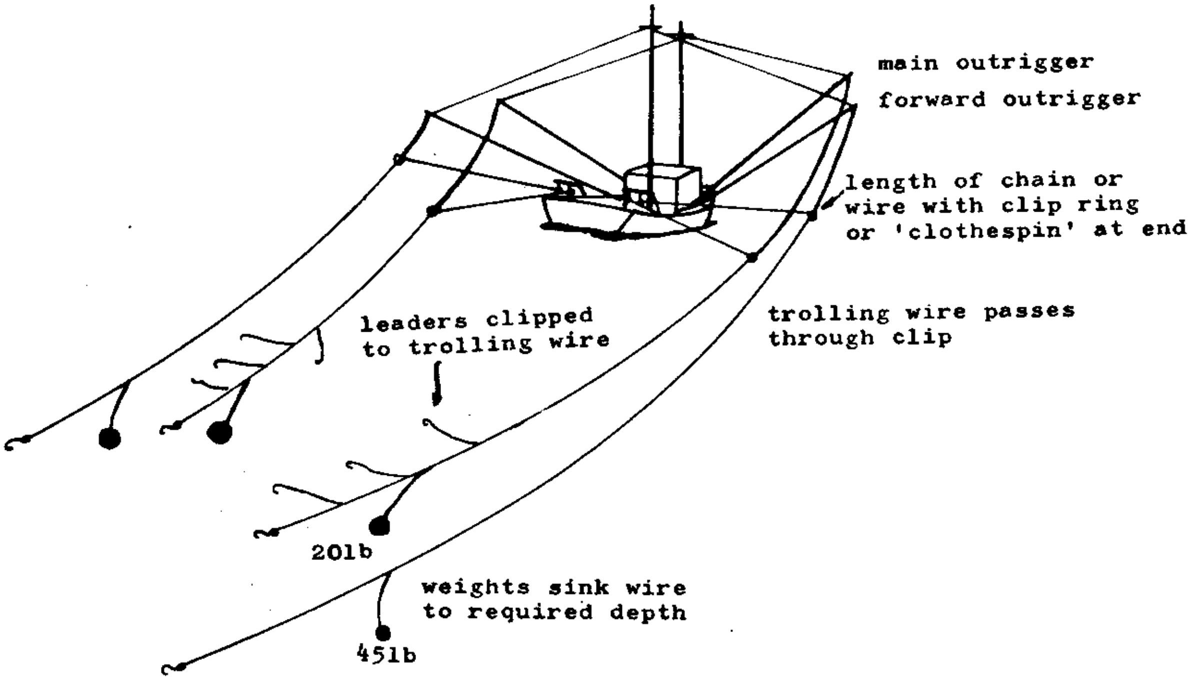


Fig. 11: Trolling: Trolling is used to catch relatively high priced pelagic species. Towed lines, each with several lures/hooks are rigged from outriggers. The piano wire lines are hauled by means of trolling gurdies, each barrel working its invividual line. The lines are towed at different depths by varying the weights.

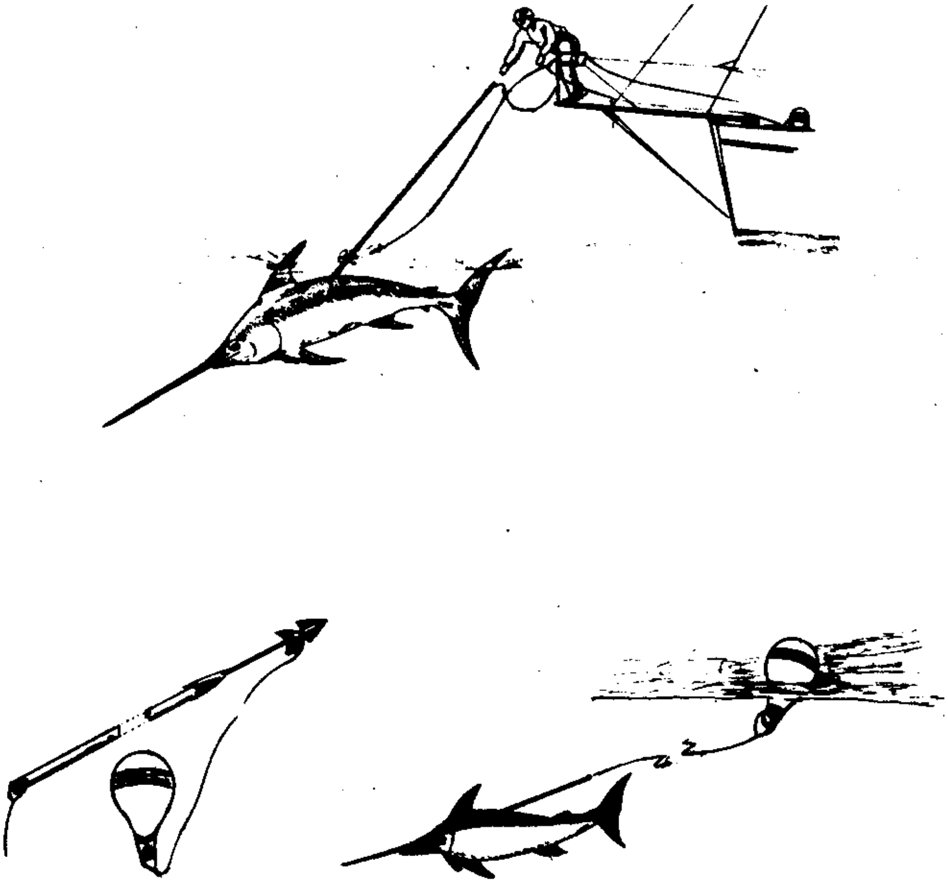


Fig. 12: Harpooning: Harpooning operations are usually restricted to high individual value species, particularly swordfish which appear at the surface. The boat maneuvers into position so that the "striker" can harpoon the fish. The buoy is used to tire out the fish and mark its position so that it may be retrieved and brought aboard.

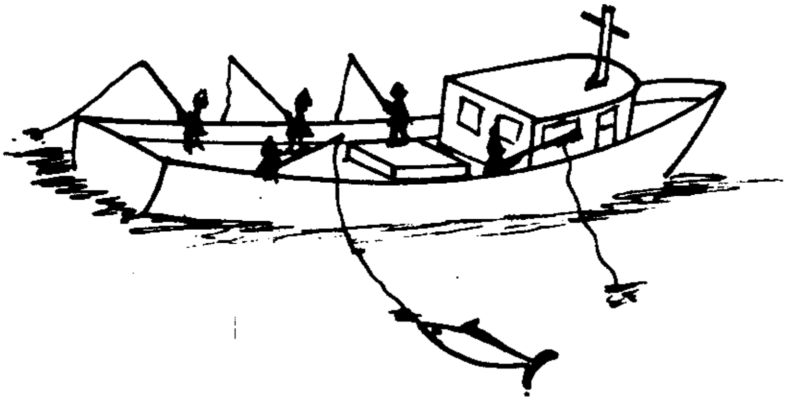


Fig. 13: Pole & Line Fishing: Pole and Line bait boat fishing is undertaken by hand using bamboo poles with barbless hooks. Power is required for circulating pumps to maintain the live bait in seawater tanks.

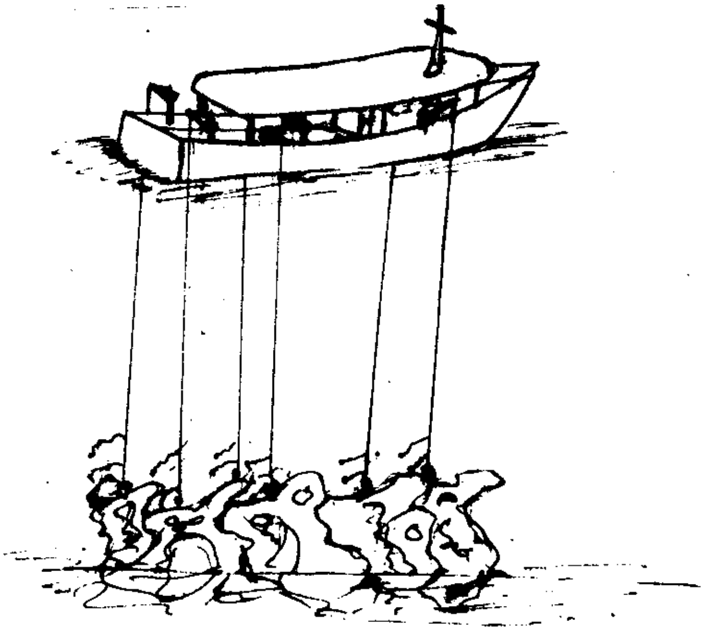


Fig. 14: Bottom Line Fishing: This is undertaken with the vessel anchored over a reef or drifting across open sea bed. Four to six lines each holding several hooks are worked individually from powered reels.

SAIL-ASSISTED FISHING VESSELS :

RESULTS OF FULL-SCALE TRIALS

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SUMMARY

The paper describes the conduct and analyzes the results of systematic trials performed aboard experimental sail-assisted fishing vessels of two types :

- multi-purpose schooner,
- catamaran.

The measurement campaigns undertaken are part of a long-range project conducted by the French Agency for the Mastery of Energy (AFME), which aims at assessing the efficiency of sail-assisted power for the fishing industry.

The results obtained thus far indicate the savings achieved under various conditions and clearly demonstrate the potentiality of such designs, especially when they are compared to more conventional ones. The possibility for further improvement and the different corresponding solutions are also discussed.

INTRODUCTION

The energy crisis, in provoking a strong increase in the price of marine fuel, has considerably affected the economic situation of sea fisheries. In an effort to right this state of affairs, several measures may be considered, among which we can cite :

- the limitation of the power under way
- the improvement of the hull lines and of the propeller efficiency of fishing boats
- the recourse to less energy consuming fishing techniques
- the recourse to sources of energy other than gas-oil.

The first idea which comes to mind is evidently to use wind energy. However, from ancient times, sailing shares with the utilization of less energy consuming fishing techniques, such as trawling (straight fishing nets, long lines, lobster pots) a negative image of laboriousness.

Let it be said from the outset that the technical progress in the design of rigging, due in large part to yachting and offshore racing, and in the handling of fishing equipment through the use of automation, have radically altered the situation. It is now permissible to efficiently operate fishing boats using less energy consuming fishing techniques, and equipped with an auxiliary rigging.

In France, a few pioneers have gone in this direction, often under difficult conditions.

Measurements campaigns under actual operating conditions have for some of them been undertaken under the sponsorship of the French Agency for the Mastery of Energy (AFME), in order to assess as precisely as possible the advantage of those solutions from an energy saving point of view.

They are part of the general strategy of the Agency for the qualification of energy saving pilots as well as prototypes. The Agency thereby wishes to obtain a reduction in energy consumption in the field of fisheries, all the while in showing the profession, which is experiencing real difficulties, that it can consider the recourse of new economical techniques.

Two sets of trials are presently under way, sponsored by the AFME within the scope of small fisheries.

Preliminary results already permit to draw a certain number of interesting conclusions concerning the qualities of the vessels and are described in the present paper.

The first set of trials were started in 1981 ; they concern two prototypes of catamarans for coastal fishing equiped with auxiliary sails and destined for small-scale fishing : lobster pots, straight fishing nets, long lines.

The second set, begun in 1982, concerns a multi-purpose schooner capable of practising, according to the season, automated long line fishing and towing for tuna.

1. DESCRIPTION OF THE FISHING VESSELS

1.1 THE CATAMARANS FOR COASTAL FISHING "DAR MAD" AND "VER LUISANT"

First of all, the reasons behind the choice for catamarans should be explained.

Catamarans may be of interest to fishermen engaged in coastal fishing by day, generally within a 20-mile distance from the shore.

Because they use so-called "soft" techniques (lobster pots, long lines, straight drifting nets), they need boats with strong transverse stability as well as a large deck area.

These requirements are met by conventional boats, short and very broad, requiring strong engine power since their hydrodynamic efficiency is poor. Moreover, their cargo rarely exceeds one ton of fish, and requires little hold space, when it is immediately stored in cases as deck cargo. A catamaran preserves the necessary stability and deck space requirements, while at the same time improving hull lines which are now much finer, and considerably decreasing the weight, especially if the ratio weight over length is considered for each hull.

The result is a decrease in the resistance, and therefore of the installed horsepower, in the order of 40 to 50 %, generating an even greater fuel saving.

Moreover, a design of this type lends itself well to the practical use of sails as a mean of propulsion, or at least as a substantial aid to the engines, which are then only used for handling the ship in harbor or during actual fishing operations.

Moreover, rigging design takes into account the most recent technical progress, and in particular the use of roll-up sails, which enables the master of the fishing boat to operate the sails very easily.

The two catamarans have been designed by the naval architect Sylvestre Langevin, well known for the racing catamarans and trimarans he has designed (in particular the "Elf Aquitaine").They were built at the Leguen and Hemidy shipyard at Carentan, with the help of a grant from the French Agency for the Valorization of Research (ANVAR).

Their main characteristics are the following :

11.6 m catamaran "Dar Mad" (master Etienne Gaucher)
Length : 11.6 m
Beam : 5.95 m
Weight, light : 6.5 tons

Maximum weight, fully loaded : 9 tons

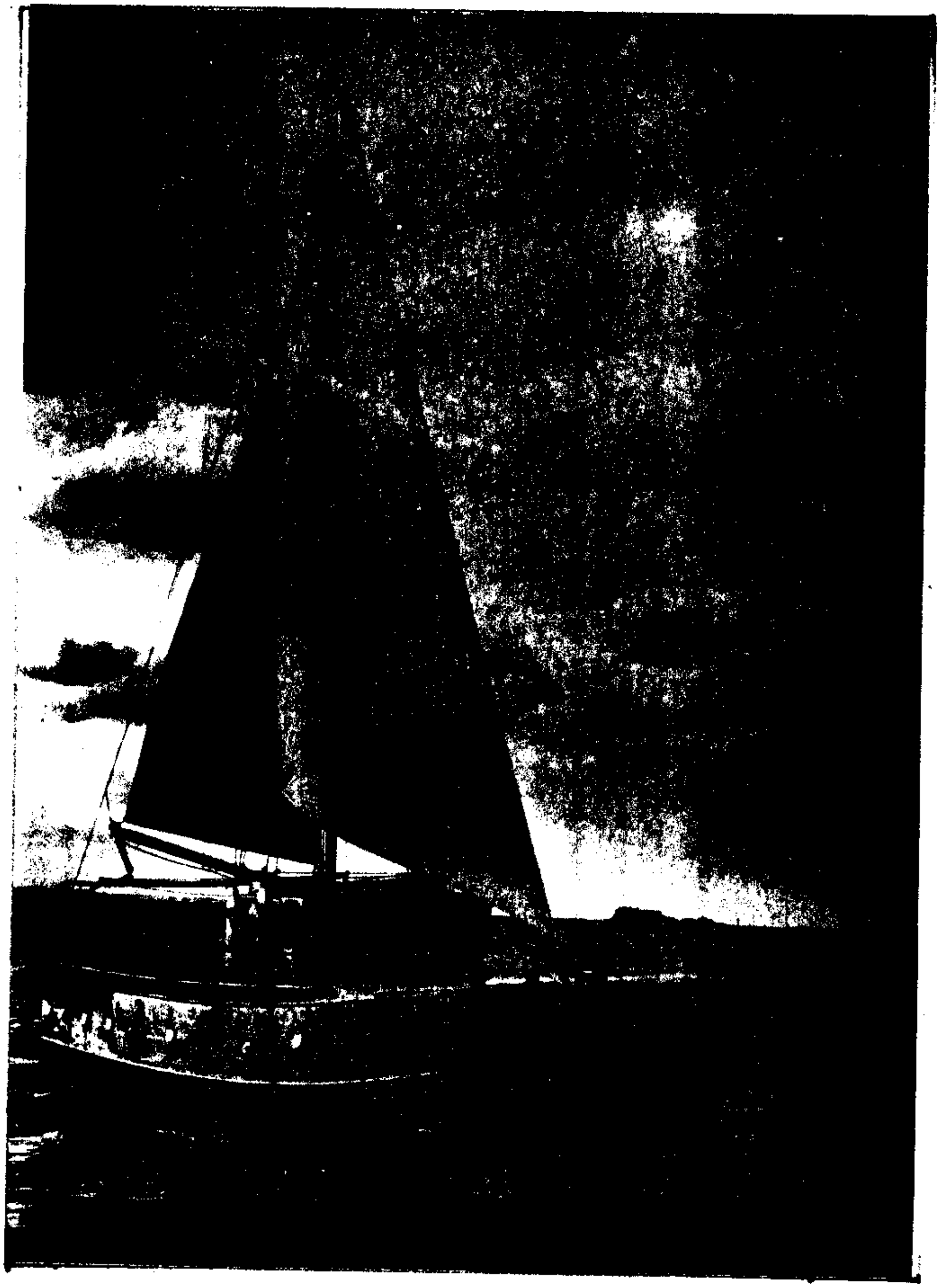

Figure 1 : Multi-purpose coastal fishing catamaran "Dar Mad"
Length : 11.6 m
Sail area : 57 sq. meters

Engine power : two Renault Marine engines
of 55 horse-power, RC 55 D model
Upper works : two multipurpose power blocks
Equipment : one Genoa jib on roller, area 34 sq. meters
one main sail on roller, area 23 sq. meters
total area 57 sq. meters
Deck area : approximately 50 sq. meters
Crew : two to three men working

Figure 1 shows a view of this catamaran.

9 m catamaran "Ver Luisant" (master Dominique Leclerc)
Length : 9.2 m
Beam : 4.90 M
Weight, light : 3 tons

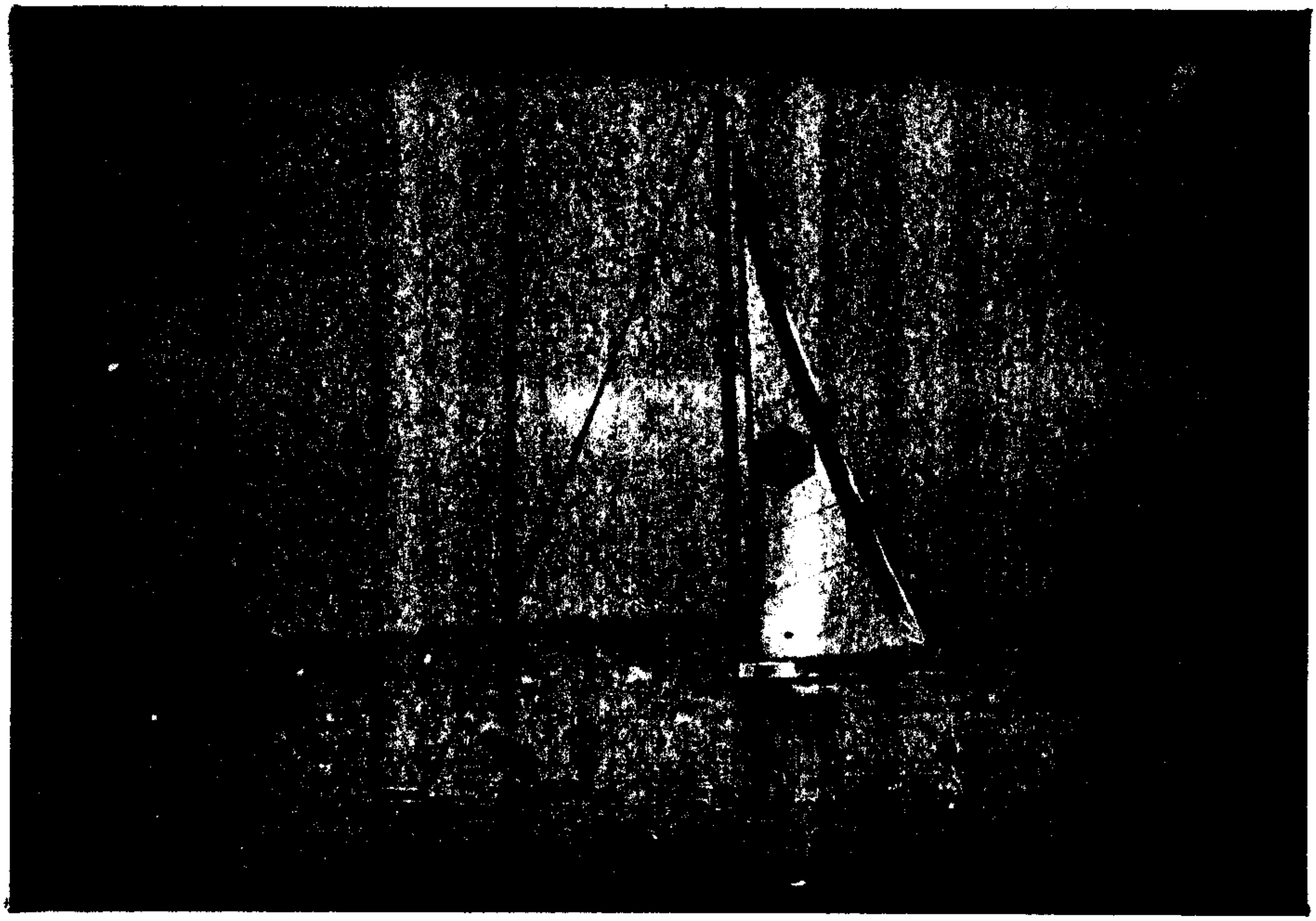

Figure 2 : Multi-purpose coastal fishing catamaran "Ver Luisant"
Length : 9 m
Sail area : 30 sq. meters

Maximum weight fully loaded : 5 tons
Engine power : two 25 h.p. Renault Marine engines, R 4140 D model
Upper works : one multipurpose power block
Equipment : one jib on roller, area 17 sq. meters
  one main sail on roller, area 13 sq. meters
  total area 30 sq. meters
Deck area : approximately 32 sq. meters
Crew : one to two men

The catamaran is shown on Figure 2.

These boats have working characteristics (deck area and stability) equivalent to 15 m boats of conventional design which would require a 230 h.p. engine for the 11.6 m catamaran, or a 140 h.p. engine for the 9 m catamaran.

1.2 MULTI-PURPOSE SAIL SCHOONER "CADOUDAL" (MASTER LEON LUCAS)

The basic idea behind that ship was to find an economic replacement for an outdated fleet of tuna fishing boats.

This fishing is carried out using towing lines, a technique which does not require much traction power. This is achieved using a sufficiently slender boat necessitating a small propulsion power under way with a possibility of using the sails as an auxiliary source of propulsion.

This schooner, as well as another one, the "Eole", have been built at the La Perrière shipyards with financial support from ANVAR. The design was performed by the Société Bretonne d'Etudes et de Réalisations Navales. Her main characteristics are the following :

Total length :	20.5 m
Length between perpendiculars :	17.6 m
Maximum beam :	6.0 m
Gross tonnage :	49.5 tons
Displacement :	62-95 tons
Power, main engine :	185 h.p.
Power, auxiliary engine :	45 h.p.
Sail area :	
Genoa jib :	139 sq. meters
main sail :	50 sq. meters
mizzen :	47 sq. meters
Crew : 6 men	

Figure 3 represents a view of the schooner.

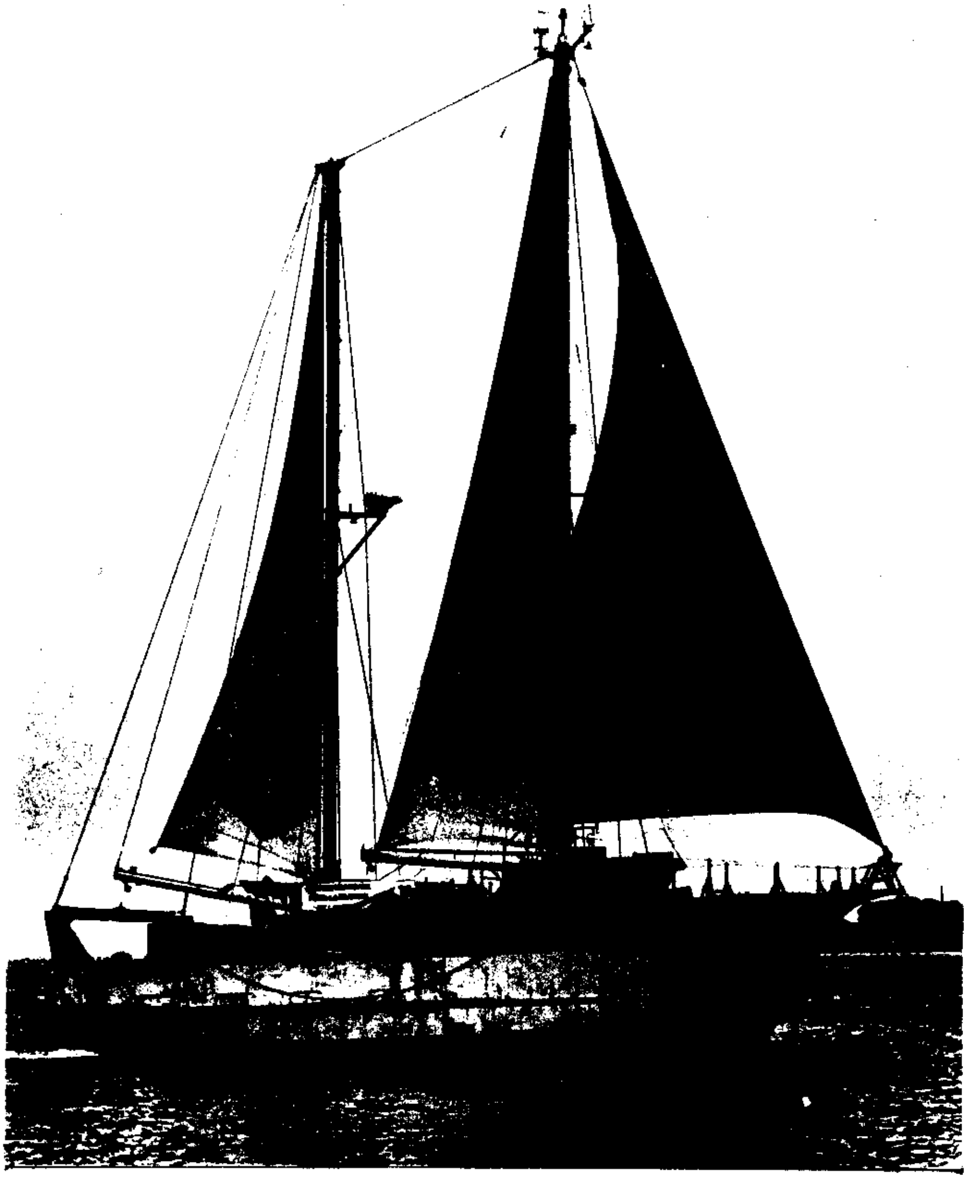

Figure 3 : Multi-purpose schooner "Cadoudal"
Length : 20.5 m
Sail area : 236 sq. meters

The comparable conventional boat would be a trawler of the same length and same gross tonnage equiped with a 400 h.p. engine.

This is a heavier, more bulky boat with a propeller designed more for towing than for the open sea.

This type of ship is generally operated above the economic speed due to the available power of the engines.

2.DESCRIPTION OF MEASUREMENT CAMPAIGNS

2.1 CATAMARANS

Basically, measurement campaigns were organized along the following lines.

The two boats, operated by their respective crews, were to undertake cruises between successive fishing harbors, the list of ports of call having been determined in collaboration with local committees of Sea Fisheries, which include most of the independent fishermen involved.

In each port of call, volunteering fishing masters would come aboard for an expedition to their usual fishing grounds and with their own fishing equipment if possible, in order to familiarize themselves with the boat under their habitual working conditions.

Their impressions would be recorded by the means of an evaluation questionnaire.

The points treated in this questionnaire are the following :

- type of fishing practised
- fishing conditions
- navigation conditions
- the fishing and handling qualities of the boat.

The boats being equiped with fuel meters, readings of consumption, of distance covered, and recordings of the operation of sails would be effected at regular intervals during the fishing expedition (both under way and fishing). Elements for comparison with their habitual boat would also be obtained from the masters embarked.

During navigation between ports, the masters of each ship would also record at regular intervals the sailing conditions, the distance travelled and the effective use of sails.

Up to this day, only the campaign concerning the 11.6 m catamaran has been conducted. It was performed under control from an observer authorized by the Central Committee of Sea Fisheries in order to associate the profession to this operation.

The cruise has taken place between 9 September and 12 November

1981. The total distance travelled was 1 175 nautical miles, among which 929 were under way in open sea, 246 concerning demonstration cruises.

33 ports were called, 140 masters were embarked, and a total of 1 500 to 2 000 fishermen were involved, in one way or another.

It nevertheless appeared, once the campaign was over, that the two primary objectives : sensibilization of the profession and assessment of the propulsive performance of the boat and energy savings achieved though a rigorous series of measurements, were hardly compatible.

This is the reason why it has been decided to redefine the campaign planned for the 9 m catamaran in the first part of 1983 towards a less ambitious measurement campaign composed of two main parts :

- measurements during systematic trials in order to assess the nautical characteristics of the boat ;
- measurements during actual operation in order to economically assess the energy savings achieved.

2.2 MULTI-PURPOSE SCHOONER

A similar approach to the one just summarized was defined concerning the multi-purpose schooner "Cadoudal". The assessment campaign presently under way consists in recording as many measurements as possible on the ship both during systematic sea trials under various conditions and during actual fishing operations, and in determining in this way if such a design represents a viable economic alternative susceptible to bring a new impetus to fishing other than trawling. It has required to equip the boat with adequate measuring devices, fuel meter in particular, and comprises three district parts.

2.2.1 Systematic trials

Their aim is to evaluate ship speed, fuel consumption and the global behaviour of the ship. Two series of trials are to be performed.

a) search for best performance according to wind speed and sailing trim

- engine alone at maximum power
- sails alone
- sails and engine at maximum power.

b) trials at various stabilized speeds

- engine alone
- sails and engine.

The duration of those trials was ten days (13 to 23 July 1982).

2.2.2 Trials under operation with long lines

Various types of data are recorded on an hourly basis :

a) weather and sea conditions, position and head
b) speed and fuel consumption function of the propulsion means used.

The boat is equipped with an auxiliary engine supplying electricity and refrigeration, the consumption of which was singled out.

The total duration was 30 days, made up of two one-week campaigns and one two-week campaign, which took place from 27 July to 3 August 1982, 6 August to 11 August 1982, and 27 August to 8 September 1982, repectively.

2.2.3 Trials under operation with towing lines

The data recorded are the same as above. The expected duration for the campaign is 30 days. It will take place in 1983 during the tuna season. As for the catamarans campaign, those series of campaign are undertaken under the control of an observer with delegation from the Central Committee of Sea Fisheries.

3. ANALYSIS OF THE TRIALS

The following analysis only deals with the assessment aspect of the boats during systematic trials. It is based, on one hand, on the data collected during the 1981 campaign for the "Dar Mad" (although their precision has slightly suffered from the sensibilization aspect already mentioned, they nevertheless constitute a reliable basis for evaluation), and of the more precise data collected during the systematic trials of the multi-purpose schooner "Cadoudal". Due to their more elaborate nature, results concerning trials of the latter ship will be presented first.

3.1 ANALYSIS OF THE TRIALS FOR SCHOONER "CADOUDAL"

3.1.1 Trial conditions

Actual sea trials were spread out over approximately ten days, which were not in sequence, thus allowing for a large variety of weather conditions. Consumption was continuously measured by a double rate meter attached on to the gas oil circuit. From its knowledge the power of the propulsion engine is obtained for each trial.

Precise gauging of the log has been achieved through trials without sail.

During trials with sail, embarked instrumentation measured the wind speed and direction. The area of spread sails has also been recorded, as well as the state of the sea, the heeling angle and the r.p.m. of the engine (in case the latter is used).

Numerous trials have been repeated under identical conditions, in order to assess the influence of the effect of sail setting.

3.1.2 Data interpretation

The various components of the equation expressing the equilibrium of forces in the longitudinal direction are to be evaluated through the trials. The equation is (positive direction pointing forward):

$$S + R + Fx + fx = 0$$

S = propeller thrust (s times power)

R = resistance

Fx = component of the lift due to sails along the longitudinal axis

fx = force due to relative wind on dead works

a) During trials with engine alone, speed V, engine r.p.m. N and hourly consumption C are recorded. From those values the following quantities are deduced.

- Engine power: in the r.p.m. range under consideration, comprised between 1 500 and 2 500, specific consumption c is nearly constant, 164 to 166 g/h.p./hour. An approximation of the power sufficiently precise for our purpose is therefore given by the relation:

$$P = \frac{C}{c}$$

- propeller thrust S is obtained from the power P by the relation

$$S = s . P$$

In the trial range, a relation of the type

$$s = \frac{a}{N} \left(1 - b \frac{V}{N} \right)$$

gives a good approximation of s as a function of engine r.p.m. N and vessel speed V. The a and b coefficients are function of the thrust and torque factors, obtained from standard curves of propeller families once propeller characteristics are known :

number of blades: 2
diameter D = 1.32 m
pitch (constant) H = 0.90 m
surface ratio: 0.40

and of each advance factor $\frac{V_a}{n\ D}$, implying prior knowledge of the wake coefficient.

b) Hull resistance is obtained as a result of model tests performed in a towing tank.

c) The wind force on dead works is of the form:

$$fx = K \frac{\rho}{2} a\ v^2$$

ρ = air density
a = projected area of dead works, approximately 20 sq. meters
v = relative air velocity

The value of the K coefficient is estimated using the results of trials wind astern and wind ahead at constant r.p.m. using the equation :

$$S + R + fx = 0$$

d) Equation R + Fx + fx = 0 yields an estimation of the value of Fx for trials with sails alone; R and Fx are calculated as functions of V as explained above.

In the same way, under trials with both sails and engine, Fx is obtained from the equation :

$$S + R + Fx + fx = 0,$$

S, R and fx being calculated as functions of V, C and N.

A dimensionless performance coefficient Cx for the sails is defined as the ratio between the useful longitudinal component and the resultant of the pressures applied on the sail

$$Cx = \frac{Fx}{\frac{\rho}{2} A\ v^2 \cos\theta}$$

A = sail area
v = apparent wind velocity
θ = list angle

Values of this coefficient for trials with sails alone and with both sails and engine provide an indication of the efficiency of sails adjustment and of their contribution to the propulsive power.

A coefficient Cy relative to the transverse component of the wind force may defined in s similar way.

3.1.3 Measurements with engine alone

The results obtained during a series of four trials at the Groix measured course are summarized on Figure 4, representing the variation of the consumption rate (expressed in liters per hour) as a function of the speed (in knots).

3.1.4 Trials with sails wind ahead and wind astern

Measurements were performed with an 18 knots wind, calm sea. Different values of engine speed were considered, the r.p.m. being kept constant during each set of measurements. Value for fx was found to be equal to 300 N wind astern, and to lie between -2 000 N and -2 400 N for wind ahead. For all r.p.m. considered, the difference between consumption rate wind ahead and wind astern was comprised between 0.7 and 1 liter per hour.

3.1.5 Trials with sails alone

The aim of such trials is to evaluate the speed performance of the boat as a function of trim in order to assess the possibilities to use the boat with sails alone for specific fishing operations, towing fishing is particular. They also allow a preliminary estimate of the efficiency of the sails.

The following observations concerning the retained measurements will be made.

Wind astern
There exist very few measurements for such trim. The best and the worst have been retained. The difference in results is an illustration of the difficulty in obtaining precise measurements before the wind.

Broad reach
The best and worst results have similarly been retained.

Wind abeam
Only one set of measurements corresponding to a very good setting of the sails is available. Other records generally exhibit

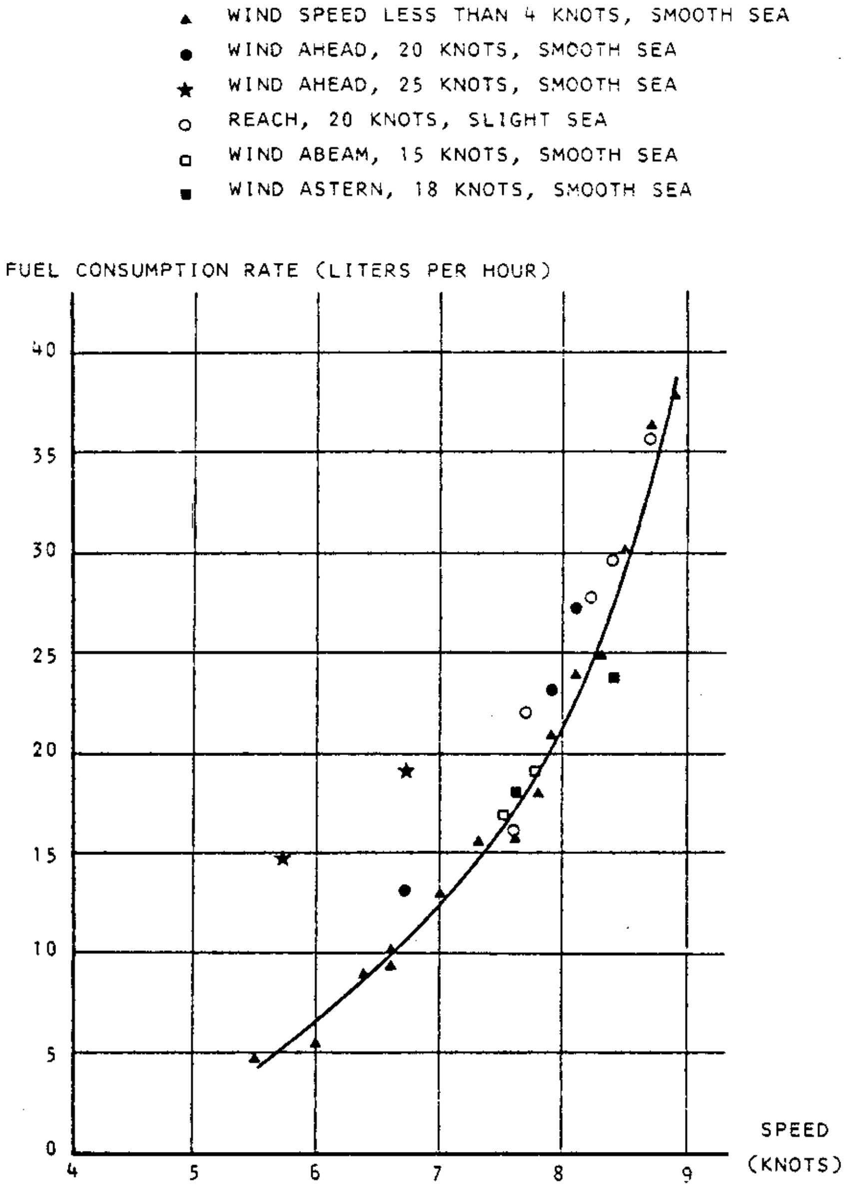

Figure 4 : "Cadoudal" - Fuel consumption rate versus ship speed, engine alone, under various conditions (the curve drawn represents the variation of fuel consumption as a function of ship speed for wind speeds less than 4 knots)

excessive list, denoting excessively planked sails.

Full and by
The two best trials as well as the two worst have been retained.

Close hauled
It is very likely to have a poor setting for such trim. The best results have been retained for the analysis. The hauling angle is

approximately 40° with respect to the apparent wind.

The results are summarized in Table 1.

trim	true wind speed (knots)	apparent wind (knots)	speed (knots)	list (degrees)
Wind astern	20	14	6.4	0
	20	15	4.6	0
Broad reach	15	10	6	0
	20	15	6.4	0
	20	16	5.2	0
	15	12	4.1	0
Wind abeam	18	18	7.0	12
	20	20	7.5	13
	23	23	7.1	15
	25	25	7.1	17
Full and by	18	20	6.6	15
	18	20	6.7	10
	18	20	5.2	10
	18	19	4.4	8
Close hauled	18	20	5.3	13
	23	26	6.6	18

Table 1

Towing speeds are obtained for wind speeds exceeding 15 knots.

Values of the Cx coefficient give a first indication of the efficiency of the sails.

	Cx
Wind astern	0.65
Broad reach	0.80
Wind abeam	0.66
Full and by	0.30-0.50
Close hauled	0.35

At certain speeds, the result is very dependent on the setting of the sails. This factor must be kept in mind when analyzing the trials with both sails and engine for which setting of the sails is more uncertain, since it is more difficult to an observer to assess its influence on the speed.

In particular, it may be seen that the sails were excessively planked during trials wind abeam and that, for close hauled trim, the shape of the jib is poor, the sheet dew coming too close to the ship axis, and the center of drift being located too much forward. We are far from the ability to come round exhibited by racing boats.

List prevents from keeping a close hauled trim in case the wind freshens; from this point of view, it seems that full sails may be kept up until a true wind speed of 23 knots. Above that speed, the speed of the ship close hauled could not increase.

3.1.6 Trials with sails and engine

The measurements retained have taken place under the following conditions:

Wind Astern
There exists no measurement for such trim. However, the above analysis shows that there is a good consistency between the various direct thrusts of the wind, using the values of propeller thrusts obtained from the recorded consumptions.

Broad reach
The series of trials took place in calm sea and 5° list. The sail efficiency is smaller than the minimum obtained during trials with sail alone. The quite large list apparently indicates that the sails were not sufficiently borne off. The last two recordings show a very clear decrease of the propulsive efficiency for high r.p.m.

Wind abeam
A first series of trials was made with wind not strong enough to feel any apparent wind. A second series of measurements relates to a true wind of 20 knots corresponding to an apparent wind of approximately 18 knots. Sea was a little rough, and list varied between 5° and 10°. The efficiency coefficient remains inferior to the smallest values encountered during the trials with the sails alone.

Full and by
A series of trials was made with true wind speed of 15 knots (apparent wind speed being approximately 18 to 19 knots), calm sea, list approximately equal to 12°. The value of the Cx coefficient is in the inferior range of trials without engine power. A drop in thrust occurs for 2 600 r.p.m., analogous to the one exhibited in broad reach.

Close hauled
Trials took place in slightly rough sea, true wind speed 15 to 17 knots, with a 20° list and a hauling angle with apparent wind equal to 35°. The dip effect was assessed in order to control the order of magnitude of Cy, which is realistic. It may be possible to define a setting of the sails yielding a better Cx.

The drop in propeller thrust at high r.p.m. seems to be much less than in some of the above situations.

The results are summarized on Figure 5, showing the variation of the fuel consumption with the speed for various trims. The curve of Figure 4 has been reproduced (dashed lines) for comparison.

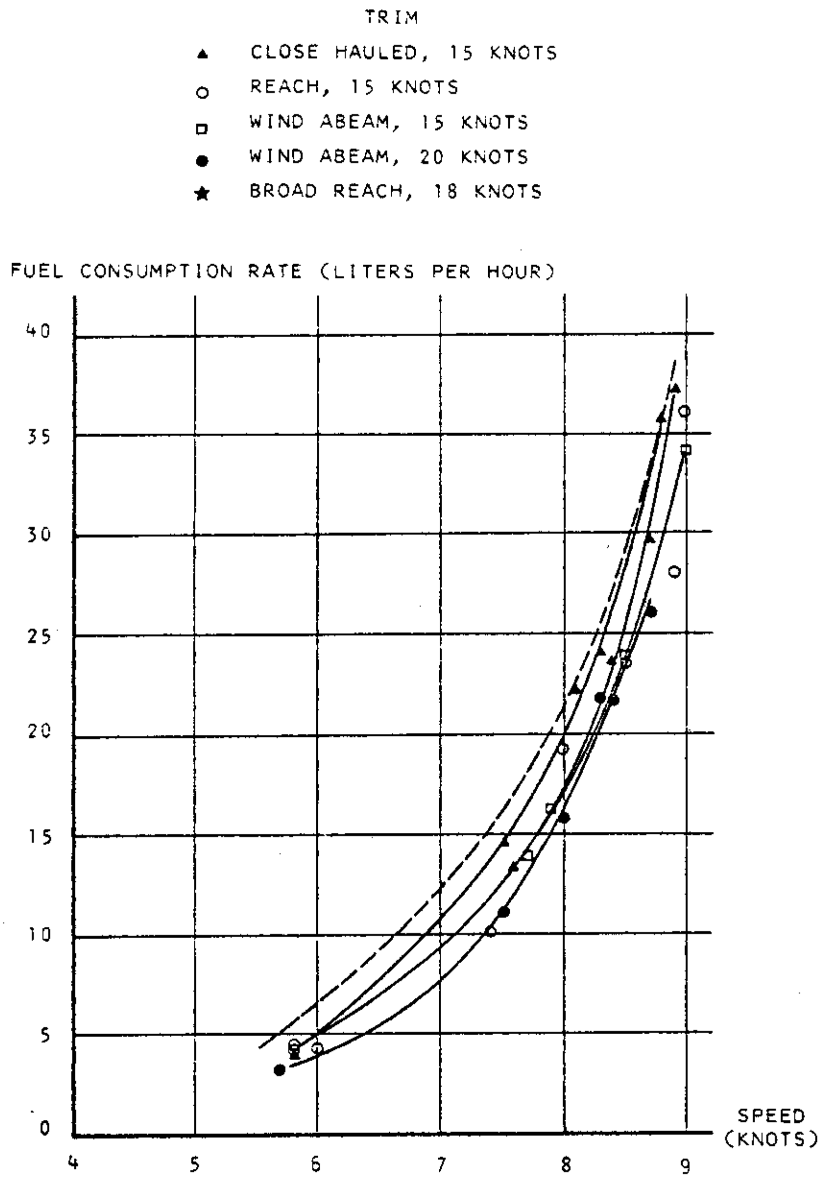

Figure 5 : "Cadoudal" - Fuel consumption rate versus ship speed, sails and engine, smooth sea (the dashed curve represents the variation of fuel consumption as a function of ship speed, engine alone)

For each trial, the propeller thrust S is evaluated, and Fx then deduced. The corresponding Cx are generally smaller than those obtained for sail alone.

The sail efficiency table must therefore be modified taking into account the results obtained, which differ somewhat from those previously obtained.

In broad reach condition, the value of Cx should be 0.32 rather than 0.4. By analogy, a value of 0.52 rather than 0.65 should be kept for wind astern.

For wind abeam, the expected value of 0.4 would seem to be exceeded in low wind; however, trials more suitable for analysis yield at best a value of 0.29. It is reasonable to retain a value of 0.35.

In reach, a value of 0.30 should be retained.

Close hauled, the average Cx is around 0.23.

3.1.7 Global comparison sails and engine

Trials took place for various speeds and under uncertain weather conditions. The diesel power necessary to achieve a relatively economic constant speed (8.2 knots in the present case) under a series of weather conditions presenting some statistical regularity may then be evaluated from a knowledge of those coefficients. The direction of the wind with respect to the ship is assumed to follow a uniform probability distribution (this would not be true in the case of a repetive course, perpendicular to the predominant wind for example). Fishing operations were not considered.

The weather statistical distribution used was obtained from an expected wind curve function of the calendar days over a year. Discarding the small portion (5 % of the time) during which wind speed exceeds 30 knots, ranges of equal duration may be defined :

20 % of the time	0 to 9 knots	(mean 4 knots)
20 % of the time	9 to 15 knots	(mean 12 knots)
20 % of the time	15 to 18 knots	(mean 16 knots)
20 % of the time	18 to 21 knots	(mean 19 knots)
20 % of the time	21 to 30 knots	(mean 24 knots)

The mean in each range was weighted to account for the wind probability distribution in this range.

R, Fx and fx are evaluated following the method previously described, with correction factors to account for the strength of the wind and the state of the sea. Propeller thrust S is obtained from the equation:

$$S + R + Fx + fx = 0$$

Specific thrust s is deduced based on similar situations encountered. P is then obtained using the relation :

$S= s.P$

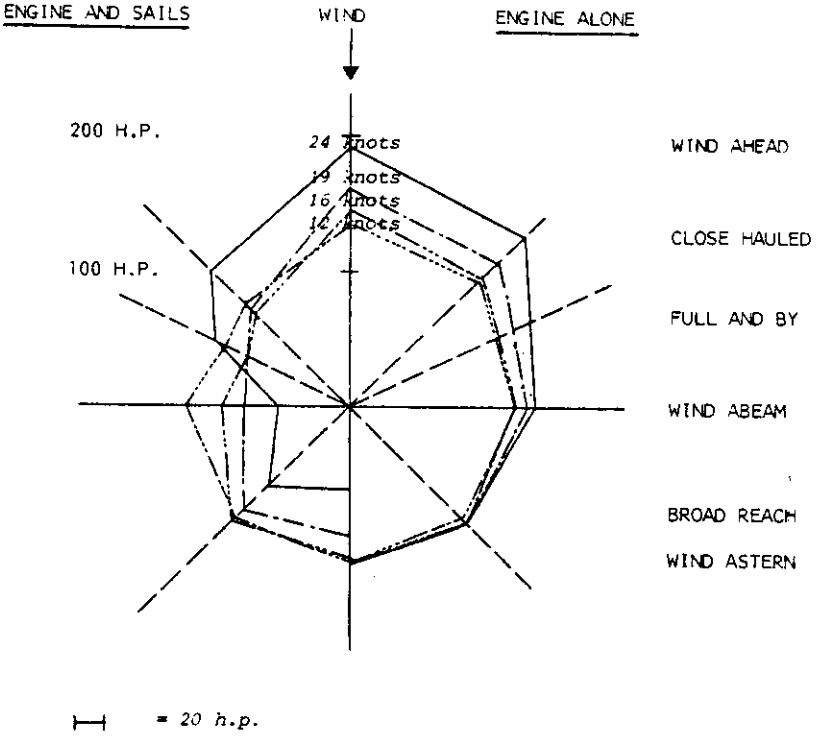

Figure 6 : "Cadoudal" : power diagram

The calculations are summarized on the power diagram of Figure 6. The right half shows the power (expressed in h.p.) which has to be supplied for different trim conditions with engine alone. An estimation of the diesel power which has to be supplied with sails to achieve the same speed (8.2 knots) is represented on the left half. Taking into account the drift angle, which deteriorates the head under close hauled trim, the proportion of the course wind ahead is larger than that in the case of the engine alone.

With engine alone, the global average power is 128 h.p. The fuel consumption rate is 25.1 liters per hour, corresponding to 3.07 liters per mile.

For sail-assisted propulsion, the global average is 109 h.p., the fuel consumption rate being 21.4 liters per hour corresponding to 2.6 liters per mile.

3.1.8 Possible improvements

The results summarized above are those obtained by processing the data collected during sea trials in a rational manner, and when necessary by making up for some missing or incomplete information. They describe the performance which may be realized with the ship "Cadoudal" operating its sails in the way this was done during the trials with engine and sails, i.e. far from the optimum.

Improvements may be achieved, through :

a) more efficient use of the sails :

Sail efficiency is not as good in sails and engine condition for two reasons: lack of experience from the crew and the fact that the influence of adjusting the sheets cannot easily be felt when the propeller already contributes to a large part of the speed. The difficulty must be overcome in order to obtain a favorable Cx diagram. In such a case the average power would only be 87 h.p. instead of the 109 recorded, and would correspond to a fuel consumption rate of 2.08 liters per mile.

b) design of an improved ship.

The schooner "Cadoudal" presents some flaws in design, which could only partly be corrected. It is easy to envision a ship with similar characteristics, but

- slightly more stable and with more sail area
- more balanced (better distribution of the work of the sails)
- with a rigging arrangement such that the sails may be planted more efficiently
- with lower dead works, the fore storeroom being reduced
- with a propeller designed to keep a reasonably good efficiency in situations when it contributes only partly to the ship power.

Numbers may be attached to each one of those improvements. In doing so, a reasoning similar to the one made before would yield the following results :

Speed	Extra power, average
8.2 knots	56 h.p. (1.35 liters per mile)
8.7 knots	87 h.p. (1.96 liters per mile)

The improved ship would in some instances exceed the imposed speed, without engine assistance. This fact was taken into account for the computation of the average.

3.1.9 Case of the comparable trawler

A trawler with same length as the "Cadoudal" would have to be heavier, bulkier; its propeller would be designed for towing rather than for open sea. This type of ship being generally driven above the economic speed because of the available power, the study was conducted assuming a speed of 8.7 knots with engine alone.

The average power is now as high as 202 h.p. with a consumption rate of 4.56 liters per mile.

3.1.10 Concluding remarks

Various conclusions may be drawn from the different analyses briefly described above depending on the details and assumptions introduced.

However, the global analysis may be condensed in a few figures only, given in the table below:

	speed (knots)	fuel consumption (liters per mile)	comparison index
"Cadoudal", engine alone	8.2	3.07	100
"Cadoudal", sails and engine	8.2	2.61	85
"Cadoudal",better adjustment	8.2	2.08	68
Improved ship	8.2	1.35	44
Improved ship	8.7	1.96	64
Trawler	8.7	4.56	149

The comparison shows that the "Cadoudal", with engine alone, is already 50% more efficient than a trawler. The sails, although summarily used, already add on a 15 % improvement. Improved adjustment should lead to a 30 % extra improvement.

The analysis for the improved schooner leads to a predicted saving with engine greater than 50 % over the corresponding motor ship (consumption rate of 44 compared to 100, or 64 compared to 149).

3.2 ANALYSIS OF THE RESULTS OF THE TRIALS OF CATAMARAN "DAR MAD"

The data recorded during the 1981 measuring campaign are not as precise as those obtained aboard the "Cadoudal". The same analysis procedure may nevertheless be applied, and leads to results useful for comparison purposes.

3.2.1 Measurements performed with engines alone

As was the case for the "Cadoudal", the value of the power is obtained from the measured consumption rate, and the propeller thrust evaluated using the method already described.

The results are summarized on Figure 7.

Values for S are reasonably proportional to the corresponding values of V, as could be expected, with the exception of a few measurements (corresponding to one engine only at speeds of 4.5, 7 and 8.6 knots ; the latter, corresponding to a power of 63 h.p. for one engine, denotes diesel overload and should be discarded ; the 4.5 knots speed is too low for the corresponding results to have any practical significance ; on the other hand, the performance obtained with one engine only at speeds of 8.3 and 8.5 knots are close to that at 8.4 knots with the two engines).

These series of measurements lead to a good estimate of the hydrodynamic resistance, which, in the same speed range, is of the order of that of a fast launch. It should be emphasized that the ratio of displacement over length to the third power, approximately equal to 0.003 for each hull, is much more favorable than for the case of the total mass concentrated on one hull only.

3.2.2 Measurements performed with sails alone

As was the case for the "Cadoudal", the aim is twofold: to assess the possibilities of fishing with sails from the observed speed capabilities, and to set up an efficiency table for the sails for various trim angles.

Measurements were only performed broad reach, wind abeam, and full and by. The sail area is always 57 sq. meters, and the wind speed is characterized on the Beaufort scale, thus making the exact determination of apparent wind less precise.

Once the value of R has been obtained from the previous curve and the aerodynamic force acting on the dead works has been evaluated following the same procedure as the one outlined for the "Cadoudal", the sail propulsion force is obtained from the relation :

$$R + fx + Fx = 0$$

The aerodynamic coefficient of the sails Cx has the same expression as given in 3.1.2, the list being negligible in the case of the catamaran.

The measurements taken into consideration are summarized in Table 2.

An obvious inconsistency exists at low speeds for broad reach and

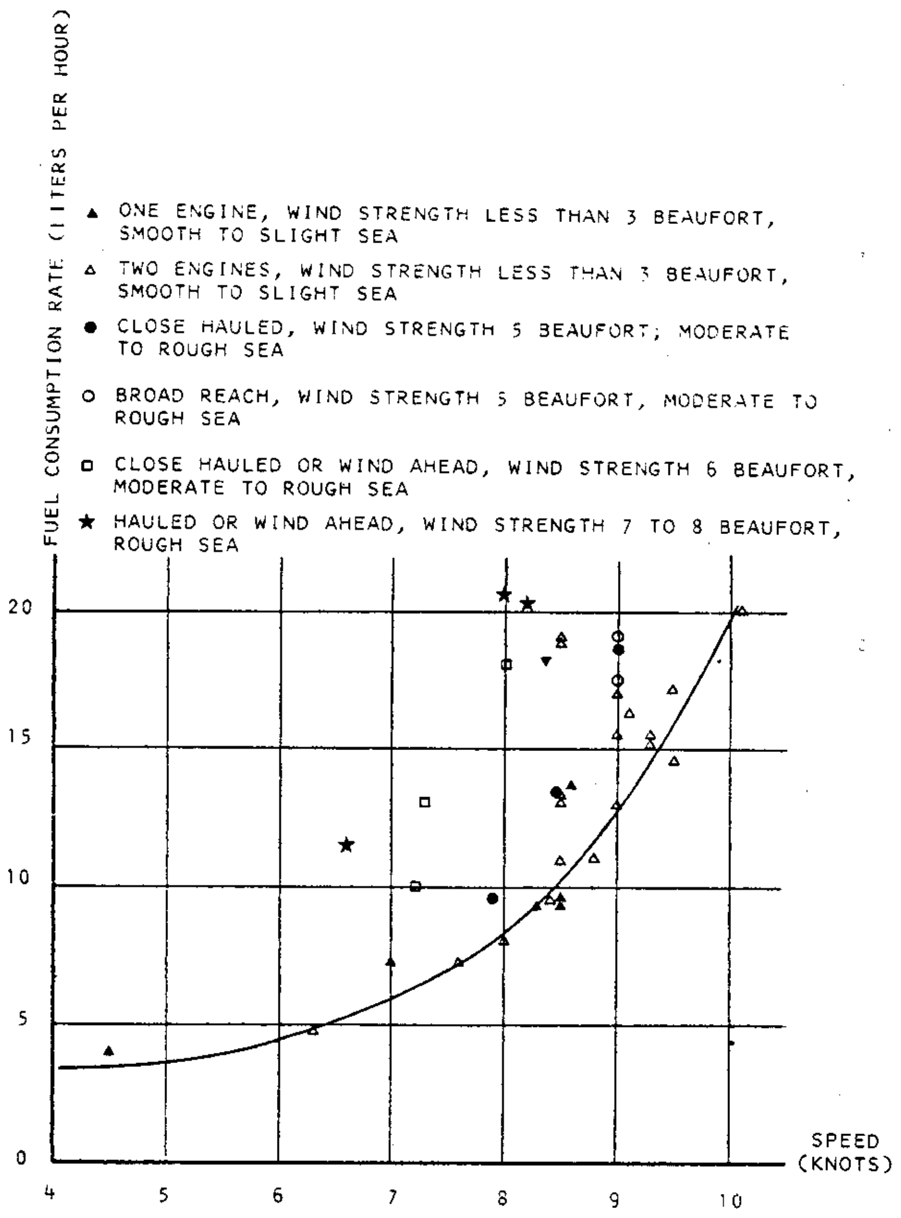

Figure 7 : "Dar Mad" - Fuel consumption rate versus ship speed, engines alone, under various conditions (the curve drawn represents the variation of fuel consumption rate as a function of ship speed for wind strength less than 3 Beaufort, smooth to slight sea)

apparently poor adjustment of the sails for full and by condition corresponding to the measurements conducted under strength 5, and especially to the measurements conducted at 4 knots under strength 6. A smoothing of all the data collected yields a preliminary table of sail efficiency:

trim	actual data		smoothed data		
	wind strength (Beaufort)	speed (knots)	strength of true wind (Beaufort)	speed of apparent wind (knots)	speed (knots)
Broad reach	3	4.7			
	4	4.0	4	13	4.9
	5	6.0	5	15	6
	6	7.0-7.1	6	19	7.1
	7	9.0			
Wind abeam	2	3			
	3	3.7			
	4	5.0-5.4	4	15	5.2
	5	5.7-6.0-5.7	5	19	5.9
	6	6.0-6.5	6	22	6.4
Full and by	3	4.1-4.0			
	4	5.5			
	5	4-5	4;5	20	5.5
	6	4.0-6.5	5-6	24	5.9

Table 2

	Cx
Broad reach	0.71 - 0.86
Wind abeam	0.56 - 0.77
Full and by	0.51 - 0.60

3.2.3 Measurements performed with sails and engines

There were no measurements made with sails and engines in full and by condition, wind astern or close hauled. This latter trim will be discarded, as it is too difficult to keep for this type of ship.

The only available data concern measurements performed :

- under broad reach condition during five cruises under noticeable wind and rough sea;
- wind abeam during seven cruises, under wind comprised between 4 and 6 Beaufort.

Figure 8 summarizes the various data collected. The curve corresponding to engines only already obtained in Figure 7, has been reproduced there for comparison purposes.

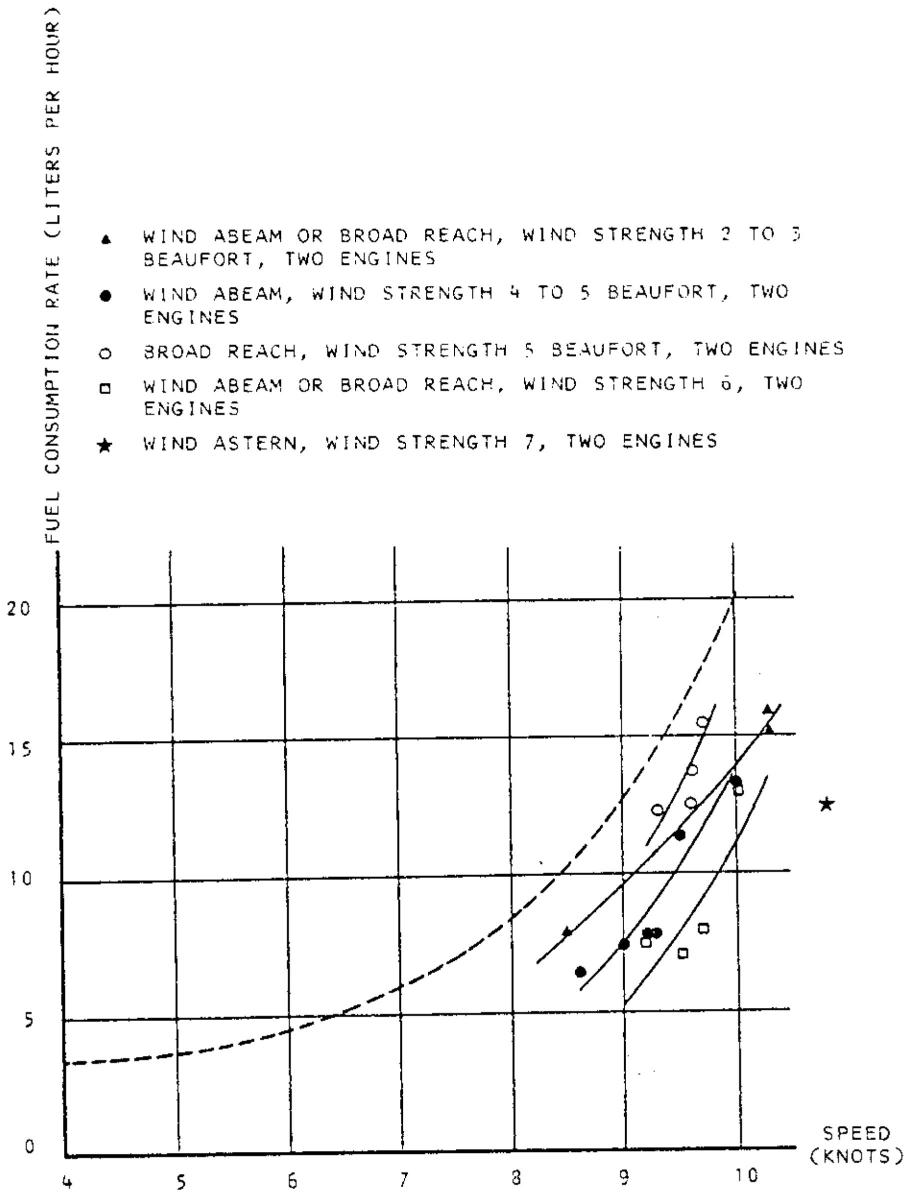

Figure 8 : "Dar Mad" - Fuel consumption rate versus ship speed, sails and engines, under various conditions (the dashed curve represents the variation of fuel consumption as a function of ship speed, engines alone)

The sail efficiency table may be complemented in the light of those results.

For broad reach under strength 5 to 6 with sails alone or under strength 6 to 7 with sails and engines, the Cx value lies around 0.75.

For wind abeam exceeding strength 4, the value of Cx is closer to 0.6 with sails alone and 0.7 with both sails and engines.

In full and by condition, the value of Cx with sails alone is approximately 10 % less than that for wind abeam.

For wind astern, the value of Cx for broad reach should be retained, and refers to the jib alone ; in other words, Cx should be reduced in the same proportion as the sail areas.

The following table is then obtained. Although the values are quite approximate, they are still valid for comparison purposes as they always refer to the same measured course:

	Cx
Wind astern	0.45
Broad reach	0.75
Wind abeam	0.65
Full and by	0.58

3.2.4 Global comparison with sails and engines

The data have been processed following the procedure already employed for the "Cadoudal": the diesel power necessary to achieve a relatively economic speed (8.6 knots in the present case) was estimated under the same weather conditions statistics as before.

The results of the calculations are summarized on the right hand side of the power diagram of Figure 9, which indicates the power (expressed in h.p.) to supply for different trim conditions, the ship being propelled only by its engines. The shaded region corresponds to the use of a single engine only (limited to 85 % of the maximum power).

In general, the values obtained do not significantly differ from those actually recorded in similar routes.

Global average power = 55 h.p.
Consumption rate = 12.0 liters per hour,corresponding to 1.39 liter per mile.

An estimation of the diesel power necessary to maintain the same speed (8.6 knots) with sails yields the results summarized on the left hand side of the power diagram of Figure 9. The shaded regions corresponds to the use of a single engine only (limited to 85 % of the maximum power).

When sailing close hauled or wind abeam with a wind speed of 24 knots, the area of the sails was assumed to be reduced to 40 square meters.

Global average power = 42 h.p.
Consumption rate = 9.1 liters per hour,corresponding to 1.06 liter per mile.

3.2.5 Comparison with the equivalent traditional ship

As was done for the "Cadoudal", and for comparison purposes, it is

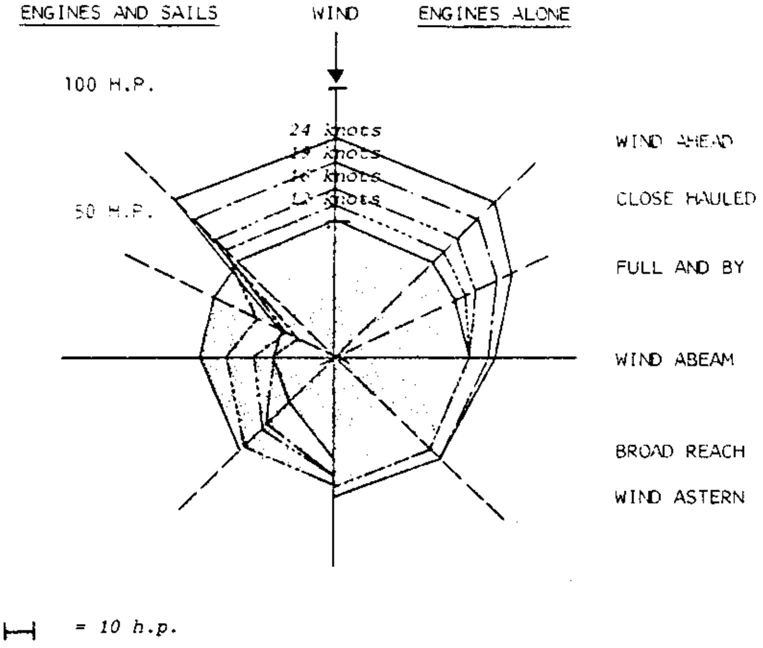

Figure 9 : "Dar Mad" - Power diagram
(the shaded region corresponds to the use of one of the two engines only)

interesting to consider a traditional ship with equivalent working capability. The beam of such a boat would be 15 m, its engine power around 230 h.p.

The procedure used is the same as the one previously defined. The analysis was performed for a speed of 8.6 knots, evidently engine alone.

The mean power is as high as 161 h.p., with a fuel consumption of 34.9 liters per hour or 4.16 liters per mile.

3.2.6 Conclusions

The diesel power which is necessary to ensure the "Dar Mad" a speed of 8.6 knots on the average drops from 55 h.p. to 42 h.p. in case the sails are used. The economy achieved in using the sails is therefore of the order of 23 %.

The number and quality of the data recorded during the trials does not in the present case justify a study of possible improvements.

Moreover, the advantages of catamarans used for working boats, independently from the use of the sails, have hardly been investigated.

Finally, route and wind conditions for a coastal fishing vessel may lead to different averages than those obtained.

The important point is that the data presented, although in limited number and within the accuracy of the measurements, serve to confirm the large fuel savings achieved for this type of ship since, with engines only and at similar speed, the "Dar Mad" burns two thirds less fuel than a traditional ship; the use of sails increases this saving, which can be as high as 75%. Based on the preliminary results obtained immediately after it first went into service, the "Dar Mad" would appear to be superior to the "Cadoudal", implying that it is a better use of sails may be made aboard a multi-hulled watercraft.

Safety aspects still have to be considered for that type of ship; the corresponding studies will set limits to the use of sails.

CONCLUSION

The present study concerns systematic trials and does not take into account the data relative to the actual operation of the boats, and in particular the ratio between the travel time and the fishing time as well as the complete set of operational constraints during the fishing period: manoeuverability, speed, possibility of using sails, etc ... These factors will be defined better following the measurement campaigns presently in progress.

A certain number of conclusions may however be drawn once and for all.

In the first place, it must be noted that the actual contribution of wind propulsion is difficult to evaluate separately from the total energy saved due to the modification of the type of ships, the boats under consideration being completely different, in particular in their hull lines, form present fishing boats.

In the case of the multi-purpose monohull, the result appears to be a reduction of one half of the consumption, which is in equal parts due to the modification of the hull and to the use of the sails.

Roughly, for the catamaran, the consumption is about four times less than that of a comparable conventional boat. The largest part of this reduction may be attributed to the choice of a well designed catamaran because that alone makes it possible to divide the consumption by three, the effect of the sails accounting for the remaining one twelfth of extra fuel saving.

BIOGRAPHICAL SKETCHES

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SOME ASPECTS OF SAIL POWER APPLICATION IN THE GERMAN SEA FISHERY

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SUMMARY

Increasing oil prices did start the discussion on sail propulsion for German fishing vessels especially the smaller ones.

Operational data of small German trawlers is presented and discussed with regard to sail application as well as data of long term wind conditions needed for reliable prediction of sail power output.

Sailing and motor sailing tests with a 24 m standard fishing vessel were performed in 1980/82. The results of these investigations demonstrate that a considerable contribution to the propulsion power can be obtained by a sail area of sufficient size.

In favourable conditions of wind force and course angle the design speed of the vessel was gained by sail propulsion only.

1. INTRODUCTION

One of the most important influecences on the economic performance of fishing vessels during the last decade was obviously the ever increasing costs of fuel. Fishermen had to face a sevenfold increase in fuel costs between 1972 ans 1982. To demonstrate this development the price of diesel oil at the German fishing port of Cuxhaven is plotted in Fig. 1.

For selected vessels of the near water fishing fleet there is statistical data available /1/(Tab. 1), showing the composition of operating costs since 1967. A considerable part of the total operating costs is accounted for by fuel, which increased from 9.6 % (1971) to 22.9 % (1982) of the total costs. With regard to additional sail propulsion for these vessels we must keep in mind that, in spite of the increasing fuel costs, the major part of the operating costs is incurred for the crew. From this fact we can conclude that any sail arrangement making an increase of the number of crew necessary will by no means improve the economy of the vessel.

On the other hand the prices for fish and fish products increased at a lower rate than the fuel price. The economic results of the German near water and inshore fishery are listed in Tab. 2 /2/. The landings are made up of wet fish for human consumption, industrial fish for fish meal production and shrimps, wet fish being the major part. In these circumstances a reduction of fuel consumption is one of the main problems for owners and skippers of fishing vessels.

On the gear side, different types of low energy fishing gear, e. g. set nets, longlines, danish seines, were improved and widely used by small fishing vessels. On the vessel side, the fuel consumption was decreased by slow steaming and main engines were prepared for the use of low grade oils to reduce the fuel bill. Another possibility for reducing the fuel consumption of fishing vessels would be the use of wind power for propulsion which is the subject matter of this paper. The paper will concentrate on the North sea for two reasons:

1. The North sea is the most important area for the German near water and inshore fishing fleets.
2. Detailed statistical data of wind conditions, operating conditions of fishing vessels, and catches is available for this area.

2. WIND CONDITIONS ON THE FISHING GROUNDS

The estimation of the propulsive power which can be obtained by wind force must be based on long term wind statistics of the area where the vessel will operate. Unfortunately statistical wind data is not always available, especially for those wide sea areas, where no permanent meteorological observations are performed. For German coastal waters of the North Sea there is long term wind data from weather stations on seven light vessels, which can be used for detailed calculations /3/.

To describe the wind conditions of the North Sea the wind data from the light vessel "TW Ems" will be used in this paper. Until 1978, when "TW Ems" was taken out of commission, the vessel was positioned at 54° 10' N, 6° 21' E.

The data relates to a period of 5 years (Dec. 1971 - Dec. 1976). The wind speed was measurd continuously by a cup anemometer 18 m above sea surface and which recorded the average value of every 10 minute period. The wind speed at the standard height of 10 m is calculated according to the proposal of the "Informal meteorological Panel for the North Sea and adjoining waters", De Bilt 1977:

$$U(h_2) = U(h_1)\cdot(h_2/h_1)^{1/7} \qquad (1)$$

The frequency distribution of the 10 min. mean values U_{10} at h = 10 m is plotted in Fig. 2.

From this observed distribution of the mean wind speed $\bar{U}_{10}$, the variance $V_{U_{10}}$, and the standard deviation U_{10} are devided:

$$\bar{U}_{10} = \sum p\,(U_{10})\cdot U_{10} \qquad (2)$$

$$V_{U_{10}} = \left[\sum p\,(U_{10})\cdot U_{10}^2\right] - \bar{U}_{10}^2 \qquad (3)$$

$$\sigma_{U_{10}} = \sqrt{V_{U_{10}}} \qquad (4)$$

With the "TW Ems" data from Fig. 2 we get

$$\bar{U}_{10} = 7.74\ m/s;\quad V_{U_{10}} = 12.72\ m^2/s^2;\quad \sigma_{U_{10}} = 3.57\ m/s$$

Wind speed distributions which are based on long term observations are usually approximated by a Weibull distribution /4/, /5/:

$$p\,(U_{10}) = \frac{c}{a}\left(\frac{U_{10}}{a}\right)^{c-1} \exp\left(-\left(\frac{U_{10}}{a}\right)^{c}\right) \qquad (5)$$

Mean value and variance of the Weibull distribution can be expressed in terms of gamma functions:

$$U_{10} = a\,\Gamma\left(1 + \frac{1}{c}\right) \qquad (6)$$

$$V_{U_{10}} = a^2\,\Gamma\left(1 + \frac{2}{c}\right) - \bar{U}_{10}^2 \qquad (7)$$

With $\bar{U}_{10}$ and $V_{U_{10}}$, derived from the observed distribution and inserted in equations (6),(7) the Weibull parameters c and a can be calculated by means of numerical or graphic methods as described in /4/, /5/. With the data from light vessel "TW Ems" we get c = 2.4;a = 8.73. The corresponding Weibull distribution is plotted in Fig. 2.

$\bar{U}_{10}$ was calculated for the complete period of observation. When calculating $\bar{U}_{10}$ for shorter periods of one month, the variations of $\bar{U}_{10}$ during the year can be found /3/, and which show a minimum in summertime (june - august) and a maximum in wintertime (november - december) (Fig 3). The summer minimum, which makes this time less favourable for sail use, would be no handicap for most of the small German fishing vessels because they usually have their annual lay-up time of 4 - 5 weeks for repair and maintenance during these months.

The distribution of wind direction frequency is plotted in Fig. 4

Less detailed wind data, based on observations made on commercial vessels is available for other areas of the North sea. The long term mean values $\bar{U}_{10}$ derived from these observations are plotted in Fig. 5 /8/.

When dealing with cargo ships running on more or less determined routes between different ports, the prevailing wind directions are a decisive influence on the long term sailing performance of the vessel /6/, /7/. Considering fishing vessels, this problem is of minor importance, due to the way they operate on the fishing grounds. The assumption of equal probability for all course angles (ship's course/true wind direction) should be reasonable as a first approximation in this case.

3. THE COMPOSITION OF THE GERMAN FISHING FLEET

The German sea fishing fleet is organized in three main sections:

1. Distant water trawlers (Große Hochseefischerei)
Wet fish and freezer trawlers owned by fishing companies. Size: 700 - 3600 GRT. Crew: 18 - 75 depending on GRT, HP of the main engine and fish processing equipment. Area of operation unlimited. Gear: bottom trawl and midwater trawl. Number of vessels: 31 (31.12.81)

2. Near water trawlers (Kleine Hochseefischerei)
Wet fish trawlers operated by skipper owners. Size: up to 175 GRT. Crew: 4 - 5. Area of operation limited

to the Baltic and to the North Sea south of 63°N and east of 7°W, and 10°W for the west coast of Ireland and the Channel. Gear: mainly bottom trawl, seasonal use of mid-water trawl, pair trawl and beam trawl.

3. Inshore fishing vessels (Küstenfischerei)
Small fishing vessels operated by skipper owners. Size: 37 GRT max. Crew: 1 - 3. Area of operation limited to the coast of Germany and adjoining countries (German bight and western Baltic) Gear: Bottom trawl, beam trawl (shrimp trawl). Increasing use of low energy fishing gear, mainly gillnets, in recent years. Number of vessels (near water + inshore): 646 (31.12.81)

The modern distant water trawlers powered by diesel engines were developed from steam trawlers which were introduced at the end of the 19th century. There is no tradition or experience of sail propulsion on this type of vessel since the first German steam trawler started to operate on the North sea fishing grounds in 1885, and there is obviously no realistic chance for sail use on these vessels in the near future. Therefore the problem of sail propulsion for distant water trawlers can be omitted from this paper. On the other hand the type of fishing vessel of section 2 + 3 was a sailing vessel by origin. There was no mechanical propulsion until 1903 when the first experiments with internal combustion engines were performed by the German Sea Fisheries Society (Deutscher Seefischerei-Verein) /9/, /10/.

In a comparatively short time the sail as the main propulsive device was replaced by diesel engines. In 1925 4 out of a total of 72 near water fishing vessels were still sailing. In 1926 all vessels (68) were powered by motors /11/. Up until the late 30s vessels of this type were designed with auxiliary sails to improve their sea keeping behaviour. For these reasons a discussion of sail use on fishing vessels should concentrate on this type. In 1981, 646 near water and inshore fishing vessels were operating, more than 40 % of a size between 14 m - 18 m length over all (Fig. 6) /2/. Powers range up to 600 HP with the majority below 300 HP (Fig. 7). In this diagram the influence of administrative regulations on the fishing fleet can be recognized.

The number of crew with marine engineering certificate is governed by main engine power as follows:

$P < 300$ HP : 1 man
300 HP $< P <$ 600 HP : 2 men
600 HP $< P$: 3 "

4. MODE OF OPERATION ON THE NORTH SEA FISHING GROUNDS

The data for this section is based on the statistics of landings at the three main German fishing harbours of Bremerhaven, Cuxhaven and Hamburg. The statistics refer to the North sea fishing grounds (Fig. 8) and vessels > 35 GRT, all trawlers (Fig. 9). Tab. 3 a - c shows the statistical data for the last 3 years (1980 - 1982). The mean duration of trips to the different fishing grounds is plotted in Fig. 10, and vary between 17 days (Shetlands 1980) and 5.5 days (Deutsche Bucht 1982), according to the distance from German ports.

The days spent fishing as percentage of days at sea are plotted in Fig. 11. For all fishing grounds the vessels are fishing about 65 % - 70 % of the time. This value is not very exact because every day the gear is shot, even for a short haul, is revorded as fishing day. A more detailed statistic may indicate 50 % - 60 % fishing time.

With respect to the use of sails we have to consider days running and days fishing separately. Sailing will not always be possible especially when bottom trawling on fishing grounds where fasteners are abundant and a great number of vessels are working simultaneously. or when working with gill nets or longlines.

Trolling seems to be the only method where sails can be used without difficulty. It is more or less equal to the free running condition of a vessel where sailing will always be possible, favourable wind speed and direction assumed. But the application of this fishing technique is limited to certain pelagic species like tuna or salmon which are not available in the areas where German near water and inshore vessels are working.

5. SAILING TRIALS WITH A 50' GERMAN STANDARD TRAWLER

In April 1980 sail propulsion tests with a former German standard trawler were performed by The Federal Research Institution for fisheries, Institute for Fishing Technology (Bundesforschungsanstalt für Fischerei, Institut für Fangtechnik) in cooperation with the Hamburg Ship Model Basin (Hamburgische Schiffbau-Versuchsanstalt) to obtain full scale test data for the estimation of the sailing performance of small fishing vessels /12/, /13/. These trials were continued in 1982.

5.1. THE STANDARD TRAWLER KFK (KRIEGSFISCHKUTTER)

In the late 30s the German government started a programme to standardize small fishing vessels. This work resulted in a serie of 7 vessel types (A - G) at a range of 10 m (A) to 22 m (G) length over all /14/, /15/.

The research and development work was concentrated on the type G (Fig. 12, Fig. 13) including model tests at the Vienna Ship Model Basin /16/. Fig. 14 shows the results of these tests. Starting with the hull form of a successfull traditional fishing vessel (Normalform L = 22.0 m) the lines were improved while keeping the main dimensions and displacement constant. With this hull form (Maierform, L = 22.0 m) the Shaft horse power at V_s = 9 kts was decreased by 37.9 % compared with the original design. In another variation (Maierform, L = 23.9 m) the length over all was slightly increased at constant desplacement, and a total reduction of 43 % SHP at 9 kts was measured with this final hull form. The main dimensions of the KFK are:

Length over all	L o.a.	=	24.00 m
Length between perpendiculars	Lpp	=	20.57 m
Beam moulded	B	=	6.25 m
Depth	D	=	3.00 m
Draft moulded	T	=	2.11 m
Draft max.	T_{max}	=	2.85 m
Displacement		=	119.00 m^3
Propeller			
Diameter	Dp	=	1220.00 mm
Pitch	P	=	820.00 mm
Disc area ratio	A_E/A_0	=	0.47
Number of blades	n	=	3

Full scale tests with 3 vessels confirmed exactly the model test results /17/, Fig. 15. During World war II 600 KFK were built and used as mine sweepers and patrol boats by the German navy. Most of them were destroyed, the remaining 130 vessels were converted to trawlers in 1945. In 1982 about 20 KFKs were still fishing.

5.2. KFK "FREDDY"

The trials were performed with KFK "Freddy", now owned by the German section of the British Petroleum Company and used as a yacht (Fig. 16).
There is a total sail area of 180 m^2:

main sail:	78,5 m^2
mizzen jigger:	41,0 "
jib:	31,5 "
outer jib:	29,0 "
	180,0 m^2

Displacement: 98 t
The rig is of traditional design. Sufficient stability is provided by 15 t ballast, giving the vessel a positive righting lever up to 90° angle of heel (Fig. 17).

5.3. TEST RESULTS

5.3.1. SAILING TESTS

The first series of trials were performed in April 1980 in the western Baltic. In April 1982 a second series were performed to complete the test data from 1980. Ship's speed (V_s), apparent wind speed (U_a) and direction (ε) were measured simultaneously at different apparent course angles by means of an electro-mechanical propeller log and a cup-anemometer mounted on top of the main mast 22 m above sea level.
From this data the true wind speed (U) and the true course angle (χ) were calculated (Fig. 18):

$$U \sin\chi = U_a \sin\varepsilon \qquad (8)$$

$$U \cos\chi = U_a \cos\varepsilon - V_s \qquad (9)$$

$$\operatorname{tg}\chi = \frac{U_a \sin\varepsilon}{U_a \cos\varepsilon - V_s} \qquad (10)$$

This calculation does not take into account drifting of the vessel. If we do so, the apparent course angle has to be increased by the drifting angle β. At high values of χ the drifting angle is of minor importance, but at a range of $\chi < 60^0$ the influence of drifting cannot be neglected. For future trials with KFK "Freddy" measurements of β are intended to investigate the drifting performance of the vessel.

For 10^0-ranges of χ ($60^0 < \chi < 160^0$), V_s against U is plotted in Fig. 19 a-c. By regression analysis the curves $V_s = f(U)$ were determined for the 1980-data (solid lines) and the (1980+1982)-data (dotted lines). Some differences in the results were found at $\chi > 130^0$. It may be that the number of measurements in this range was not sufficient to obtain reliable results.
From Fig. 19 a-c ship's speed curves $V_s = f(\chi)$ can be derived (Fig. 20). Combining these curves with Fig. 15 we find the corresponding power output of the sailes (Fig. 21). If we assume, that every cours angle $0^0 < \chi < 180^0$ will have the same probalility the mean value:

$$\bar{N} = \frac{1}{180} \int_0^{180} N(\chi) \, d\chi \qquad (11)$$

represents the power which can be obtained at different true wind speeds U (Fig. 22).
$\bar{N}$ multiplied with the probability of the wind speed (see section 2) and integrated gives the long term average

power output of the sails which can be expected for the area considered:

$$\tilde{N} = \int_{U=0}^{\infty} p\ (U)\ \bar{N}\ (U)\ \ d\ U \qquad (12)$$

With the test data of KFK "Freddy" and the wind data from light vessel "TW Ems" we get $\tilde{N}$ = 29.3 SHP. If we assume $\tilde{N}$ propartional to the mean wind speed $\bar{U}$, $\tilde{N}$ can be calculated by means of Fig. 5 for other parts of the North sea.

5.3.2. MOTOR SAILING TESTS

In order to establish the propulsion performance of the test vessel under engine power, test runs without sails were performed in absolutely calm weather as well as under the wind conditions of the pure sailing and motor sailing (Combined propulsion) tests. The engine is a high speed diesel engine

DAIMLER-BENZ TYPE OM 346

with NCR of 150 HP (110 KW) at 1800 rpm driving via reduction gear 1 : 3.5 a three bladed propeller of

D_p = 1.00 m
P/D = 0.86
A_E/A_O = 0.40

For the corresponding Wageningen B-Series propeller the open water characteristics were derived according to /18/, leading to the relationship between advance velocity V_A, number of revolutions n_{Prop} and delivered power P_D as presented in Fig. 23.

From the trials in calm weather, where not only shipspeed V_S and revolutions n_{MOT} were measured, but also the power output was estimated from fuel consumption measurements, the velocity scale between V_A and V_S was determined corresponding to a wake fraction $W \approx 0.24$:

$$\frac{V_A}{V_S} = 1 - W \approx 0.76 \qquad (13)$$

With this velocity scale the measured relationships between shipspeed V_S and revolutions n_{MOT} can be plotted into the diagram both for calm weather and for U_{22} = 20 kts corresponding to Beaufort 5. At a shipspeed of 9 kts, e.g., the required power is 25 % higher than in calm weather.

Under combined motor and sail propulsion (in the "motorsailing" mode) 29 measurements of ship speed, wind speed and relative courses were taken at three engine speeds of 1200, 1400 and 1600 rpm with full sails of 180 m^2 "properly" trimed on each course respectively.

The average ship speed values for U_{22} 20 kts, for four course angles χ = 60, 90, 120 and 150^0 and for the three engine speeds can be plotted into Fig. 23 in the same way as for pure motor propulsion.

For pure sailing a certain small shaft friction torque on the free milling propeller was assumed and the sailing speeds for the same wind speed and course angles were plotted in the same diagram in the vicinity of the zero torque line $Q = 0$, thus completing the motorsailing lines for the four selected course angles .

The ship speed - power relation can now be read from the diagram Fig. 23 for all three operation modes - "motoring", "motorsailing" and "sailing" and plotted e.g. as ship speed against power with parameters relative course and revolutions for the selected wind speed $U_{22} \approx 20$ kts (corresponding to Beaufort 5) as in Fig. 24.

At a ship speed of 9 kts, e.g., the power requirement under motor is 100 KW (136 HP) at Beaufort 5 and 80 KW (109 HP) in calm weather. When motorsailing with full sails at Beaufort 5, the required power is 40 KW (54 HP) at 150^0 course and 8 KW (11HP) at 90^0 course relative to the true wind.

If the engine is stopped and the propeller free milling the sailing speed would be 6.8 kts at 150^0 and 8.6 kts at 90^0 course.

If the full engine power of 100 KW (136 HP) would be maintained when setting sails the ship speed would be increased from 9 to 10 kts only at 150^0 and to 10.8 kts at 90^0 course.

It is obvious that considerable power reductions are possible when maintaining ship speed in the motorsailing mode but only small speed increase when maintaining full engine power.

If the driving forces generated by a given rig and depending on the apparent wind are known from model tests or from evaluations of full scale measurements, as in the present case, the power savings by wind assistance may be estimated for a given shipspeed at all significant windspeeds and on all relative courses in a similar manner as indicated above. Fig. 25 shows, as an example, the required power at a constant shipspeed of 9 kts with and without wind assistance for the tested KFK "Freddy" versus course angel relative to the true wind with parameter true windspeed U_{10}. For each windspeed U_{10} the average power reduction $\overline{\Delta P}$ is indicated under the assumption of equal frequency of all relative course angles.

If the probability distribution of windspeeds in the operation area in known, the power reductions $\overline{\Delta P}$ can be averaged over all windspeeds weighted with the expected frequency p of each windspeed respectively. This has been done in table 4 for two examples of windspeed distributions with average windspeeds $\overline{U}_{10}$ of 12 kts (e.g. Caribean Sea) and of 15 kts (e.g. North Sea) and again for a constant shipspeed of 9 kts.

The resulting average power reduction at the Propeller $\widetilde{\Delta P}$ of 20 KW (27 HP) and 29 KW (39 HP) may be regarded as a potential power from the sails, and refering to the sail area of KFK "Freddy", this yields about 0.11 or 0.16 KW per square meter of sail area depending on the windiness of the sea area. The corresponding fuel savings at 9 kts shipspeed would be about 105 or 150 kg per day corresponding to about 23 % or 34 % of the respective fuel consumption without sail assistance.

The potential power from the sails is, of course, not only depending on the wind conditions but also on the shipspeed and on the efficiency of the rig. For modern rigs power savings up to 0.25 or 0.30 KW/m^2 can be expected. At lower shipspeeds the absolute power savings are decreasing but the percentage of saving of the full power requirement is increasing until reaching 100 % saving at a shipspeed low enough that it can be achieved on average by sails alone.

6. CONCLUSIONS

The economy of sail assisted fishing vessels depends on two main factors

1. Wind conditions of the area considered. As a first approximation the wind conditions can be described by the long term mean wind speed $\overline{U}_{10}$
2. Operating conditions of the fishing vessel considered. The use of additional sails will not always be possible, depending on the fishing technique performed by the vessel

Both factors have to be carefully investigated before dealing with technical problems of a specific rig. To get sufficient propulsion power from the sails the sail area should be as large as possible. With respect to the transverse stability of the vessel there will be an upper limit for the sail area. A certain amount of ballast, which reduces the loading capacity, will be necessary in almost any case.

The influence of man power on the economy of the vessel has to be considered. When planing additional sails for a fishing vessel the handling of the sails should be possible without additional crew.

PERSONAL BIOGRAPHY

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1938	Born at Köslin (Pommern)
1945 - 49	Primary School at Kopenhagen, Aalborg
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1958 - 66	Studies in mechanical engineering and naval architecture at the Universities of Aachen, Hannover, Hamburg
1966	Diploma in naval architecture of the university of Hannover
1966 - 70	Research assistant of Prof. J. Hansen at the Institut für Schiffbau, Hamburg (statistics and ships construction)
1970 - 72	Head of the documentation center for naval architecture and marine engineering of the Schiffbautechnische Gesellschaft at Hamburg
1972	Research staff member of the Institut für Fangtechnik der Bundesforschungsanstalt für Fischerei, Hamburg

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1940	Born at Stuttgart
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1959 - 66	Studies in mechanical engineering and naval architecture at the universities of Stuttgart, Hannover, Hamburg
1966	Diploma in naval architecture of the university of Hannover
1966 - 77	Research assistant of Prof. O. Grim at the Institut für Schiffbau, Hamburg (hydrodynamics of ships)
1978	Research staff member of the Hamburg Ship Model Basin (HSVA)

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year	crew %	fuel %	repair + maintenance %	depreciation %	other costs %	vessels investigated no.	 specifications
1967	35.2	11.7	10.3	11.6	31.2	89	20 m l o.a. 24 m
68	35.1	9.8	7.8	10.6	36.7	89	(north sea vessels)
69	-	-	-	-	-	-	
1970	39.5	10.8	8.7	12.1	28.9	45	20 m l o.a. 24 m
71	41.0	9.6	10.2	9.1	30.1	"	"
72	-	-	-	-	-	-	
73	39.8	10.6	22.5	11.1	16	28	L 17 m,N 150 HP
74	37.8	14.7	20.0	9.5	18	"	"
75	37.2	17.4	16.4	9.5	19.5	"	"
76	41.4	16.5	15.6	8.5	18	50	L 17 m,N 150 HP
77	44.0	15.7	15.7	6.9	17.8	"	"
78	43.8	13.1	16.5	8.2	18.4	"	"
79	42.2	16.6	15.3	8.6	17.3	"	"
1980	38.4	21.4	15.6	6.5	18.1	49	"
81	38.4	21.4	15.6	6.5	18.1	49	"
82	39.1	22.9	13.0	5.6	19.4	45	" (Jan. - Sept.)

Tab.1 Operating costs of selected vessels of the near water fishers /1/

Year	Landings [10^6kg]	Earnings [10^6DM]	Kilo-Price [DM/kg]
1970	177.4	74.7	0.42
1971	139.5	82.6	0.59
1972	130.4	92.3	0.71
1973	133.1	102.2	0.77
1974	138.5	103.5	0.75
1975	116.3	96.3	0.83
1976	128.8	106.6	0.83
1977	110.9	118.0	1.06
1978	105.0	111.9	1.07
1979	77.6	87.1	1.12
1980	91.9	94.5	1.04
1981	103.4	121.1	1.17

Tab. 2 Landings and proceeds of the near water and inshore fishery /2/

	number of trips	days at sea	days fishing	df/ds	ds/t	total catch
	t	ds	df			[ts]
a. 1980						
Shetlands	2	34	24	0,71	17	76
Fladengrund	38	423	278	0,66	11,1	602
Ostkante	47	602	412	0,68	12,8	1428
Gat	370	4053	2672	0,66	11	8081
Gr. Fischerbank	155	1510	1020	0,68	9,7	2258
Doggerbank	44	449	309	0,69	10,2	645
Sudl. Schlickb.	118	918	658	0,72	7,8	1514
Deutsche Bucht	843	4878	3150	0,65	5,8	12336
Σ =	1617	12867	8523			24940
b. 1981						
Shetlands	6	77	50	0,65	12,8	235
Fladengrund	37	408	257	0,63	11,0	865
Ostkante	61	745	522	0,70	12,2	2674
Gat	184	1844	1227	0,67	10	3032
Gr. Fischerbank	113	1012	680	0,67	9	2286
Doggerbank	29	244	159	0,65	8,4	505
Sudl. Schlickb.	134	960	662	0,69	7,2	1790
Deutsche Bucht	1107	6379	4269	0,67	5,8	18151
Σ =	1671	11669	7826			30138
c. 1982 Jan. - Okt.						
Shetlands	-	-	-	-	-	-
Fladengrund	11	143	98	0,68	13,2	147
Ostkante	76	907	643	0,71	11,9	4477
Gat	30	289	198	0,69	9,6	374
Gr. Fischerbank	76	754	518	0,69	9,9	1853
Doggerbank	6	57	43	0,75	9,5	129
Sudl. Schlickb.	88	776	544	0,70	8,8	1256
Deutsche Bucht	574	3186	2172	0,68	5,5	7326
Σ =	861	6114	4216			15563

Tab. 3 a - c Near water fishing vessels > 35 GRT. Operating data and catches at the North Sea fishing grounds 1980-82

			$\overline{U}_{10}$=12 kts (6.2 m/s)		$\overline{U}_{10}$=15 kts (7.7 m/s)	
U_{22} kts	U_{10} kts	$\overline{\Delta P}$ KW	n –	n $\cdot$ $\overline{\Delta P}$ KW	n –	n $\cdot$ $\overline{\Delta P}$ KW
(5)	4.5	(0)	0.21	0	0.12	0
10	9	8.5	0.27	2.29	0.21	1.78
15	13.5	22	0.27	5.94	0.24	5.28
20	18	41	0.17	6.97	0.22	9.02
25	22.5	58	0.06	3.48	0.12	6.96
30	27	67	0.02	1.34	0.06	4.02
(35)	31.5	(67)	0	0	0.03	2.01
Refering to A_S = 180 m^2			$\widetilde{\Delta P}$=20.02KW (27.23 HP) P/A_S= $\widetilde{\Delta p}$=0.11 KW/m^2 (0.15 HP/m^2)		$\widetilde{\Delta P}$=29.07 KW (39.54 HP) $\widetilde{\Delta p}$= 0.16 KW/m^2 (0.22 HP/m^2)	

Table 4: Average power reduction by sail assistance, KFK "Freddy", 180 m^2 ketch rig. shipspeed 9 kts

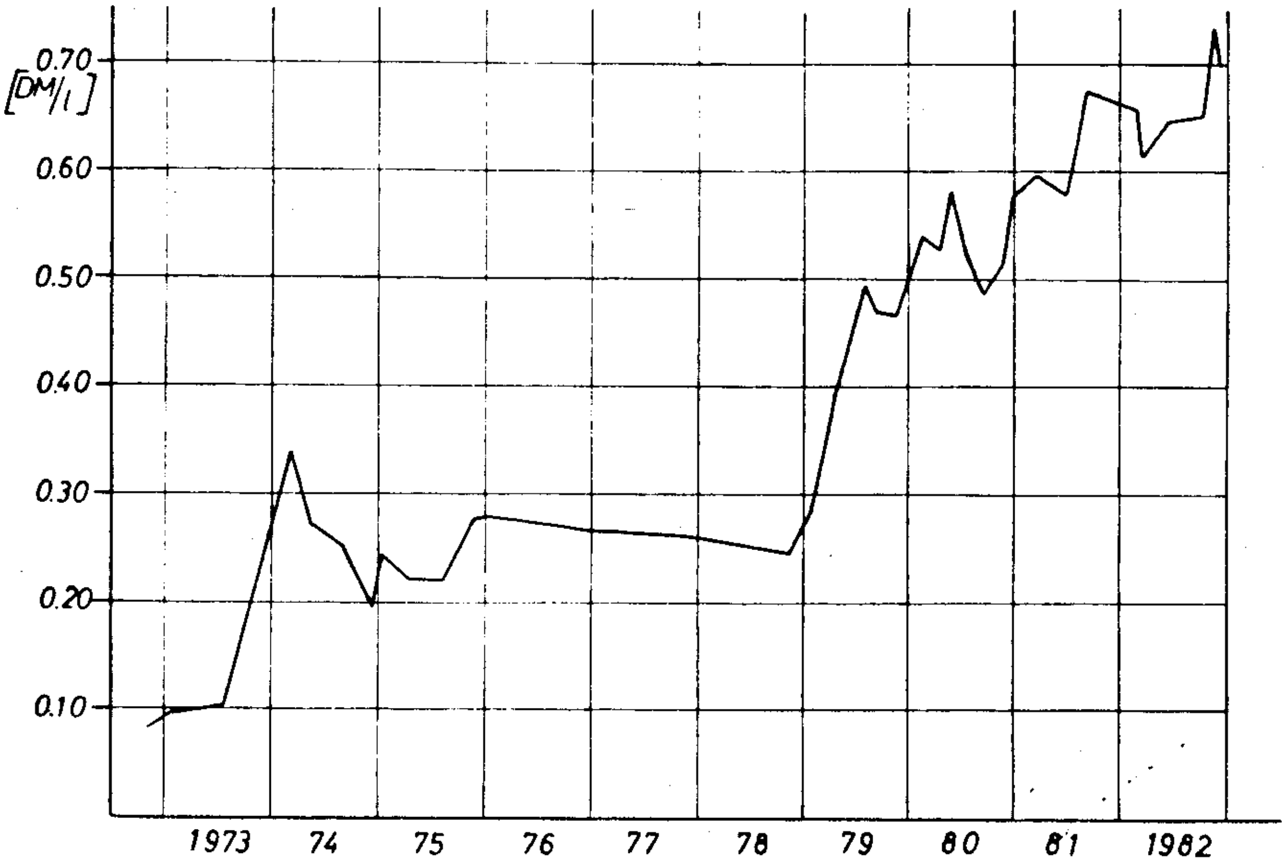


Fig. 1 Diesel oil price at German fishing harbour of Cuxhaven

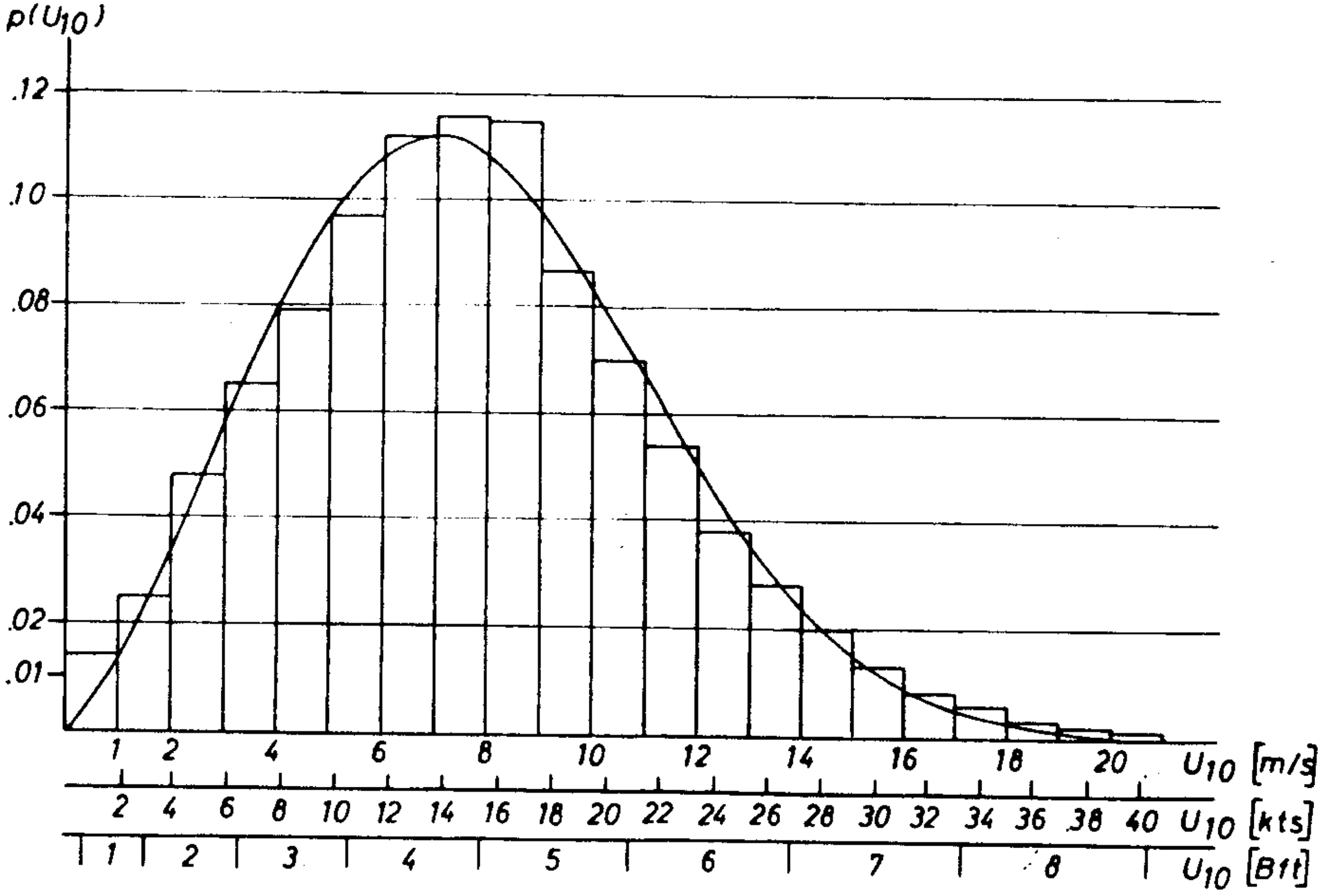
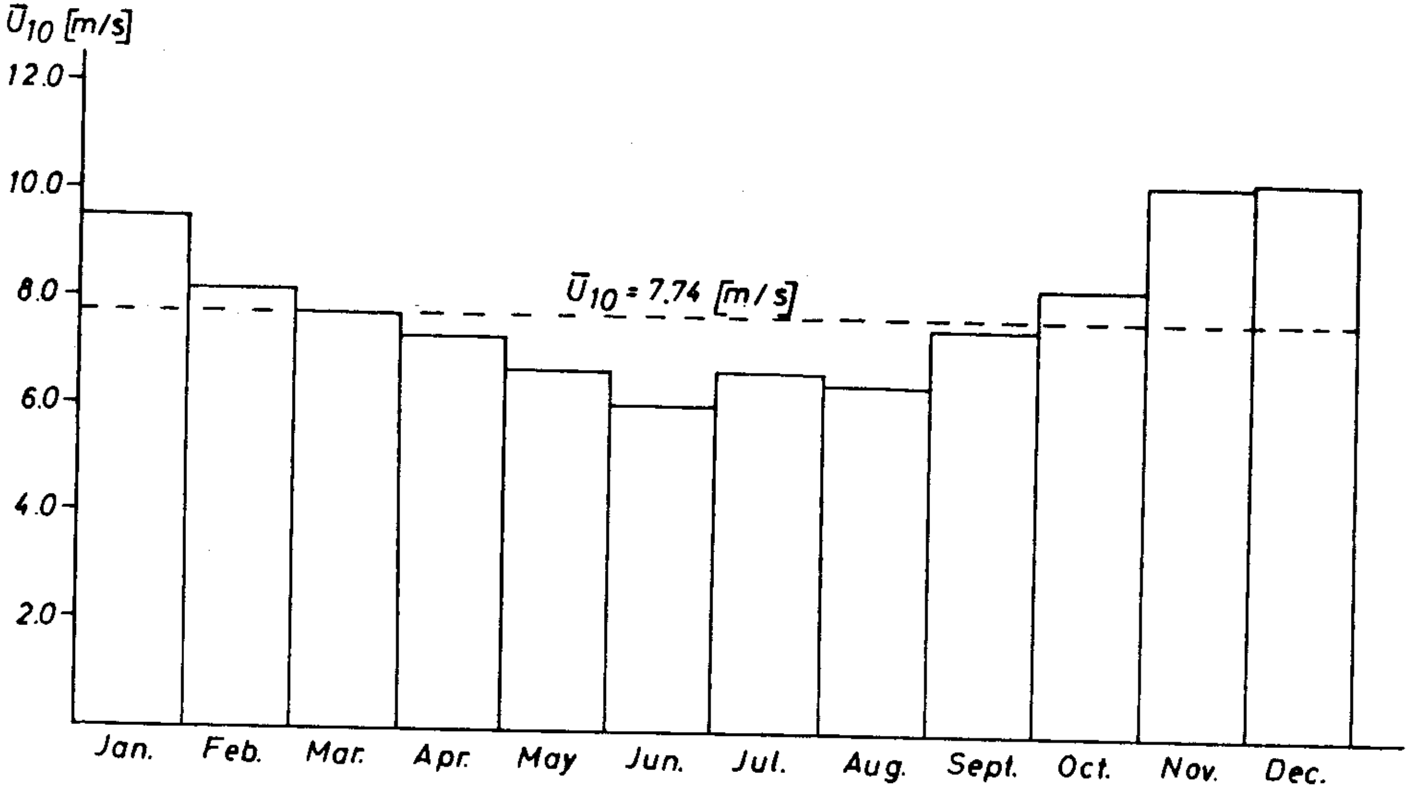


Fig. 2 Frequency of wind speed U_{10} at light vessel "TW Ems" 1971-76



<u>Fig. 3</u> Variation of mean wind speed $\bar{U}_{10}$ jan.-dec. at "TW Ems"

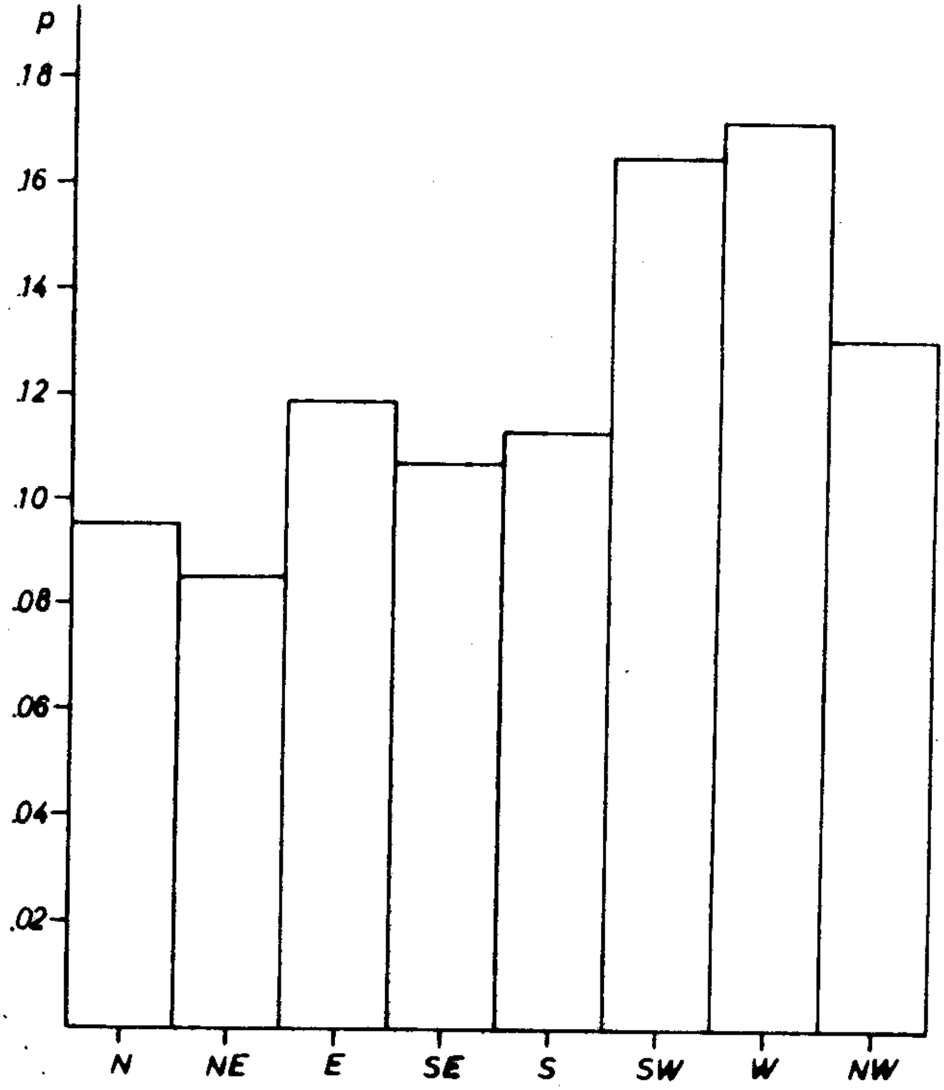
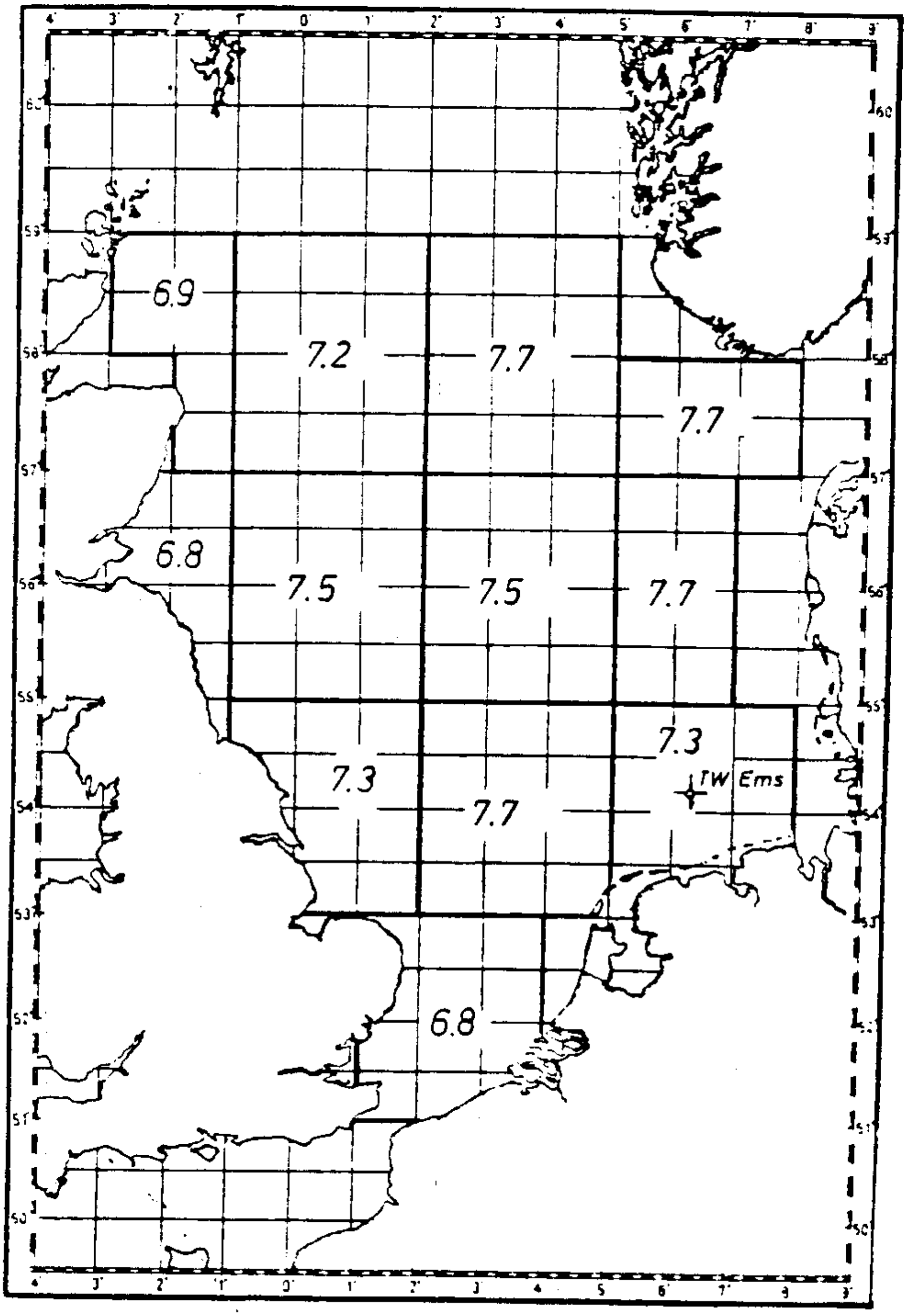


Fig. 4 Frequency of wind direction at "TW Ems"



<u>Fig. 5</u> Mean wind speed $\bar{U}_{10}$ for the North sea /8/

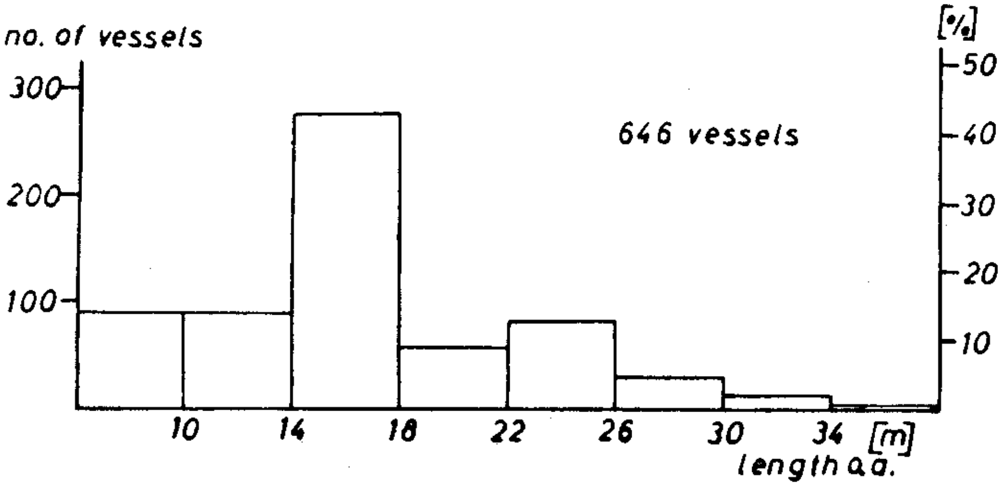


Fig. 6 German near water and inshore fishing vessels, lenght over all

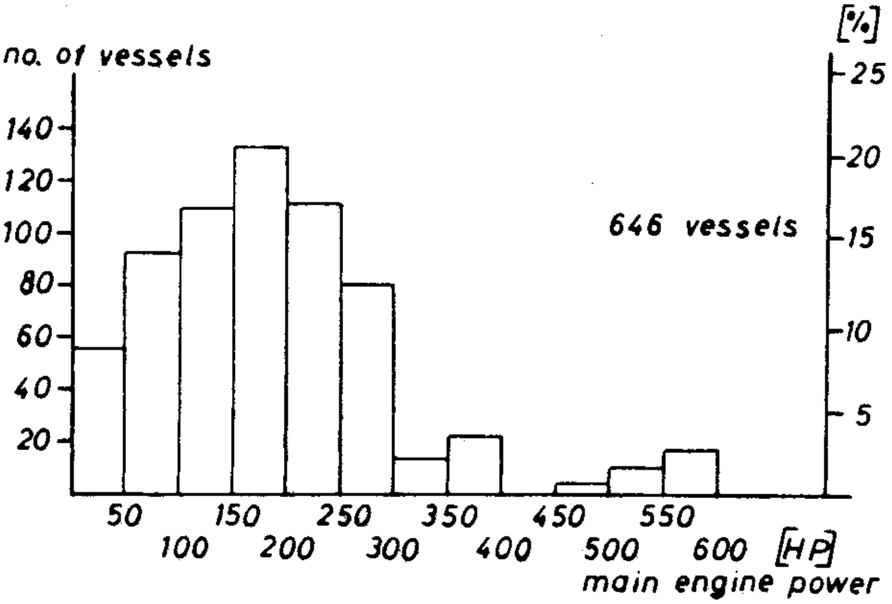


Fig. 7 German near water and inshore fishing vessels, main engine power

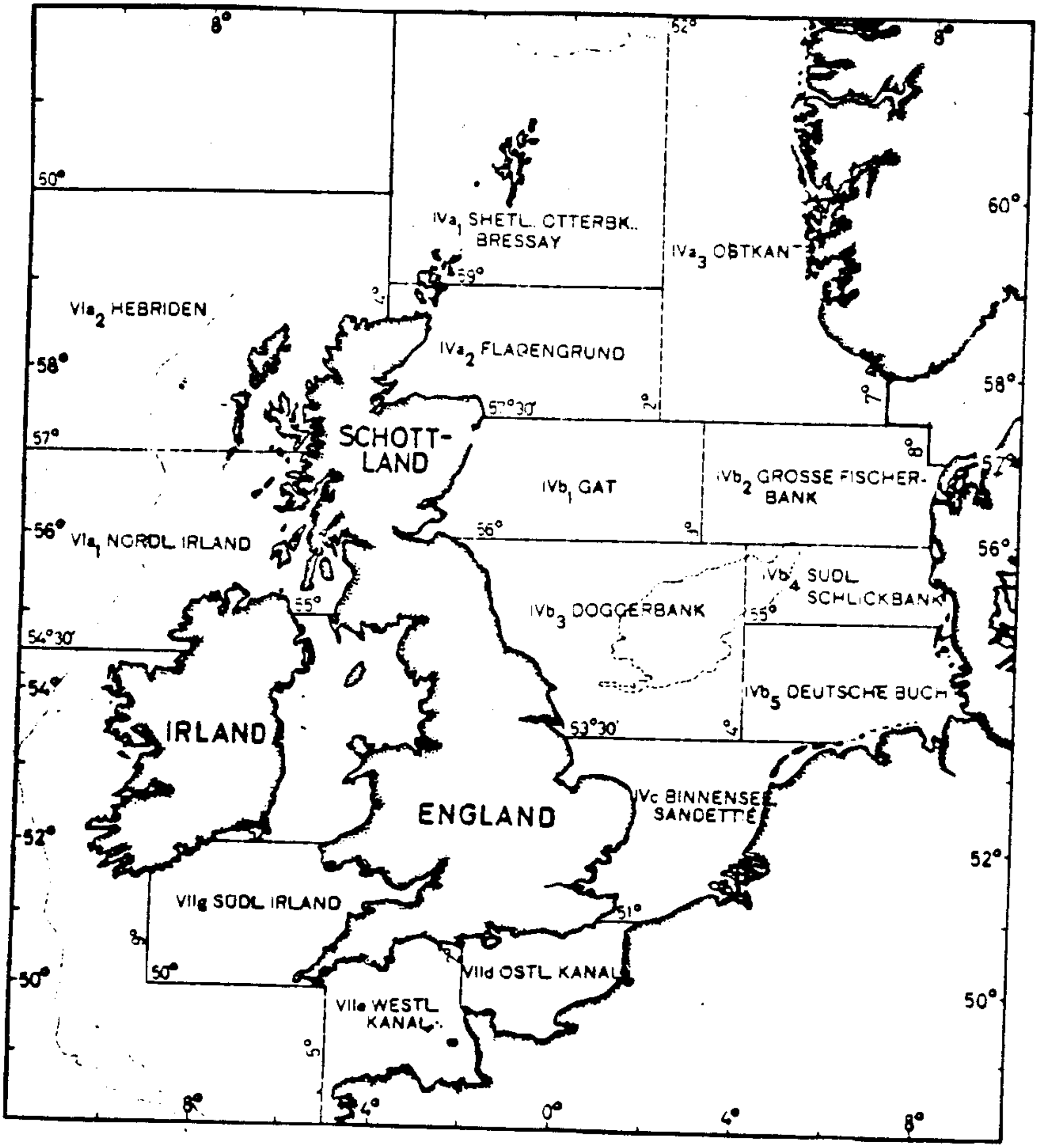


Fig. 8 North Sea fishing grounds

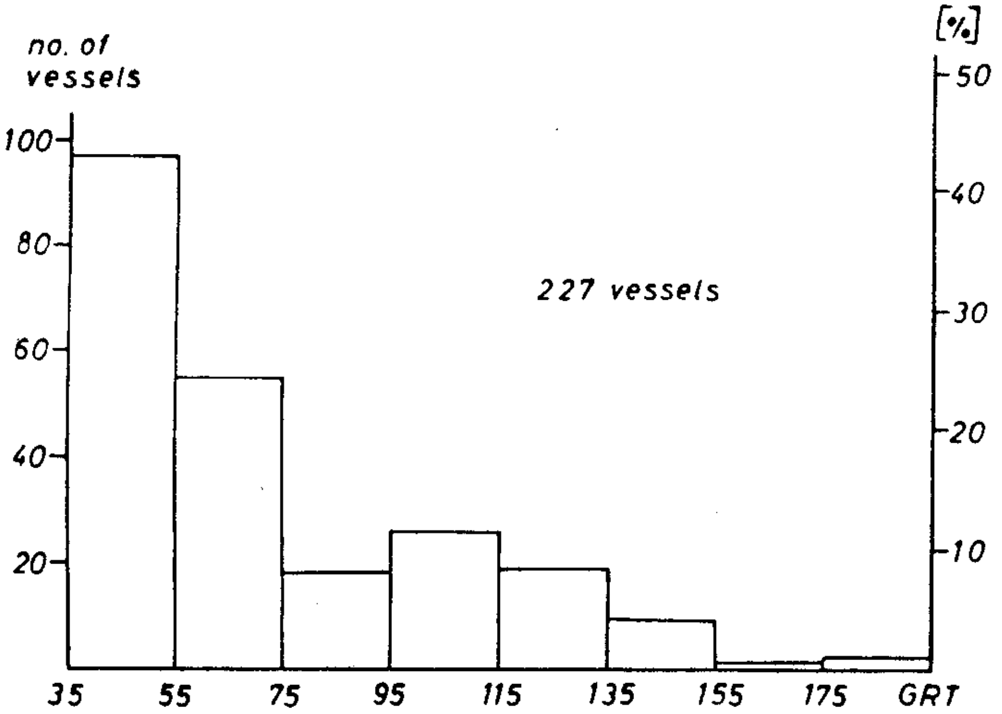


Fig. 9 Near water fishing vessels > 35 BRT

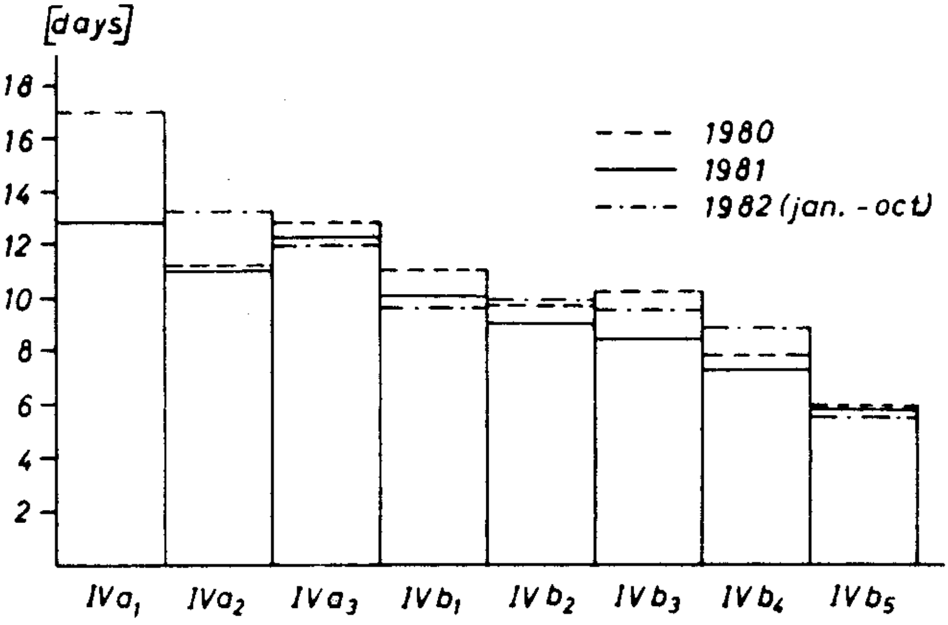
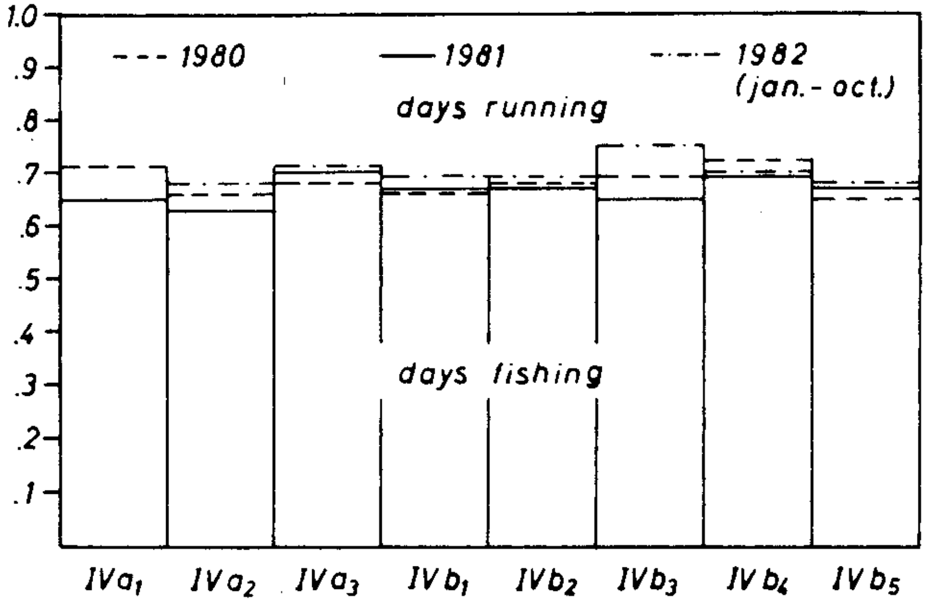


Fig. 10 Days at sea per trip. North Sea 1980-82



IVa_1	Shetlands, Otterbank
IVa_2	Fladengrund
IVa_3	Ostkante
IVb_1	Gat
IVb_2	Große Fischerbank
IVb_3	Doggerbank
IVb_4	Südl. Schlickbank
IVb_5	Deutsche Bucht

Fig. 11 Days fishing in per cent of days at sea. North Sea 1980-82

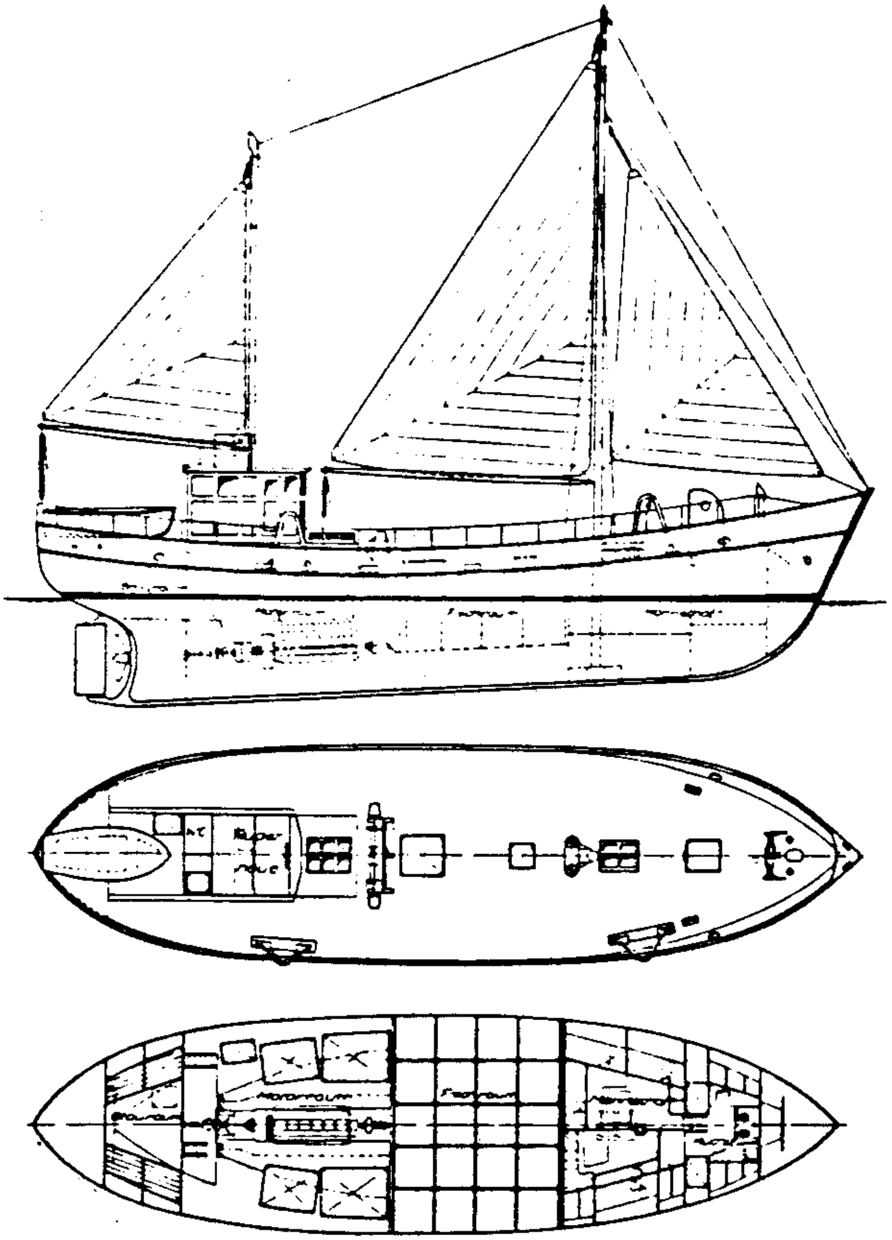


Fig. 12 Reichsfischkutter Type G (KFK)
General arrangement /15/

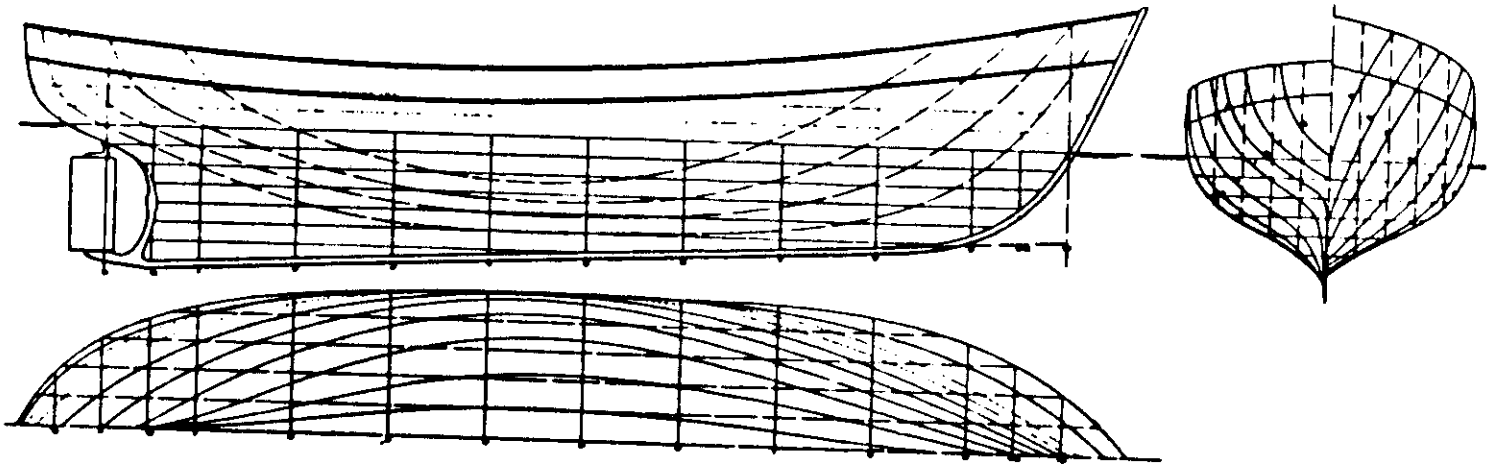


Fig. 13 Reichsfischkutter Type G (KFK). Lines /15/

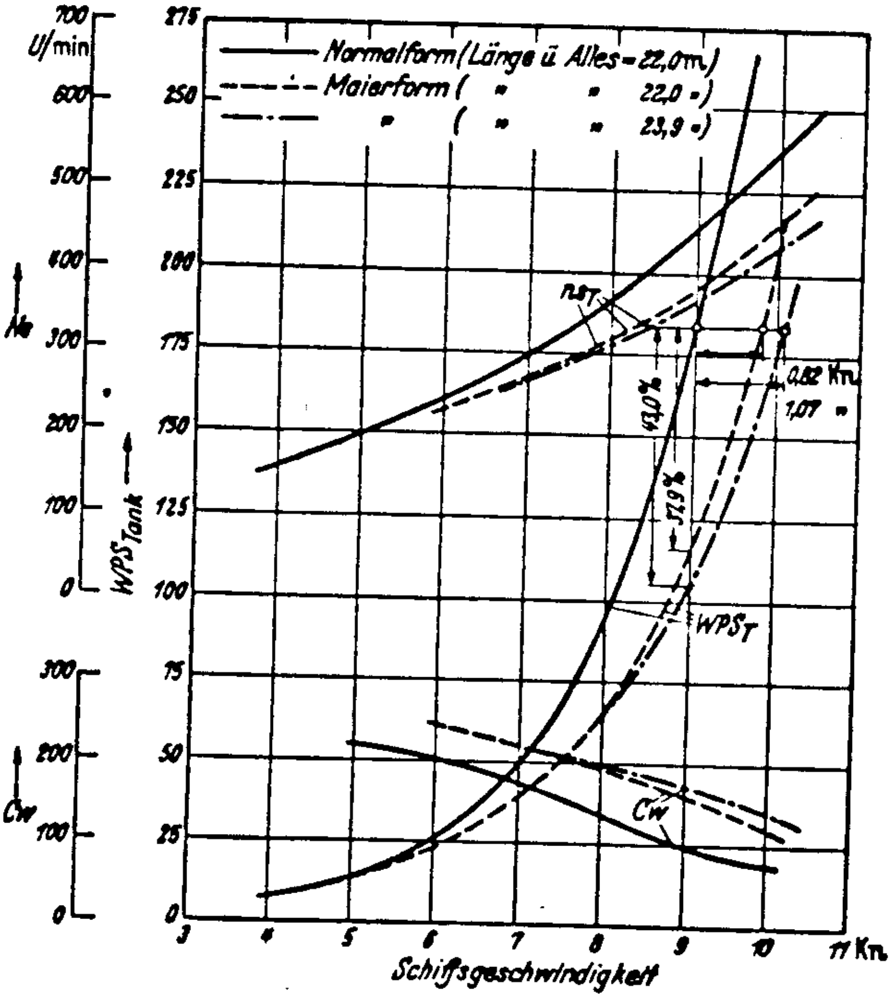


Fig. 14 KFK Results of model tests at the Vienna Ship Model Basin /16/

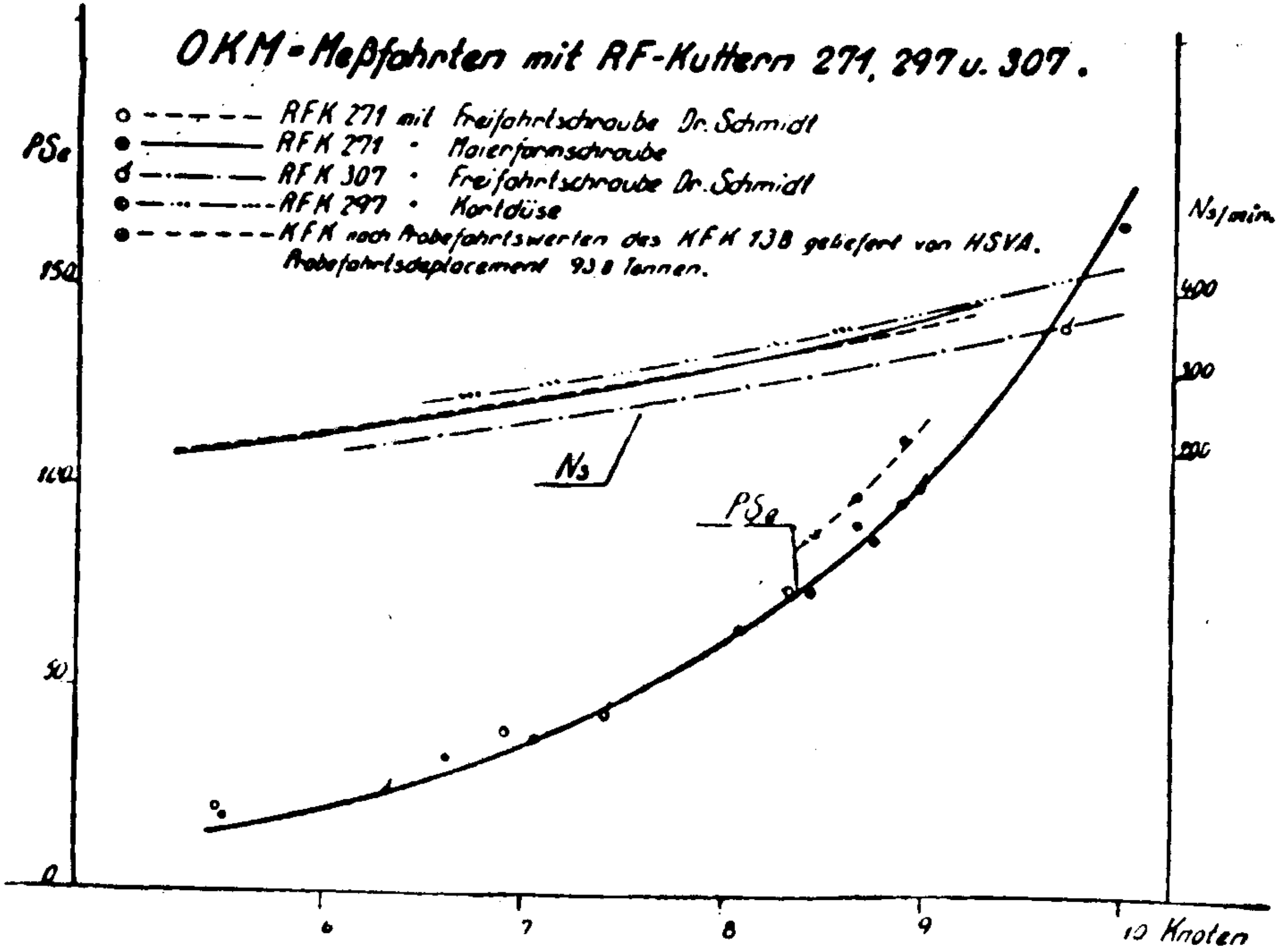


Fig. 15 KFK Results of full scale trials /17/

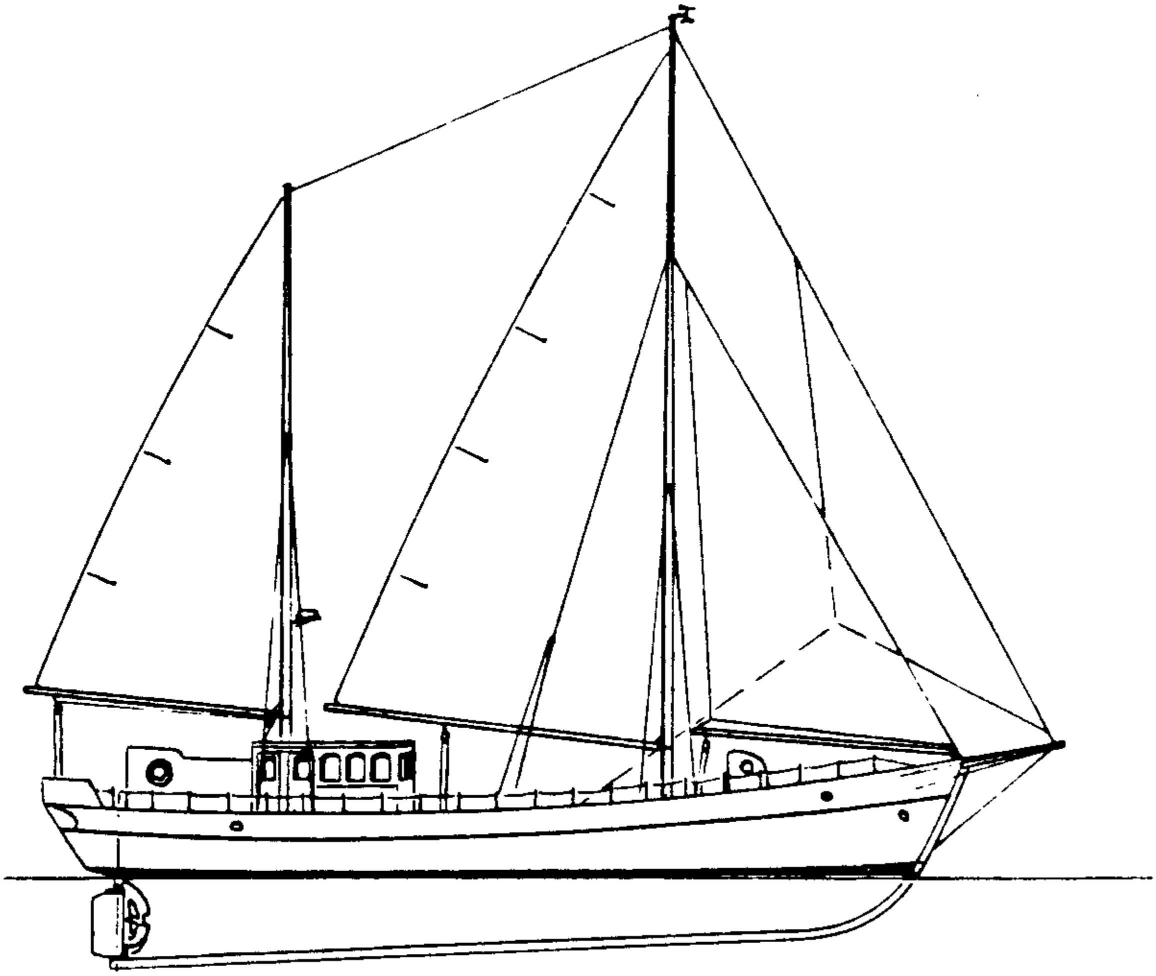


Fig. 16 KFK "Freddy". Side view and sail arrangement

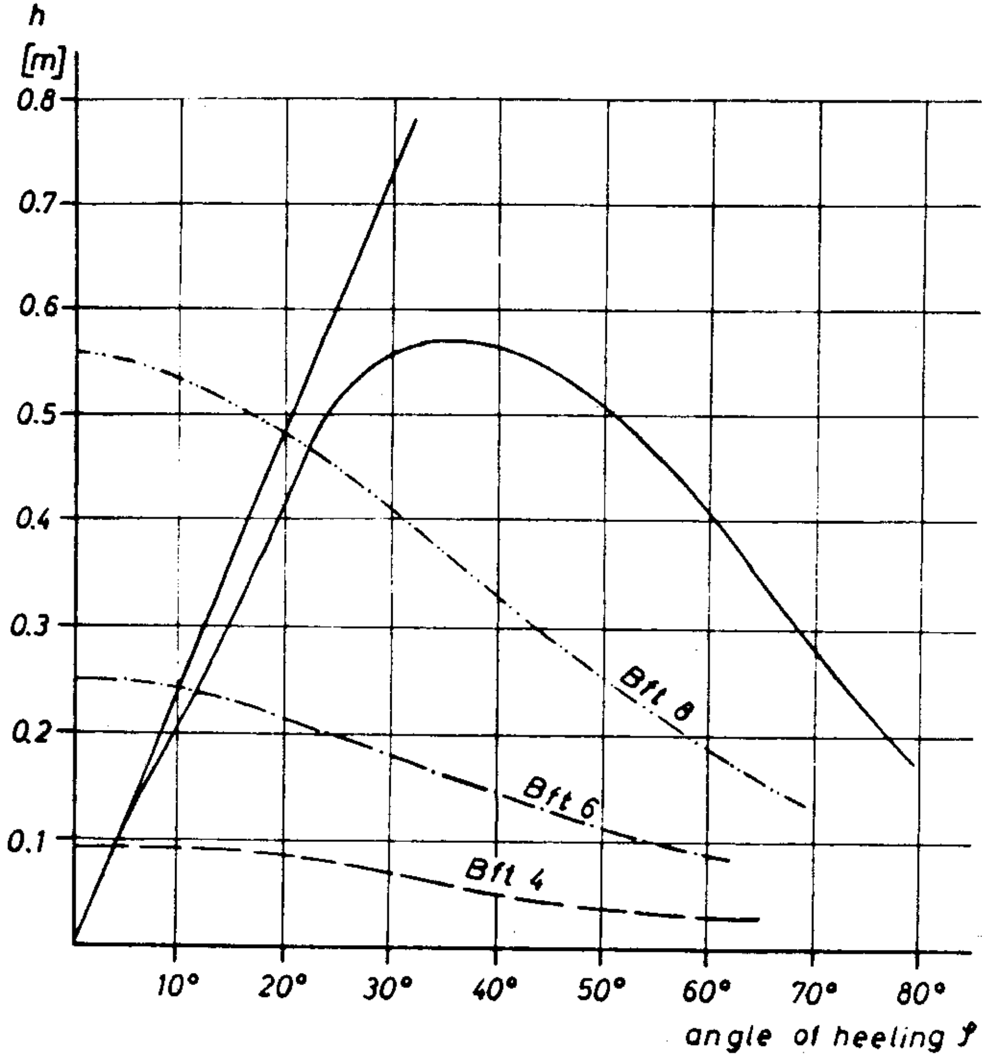


Fig. 17 KFK "Freddy", Righting lever and heeling lever of wind pressure

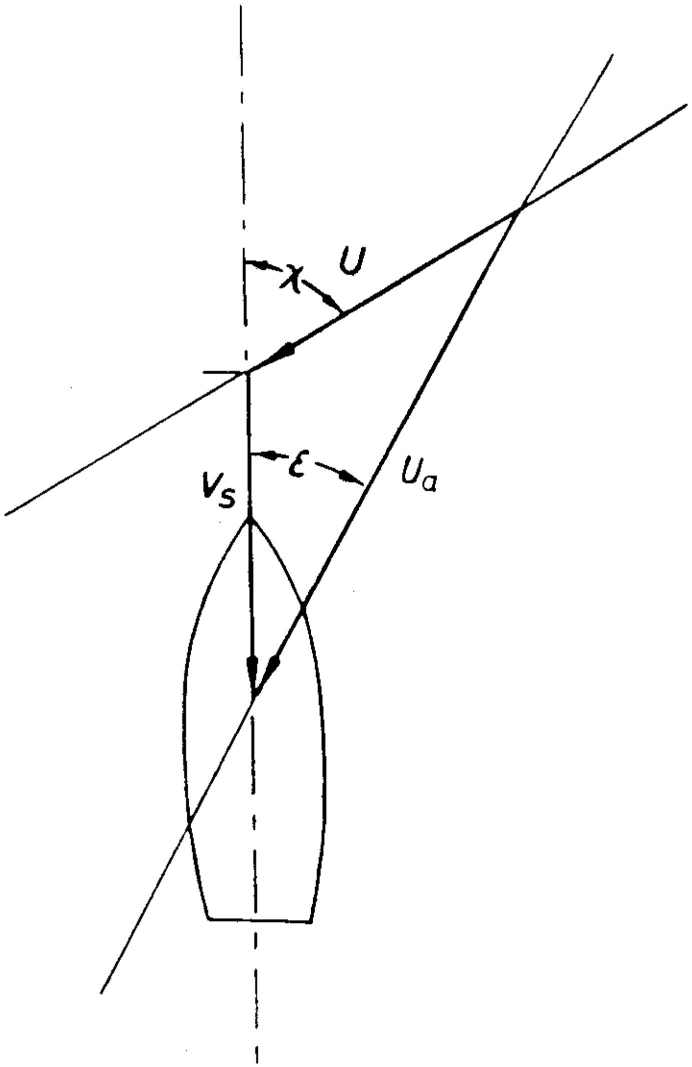
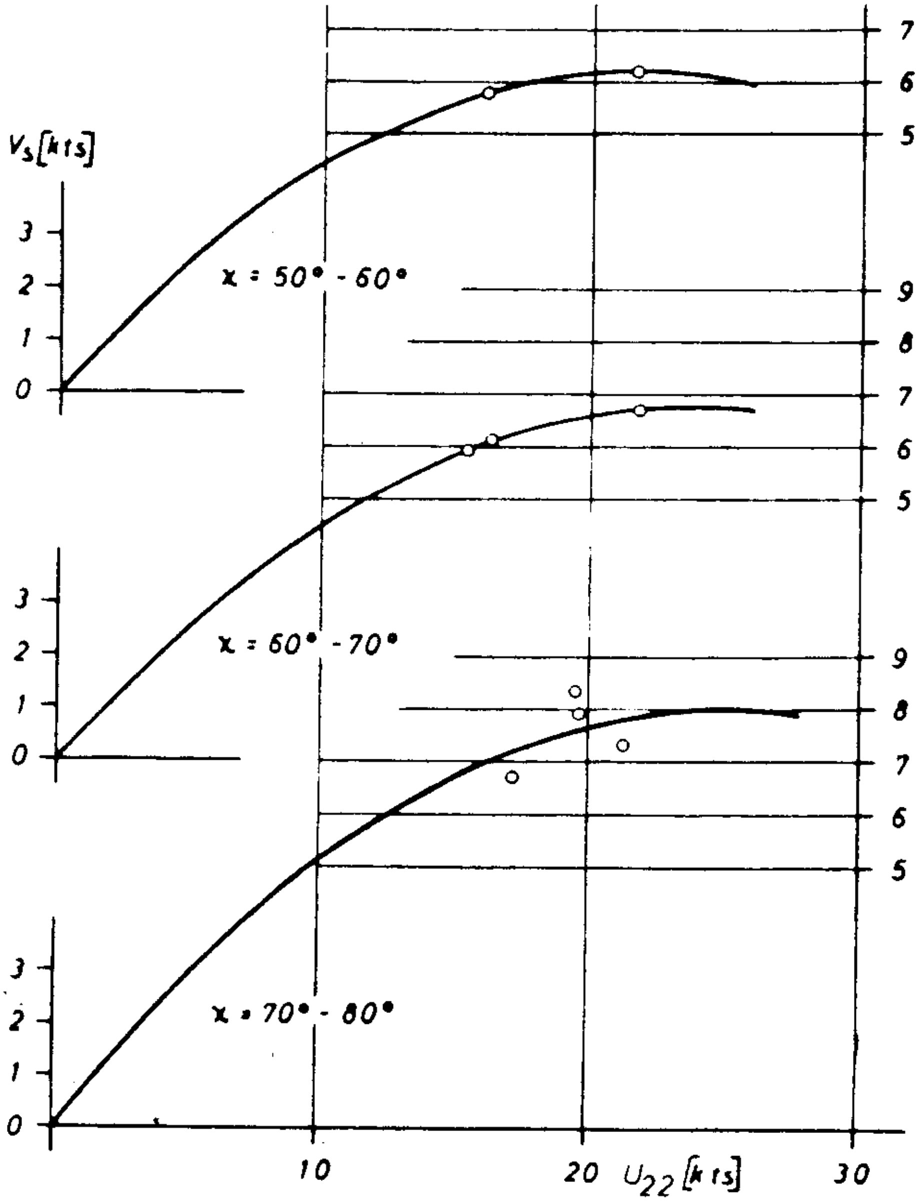


Fig. 18 Speed diagram



<u>Fig. 19 a</u> KFK "Freddy", ship's speed Vs versus true wind speed V_a, $\chi = 50^{\circ} - 80^{\circ}$

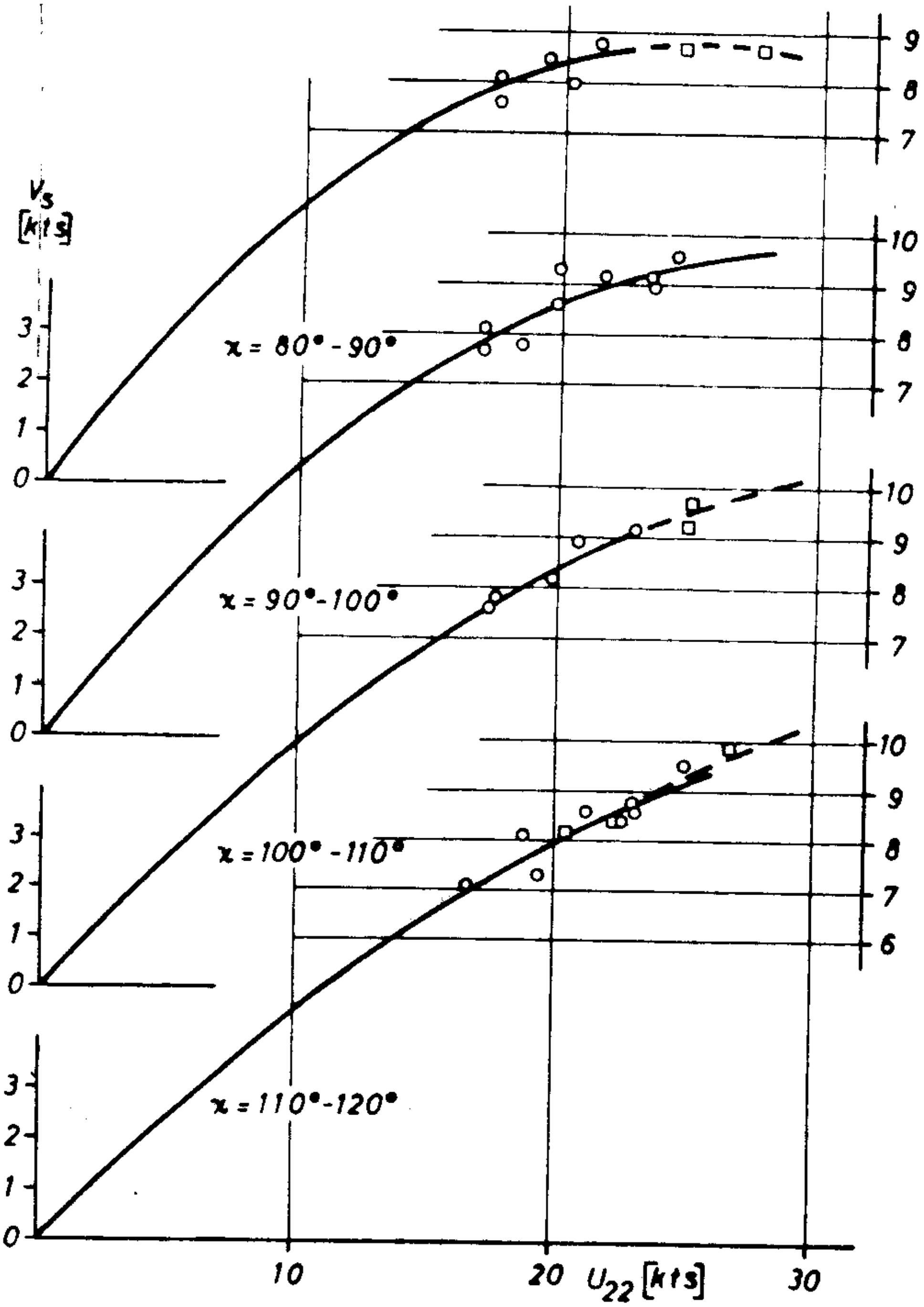


Fig. 19 b KFK "Freddy", ship's speed Vs versus true wind speed V_a, χ = 80° - 120°

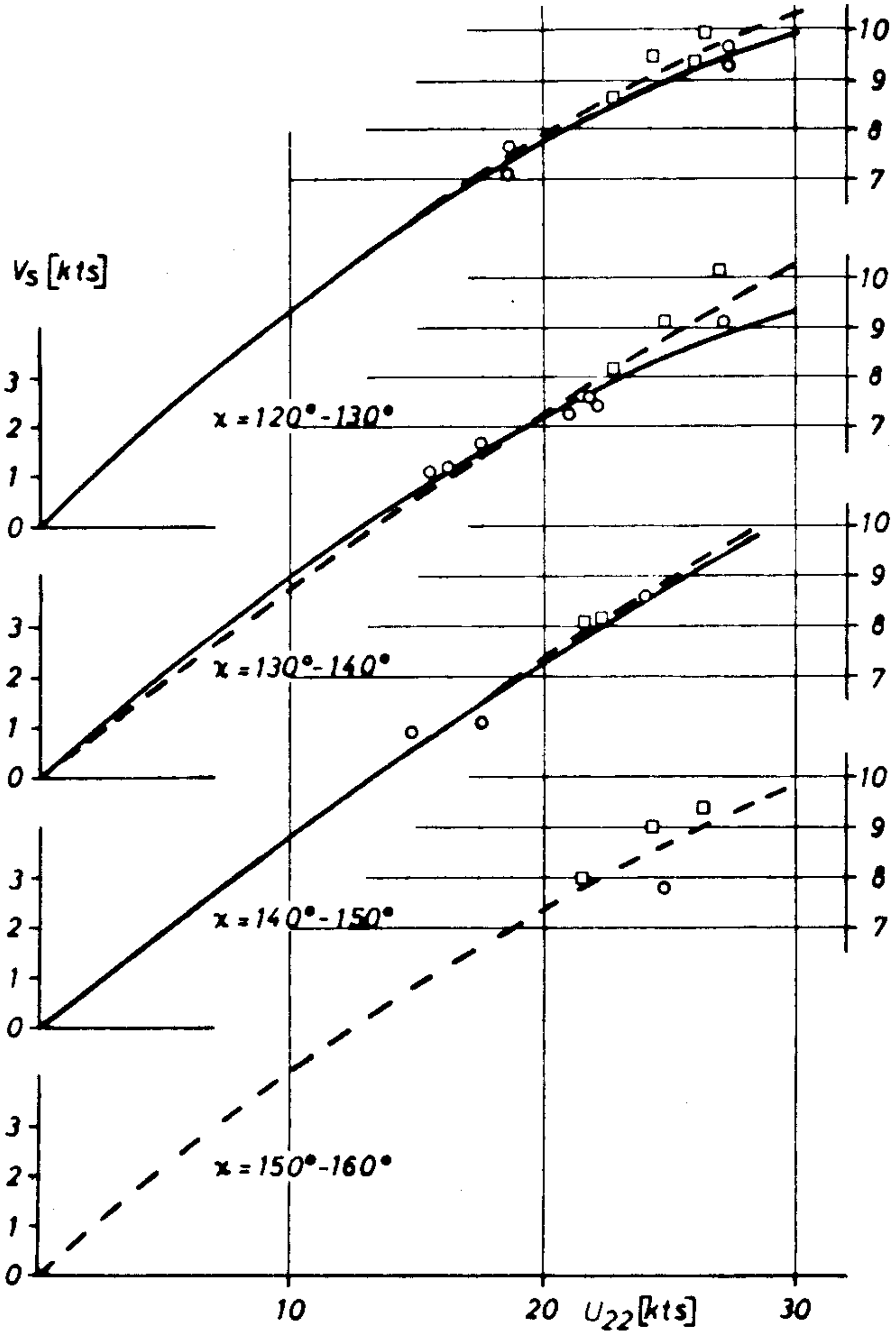


Fig. 19 c KFK "Freddy", ship's speed Vs versus true wind speed V_a, $\chi = 120^0 - 160^0$

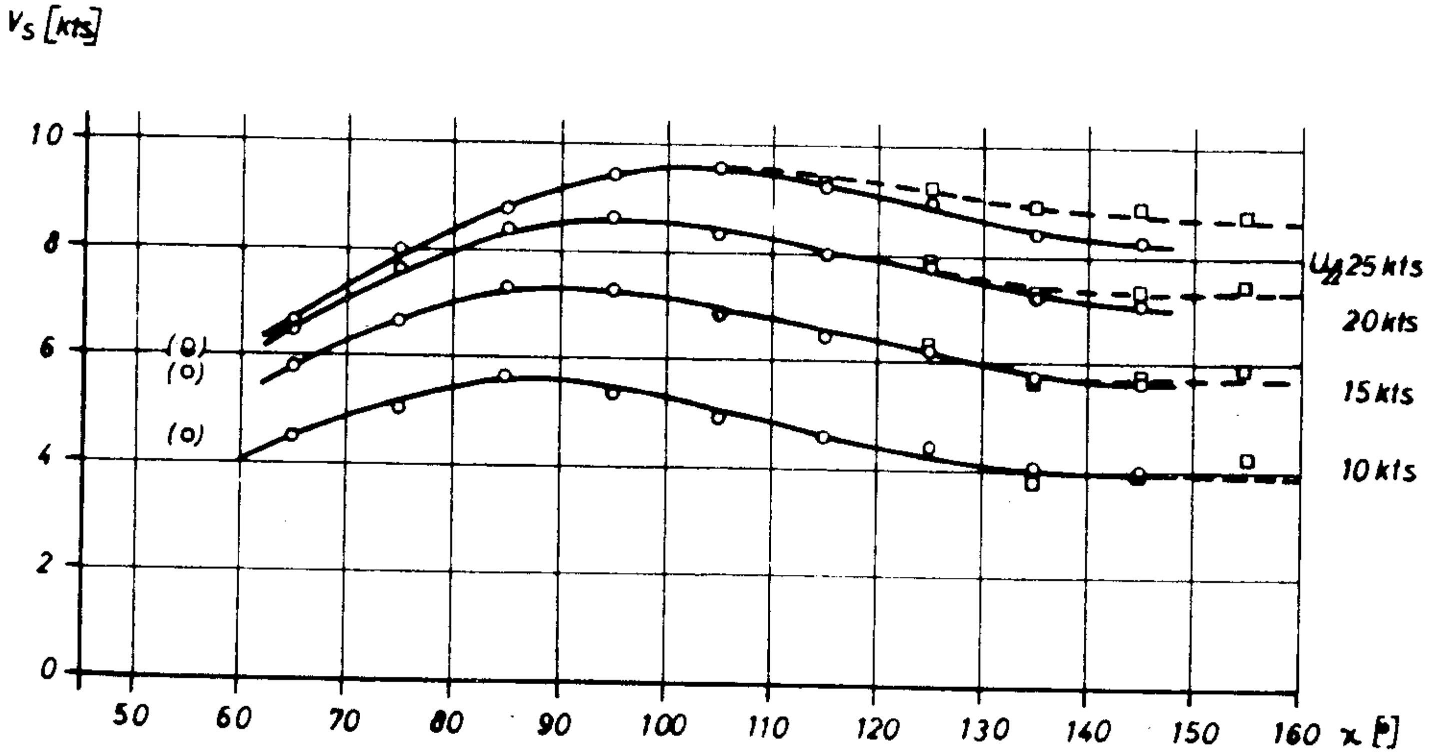


Fig. 20 KFK "Freddy", ship's speed Vs versus course angle to true wind χ

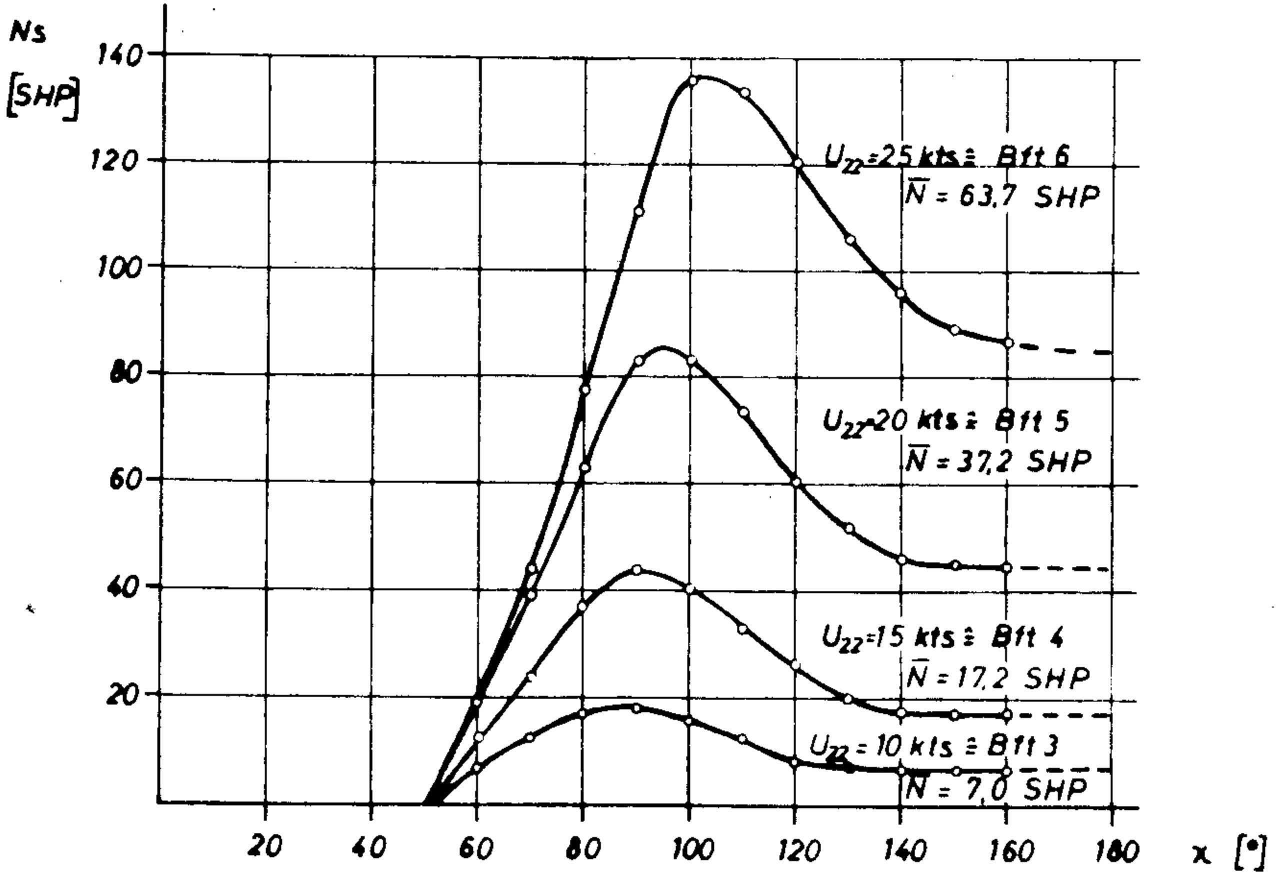


Fig. 21 KFK "Freddy", wind propulsion power

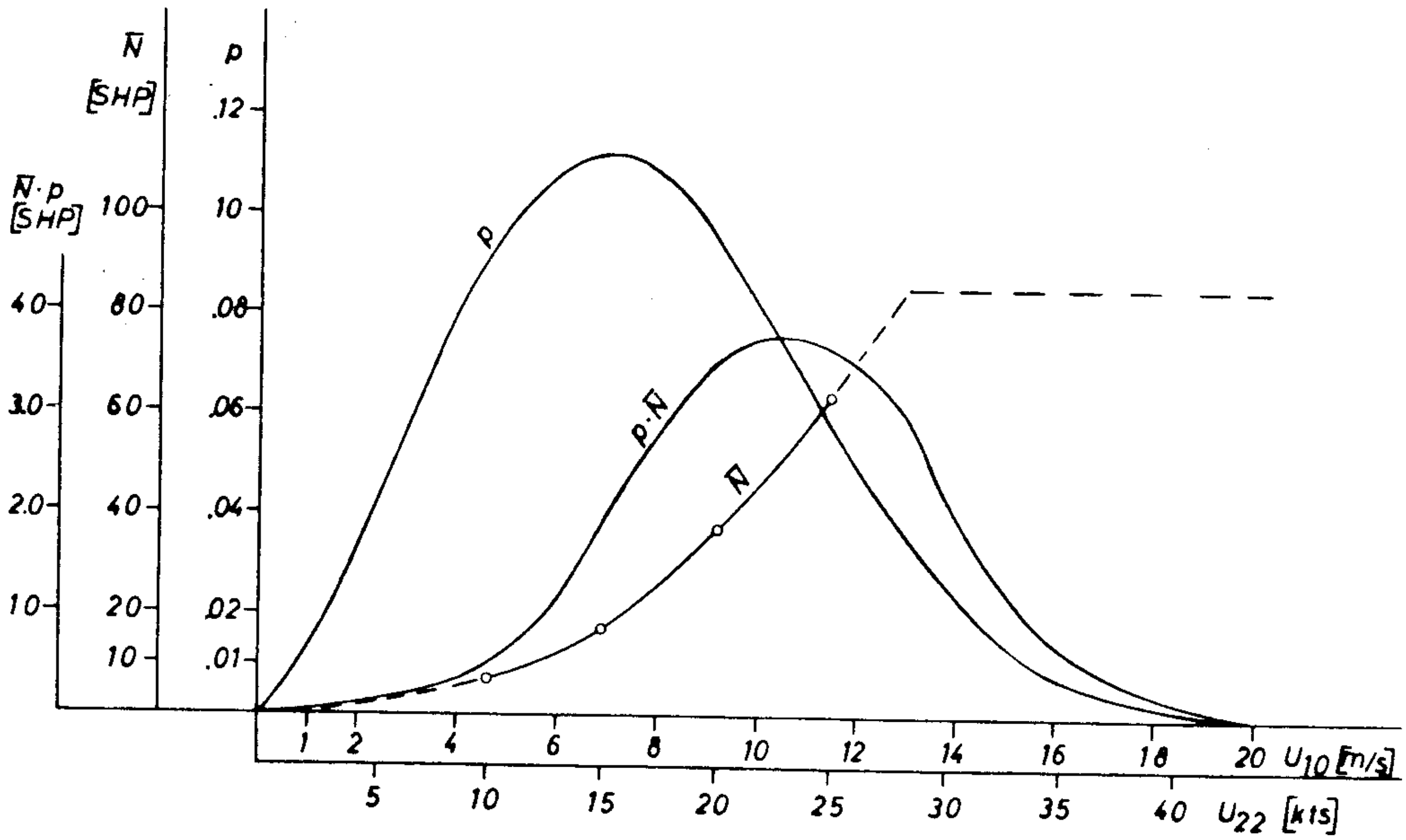


Fig. 22 KFK "Freddy", long term power output

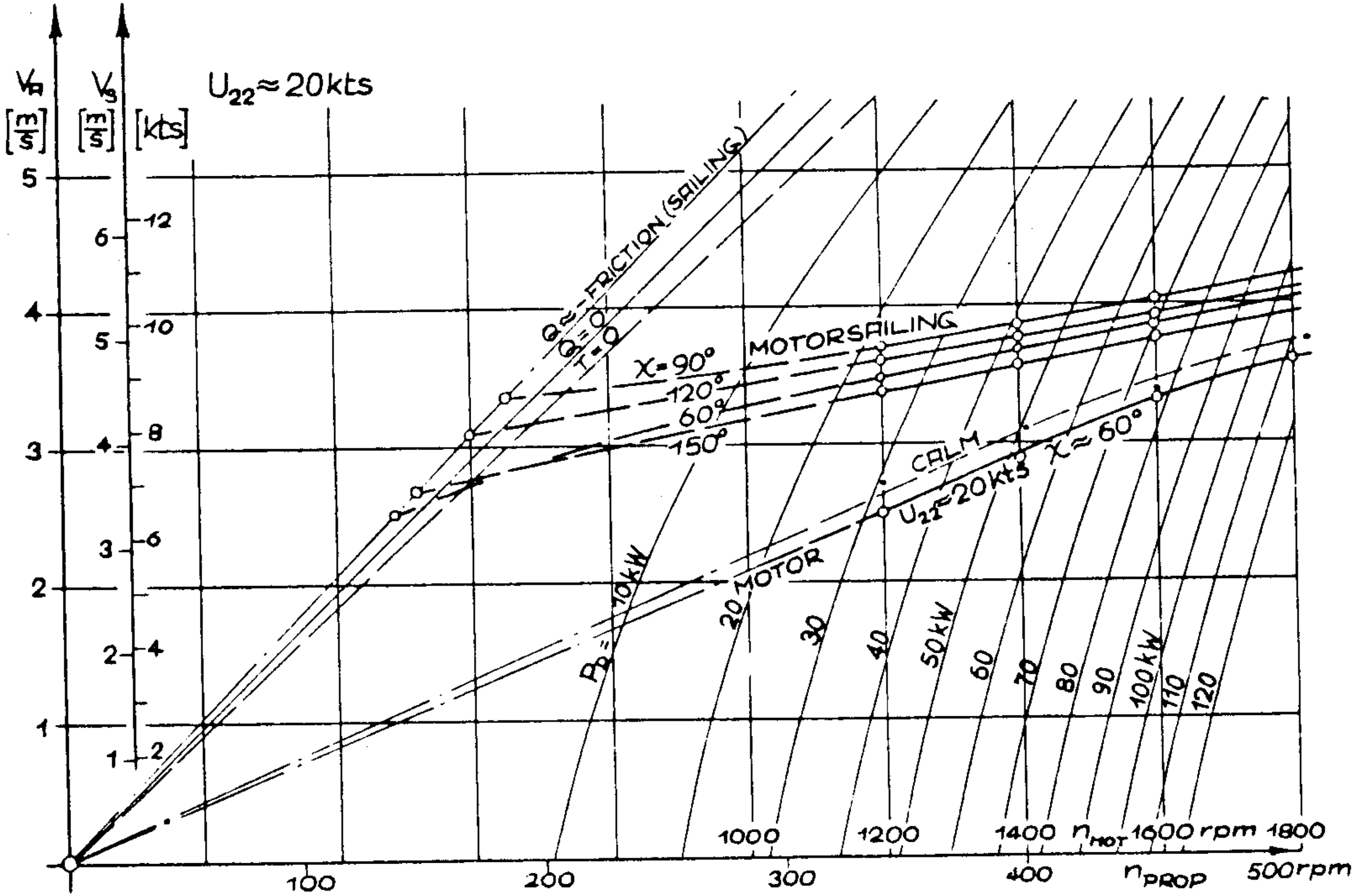
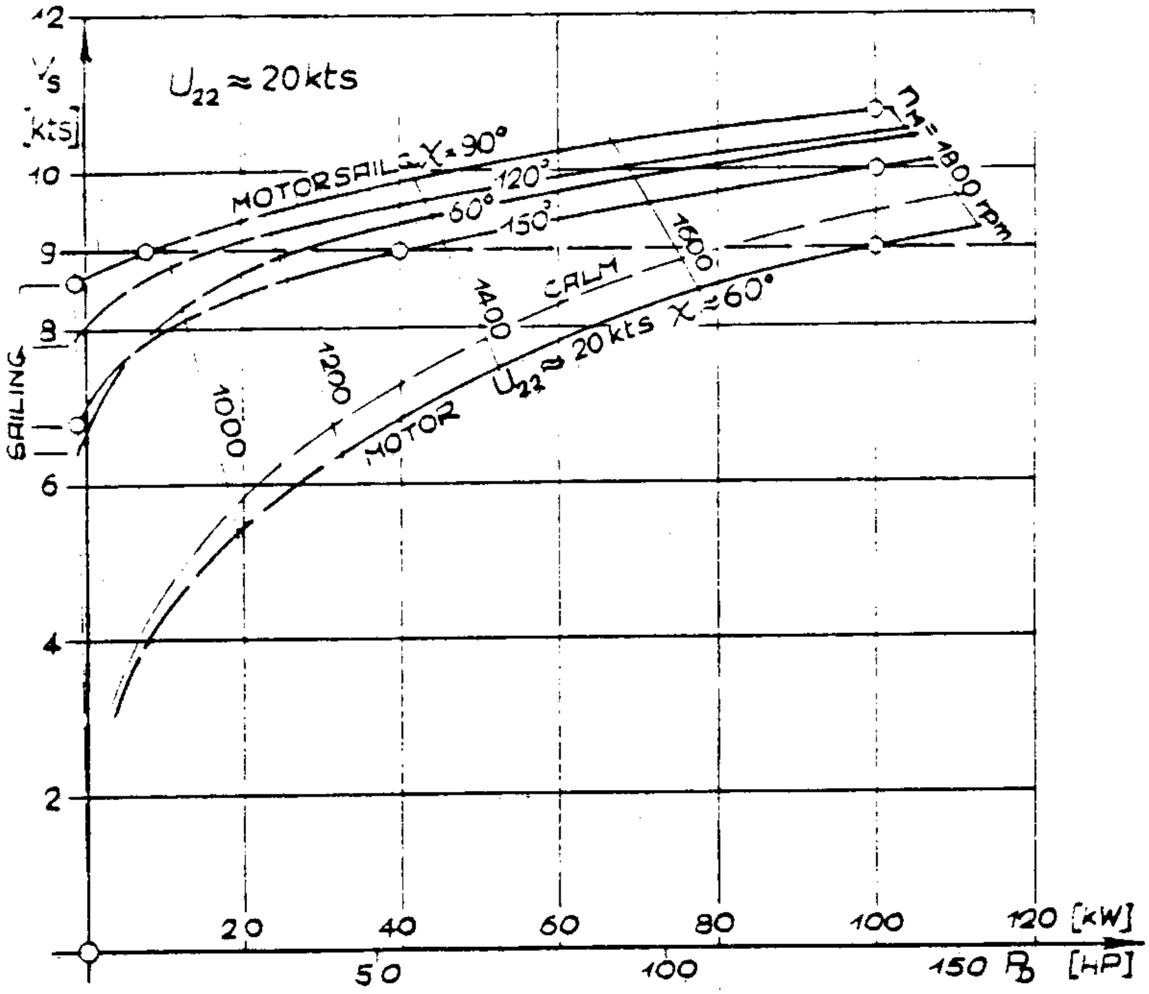


Fig. 23 Speed-revolutions-power relation of the propeller B 3-40/86 Dp=1.0 m



<u>Fig. 24</u> Achievable shipspeed depending on delivered power

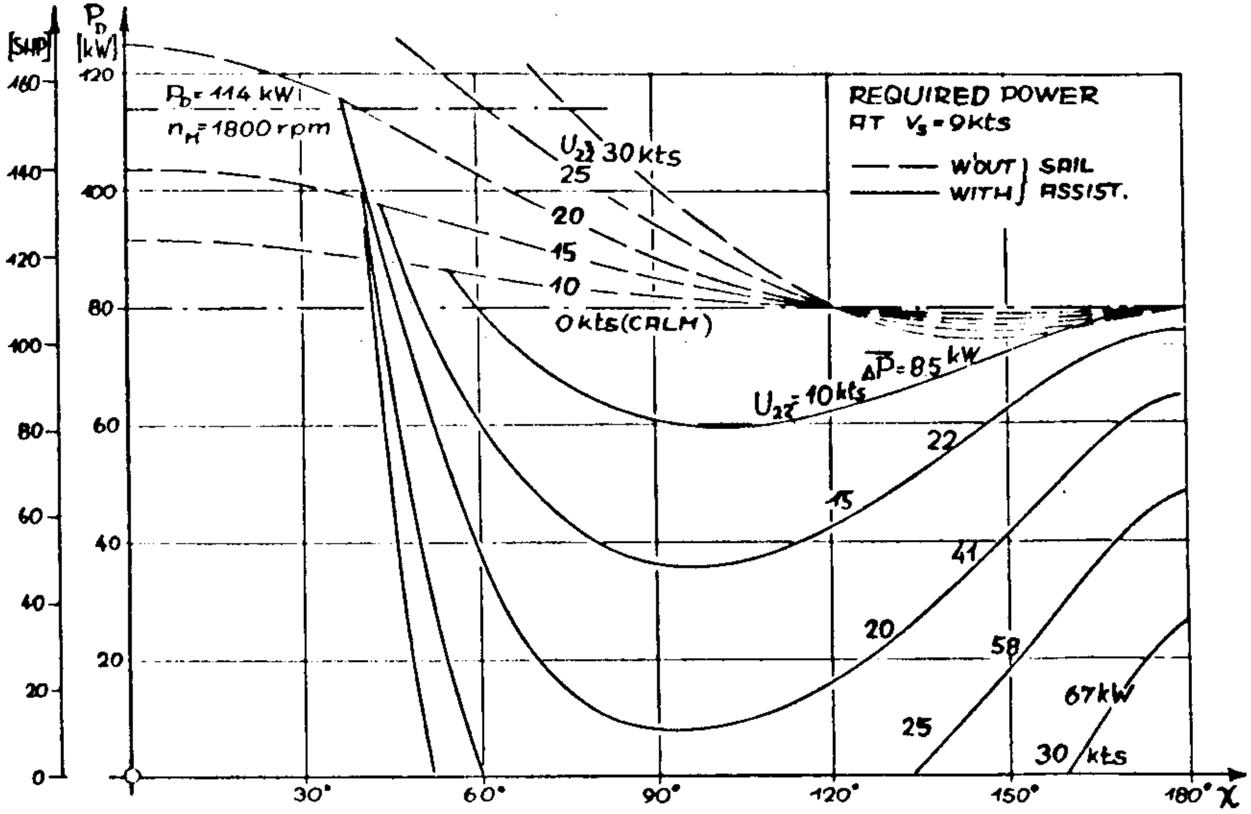


Fig. 25 KFK "Freddy". Required propulsive power at VS = 9 kts

THE PHILOSOPHY OF FISHING VESSEL SAIL ASSISTANCE

Dag Pike
Consultant

Sail Assistance for fishing vessels must be divorced from the romance of sail and environmental considerations and be based on hard economic facts. The economics of fishing are very different from those of cargo vessels and technology must be developed to exploit the required characteristics of fishing vessels.

Introduction

This paper is not against sail assistance, but is aimed at bringing a sense of realism to a subject which is confused by emotive and conservationist issues. Whilst it would be nice to argue a case for sail assistance on the grounds of conserving finite fuel resources and on the romance of sail, the value of sail assistance will be judged almost wholly on commercial grounds.

Reports on sail assistance technology tend to fudge this question of commercial viability and when it comes to the application of sail assistance to fishing vessels, the situation tends to be even more confused because of the increased number of variable factors involved. The purpose of this paper is to attempt to put sail assistance for fishing vessels into perspective and to establish a philosophy under which a viable appraoch can be made. There is no easy and obvious approach otherwise it would have been done a long time ago. Modern technology can change the appraoch but it must be coupled with a clear understanding of the commercial factors involved.

Competition

Sail assistance is a means of reducing the amount of fuel consumed. In general this reduction in fuel consumption will be judged in a situation where speed and performance are maintained at the previous levels and will be expressed as a percentage saving. However, sail assistance is not the only way of reducing the fuel consumption and other possibilities and the potential percentage savings are:

Reducing weight	2%
Improving the hull shape	8%
Improving hull finish and the use of special paints	6%
Use of slow revving propeller	12%
Use of reaction fins or nozzle	5%
Improved main engine efficiency	16%
Use of shaft driven alternator	2%
Better utilization of waste heat	2%

All of these methods of reducing fuel consumption involve alterations or improvements in the ship amd additional capital expense, in the same way as employing sail assistance. They may not all be practical or possible and can conflict with each other. What must be remembered is that when more than one of these methods is used the percentage saving is reduced because the percentage is on a smaller total and sail assistance must take its place in the line. A claimed 30% ptential saving in fuel consumption by the use of sail assistance could easily be reduced to 20% of the original fuel consumption if other methods of fuel saving are used, and there will also be the negative factors of increased weight and drag.

If fuel consumption is the only criteria, then reduced speed and careful use of the throttle can show the biggest saving. A reduced speed requirement allows sail assistance to have a bigger potential as it can provide a higher proportion of the required power. However, reduced speed means longer time for a given distance which can increase crew and capital costs. The latter factor can be particularly significant in these days of high interest rates.

Capital Costs

A factor often ignored in assessing the potential of sail assistance is the effect of capital costs. The object of sail assistance may be to reduce fuel consumption, but at the end of the day it is only the overall savinf which counts and this has to be measured in dollars. The promised fuel savings may look very attractive against the capital investment involved, but the servicing of the capital involved must be taken into account and this can dramatically reduce the overall savings.

A recent case illustrates this point. A proposal for a sail assistance outfit for a coastal tanker was priced at $160,000 and it was suggested that as this would save $70,000 !er year from the fuel bill, the system would pay for itself in just over two years. This ignores the additional costs of installation, the cost of the time the ship would be out of commission, crew training, all of which could easily bring the capital cost up to $200,000. Interest charges on this amount to give an annual bill of say $30,000, which reduces the saving to around $40,000 per year, almost half of the previous figure and maintenance costs could reduce this still further.

These figures are not difficult to work out and any owner contemplating sail assistance is going to look at the bottom line. With fishing boats this is going to be harder to evaluate because of the more variable nature of the operations, but a very important point to remember with all sail assistance projects is that the capital costs still accrue even when the vessel is lying in harbour whilst the fuel savings are only made when the vessel is steaming.

Fishing Operations

Fishing covers a wide range of vessel types and whilst most of these could benefit from the use of sail assistance, there are two main types of vessel which are obvious targets. The first of these are the fishing vessels, usually the larger types of vessel which spend most of their time at sea, either fishing or steaming to or from the fishing grounds. The capital investment on these vessels can be jsutified because the equipment is in use most of the time and saving fuel to offset the capital.

The other type of vessel is the small fishing boat where the mast and sails could replace the engine with perhaps a reduction in the capital cost and a total elimination of fuel costs. These savings may have to be offset against a less reliable pattern of fishing, but within the context of current high fuel costs and interest charges, this type pf craft could well become viable again.

The fishing vessels in between these two extremes represent the majority of fishing vessels in operation today. Use of sail assistance on these vessels may only have marginal benefits in terms of overall cost savings and the introduction of masts and sails could adversely affect the fishing operations to the dtriment of profits. Some fishing methods could benefit from the use of sail assistance more than others.

If the benefits of sail assistance are to be maximized for this type of fishing vessel, then the pattern of fishing will have to adapt to sail assistance, possibly using alternating crews and fishing methods will have to adapt to sail assistance, possibly by using fishing methods where propulsion by sail alone is feasible. Speeds must be adjsuted to make the right balance between expediency and fuel consumption. Sailing rig designs must be closely integrated with fishing systems both to reduce investment and improve efficiency.

Conclusions

Ising sail assistance on fishing vessels is much more complex a problem than with cargo vessels. The object is to catch sufficient fish of a value which exceeds the operating and capital costs of the vessel so as to make a profit, and sail assistance can play its part providing there is adequate use of the vessel to make worthwhile savings and provided the capital costs can be contained. The economics of fishing are dictated by the value of the catch rather than by the time taken to deliver a cargo as is the case with cargo vessels. Efficient fishing is paramount in any fishing vessel operation and if fishing methods are developed specifically for sail assistance, then a viable operation can result.

The prospect of a return to fishing vessel types where sail is the only form of propulsion cannot be ignored. This typed of vessel is probably only viable in small sizes where the capital costs are kept low so that time becomes a less significant factor in the operations. Small fishing vessels of this type could be viable whereas the larger types of fishing vessel appears to be an ever increasing spiral of increasing operating and capital costs in an attempt to make the vessel more efficient to catch more fish in order to meet these increasing costs. Small sailing fishing boats could break this spiral and with modern technology appears to be one of the most promising avenues to explore in sail assistance.

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IMPROVEMENTS IN HULL AND RIG OF TROPICAL FISHING BOATS - KATTUMARAMS, VALLAMS AND DOUBLE HULLED BOATS

By E W H Gifford and C J Gifford
Gifford Technology, Southampton

SUMMARY

The beach fishermen of South India land a large proportion of the total national catch. Although their boats are simple and of antique form, tied-log rafts (kattumarams) or dug-outs (vallams), recent studies show that these artisanal fisheries are substantially more efficient in economic terms than those using harbour-based mechanised boats. There is thus an incentive to encourage these traditional methods rather than the often subsidised modern ones.

Unfortunately there is now a serious shortage of suitable logs for kattumarams and a complete dearth of trees large enough for vallams, so that prices are beginning to rise. Moreover, the methods of construction result in high-drag in the kattumarams and low stability in the vallams. The new designs, commissioned from the authors by local boat builders primarily to overcome the timber shortage by using local marine plywood in the "stitch-and-glue" method, take the opportunity of improving the speed and load-carrying capacity of the boats whilst retaining the familiar characteristics of the traditional boats, such as good paddling for the kattumarams and good rowing for the vallams.

The paper describes trials of the lateen rig used in these new boats, also a design for a detachable outrigger foil for retro-fitting to new and old vallams to give substantially increased sailing speeds.

The new boats have been well received, 35 orders being placed for kattumarams (Kottarkats) in the first 4 months, payment being direct from fisherman to builder without subsidy.

Finally, the paper gives details of experiments with a variety of rigs (sprit, lug and lateen) fitted to the authors' double hulled surf beach fishing boats which lead to the conclusion that the improved lateen appears to be most suitable for small boats in tropical wind-systems, typical of Indian Ocean monsoon zones.

INTRODUCTION

Whilst most fishermen of the temperate zone gave up the use of sail long ago, there are several hundred thousand in the tropics whose boats are still fully rigged and which show, in South India, a better return on capital than the modern mechanised boats, whose trawls, it is claimed, are steadily reducing the fish stock.1 It is interesting to note that a large number of these sailing fishing boats are in India, which is said to be the tenth largest industrial nation of the world.

These Indian fishermen have been sailing for generation after generation and although their rigs may acknowledge visits from the North (an occasional sprit-sail, for instance) both rigs and boats have more in common with those of Egypt and the Euphrates. Any attempt by a European to improve these traditional craft must be made with understanding and discretion.

IMPROVEMENTS OF EXISTING BOAT TYPES IN INDIA

Jim Brown in "Knock on Wood"[2] has very lucidly explained the plight of canoe people brought about by the shortage of trees for boats. In India this problem affects the fishermen using kattumarams and vallams.

Kattumaram

Contrary to the Western world's terminology this is not a double-hulled boat nor is it outrigged; it is a boat-raft, kattumaram being a Tamil word for "tied-logs". These boats exist in a variety of forms along the coasts of Kerala, Tamil Nadu, Andhra Pradesh and Orissa. They are used mainly by fishermen of the ancient Dravidian culture and they exist in their tens of thousands. Most are sailed and they sail well under a type of lateen that, in some versions, is very close to the rig of the International Finn.

Their main advantages are suitability for moderate surf crossing (they are unsinkable) and low cost. For the unsinkable quality a low density wood is needed and Albizzia has been commonly used, but large logs of this species are no longer available at a suitable price. This shortage does not yet seriously affect the smaller kattumarams, nor the big craft made of a large number of thinner trunks such as those found in the Madras district. (Fig 1)

In the extreme South, however, in Kanyakumari and Tiruneveli Districts the kattumarams are of large size (24ft by 4ft, 7.3m x 1.2m) needing 5 logs each of 2ft by 1ft 6 inches (0.6m x 0.5m) scantling and these are becoming very scarce indeed (Fig 2). This is not surprising, since each boat lasts only about 10 years before the wood becomes brittle and regular replacement of an ever increasing number of craft needs thousands of large trees each year. Furthermore, this wood is also used in the Indian match-making industry and the demand leads to increasing prices.

It was for this specific reason, not to improve sailing performance, that the authors were asked to design a plywood version using the stitch-and-glue technique already employed in their Sandhopper and Sandskipper boats. The brief was to produce a boat of similar overall dimensions to the existing kattumarams, capable of being paddled in the Tamil manner with a double paddle made from a split bamboo, and sailed with the traditional rig, and two dagger boards thrust down between the logs.

Freed from the restrictions of the traditional material, the designers could have changed the shapes considerably but in the first instance kept close to the original dimensions, even introducing a deck, partly for reasons of strength but mainly to simulate the raft so that the paddlers could kneel or squat in their accustomed manner. The principal changes made were much reduced weight (to approximately one third of the original kattumaram) a stiffer midships section, and a better longitudinal profile with a finer entry and a flat straight run (Fig 3). This gives a much improved sailing capability and a boat that can easily attain half wind speed on a close reach with a maximum of more than 7 knots (Fig 4). The boat tacks through 90° with this rig which is a variant on the local style (Fig 5). About forty of these boats have been built already by a cottage industry boatyard of the Kottar Social Service Society at Muttom in Kanyakumari District and a second workshop has just been opened by the South India Federation of Fishermen's Societies at Anjengo, near Trivandrum in Kerala State. Unfortunately from the sailing point of view, the boat goes even faster with a 7hp kerosene outboard engine and this is now a popular combination, some crews going 20 miles offshore for 3 days and 2 nights, lining for squid. They also carry sail, at present for emergency, but we expect that eventually a combination of sail and outboard will evolve, particularly in the monsoon periods of stronger winds. A larger version of Kottarkat, as this plywood kattumaram has been named, has now been built.

It should be noted that the price of these boats (R.9,000) is less than that of the equivalent large kattumaram (R.10 - 12,000) and this is without any subsidy or Government assistance.

Vallam

These lovely boats are dugouts with sewn wash-boards and clearly are of very ancient origin (Figs 6 and 7). They are mainly in the State of Kerala, where about 8,000 are in use for a wide variety of fishing.

Each boat is carved from a single trunk of the giant mango but such trees can no longer be found as mango cultivators are now growing a smaller variety. As no substitute timber exists, this very efficient craft is likely to disappear.

Following on the Kottarkat's success the authors were asked to design a ply-wood vallam. These boats are always rowed, unlike the kattumarams which are normally paddled, so it was possible to make a substantial increase in the beam. (Fig 8). As this boat is also much lighter than the dugout, it is faster both under oars and sail.

The rig illustrated is close to local practice except that the mast is moved a little further forward to facilitate tacking, although this is an infrequent operation in the Indian Ocean (Fig 9). A dagger board is fitted instead of the leeboard of the vallam but this may take some time to be accepted.

At the time of writing a larger sail is being made, as the increase in hull stiffness is such that with the right rig the boat will certainly achieve half wind speed. The prototype has reached 7½ knots in the UK in a 14 - 16 knot breeze. With a 7hp outboard its maximum speed is 9 knots. It can carry twice as much net as the equivalent dugout. It has been named the ply-vallam by the authors, but papadom-vallam by the fishermen!

At R.9,000 it is substantially cheaper than the current price of R.12,000 for a secondhand vallam. A co-operative factory is soon to be set up at Quilon in Kerala for the local manufacture of these boats, and it is hoped to have ten boats fishing before the monsoon in June.

A further development of the vallam which the authors are testing in the UK is the fitting of outriggers so that a larger sail area can be carried. The aim is to attain 9 - 10 knots in wind speeds of about 15 knots to encourage sailing rather than motoring. The traditional form of floats such as used on trimarans or conventional outriggers are inconvenient for fishing boats as they obstruct fishing gear.

A colleague of the authors, Malcolm Barnsley, has developed a hydrodynamic foil of much more compact shape which can be fitted to a single outrigger beam (Fig 10). The foil has only small static buoyancy, just sufficient to stabilise the boat in light winds; as speed increases hydrodynamic lift develops, so that the mainsheet can be hardened in as the boat accelerates. This is a simple technique to learn, particularly in the steady wind states of the tropics. Trials made on the prototype have been very encouraging as a speed of 8½ knots was attained in a wind speed of 18 knots, using a relatively small sail (Fig 11). Trials with a sail area more suited to the tropics will be made soon.

Double-Hulled Boats

The earlier development of these boats arose from the authors' wish to produce a substantial boat capable of working from open beaches in all weathers suitable for fishing, and so be independent of harbours[3] & [4]. Although this capability was demonstrated by the 5-ton Catfish (36ft, 10.9m) in Ghana over a period of 2½ years during the seventies, the authors now believe that the greater need is for smaller boats for artisanal fishermen.

With the exception of the Overseas Development Agency of the British Government and the Intermediate Technology Industrial Service, most development organisations seem reluctant to accept that double-hulled boats are economic, so progress has been comparatively slow but nevertheless steady. A project in Sri Lanka, with the 24ft (7.25m) Sandskipper is giving a further demonstration of capability (Fig 12).

Several rigs have been tried over the years. The first was on the Sandskipper prototype in Ghana in 1975 using a conventional Scottish lug, slung between the legs of a bipod mast. The sail area was quite small (180 sq ft, 15m2) and consequently inadequate. As the Ghanaian fishermen showed little interest in sail, this development was not followed up.

Later, three boats were built in Sri Lanka and the prototypes fitted with a version of the oru rig, the authors feeling that this, being a familiar sail to the Sri Lankan fishermen, would be more readily accepted. The rig performed quite well but is locally regarded as archaic (the sailing oru really only persists because of local regulations restricting fishing to sailing boats as with the Chesapeake sharpies and the Falmouth oyster boats). Its windward performance is not good because of the low aspect-ratio of the rig. Consequently the rig was changed to a larger (250 sq ft, 23m^2) version of the original lug set outside a taller bipod. This gave really good sailing and a speed of 9 knots in an 18 knot breeze on a close reach has been recorded. It was quickly realised that the halyard forces required to set up a high aspect-ratio quadrilateral sail of the lug type are higher than desirable for a fishing boat.

Some parallel experiments on lateens on the smaller Sandhopper double-hulled boat (20ft, 6.1m) were beginning to give some good results so this rig has now been adopted for all the authors' fishing boats.

Lateen Rig

Obviously this is an old rig, much older than inferred by its Northern name (lateen - Latin - i.e. Mediterranean). There is no certainty but an increasingly held view amongst experts that this is an Asian, possibly an Indian, development of considerably antiquity. It is certainly widespread in the tropics in a variety of forms of varying efficiency, so it is sensible to examine this familiar rig.

The nature and performance of the lateen turn upon the characteristics of the long single yard. Once the sail is hoisted, stretch in halyards and stays is relatively unimportant. But it is essential that the yard is of adequate stiffness to suit the sail, and few present-day rigs achieve this; unduly bendy spars will spill wind too soon and produce drag and little lift. This is a common fault. With small sails it can be overcome by buying the finest bamboo of the largest section obtainable; for slightly larger sails the bamboos can overlap at the halyard and be well lashed together (Fig 12). With an even larger sail, the lower yard can be a teak pole topped with a more bendy bamboo tip, as thinnings from teak plantations are not expensive.

In UK the authors have successfully experimented with yards built as hollow plywood beams, with bamboo tips. This seems to give the optimum balance between light weight, strength and controlled stiffness (Fig 13).

The next most important point is the angle of the yard. Research work done in wind tunnels on forestay angles on Genoas indicates that the steeper the angle the more efficient is the sail, and that this effect is quite marked. So the lateen yard must also be steep. This, in combination with the need for large sail area in gentle winds and a high aspect-ratio for efficiency, means that the spar will be long, probably longer than the boat. But the spar is relatively light and a suitable fixed crutch at the stern of the boat overcomes the problem of stowage when not in use (Fig 14).

The lateen is not a difficult sail to reef but taking in a deep reef is a lengthy operation, probably one of the reasons this rig dropped out of use in temperate climates. But in most tropical regions the winds are remarkably steady and the sail area required varies by the season rather than by the hour.

To deal with the most likely short-term variations in wind the authors use a diagonal reef which is quick and easy, but for seasonal variations a bonnet is used, which can be removed during the monsoon together with the lightweight yard-tip.

An essential piece of gear for the management of a lateen is the vang, the rope controlling the horizontal swing of the yard. Proper use of the vang greatly reduces the sheet load when close hauled and assists in setting the sail when running. This reduction of sheet load makes the use of cotton sailcloth more acceptable as there is less need for the toughness of a fabric such as Dacron which, apart from its high cost, degrades in sunlight.

One of the traditional methods of tacking a lateen, when set on a single mast, is to run off downwind and lead the mainsheet fall round the bow and back up to the weather quarter. The remainder of the mainsheet is let go so that the mainsail blows out in front of the boat like a flag. The mainsheet is then hauled in on the other side of the boat on which has now become the leeward side. Meanwhile the vessel is turned back onto the wind. In effect this is a gybe without any shock. This method has been used successfully with the authors' boats but it does need sea room, and most fishermen in India prefer to take down the sail, paddle the boat round and set it again on the new tack.

However, using a short bipod mast well forward avoids all these problems as the sail can be set between the legs of the bipod and tacked through the wind in the normal way. This position of the mast has the additional advantage of keeping all gear well clear of nets.

A double halyard arrangement is used with the weather halyard set up to act as a backstay whilst the leeward one is slackened away (Fig 14).

No mention has yet been made in this paper of the Bermudan sail, so characteristic of modern sailing boats. This was not used in the double-hulled boats where the bipod mast was preferred because it does not obstruct the bridge deck and the fishing gear.

The Bermudan rig, moreover, has a headsail which requires a tight luff and complex staying which are inconvenient for fishing. It seems unlikely that the better sailing performance of this rig compared with the lateen would be sufficient to outweigh the disadvantages of unfamiliarity and complication. Nevertheless it is recognised that no comparative data exists and the authors hope that they may soon be able to supply this. In any case, a small engine will be carried for direct windward work or for when the wind is very light, so optimum windward performance may not be required. The important factors are overall efficiency, cost, handling and fishing.

Future Work

The authors' associated Company, Gifford Technology, has been appointed by the Commission of the European Community to investigate methods of energy saving in the propulsion of artisanal fishing boats. This is a substantial programme, probably extending over two years, which will investigate the relationship between hull form and propulsion methods (inboard engine, outboard, sail) and relate these to fishing function and climate. An important part of this work will be a rigorous analysis of the relative efficiency of different rigs and sailcloths. It is possible that the difference between good quality cotton sailcloth and manmade fibres may not be as important as race results indicated when the new cloths were introduced. Races are won by comparatively small margins. Because of the difficulty of interpretation of wind tunnel tests, especially where cotton cloth is concerned, a pair of identical 20ft Sandhoppers will be used, as double-hulled boats will eliminate heeling angle variation. One boat will be fitted with a modern Bermudan rig acting as a trial horse, and the other will in turn have the rig variations, which will include centreboard/ leeboard comparisons. The boats will be sailed in company and thus have direct comparisons but their courses will also be observed through theodolites at the ends of a measured baseline and thus actual speeds and courses will be continually observed and computed. Wind speeds will be measured and electronically averaged.

Funds are not unlimited so the first rigs used will be lateen, spritsail and gaff with, of course, the Bermudan pacemaker. Later trials will, it is hoped, enable more development to take place on whichever rigs show the most promise.

CONCLUSIONS

The first conclusion is that the lateen is an efficient sail for tropical fishing, with considerable potential for development. The second is that it is at least as important to improve the hull as it is to improve the rig, and that fitting good sails to a heavy hull may give disappointing results.

ACKNOWLEDGMENTS

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BIOGRAPHICAL NOTES

Edwin W H Gifford, OBE, BSc, FICE, FIStructE, FRINA

Specialised in structures and marine civil engineering, started design of small fishing boats in 1960 and small hovercraft in 1968. Awarded OBE and RINA's Small Craft Group medal in 1981 for work on artisanal fishing boats.

C Joyce Gifford, BSc

Geographer, formerly lecturer at Southampton University, special interest in meteorological and geomorphological aspects of tropical fisheries.

The authors are joint directors of Catfish Ltd, a non-profit-making company building experimental small fishing boats.

In conjunction with Gifford Technology they have been appointed by the British Overseas Development Administration, the Intermediate Technology Industrial Service and the Commission of the European Communities to participate in a variety of projects for the improvement of artisanal fishing boats.

Fig. 1 KATTUMARAM - MADRAS

Fig. 2 LARGE KATTUMARAM AT OVERI KANYAKUMAN

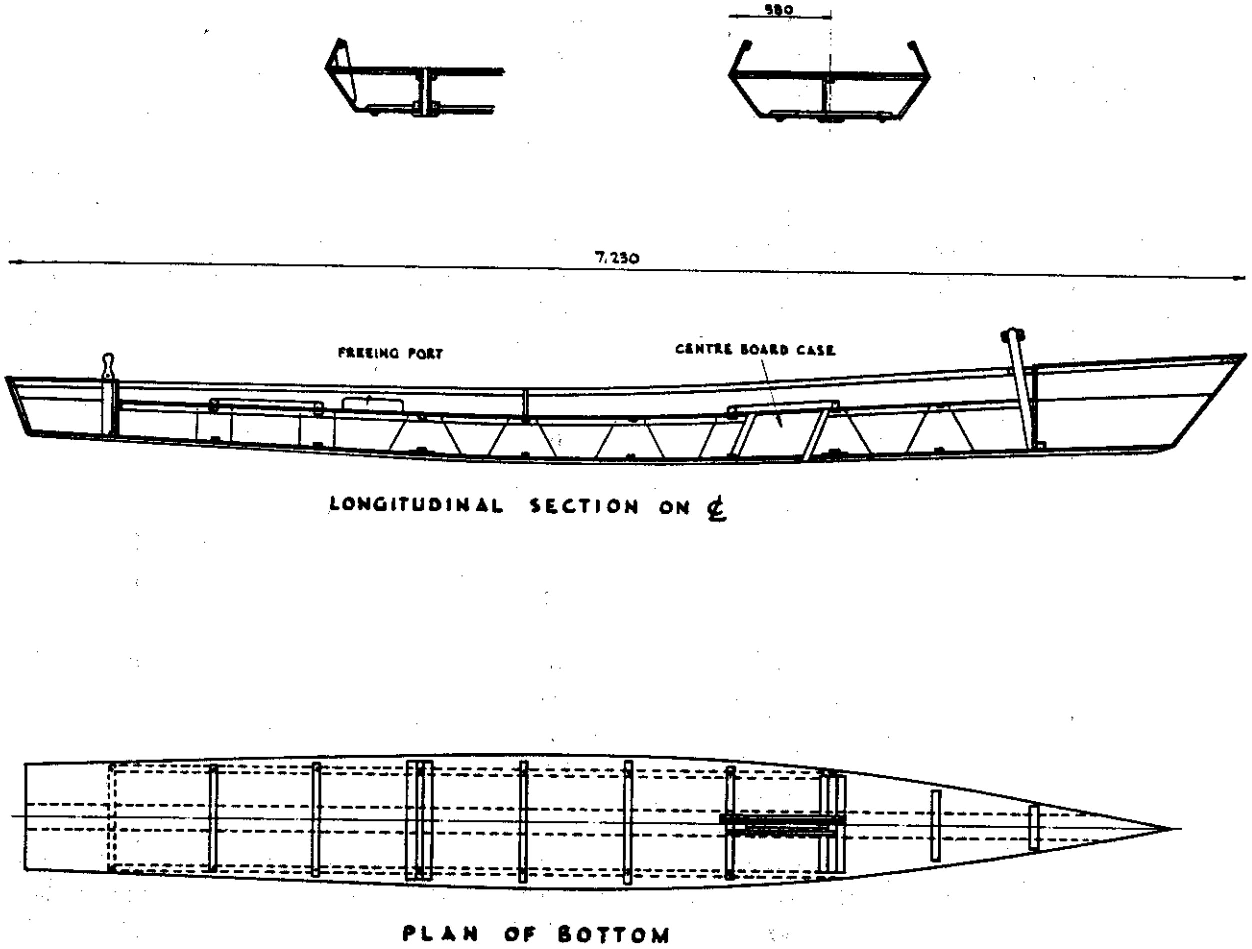


Fig. 3 PLYWOOD KATTUMARAM, 'KOTTARKAT STRUCTURE

Fig. 4 "KOTTARKAT" IN U.K.

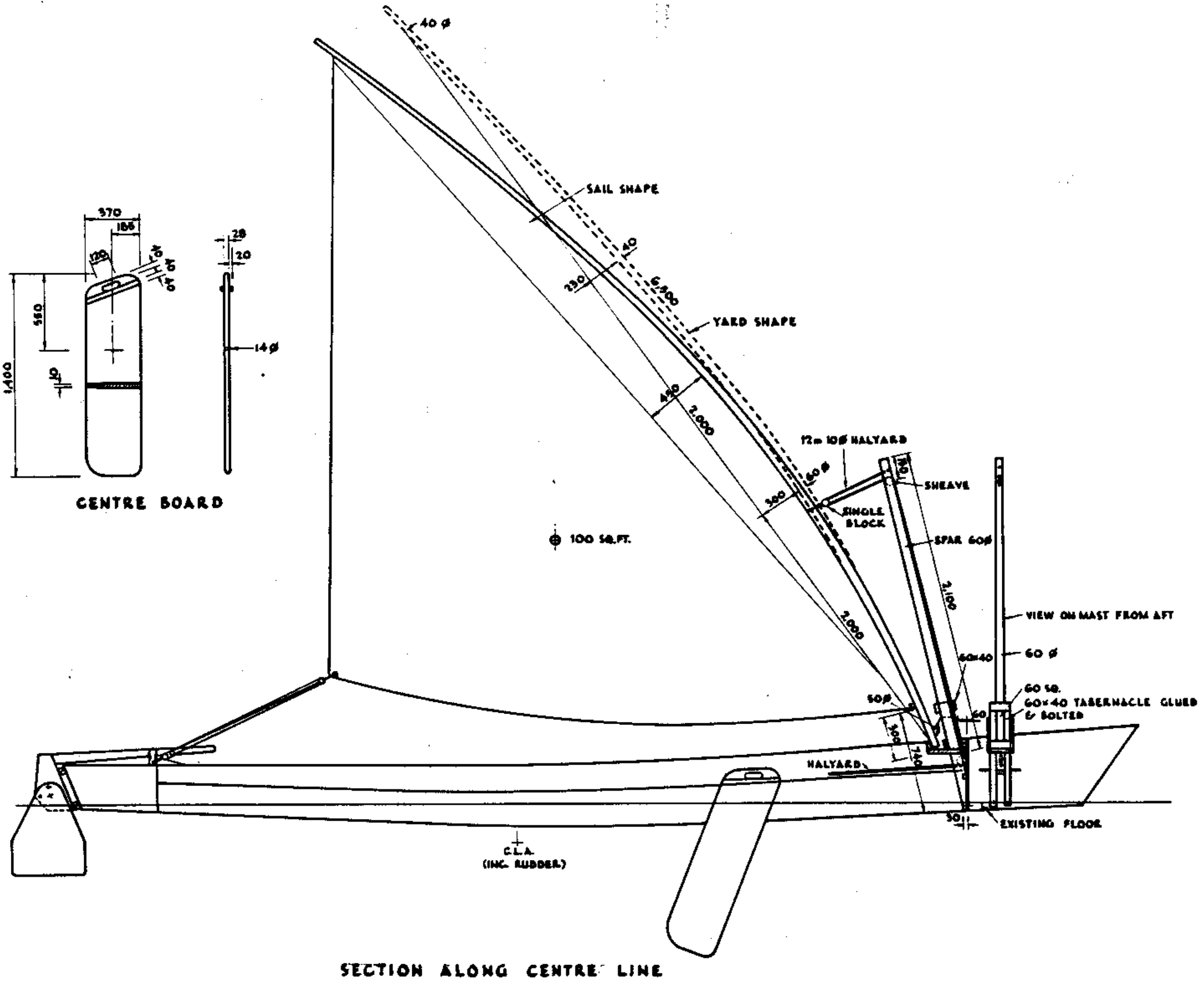
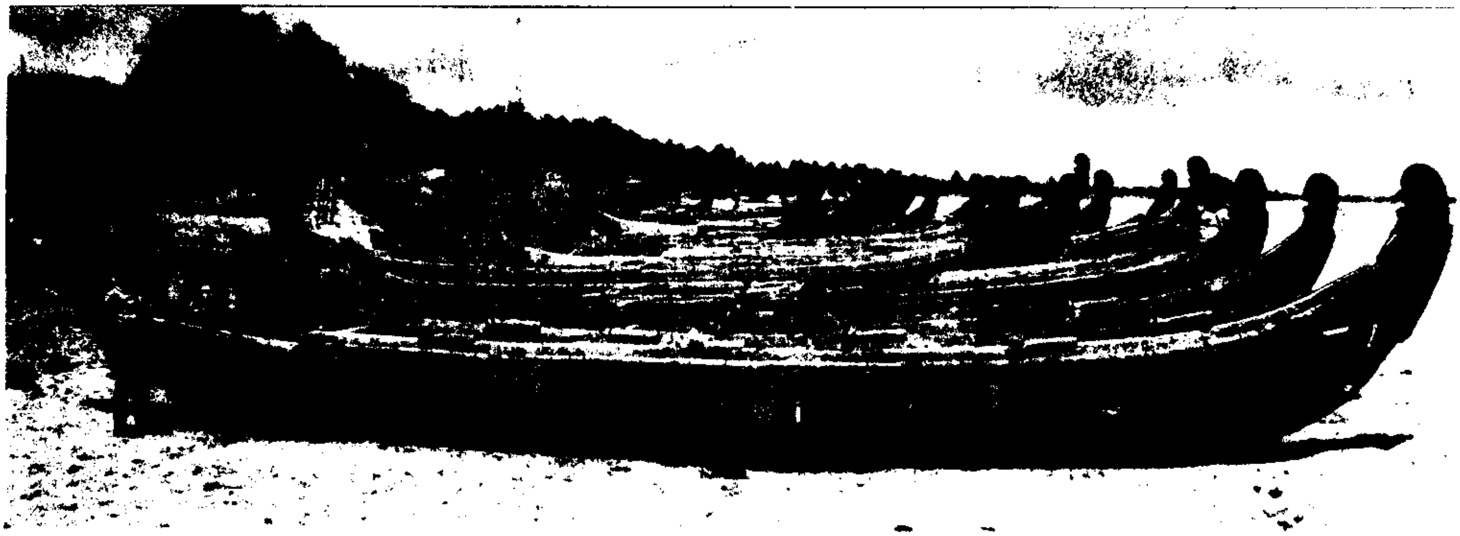


FIG. 5 'KOTTARKAT' RIG



- > Fig. 6 VALLAMS AT QUILON - SOUTH INDIA

Fig. 7 VALLAMS AT QUILON - SOUTH INDIA

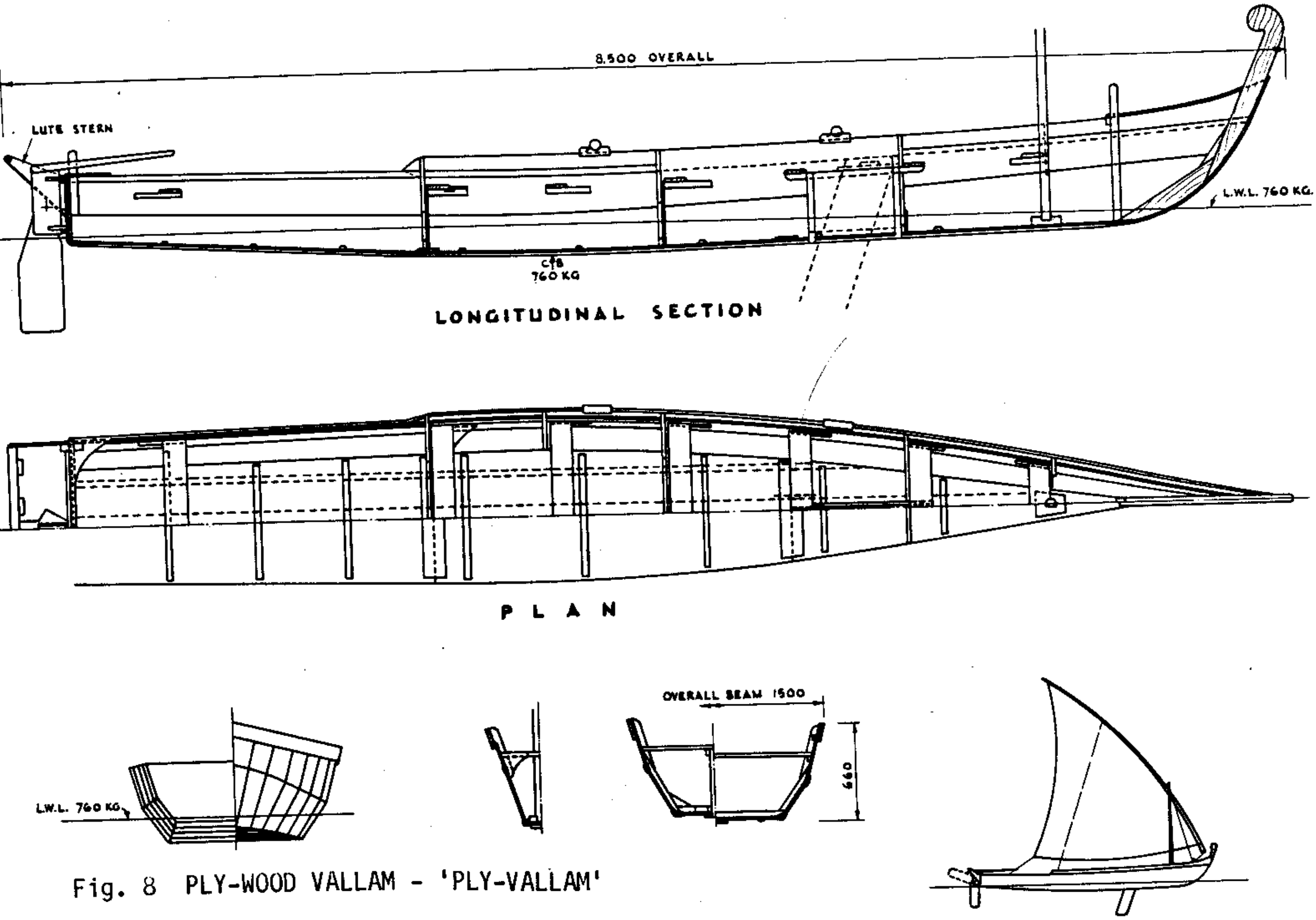


Fig. 8 PLY-WOOD VALLAM - 'PLY-VALLAM'

Fig. 9 PLY-VALLAM

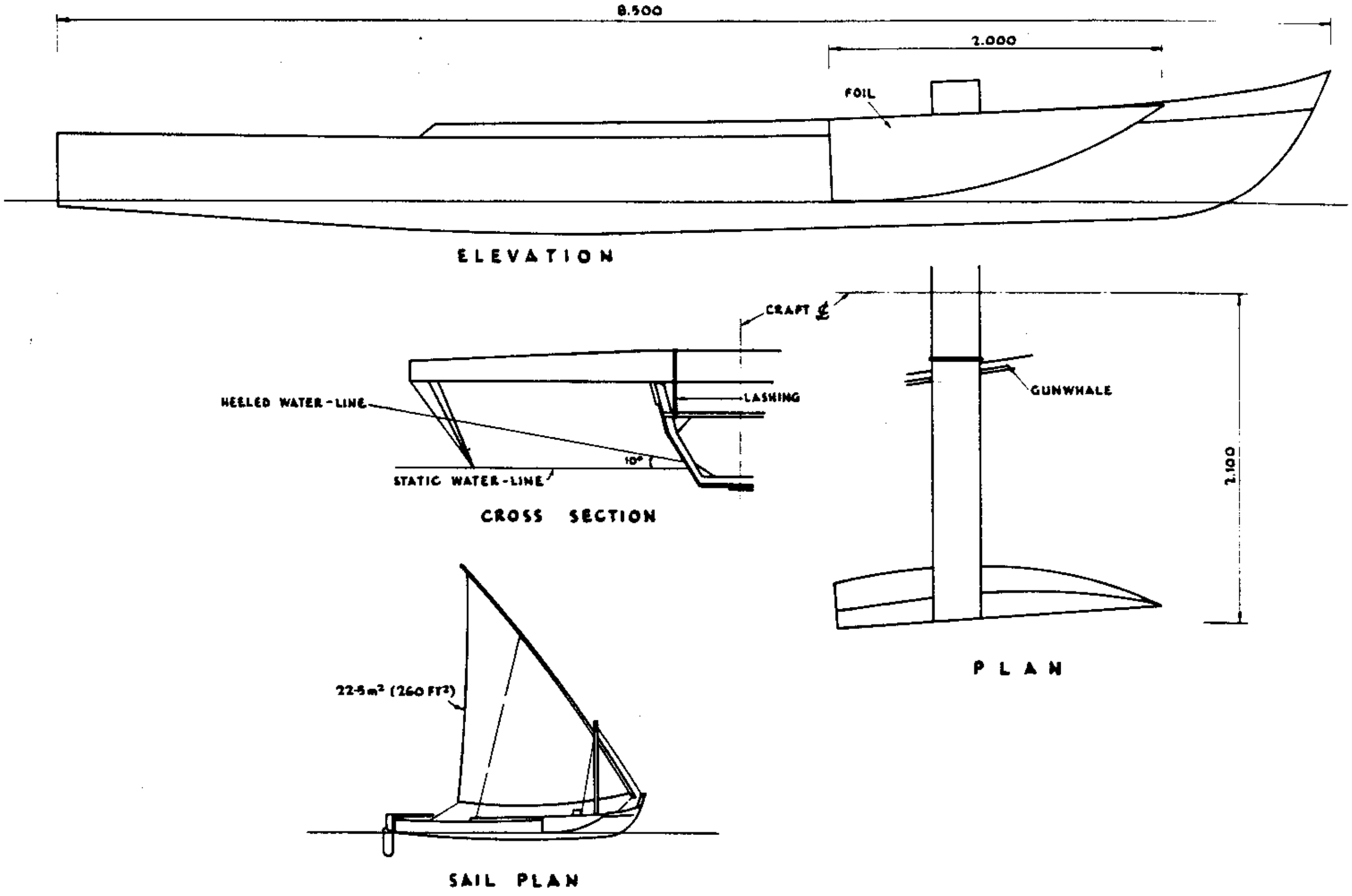


Fig. 10 HYDROFOIL OUTRIGGER ON PLY-VALLAM

Fig. 11 OUTRIGGED PLY-VALLAM IN U.K.

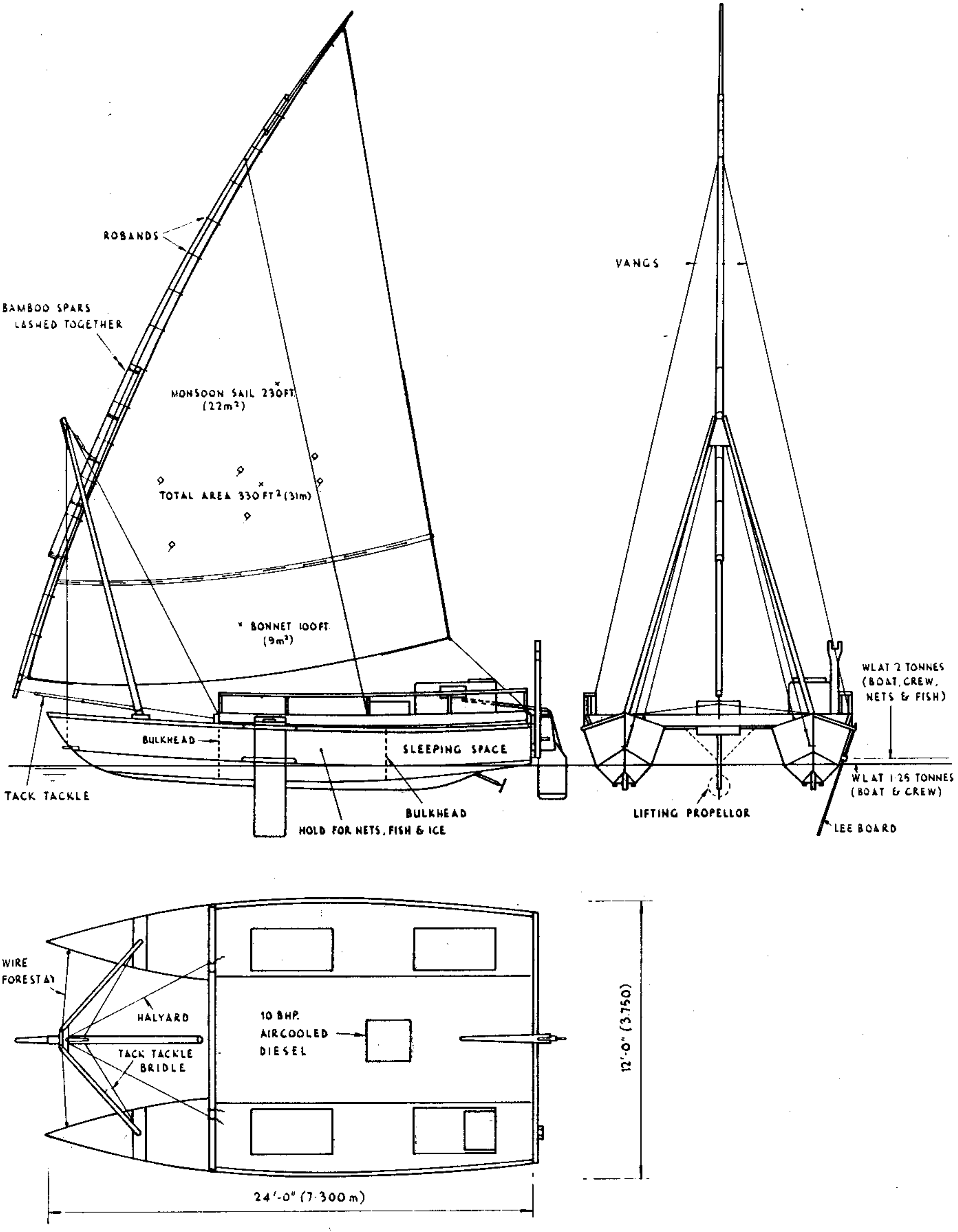


Fig. 12 MODIFIED SANDSKIPPER IN SRI LANKA 1983

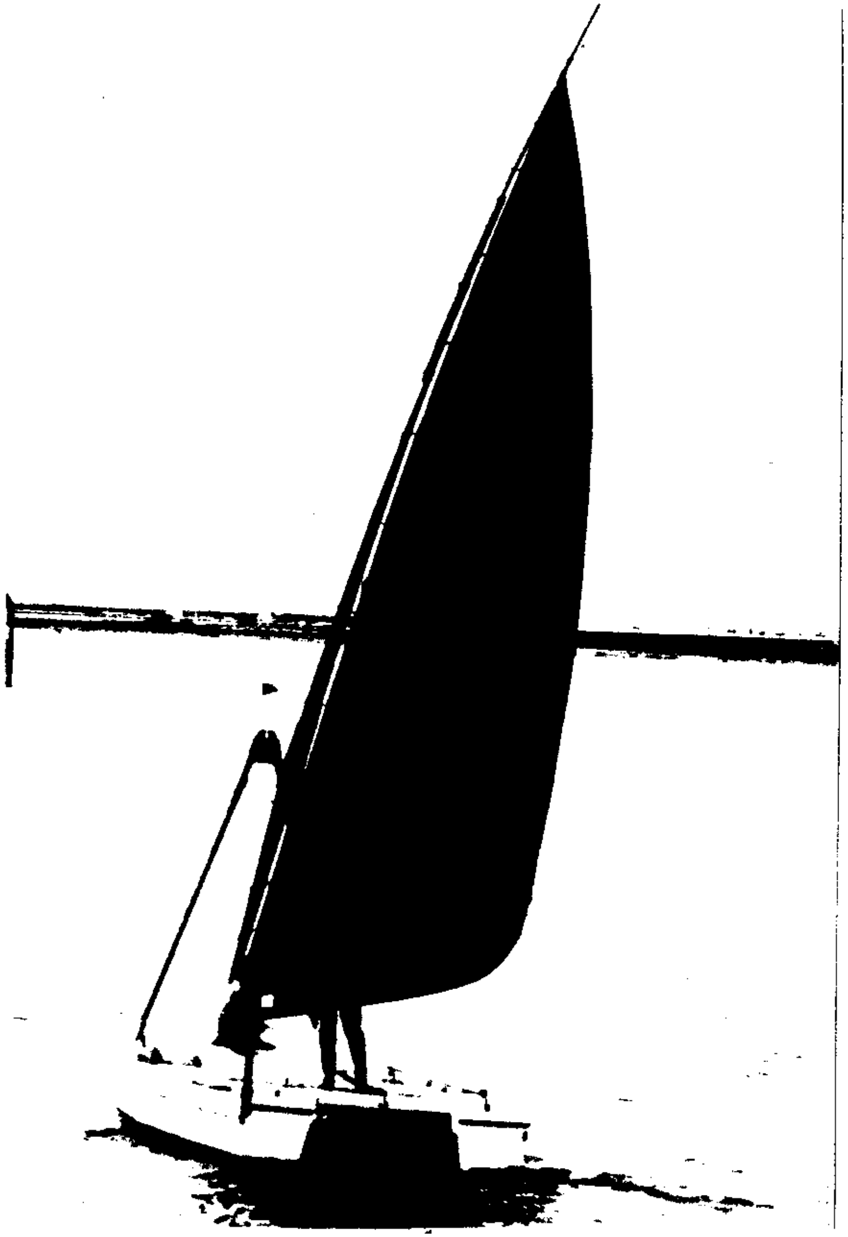


Fig. 13 SANDHOPPER WITH LATEEN ON PLY-WOOD BOX YARD

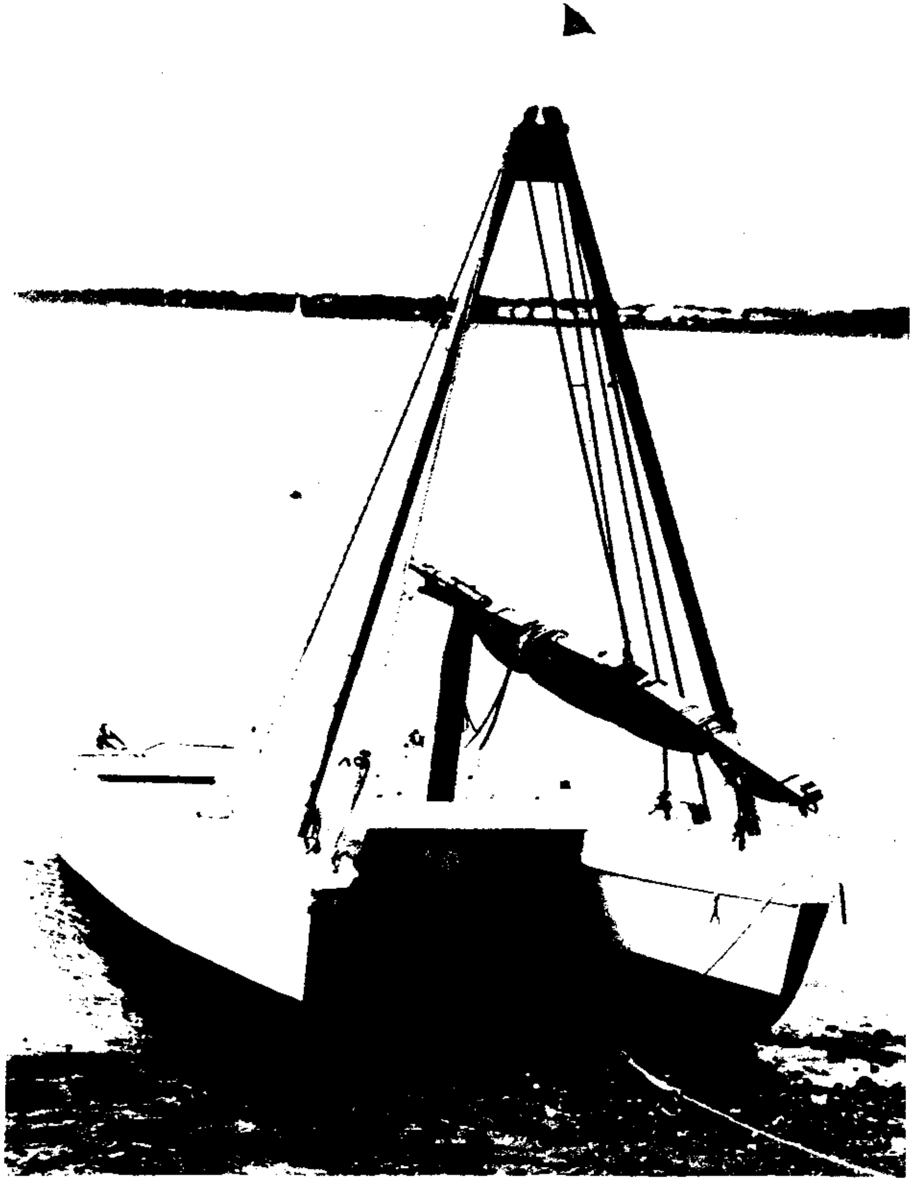


Fig. 14 SANDHOPPER WITH LATEEN STOWED

Sail Powered Pearl Fishing Catamaran : DMB

By Lock Crowther
Crowther Multihulls
Box 35 P.O.
Turramurra, (Sydney)
NSW - Australia 2074

The pearlshell racks and seedling plant of Cygnet Bay Pearl is located on King Sound in the tropical north of Broome, one of the most isolated areas of the island continent. The company produces cultured pearls.

Bruce Brown and his brother, being able to discover the Japanese secret of producing cultured pearls, spent 10 years experimenting with various ways of inserting the necessary irritative substance into the oyster so that the oyster would survive and grow a perfectly-shaped pearl surrounding the irritation.

I understand their method is similar to that used by the Japanese but, of course, the details are secret.

Only a percentage of the oysters produce pearls and it is necessary to regularly visit the grounds where the pearl shell oysters grow naturally so as to replete the pearl farm back on the Australian mainland.

The pearling grounds lie approximately 240 miles across the south-east trades so providing an ideal situation for the use of sail. Sailing pearling lugger have, of course, worked out of Broome since the last century and there are indications that Asian peoples used the north of Australia for pearling and beche de mer in centuries past.

In any case, the pearl farming is quite a change from the crocodile shooting that originally supported the Browns.

The brothers considered that a modern sailing catamaran would be the ideal vessel for their purposes and to replace their existing traditional diesel trawler. Accordingly, they approached me for a design.

When the pearling catamaran arrives at the grounds it will lower two to four divers over the side on hoses.

The divers receive about $2 per shell and the vessel will hold about 4000 shells, or two tons. It may take up to eight days of drifting backwards and forwards to gather a full load.

The shells are stacked in crates in tanks through which sea water is circulated continuously to keep the shells alive. The vessel has to carry 16 1/2 tons of sea water in the tanks on the way back to the base.

Currently, in this remote area fuel costs approximately 60¢ per litre, and with a sails, rig and equipment cost of $50,000 it will take something like three years to recover the fuel saved, assuming that the maintenance

Parts of this article first appeared in the December issue of "Professional Fisherman," and are reproduced with permission of the author.

like three years to recover the fuel saved, assuming that the maintenance costs for the rig are not higher than the cost of engine maintenace.

Should fuel costs increase, as seems likely, and should sail power prove reasonably economical, then more sail powered vessels of the work boat type could appear on the Australian scene.

Detailed thinking behind the design is as follows.

1. A waterline length of greater than 21 metres is necessary to obtain Government assistance with the construction of the vessel.
2. The sea water tanks for the pearl baskets had to be located close to the centre of gravity and this dictated the general arrangement of the boat. Divers have to work inside the tanks to stack the baskets, making for fairly large tanks.
3. The tropical sun in north west Australia is fierce and shade for the helmsman and crew is essential. As the crew of, say, 10 people will be at sea for an average of two to three weeks, it is necessary to carry sleeping accommodation, cooking, stores, desalination plant for fresh water and considerable additional equipment.
4. Engines are, of course, required in case the wind fails and for in harboring maneuvering. The two Perkins 70hp diesels are fitted with variable pitch feathering propellers so that she can sail, motor sail and generate power from the propeller shafts under sail. She needs an auxiliary power plant for the dive compressors, sea water tank pumps and electricity. Under power she achieves a comfortable 10 knots with a top speed of 11 knots.
5. On the way to and from the pearling grounds the divers will have little to do so there was no point in having a rig with expensive sail handling equipment for short handed work. The most important thing is to reduce wear and tear and keep it all simple, bearing in mind the remoteness of the location. The two equal height masts reduce the size of the sails and the capsizing moment. The headsails hank on; the main and mizzen have slides and all sails are constructed from ultra-violet proofed cloth and stitching protected with an anti-chafe coating.

I had the pleasure of crewing on her maiden voyage from Perth to Broome. She sails quite comfortably at 9-13 knots and easily reaches a speed of 18 knots under reefed mainsail alone in 34 knots of wind.

On a long voyage there is no requirement to keep pulling into port for refueling, so the overall passage time is very little different from that of a power boat.

Even in light winds the average speed is high. We had 11 knots on the log in 8 knots true wind.

Construction was by SBF Engineering of Perth and is all welded aluminium. The two deckhouses are comfortably fitted out with six berths, lounge, dining table, chart table, freezer, fridge, microwaven oven, hot showers and 240v power. A 20kVa MWM alternator set provides the 240v power which, in addition to the domestic loading, also powers circulating water pumps, bilge pumps and de-salination plants.

The 24v power for engine starting, SATNAV, autopilot, radar, etc. is supplied from the generator via a rectifier to two battery banks. 24v power can also be obtained from a propeller shaft driven alternator.

At present the gearing for the shaft driven alternator is too low as it takes about 13 knots to get 20+ amps under sail. Once this is corrected the system will work well.

Because of the vessel's size and weight she is very stiff and can carry full sail in quite strong winds. For the skipper's guidance we have produced a sail polar diagram which shows wind speeds and directions.

SBF Engineering of Naval Base, just to the South of Perth in Western Australia, are becoming well known throughout Australasia for their aluminium vessels.

The company had tended to specialize in comparatively lightweight high speed boats, including the much publicized Rottnest Island ferry "Sea Flyte." However, it has also built large numbers of yachts and other slower vessels in aluminium and steel.

"DMB" is not the first catamaran built by SBF Engineering -- a 53' pleasure catamaran was constructed previously, and the company is currently finishing a 50' motor sailing catamaran for the Lizard Island Research Station in Queensland. Both these vessels were also designed by Lock Crowther.

Design No. 69: Aluminium Trawler/Game Fishing Catamaran: Crowther 46

Originally this vessel was designed as a maximum versatility marine biological research vessel for a remote island station on Australia's Great Barrier Reef. The catamaran concept is ideal for motor sailers and this vessel sails well saving considerably on fuel costs.

Accommodations are for nine below or considerably more on day trips which means she is entirely suitable for game fishing or just plain cruising. Below decks there are two forward cabins each containing three berths and ample storage. Further aft in the port hull is an owners cabin with a pull-out double berth, seat, desk and hanging locker. The same area in the starboard hull is set up as a laboratory with sink and bench space. This area can of course be fitted out with individual requirements. Right aft on the starboard hull against the engine room bulkhead is a toilet and shower.

The main cabin area between the hulls is a large saloon with "U" shape galley, freezer, dinette, settee/berth and inside steering station. There is full headroom throughout.

Right forward in each hull is a large hold/storage area with a watertight floor. Here are stowed spare sails, minor cargo, motor bikes, etc. This area and the engine rooms aft are divided off from the main accommodations by watertight bulkheads. These bulkheads plus watertight doors leading to the forward cabins ensure she will meet maritime regulations requiring continued operations with any one compartment holed and flooded. This also ensures that she is almost impossible to sink, despite the aluminium construction. The structure will meet maritime regulations for strength and there is no problem meeting full offshore survey requirements.

Twin 40 H.P. diesels (Lister) located in separate engine rooms are accessible via large deck hatches and provide 11 knots. They are rubber mounted to drive via variable pitch feathering propellers. These propellers allow efficient sailing in the feathered position and can be varied in pitch for optimum fuel efficiency in any sea condition, from motor sailing in light weather with one engine ticking over at a high setting to pushing into a storm with low pitch for maximum thrust. Of course pitch can be optimized for maximum bollard pull -- around 5,500 lbs. -- when trawling.

A small 4 kw diesel generator set provides 240V or 110V power for domestic appliances. It can also supply 12V D.C. to the batteries in addition to the main engine alternators. Either or both engines can be fitted with a hydraulic pump to operate such equipment as anchor winch, trawl winch, long line capstan winch, etc. The anchor itself is self stowing locking in under the fore beam. The chain drops into a self-draining locker in the wing deck.

Additional self-draining lockers are provided in the wingdeck leading edge and the whole area acts as a permanent ventilation system forcing air via baffles into the forward cabins.

The cockpit has a full bench behind the cabin containing an outside steering station sheltered by a spray/sun dodger roof and windscreen. All sail controls lead to this area so that one person can set sails, roller reef headsails, adjust sheets, etc. without any problems.

The mast aft rig makes the mainsail small and easily handled. It needs reefing only in extreme conditions. The two headsails are intended to be operated independently. Both are fitted with roller furling/reefing equipment. The larger headsail is of light cloth to assist setting in sloppy light wind conditions. The other sail is a general purpose sail which operates over a full range of wind strengths being progressively reefed to storm jib size. The boat will sail under this sail alone which makes it ideal for lazy people.

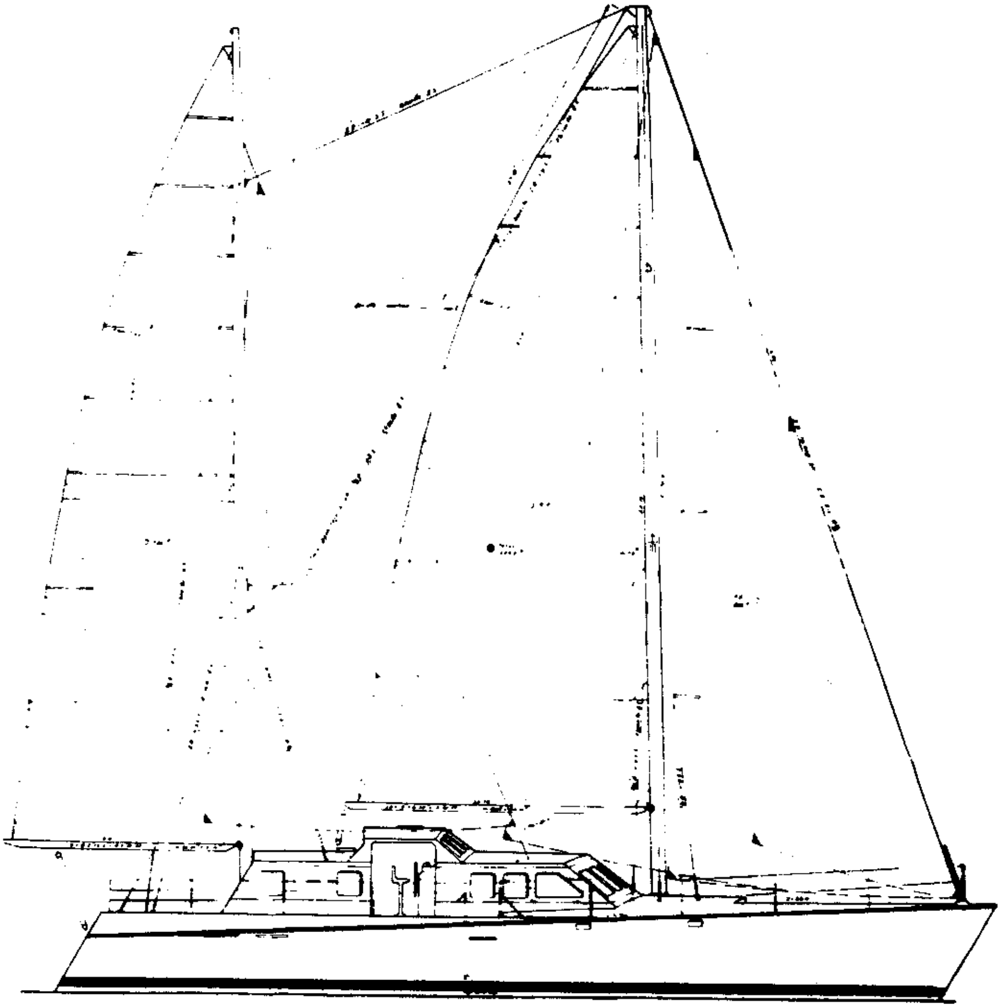
If desired, a section of the cockpit floor is designed to drop down below the waterline to form a dive platform.

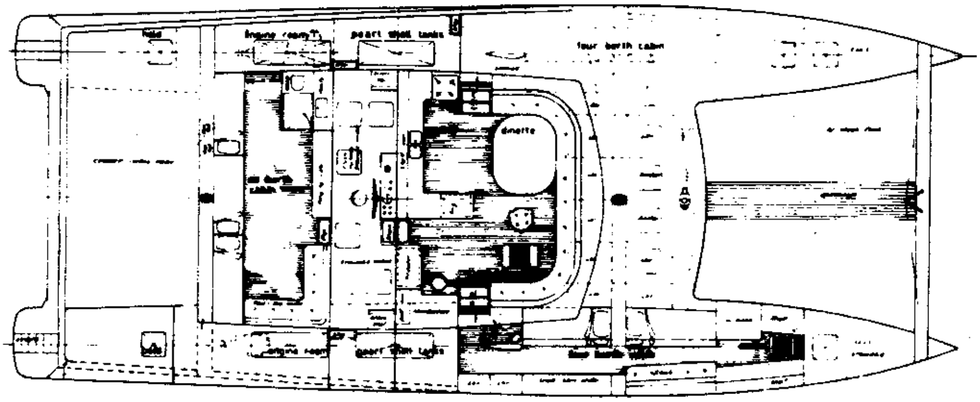
Oil cargo tanks are incorporated into the bilges providing 3900 litres of additional fuel capacity. These tanks are intended to be used to transport fuel oil to remote areas. They do provide an incredible range under power and along with the sails make her a true ocean passage vessel.

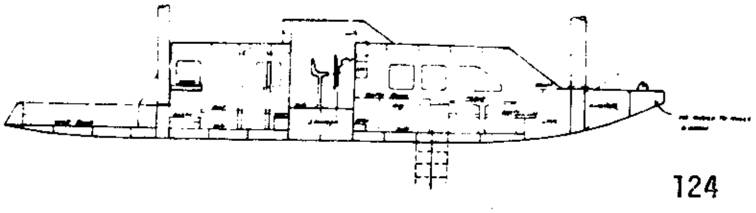
The hulls are fitted with long skegs allow the vessel to be beached for antifouling and protect the rudders and propellers. She draws about 3'-7" making her ideal for shallow reef strewn areas.

Experienced amateurs can fairly easily learn to work in aluminium and in fact many of our designs are currently under construction by amateurs in this material. For large boats (45 feet up) it has proven the quickest, cheapest lightweight form of construction available. Corrosion is negligible and provided care is taken to avoid electrolysis, the maintenance requirements are minimal. It is incredibly strong and light and should you run her aground, the worst that can happen is a few dents.

DMB



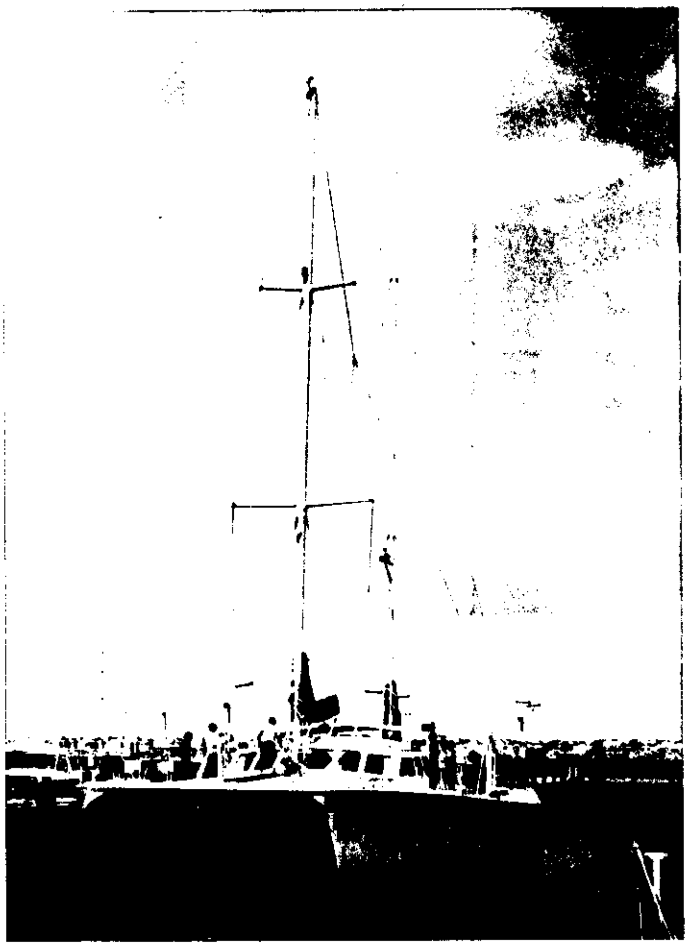


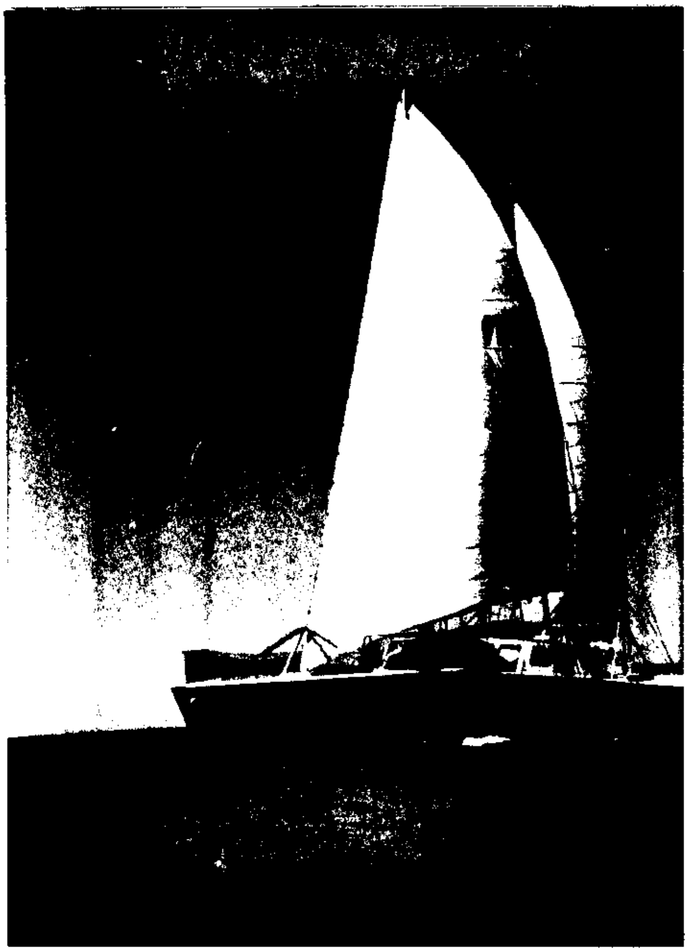


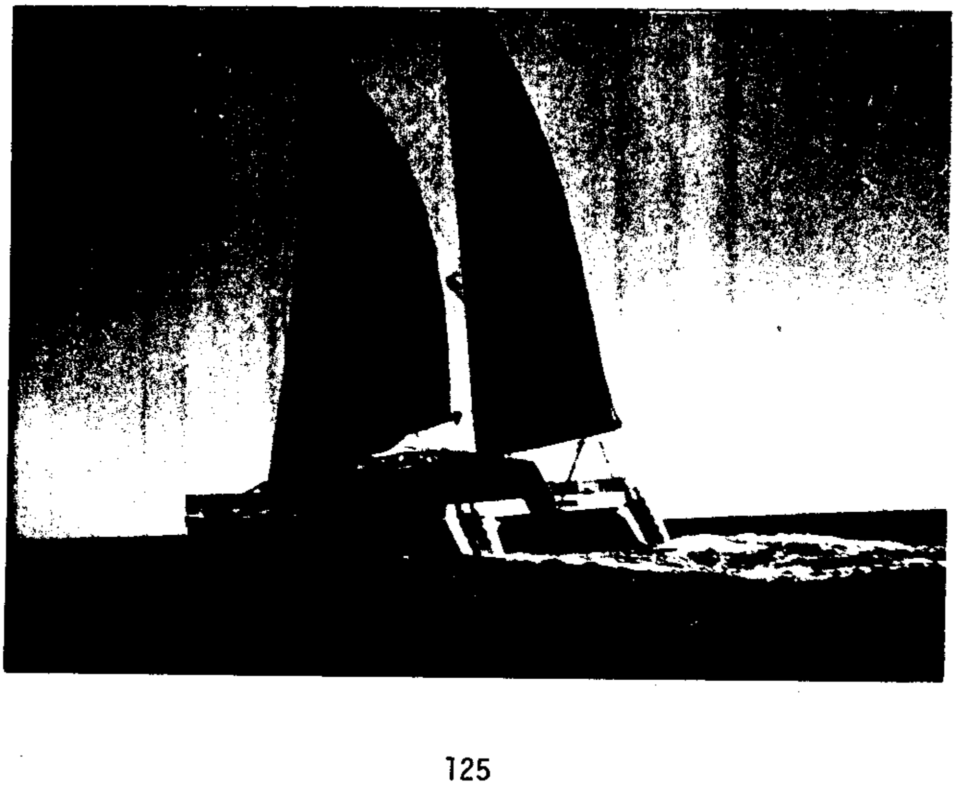
"DMB"

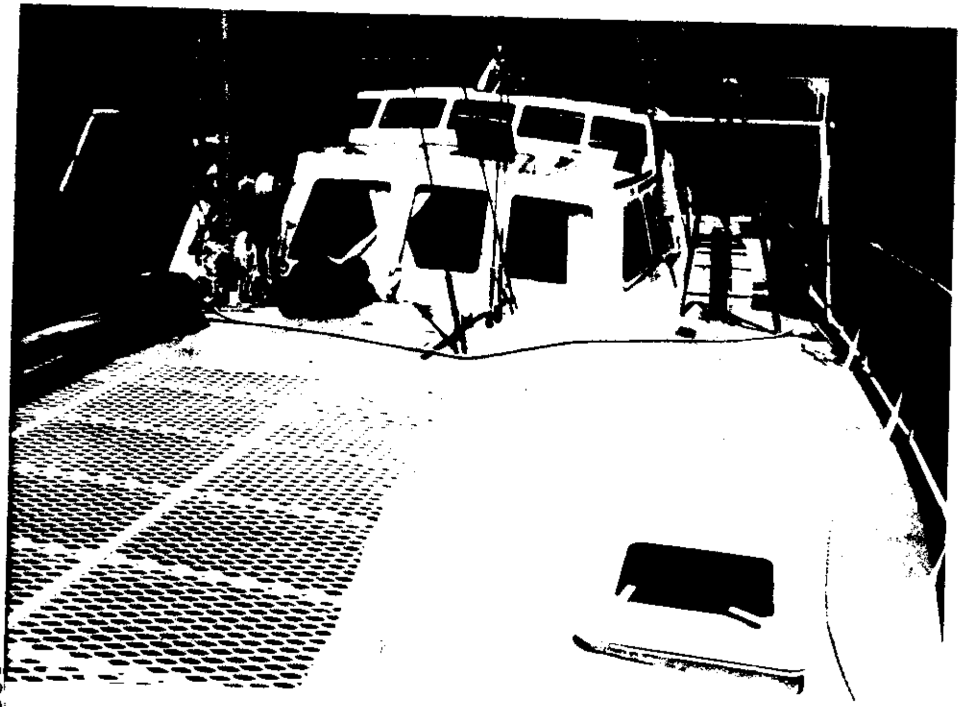
SPECIFICATIONS:

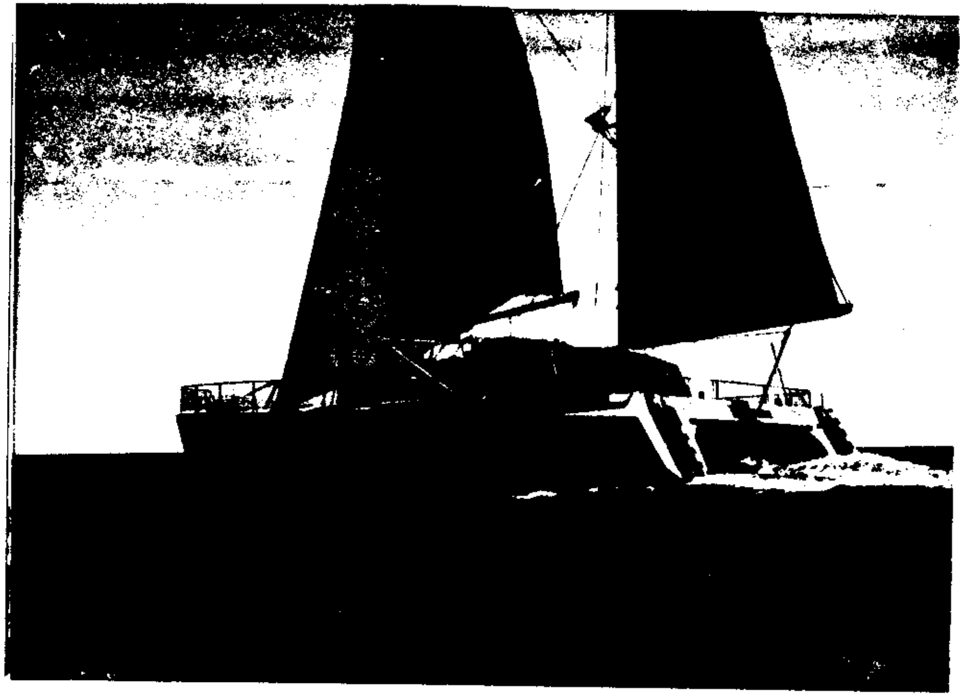
Name: "DMB"
Type: Pearlshell diving vessel, carrier boat, accommodation platform and display emporium. All aluminium, diesel powered sailing catamaran.
Owner: Cygnet bay Pearls Pty Ltd, Broome, WA
Designer: Lock Crowther, Turramurra, NSW
Builder: SBF Engineering Pty Ltd, Naval Base, WA
LOA: 73'6"
DWL: 69'.0" (21.03 metres)
Beam OA: 30'9"
Measured depth: 8'9"
Draft DWL: 4'0"
Displacement empty: 38,000lbs, DWL: 60,000lbs, loaded: 78,000lbs
Cargo capacity: 32,000lbs seawater and 4,500lbs pearlshell
HullL/B DWL: 11.68
Power: 2 x 27 shp Perkins diesel engines
Propellers: 2 x variable pitch
Gearboxes: 3:1 reduction
Sail Area: 2443 sq. feet with 1 genoa 2798 sq. feet
Max. stability: DWL 690,000 ft lbs
Cruising speed under power: 9 knots
Range: 1,350 nautical miles
Construction: multi chine welded aluminium to Bureau Veritas and USL
Accommodation: for 14+
Wet tanks: Re-circulating to carry 4,500lbs of live pearlshell
Fishing equipment carried: 'Hookah" diving gear for four peal divers
Area to be fished: North-western Western Australia
Electrical installation: By B&H Electrics of Perth
Hydraulic Equipment: Manufactured and installed by M&J Engineering
Sails and rigging: From Rolly Tasker of Fremantle
Sail Winches: Barlow, Australia — "Handraulic"
Fishing winches: M&J Engineering — Hydraulic
Propellers: Westmeaken controllable pitch from Antelope Engineering, Sydney.
Auxiliary engine: MWM Australia
Aluminium: Comalco
Echo sounder: Furuno color
Radar: JRC
Satnav: NCS
Radio: SSB Codan
Auto pilot: Cetec Benmar

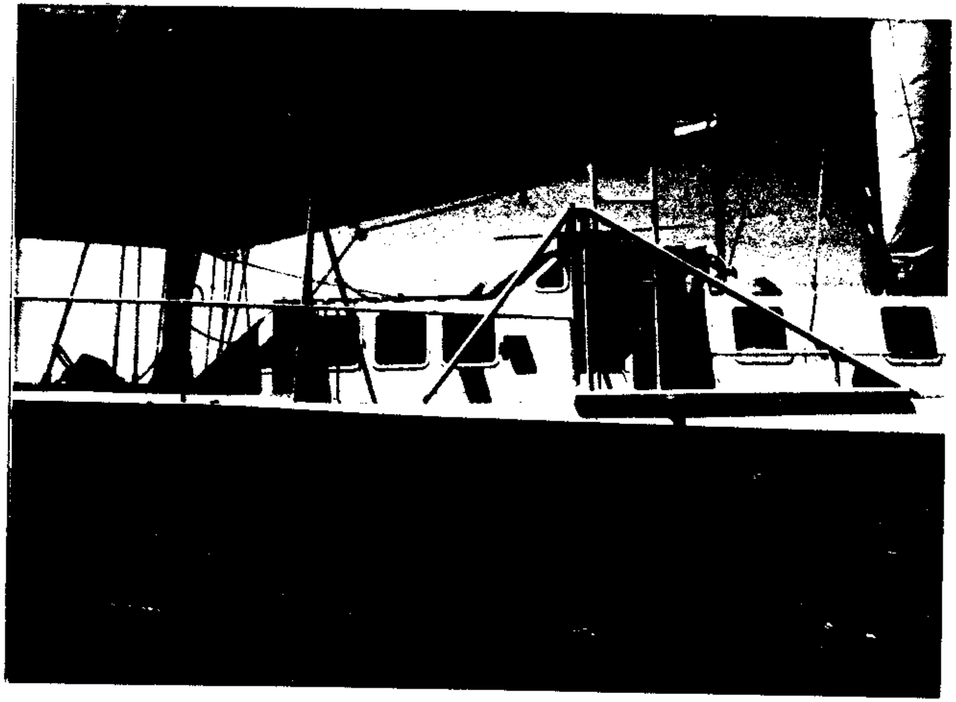


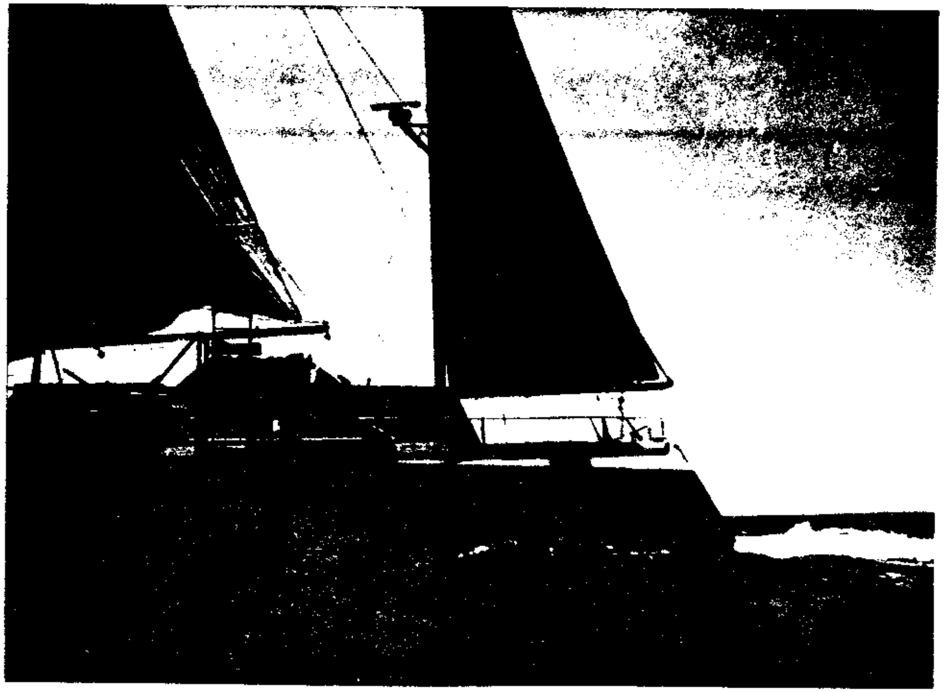












A State of the Art Sail-Assisted Fishing Vessel for the Third World

Frank Crane, Director Aquarian Research
David A. Olsen, Ph.D., Director, Thompson Management, Inc.
August Ciell, Beeline Seafoods
Thompson Trawlers
3000 N. Atlantic Ave.
Cocoa Beach, FL 32931

The modern era of fisheries development has been marked by an increasing awareness of energy efficiency. As petrochemical prices have continued to rise, energy efficiency has become nearly a developmental equivalent for economic efficiency. At the same time, population pressures have increased the demand for marine protein so that the harvest of underutilized resources has become an increasing priority. In developing nations, the quandary between need for protein and deficit balance of payments created by petrochemical imports has plagued all concerned.

One solution to these problems involves the reintroduction of sail as an auxiliary power source. We say auxiliary here because sail alone tends to limit access to the resource, both temporally and geographically. As an auxiliary, sail simply enhances profitability of existing fishing operations. Although there has been much discussion of the sail assist concept, much of it has centered on the reuse of historical hull forms and sail plans. Effective reintroudction should utilize the tremendous body of engineering data available if an efficient hullform, and a workable sail plan, are to be cpmbned into a functional fishing platform for use in today's fisheries.

Today I would like to discuss one such effort to develop a fishing vessel which can attempt to address these concerns. The vessel in question is the 38' sail assisted multi-purpose fishing boat developed by Aquarian Research.

Some background on the history of the project may be of interest in order to bring out the degree of collaboration between state of the art sail and fishing technologies that has been employed. The genesis of the project came from the U.S. Virgin Islands Saltonstall Kennedy funded fishery project. Information and experiences gained there, and throughout the Caribbean, indicated that, although many of the more developed areas were converting from sail and sail assist to pure engine powered fishing boats, this conversion was not being successful.

The reasons for this lack of success were various and included:

1. Small outboard powered boats, which extend the range of fishing activities, have proven unreliable and expensive to operate.
2. Larger inboard powered vessels were expensive to purchase and operate.
3. Expansion of fishing activities resulted in resource over exploitation which made the vessels become uneconomical.
4. Increased fuel utilization created economic problems within

the country in terms of hard currency necessary for petrochemical imports.

The boat design criteria, then, were set out to deal with these problems. It was our goal to produce a boat which could operate in conditions ranging from primitive low technology environments, and yet still sompete with the high technology approach that we take with the remainder of our domestic fleet. The design addressed the following areas:

1. Range of operations - instead of relying on boat speed to expand the area of fishing operations, we chose to work on a design that could spend longer periods at sea comfortably and refrigerate the catch.
2. Fuel efficiency - Although designed as a sail assisted boat, fuel efficiency under power was incorporated into the project through efficient hull form, size and low horsepower requirements.
3. Resource limitation - The boat is designed to be fished in a variety of resources, allowing maximization of returns through utilizing a variety of resources.

The basic design criteria selected are in Table I.

We felt the optimal vessel could be developed from these general specifications.

The boat specifications to meet these criteria are shown in Table II.

The design by Robb Ladd N.A. incorporates a shallow canoe body with a high center of buoyancy and a low center of gravity to insure a most stable hull form. By using modern hydrodynamics, and an approach using beam as a dimension towards cargo carrying capability, and an aid towards stability, we were able to exceed our original goals.

Boat speed and performance are greater than anticipated by our computer analysis.

We constructed a C-flex plug of hull and deck, and built a split hull mold, deck mold and various small parts molds for the production of the boat.

The FRP lay up was designed to A.B.S. commercial standards and uses the newest P.P.G. fiberglass products. All materials are applied by hand to maintain the highest quality laminate. Longitudinal and transverse framing are high density foam covered with glass. The bulkheads are marine fir or cored fiberglass.

The hull to deck joint is first mechanically fastened, and then heavily glassed together.

The ballast is 7000lbs. of lead within the keel encapsulated in glass.

The rudder is FRP shell over a S.S. rudder stock with provision for a tiller on deck.

All metal is of marine grade alloy to cut maintenance dollars.

To date, four boats have been completed. The first has served as prototype for testing various fishing gears. It has bottom longline shrimp and groundfish trawl and trolling gear on board. The second is similarly equipped and is being employed under a lease arrangement to the Virgin Islands Government in a program of exploratory fishing. The other two are working as productive members of the Thompson Management Fleet.

Performance to date has been extremely encouraging.

To date, we have logged hundreds of miles in our prototype in all weather conditions and in a variety of fisheries, captained and crewed by non-sailing fishermen. Except for its maiden voyage, the boat has performed beyond our expectations, i.e. in very light air, 4-7 knots real wind, she sailed to windward and came about smartly and close reached very well at 3-4 knots using a 3 blade fixed prop with a moderate cargo load.

We have engaged the prototype in various fisheries during field tests with good results in each type:

1.) Bottom longlining using 5 miles of line set in the Gulf-stream current. Setting up to 3500 hooks per day, this operation is normally carried out with the engine running, for safety, so the boat can be stopped quickly.
2.) Trolling under sail using 4 lines, 2 on outriggers and 2 over stern.
3.) Trawling has been done both under power and under sail using the engine for hydraulics only. We were able to set 56' shrimp nets and doors, and tow at 2½ knots plus retrieve nets and doors in 20-25 knots of wind.
4.) Surface longlining, traphauling, vertical set lines seining and gillnetting have not been tried although we have both the deck space and manueverability to accommodate these fisheries.

The prototype boat is equipped as a high technology fish boat, incorporating sophisticated elctronics and hydraulics to power the fishing gear.

Electronics include a 2000 watt color scope fish finder, a radar with radarwatch to aid in navigation and positioning, a Loran-C with computer A, speedo/log, sea temperature gauge to aid in pelagic fish locations and raid telephones. Additional equipment under consideration is a Satnav and Weather Fax to obtain ocean surface water temperature maps.

Our sailing gear includes a Hood roller furling headsail and a stow-away mainsail system so that the sails can be easily and efficiently handled by one man. Sheet leads were kept simple and straightforward to a common winch area that does not interfere with fishing operatings.

We opted not to use a self tending jib on our prototype, although this is easily installed and gives even less chance of interference to fishing.

The fishing gear includes 2 trawl winches and 600 ft. of wire on each, a longline reel with 5 miles of wire and a trap haul/windlass for pulling traps, hauling in the bag and hauling the anchor.

We have a gallows frame on the aft deck which provides us with two points for trawling and allows easy maneuverability. This also provides us with attaching points for the backstay from the mast and sheet for mainsail, which keeps these things well above deck level.

Boats in remote areas may be equipped with less sophisticated, yet very reliable, electronics. A typical set up might include a white line recording fish finder, sea temp, gauge, and VHF radio or C.B. radio. Sailing gear could include rollover furling or hank on headsail and a slab reefing traditional mainsail.

The fishing gear could be powered by D.C. or a simple belt driven hydraulic pump depending on the fishery in which the boat will engage.

We currently have under development for us a small self powered salt water ice machine that will produce 500 to 800 lbs. of soft ice/24 hrs. This unit will allow longer trips, and will be able to land a better product.

Maintenance costs are minimal, and we are extremely pleased with the performance to date. Its sail performance ability has been tested in both light and heavy weather. Aquaria I has been to, and returned from, the Bahamas in 35 to 40 knots of wind in November, and has fished since January in conditions ranging from 0 to 65 knots. Aquaria II was delivered to the Virgin Islands in 35 knots of wind.

These trials have shown us that we have a stiff, stable working platform that will sail as close as 40° to the wind. She handles well in all conditions. We were particularly concerned that its design would perform well in light weather, since much of the world's fisheries are found in light to moderate airs. The design minimizes wetted surface, and the propeller location maximizes thrust and has doen well in light airs.

Fishing performance has been extremely encouraging. When compared to our fleet of 60 to 90 foot longliners and trawlers, the economic advantages are obvious. We are currently adding a total of three of the series to our fleet operations.

Finally, although final evaluation is ongoing, we are becoming increasingly convinced that the operating efficiencies and catching power of our sail assist will significantly improve the profitability of our fleet operations.

TABLE I

DESIGN CRITERIA FOR SAIL ASSIST FISHING BOAT

1. 34′ - 38′ L.O.A.
2. HULL SPEED 7½ - 10 KTS.
3. FUEL CONSUMPTION OF 1 GPH OR LESS
4. FISH HOLD FOR 5000 LB. ICED FISH
5. 175 - 200 GALLONS OF FUEL
6. 60 - 120 GALLONS OF H_2O
7. 2 MEN - FISH/SAIL
8. ACCOMODATIONS FOR 3 - 4 MEN FOR 4 - 7 DAYS
9. SAIL AREA ENOUGH TO PERFORM IN HIGH TO MODERATE WINDS
10. REASONABLE WINDWARD PERFORMANCE
11. TRUE MULTIPURPOSE CAPABILITIES
12. BOLLARD PULL OF 3500 LBS. OR BETTER

TABLE II

SPECIFICATIONS
FOR
AQUARIAN 38′ SAIL ASSIST MULTI-PURPOSE FISHING VESSEL

L.O.A.	37′6″
L.W.L.	33′4″
BEAM	13′0″
DRAFT	5′0″
FISH HOLD	6,500 LBS.
WORK DECK AREA	260 SQ.FT. (APPROX.)
FUEL CAPACITY	240 GAL.
F.W. CAPACITY	100 GAL.
SAIL AREA	734 SQ.FT.
HULL SPEED	8.5 KNOTS (APPROX.)
ENGINE	PERKINS DIESEL 4.L08M 50 HP
BALLAST	7,000 LB. LEAD

A MODERN PRACTICAL SEAMAN'S VIEWS ON COMMERCIAL SAIL

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ABSTRACT AND INTRODUCTION

Firstly, in Part I it is intended to consider and compare the rigs that may be used on fishing boats and possible means by which fishing boat performance may be increased, and in Part II, rigs for what are defined as fishing ships will be considered. Finally, it is proposed to look briefly at the rigs under serious consideration for larger commercial vessels such as ocean going passenger cruise liners and cargo ships. The effort going into this field may encourage fishermen to consider sail more seriously as an alternative source of motive power for their craft and stimulate some discussion at this meeting.

GENERAL

All forms of commercial sail have been much considered and talked about over the last ten years and various symposiums have been organised, doubtless encouraged by the rapid rise in fossil fuel costs in that period.

It has been said that if it could be harnessed, the hot air generated at these symposiums would drive a fleet of supertankers from Europe to the Persian Gulf and back again. Sadly, however, there has been more talk and more papers read than actual full scale experiments carried out.

We are considering here "Commercial Fishing Vessels", and it is contended that these need to be divided into two classes. Where to divide them is a problem. Straight length or tonnage is bound to be arbitrary and produce anomalies, and so it is proposed to use the definitive point used to explain to landsmen the difference between a ship and a boat in that dim and distant past when the writer was a boy. It was said then: "A ship is a vessel which can carry a boat in davits".

Generally speaking, by this definition it follows that a ship is usually a vessel able to accommodate her crew on board for a voyage lasting several days. In measurement terms, a boat by the above definitions will seldom exceed 35 ft. (10.67 m.) in length, and any sails fitted can be relatively simple and unsophisticated, but on the other hand, the sails found on many small craft in under-developed countries can be much improved at small cost and as a result, greatly increase the practical and financial viability of many fishing communities.

Care has to be taken with regard to the improvements proposed, and it is contended that they must be inexpensive and hard wearing, virtually unbreakable and easily repairable with local materials. There used to be a saying in Africa amongst the farmers when referring to their unskilled labour force: "Give them the job and they will finish the tools", (with apologies to Winston Churchill). It is worth bearing in mind.

Some twenty years ago in Jamaica there was a grand Government scheme to make loans to fishermen to buy outboard motors for their fishing canoes. It was pointed out that this would enable fishermen to reach their fishing grounds more quickly each day, spend longer fishing and return more quickly before dark. It did not work that way. Once in possession of the motors, the fishermen stayed in bed longer, speeded out to the fishing grounds, fished for the same time as before and sped back. Then they found that petrol had to be paid for, repairs were costly and the loan still had to be repaid from the same income as before. This is obviously the sort of situation which needs to be avoided.

PART I

RIGS FOR FISHING BOATS

In this section as defined above, we are considering craft up to around 35 ft. (10.67 m.).

It goes without saying that all forms of square rig are unsuitable and, except possibly at the top end of the scale, only single masted rigs are worth considering. These are listed below with comments.

BERMUDAN SLOOP

An efficient sailing rig, but requiring a tall mast for optimum efficiency, it is only considered at all suitable for smaller craft where its disadvantages even then will tend to militate against it. Roller furling increases its handiness but also its expense and vulnerability.

GUNTER RIG

The gunter and sliding gunter rigs give almost the same result as the bermudan sail with the advantage of not having to have such a tall mast. It is still a somewhat "yachty" rig and not really recommended for a working boat, except in special circumstances.

DIPPING LUG & LATEEN RIG

These two rigs are extremely close to each other in practice, although their origins are different. Since they can be set on a short simple mast and have a minimum of working gear, they are highly recommended. As a working rig they are efficient to windward and easy to operate. Spars can be made from local material and rigging from readily available stocks. Lateen rig has been very popular for 2,000 years in the Mediterannean.

STANDING LUG

Generally this rig requires a headsail of some sort in addition to itself, and also needs a slightly taller mast. It would appear to have no advantage over the dipping lug or lateen.

SPRITSAIL

A very early form of fore and aft rig which has found favour in many countries. In a highly developed form it was to be found until very recently in the 100 ton working cargo barges of the River Thames in England and was also found in the Baltic and is frequently seen in fishing canoes in the West Indies.

It particularly lends itself to that type of rectangular sail popular in many under-developed countries where the area is not measured in square feet or square metres but in flour bags, since these are the source material for local sailmaking.

JUNK RIG

This rig in two or three mast versions (depending on the size of the craft) is one that is extremely popular with its devotees. Its main disadvantage would appear to be the expertise required in sailmaking. Doubtless this is easily found anywhere between Singapore and Japan, but a considerable education programme would be required to provide the sails (and the crews to handle them) in other parts of the world. It is highly recommended within these limitations and also with the thought that it will not always be easy to install the strong unstayed masts in craft which were not originally conceived to take them.

LJUNGSTROM RIG

This is so efficient as a sail plan, both to windward and downwind (when the double sail is goosewung), that it is felt that some effort could be put into mass producing those parts which are relatively difficult to make in unsophisticated communities.

The ease with which sail can be shortened or furled entirely has to be experienced to be believed, and when furled, the sail is entirely clear of any working area. (Fig. 1).

The main requirements for manufacture are the mast heel fitting and the relatively friction-free deck fitting. Well made masts would be a further advantage, but locally made ones should be adequate.

It is thought that a package could be put together containing a mast thwart (with bearing) of adjustable length having a leeboard or a fitting for a leeboard at either end plus the heel fitting with a mast and sail as optional extras.

The combination of an aerodynamically efficient sail which is ridiculously easy to furl or reef, plus the addition of leeboards, could dramatically increase the performance of the dugout canoe and similar craft which are to be found in many under-developed countries.

OTHER RIGS, DEVICES AND MODIFICATIONS

There are, of course, many more modern sophisticated devices - wingsails, rotors, kites and the like and modifications to the main theme such as bipod masts and wishbone spars, but the view has been taken in this paper that such refinements would be either uneconomic or too tiresomely sophisticated for fitting in small fishing boats in general.

(In any case, none have yet been encountered by the author with any overall advantages over the Ljungstrom rig which was invented in the nineteen thirties).

Doubtless that was the view taken by old salts like me when the idea of putting engines of any sort into fishing boats was first suggested, however, one must remember that fishing boats - even sailing craft up to 100 tons and more - were still being built without engines over a hundred years after the first mechanical driven vessels first frightened the horses on the canal banks.

ENCOURAGING THE USE OF SAIL

The small boat fisherman in an under-developed country is not interested in the niceties of sail. To most, its adoption is a retrograde step or a sign of poverty and even stupidity. He wants a simple and reasonably efficient method of propelling his craft and he will frequently need considerable convincing that sail has any value, whatsoever. Some who use primitive sail will see no virtue in improving its performance.

Within the last few years, when many deep sea fishing vessels could not sell their catch for sufficient money to pay for the fuel used during the voyage, the Technical Director of the State owned authority responsible would not even discuss the possibility of using auxiliary sail, but dismissed it as "an absolutely useless idea".

Sixty years ago when sailing fishing boats of all sizes were still common, there used to be an annual race and considerable honour went to the winner. The race encouraged owners and skippers to improve their boat's sailing performance and even to express an interest in speed under sail when building new craft.

The famous Brixham trawlers raced well into the 1930's and the annual race between American and Canadian Grand Banks fishing schooners had a great effect on the design and rig of these vessels in both countries. Even those craft not seriously interested in becoming "Cock of the Fleet" nevertheless followed the successful trends of their faster sisters.

Perhaps some establishment of local competitions for performance under sail could be attempted if only to demonstrate the very considerable difference in time taken over even a relatively short distance between one sailing craft and another. If the prizes were sufficiently substantial, the effort to improve the speed of many fishing craft would be substantial, and if it was possible to encourage International or inter-area competition, then imitation of the winner would result in general improvements to rig and hull designs with consequent overall benefit.

CONCLUSION ON RIGS FOR FISHING BOATS AS DEFINED

It is contended that where it is practical or possible to fit it, the Ljungstrom rig will give the best all round performance coupled with the greatest ease of handling.

Sailing, reefing and furling can be carried out by the helmsman in minimal time without any aid from other crew members in all craft up to 35 ft. (10.67 m.) in length (and even beyond) which covers all craft in the category under discussion.

The rig also offers the minimum of interference to the main activity of the boat - fishing.

Some cost will be involved in fitting the gear initially, but it is contended that this would be less than the cost of an outboard engine, and its running cost and repairs would be somewhat less.

Goosewinging the sail before the wind overcomes the natural shortcoming of fore and aft sail when running by doubling the sail area spread.

Second choice would be the dipping lug which has a slight advantage over the true lateen since reefing can be arranged more easily.

Of the other rigs, the spritsail, when modernised a trifle (as has been done by Mr. Gifford), is probably the best, with the remainder only finding favour amongst their own particular devotees.

IMPROVEMENTS OTHER THAN IN RIG

As has been indicated in the "Ljungstrom package" referred to above, improvement in sail performance to windward can also be achieved by the addition of leeboards, centre-boards and dagger plates. Improvements in stability of narrow craft can be achieved with outriggers or the encouragement of catamaran or trimaran hulls, and these latter have the advantage of increasing deck working space for fishing.

For very small canoe type craft, a form of sliding seat to enable the crew to "sit the boat out" and act as moveable ballast will increase the sail carrying power of the craft and thus her speed.

Ultra-violet light has a very deleterious effect on most types of cloth (including dacron), but there is now a sprayed on material which - it is claimed - much reduces this effect. If such material, and the equipment to apply it, can be made available at a nominal cost, the life of sails may be considerably extended. Fishermens cooperatives or Government departments responsible might buy the material in bulk and loan or hire the spraying equipment as required.

ENGINE REQUIREMENT

Where an engine is considered a necessary part of the boat's equipment, it need only be of very small size to enable a moderate speed to be achieved in flat calm and entrance and exit from harbours to be executed with ease. By the same token, fuel capacity need only be enough for the above requirements

PART II

RIGS FOR FISHING SHIPS

This heading seems rather self-important, but we use the word "ships" as defined above, and thus consider all vessels above 35 ft. (10.67 m.) in length. Apart from fish factory and mother ships, the upper region for vessels under consideration will probably be around 120 ft. (36.58 m.). Those interested in sailing rigs for vessels over 120 ft. (36.58 m.) in length will be interested in Part III of this paper, where current ideas for sailing rigs on commercial passenger and cargo ships up to 400 ft. (121.92) will be discussed.

Let us now view the possibilities:-

SQUARE RIG

(a) Ship, Barque and Barquentine

Since we are taking our upper limit as 120 ft. (36.58 m.) on deck, these three rigs are really out of court, although at the top end of this bracket we are nearing the point where they might be considered, and they will be discussed in Part III.

(b) Brig and Brigantine

For general handling under sail, no argument is put forward for either of these rigs for installation in fishing craft. Historically there is little trace of them being used for fishing except in the whaling trade and among the trans-Atlantic Grand Banks vessels where even ship rig was occasionally found. If any fishing operation called for a vessel to heave-to and remain virtually stationary, then square rig would have some merit.

TOPSAIL SCHOONER

Although not technically a square rigger since only a square topsail is set, the same lack of argument in favour of this rig applies as for square rig. Traditionally the French Grand Banks Fishermen were two-masted gaff topsail schooners with the deep topsail fitted on a double yard, the lower one of which acted like a roller blind to roll up the square topsail for either reefing or furling.

The existing pair of sail training ships attached to the French Naval Academy at Brest are perfect examples of this rig, but again, no supporting argument is offered for this rig for fishing craft. (The square topsail and a "drabbler" set below it may well have been useful on passage to and from the Banks.

TWO AND THREE MASTED SCHOONER

Up to about 100 ft. (30.48 m.)two masts are suitable, but above this three masts become gradually more necessary. The detailed rig on each mast can vary with the choice of bermudan, gaff and staysail rig. Some sails can be fitted these days with "off the shelf" roller furling and reefing gear which makes for easy handling.

Taking all in all and seeking a reasonable compromise between windward and downwind performance, coupled with simple handling, the rig prescribed for the MICASS (Mini Container Auxiliary Sailing Ship) is recommended. (Fig. 2).

The area is 5,000 sq. ft. (465 sq.m.) which according to formula * will provide 200 BHP in wind force Beaufort 5 (not contrary), and this is the same as the output from the two diesel engines driving the twin screws. Under these conditions and with stronger fair winds, the vessel can rely on sail alone, while at lower wind speeds (or if the wind is contrary), one or both engines may be used as required. To compensate in part for the poor performance of fore and aft sail with the wind right aft, a second roller headsail is provided which may then be goosewung (set on the opposite side) to increase the downwind sail area. A simple form of spinnaker boom may be used to improve the spread.

It can be seen that the rig leaves the decks well clear for fishing work and at the smaller end of the size scale, the middle mast could be dispersed with entirely.

Roller furling and reefing gear, both hand-operated and power driven, is readily available depending upon the degree of sophistication required, and by making all the staysails identical in size, the provision of a spare is simplified.

As stated above, the ability <u>in this size of vessel</u> to provide a usable horse power from sail alone equal to that designed to be provided by the engines promises a very considerable fuel saving in general service, depending finally on the weather encountered and the attitude of the skipper. Conservatively it is predicted that fuel costs can be cut by half, but this will depend to some extent on the type of fishing being undertaken.

It is worth noting that the recent Brittany Sailing Tunny Fisherman project produced vessels very similar to the MICASS in rig and deck layout but appreciably smaller. They were expecting very large fuel savings, but to date the reports after actual service at sea have not been seen.

OTHER FORE AND AFT RIGS

At the smaller end of this range, bermudan ketch and Ljungstrom rig are possible contenders, and claims have been made for the potential use of the latter in large vessels, but no actual examples of this rig in vessels over 40 ft. (12.19 m.) have actually been sighted. Junk rig is to

* 5,000 sq. ft. (465 sq.m.) of sail = 200 horse power in Beaufort 5 not contrary, generally assumed to mean 100 horse power on average.

be found in the Far East in vessels of 100 ft.(30.48 m.) and more, and the only objections would seem to be those expressed in Part I. It would certainly be interesting to see two similar vessels - one junk rigged and one rigged as the MICASS - so that their initial cost, running cost and overall practical efficiency could be directly compared on an operational basis. It would be surprising if, today, the junk rig would show any substantial overall advantage, although it can be readily seen that before the advent of easily obtainable roller furling gear, the junk rig had some distinct benefits. After all, it has had a couple of thousand years to develop and be refined.

INFLUENCE OF FUEL PRICES ON USE OF WIND POWER

Every time that the price of fossil fuel takes a violent leap upwards, attention is focused on harnessing the wind power which is so frequently referred to as being "FREE". Yes it is free, but sadly it is not constant either in strength or direction, and the means of harnessing it are by no means free and generally require more manpower to produce a quantity of horsepower than an internal combustion engine. In these days of unemployment, this could be a further benefit, but employers do not always take that view.

At the moment we are seeing a slight fall in the price of crude oil (which is likely to be only temporary), but a glance at the spot price of gas oil over the last ten years shows the continuous rise in price overall with two sudden leaps upwards in 1974 and 1979. These prices were actually taken at Southampton, England on the first of June, and the assistance of the Esso Petroleum Company, London is gratefully acknowledged.

June,	1971	$39.12	per	tonne	
"	1972	$40.44	"	"	
"	1973	$47.80	"	"	
"	1974	$130.35	"	"	(increase of roughly 200% from previous year).
"	1975	$127.00	"	"	
"	1976	$137.90	"	"	
"	1977	$141.90	"	"	
"	1978	$136.40	"	"	
"	1979	$390.00	"	"	(increase of roughly 200% from previous year).
"	1980	$334.00	"	"	
"	1981	$305.00	"	"	
"	1982	$310.00	"	"	
Feb.	1983	$295.00	"	"	

All prices are in U.S. Dollars per tonne, free of any tax, duty or delivery charge. Note that between 1971 and 1979 the price increased ten fold.

Sadly for the proponents of the use of wind power, the present pause in the rise of crude oil prices (and in fact the slight fall in prices of crude and refined oil) is used as an excuse for an outbreak of Micawberism amongst ship owners and operators. They appear to work on the politicians' motto - "Don't do anything unless you are forced into it".

On the contrary, it is contended that all fossil fuels are bound to rise in price - in real terms regardless of inflation - as the more easily recoverable deposits are worked out and it becomes necessary to extend operations to sources more difficult and more expensive to service.

To expend money now to research the alternative possibilities seems to be an imaginative and intelligent step on the same basis that some large and successful businesses automatically increase the budget for research following a year where profits drop.

FORECASTING THE BENEFITS OF SAIL POWER

About two hundred years ago when steam engines first made their - to some - unwelcome appearance on this planet, the engine makers had to devise a means of demonstrating to potential customers the benefits of purchasing and installing one of their infernal machines. They chose a method of comparing the work output of their contrivances with the major source of easily measurable power then available and understood. They called it "a horse power" and the term was in due course extended to cover mobile steam engines, and when in turn they were challenged by the internal combustion engine and the electric motor, ways of measuring the comparative output of these newcomers were devised, accepted and understood - more or less - by one and all.

No doubt if we still depended on water or wind power to grind corn and pump water, ways would have been found to describe in horse power the output of windmills and water wheels, but there has never been sufficient demand. (Perhaps it has been done in Holland).

Now some of us are advocating the use of wind power on fishing and commercial vessels - not for romantic reasons, but to lower the operating costs and increase the financial viability of these vessels, even to reduce the installed engine power.

Put yourself in the position of a shipowner considering building a new vessel and the question of her power unit. From previous experience and from qualified technical advice, he can discover the amount of power required for his projected vessel and then it is a simple task to draw up a table showing the various alternatives open to him. Manufacturers' brochures and available reference books will tell him the horse power, weight, size, fuel consumption, revolutions per minute and initial cost of all engines available. Coupled with opinions (his own and others) on the reliability and spares availability factors, he can make his choice.

If, perhaps, he is sufficiently imaginative and intelligent to consider fitting the vessel with equipment to harness the wind power, what similar information can he obtain?

Frankly very little. If his Naval Architect proposes some plan he may be able to get an estimate of cost and weight and, of course, fuel consumption is nil, but it is more difficult to obtain accurate information on the amount of man hours which will have to be applied, and sadly neither his own experience nor the Naval Architect's is likely to be of help. Worst of all, he can get no information on the practical horse power the equipment is even expected to provide, which usually results in his discarding the idea entirely. After all, who would spend several thousand dollars on an engine without knowing its horse power, let alone the other statistics?

There is, however, a simple rule-of-thumb formula to which reference has been made above, and it reads:-

5,000 sq. ft.(465 sq.m.) of sail in wind force Beaufort 5 (not contrary) = 200 horse power.

It has to be accepted that the wind will be contrary some of the time, and that at other times the wind will be less than force 5. To balance this it may be greater than force 5 at times, but sadly if it becomes too strong, it will be necessary to reduce the sail area spread on safety grounds and to prevent excessive heeling, but in this state a greater horse power than 200 will be generated.

On a moderate further rule-of-thumb basis, it is conservatively estimated that the 5,000 sq. ft. (465 sq.m.) of sail will produce 100 horse power on average throughout an operating period of twelve months with the variation in wind strengths and directions that the seasons and voyages will provide.

Whether highly accurate or not, this does give a yardstick on which to work and a reasonable means of forecasting the benefits likely to be obtained.

We have already quoted the MICASS design where the engine power is rated at 200 BHP and the sail area happens to be 5,000 sq. ft. (465 sq.m.) odd. On this basis we can reasonably expect to effect a saving of 50% on fuel costs over a twelve month operation. In fact, the saving should be greater than this, for although the engines are rated at 100 BHP each, they will, in fact, be developing less than this at cruising speeds.

The main advantage of this formula is that it provides a ready means of forecasting the sort of power that a designed sail plan will produce and enable a reasonable financial judgement to be made on whether to fit it or not.

There has been a case recently where a tanker company has decided to fit a sophisticated wing sail which has an area of 2,000 odd sq. ft. (186 m^2) and which - it is claimed - is twice as efficient as conventional sail. Applying the inventor's claim of double efficiency, this device is still only going to produce 80 horse power on average through the year, and is going to cost over five times as much as a conventional sail plan of 4,000 sq. ft. (372 sq.m.) which will produce the same power from the wind.

Furthermore, by relating the sail produced horse power to the engine produced horse power, and knowing the engines daily fuel consumption, coupled with her expected hours at sea in the year, the possible fuel saving in tonnes - and hence dollars - can be calculated with more chance of being correct than by previous guesses which were often wildly optimistic.

Some small effort with a ruler and pencil on general arrangement plans of various sized vessels will soon bring one to the conclusion that it is relatively easy to fit sufficient sail area of simple form to a vessel up to 100/120 ft. (30.48/36.58 m.) long to provide all the horse power required in force 5 and above.

Try again on a cargo ship of 2,000 tons and you will be able to provide enough horse power from sail to save ten per cent of her fuel.

Then try putting your sails on a 100,000 ton tanker and compare the theoretical sail horse power produced with the ship's engine power, and you will be very disappointed indeed unless you can fit masts of several hundred feet in length (solving all the engineering problems let alone meeting the cost), not to mention allowing for a method of passing under important and well known bridges.

Scaling up is therefore a serious problem and will be referred to again later.

RETRO-FITTING AUXILIARY SAIL TO EXISTING VESSELS

Due to the fact that today motor cruisers are of an entirely different hull design - both underwater and above deck - to sailing yachts, the belief has grown up in certain circles that sail cannot be retro-fitted to a vessel designed to be power driven.

Obviously care must be taken with stability and some results will be more effective than others, but generally speaking, retro-fitting is perfectly practical and again, generally speaking, the larger the craft the more so, (as far as hull design goes) up to say a length of 300 ft. (91 m.) when the scaling up problem referred to above begins to be encountered.

If the hull design of a sailing cargo carrier and a steam cargo ship of the 1920's (when the last sailing cargo carriers were built) are compared, there is indeed very little difference, while in the Mediterranean today, motor fishing and small cargo vessels are still built to designs used for a hundred years and more.

Possibly sailing performance might be improved by designing a hull for the purpose, but when talking of sail assisted commercial vessels rather than pure sailing vessels, retro-fitting of sails to hulls designed for power is generally perfectly practical.

Be encouraged by the fact that two of the most successful sailing cargo carriers in the last century started life as steam ships and ended their careers without engines as highly efficient sailing cargo ships. They were GREAT BRITAIN (now being restored at Bristol, England) and LANCING, long since broken up.

Incidentally, while GREAT BRITAIN still had her boilers and steam engines and a full spread of sail, she averaged 9.3 knots over twenty-seven voyages from England to Australia using steam 10% of the time, steam and sail 30% of the time and the remaining 60% using sail alone. A very creditable performance for a vessel 130 years ago.

Plans to retro-fit auxiliary sail to fishing vessels and coastal cargo ships have not encountered any problems with lack of stability, but the layout of funnel and superstructure has precluded the best type of sail area being proposed. Obviously if a vessel is being built to have auxiliary sail, this factor can be taken into consideration and the most practical solution found.

A further obvious financial and practical problem is the extent to which power driven winches are to be fitted to reduce the man power required for sail handling.

In our fishing boats (up to 35 ft. (10.6 m.), all the requirements can easily be met with inexpensive yacht-type hand winches, but, as the size of the vessel rises more and more, power winches will be required, and these will need to be self-tailing or of the drum-winding type so that they can be operated easily by one man.

While it is well known that the Almighty and his Son are the only Skippers who are able to sail directly into the wind (or even closer than having the wind 30° on either bow), it is not always appreciated that most sail plans are very inefficient with the wind directly aft. This is especially so with the types of fore and aft rig that are most efficient when sailing against the wind, and some thought has to be given to increasing the sail area when the wind is astern. This has been done in the MICASS with a second roller jib and other methods have been employed in other vessels.

With fishing vessels in the length bracket of say 35 ft. (10.6 m.) to 120 ft. (36.6 m.) we would recommend one of the variations of the fore and aft schooner rig with facilities for spreading additional sail area with the wind aft. Up to the present time, it is contended that this sort of relatively traditional sail plan can be as power productive as any of the more sophisticated devices while being far lower in capital cost and generally far less susceptible to mechanical and electrical breakdown. Doubtless some other interesting and contrary views will be expounded at this symposium.

PART III

A SHORT LOOK AT PLANS FOR THE USE OF SAIL ON OCEAN GOING PASSENGER & CARGO SHIPS.

GENERAL

During the last fifteen years a number of schemes have been put forward for the construction and operation of ocean going commercial vessels, and while no major scheme has yet come to fruition, it is highly likely that some will become reality within the next few years. The nearest project to commercial operation has been the conversion of the private yacht SEA CLOUD to act as an 80 passenger luxury cruise ship.

This traditionally rigged four-masted barque built as a wedding present for Marjorie Hutton by Krupps Yard in Kiel, Germany in 1930 has the following principal statistics:-

Length water line	253 ft. (77.2 m.)	Displacement	3530 tons
Beam	49 ft. (15.0 m.)	Engines	6000 H.P.
Draft	16.5 ft. (5.0 m.)	Sail Area	34000 sq.ft. (3160 m^2)
No. of crew	40	No. of passengers	80

She was originally designed to have two luxury suites (solid gold taps, marble baths and priceless antique furniture) for Edward and Marjorie Hutton and five other double guest cabins. The professional crew then numbered eighty.

Nowadays she accommodates some eighty passengers in this luxury accommodation and other cabins which have been added or converted, while her crew has been reduced to around forty.

She is reported to be operating on full bookings and is even reputed to be booked up ahead for more than a year, which does show that there is some demand for this type of luxury cruise ship, but no real attempt has been made to improve the sail plan or arrange it for a smaller crew.

Some of the other schemes which are merely in the design stage are now described briefly.

PROELSS DYNASHIP (See Fig.3)

This imaginative development of square rig was researched at length by Herr Proelss and others in Hamburg, and designs for both passenger and cargo ships proposed. The basis of the rig is the large diameter unstayed revolving masts with squaresails roller furling horizontally to the centre onto vertical rollers inside the masts.

Wind tunnel tests have shown the rig to be highly efficient, and at first sight it seems highly practical, but it is contended that some problems of maintenance and repair have yet to be solved, and some of the difficulties of dealing with the weights and strains of the large sails need further consideration.

For example, to maintain the high aerodynamic efficiency which is the main claim for this rig, some method of tensioning the sails vertically is required, since even modern man-made cloth does stretch in continuous use. Thus, some means of moving the yards vertically is required for this purpose and not yet available. There are other problems too in dealing with the recovery of blown out sails and their replacement when it is remembered that when rolled up, these sails could weigh around two tons and present a cylinder 30 ft. (9.1 m.) high with a diameter of considerable proportion.

The proof of the pudding must, in the end, be in the eating, and sadly up to now, no sizeable vessel with this rig has yet been put into service, and no rumour of an active building plan has yet reached our ears. It is thus difficult to be sure that this rig's performance will measure up to the theory.

WINDROSE SHIP

This project, masterminded by Captain Mike Willoughby, came within an inch of success recently when plans to build the vessel backed by a long term contract to carry bulk cargo from Europe to Australia and back fell through at the last minute.

Broadly speaking, this was a purely traditional rig with the vessel and rig enlarged to meet present day requirements, and making use of modern materials that were not available to the last generation of cargo carrying square riggers to be built.

The project was meticulously researched, but it failed, sadly, through the inability to finalise the cargo carrying contract which would have backed the building plan. This vessel would have been 450 ft. (137 m.) long of 16,600 tons DWT and powered by 66,700 sq. ft. (6,200 m^2) of sail and a 3,900 H.P. engine.

WARTSILA WINDCRUISER (Fig.4)

The famous WARTSILA shipyard in Helsinki, Finland (which leads the field in passenger cruise liner construction having built 30% of the cruise liners built worldwide in the 1970's) has taken the idea of sailing cruise ships very seriously, and has published a booklet on their design range which they call the WARTSILA WINDCRUISER.

The main statistics of their design are:-

Length overall	295 ft. (90 m.)	Sail area	14,000 sq.ft. (1,300 m^2)
Beam	43 ft. (13 m.)		
Draft	13 ft. (4 m.)	Speed under sail	10-15 knots
No. of passengers	110	Engines	2,000 H.P.
		Speed under engine	12 knots

The vessel is rigged as a three master setting three equal sized roller furling staysails and - according to the builder's publicity booklet - everything has been worked out on a computer, while another on-board computer will control all the sails and even reduce sail to maintain the angle of heel between 6° and 8°. Presumably the computer also told them that this was the optimum angle of heel for luxury class passengers paying $1,750 per week to be on board.

While it is grand to see a major shipyard putting out a convincing brochure showing the economic viability of a sailing passenger cruise ship, the practical seaman has some misgivings over the practicability of handling three outsize staysails of around 4,600 sq. ft. (427 m^2) each.

There will be problems in constructing the clews of the sails to take the sheet loading which will frequently be in the region of 10 tons, and double this in certain circumstances. The thought of dealing with a broken sheet on a dark and stormy night (or a bright and sunny day for that matter) fills the prudent mariner with alarm and despondency.

There will be problems in constructing the furling gear with sufficient strength to withstand the torque of reefing and the initial diameter of the roller, and the thickness of the sail cloth will make the diameter of the furled sail very considerable. When reefed, the Ljungstrom effect will be considerable and the dangers of unfurling the sail and refurling it in the opposite direction will be very considerable, and could well cause alarm and despondency not only amongst the prudent (and imprudent mariners), but amongst the paying passengers as well.

The ability of the sail area quoted to produce the predicted speeds <u>while maintaining an angle of heel of no more than 8°</u> is also considered doubtful. By formula, the sails will only produce 560 H.P. in wind force Beaufort 5, and in higher winds, an angle of heel will eventually be achieved which will enforce sail reduction. The ship's 2000 H.P. engines are only predicted as producing 12 knots, so it is difficult to believe that the sails are going to produce 10-15 knots even under favourable circumstances.

FRENCH DESIGN

A French yacht designer has produced a design for a 250 ft. (76.2 m.) 80 passenger sailing cruise ship which is rigged with three very high aspect ratio bermudan sails with accompanying genoa staysails.

While at first sight this looks an efficient and workmanlike yacht rig, the practical seaman views the handling of these large tall sails with some misgivings. If the jib and staysails are to be roller furling and reefing, the problems encountered by the WARTSILA WINDCRUISER will be increased even further, since the staysails are even greater, reaching 5,800 sq. ft. (540 m^2), and the very long luff length will make for even greater difficulties.

To most people used to yachts of up to 70 ft. (21.3 m.), the three bermudan sails look fine, but the problems of stowing them on the boom must be re-assessed when it is realised that the boom is at least 15 ft. (4.6 m.) off the deck. Even if footropes are provided and double sheets are fitted to prevent the boom swinging about, the sheer physical problem of handling 3,300 sq. ft. (306 m^2) of sail under these conditions needs to be tried to be appreciated, especially when a sudden Mediterranean increase of wind requires more than one sail to be lowered and stowed quickly.

It would seem that tacking and wearing (gybing) will be manoeuvers requiring three or four men on deck at least, in addition to the helmsman and officer-in-charge, and unless all the staysails and the jib are roller furled as the manoeuver commences, it would appear to be a rather noisy performance. When tacking, three staysails and a jib would be flogging (and in their sizes, that is pretty terrifying), while in wearing (gybing), one will be experiencing three sharp bangs as the three 3,300 sq.ft. (306 m^2) bermudan sails flick over from one side to the other.

Finally there is the matter of angle of heel. It is difficult to believe that this tall sail plan will not produce a significant angle of heel - certainly enough to spill a gin and tonic - in quite moderate amounts of wind, and it is doubtful if a very high performance willbe achieved under permanently upright conditions. Racing yachtsmen love skittering along with a boat sailing on its ear, but regrettably it is felt that $2,000 a week passengers may not appreciate this fun side of sailing - especially at meal times or during the cocktail hour.

ASTACE/COLIN MUDIE DESIGNS (Fig. 5)

Another contender in the coming "Sailing Passenger Cruise Ship" stakes is the interesting modernised three masted barque design produced by Colin Mudie, F.R.I.N.A. for the Spanish shipyard Astilleros y Talleros Celaya S.A. of Bilbao, which is normally shortened to ASTACE.

This yard has built four large square rigged sail training ships in the last twelve years, these being:-

GLORIA	1100	ton 3 masted barque for	Colombia.
GUAYAS	1200	" " " " "	Equador.
SIMON BOLIVAR	1400	" " " " "	Venezuela.
CUAHTHEMOC	1700	" " " " "	Mexico.

Now, desirous of capitalising on the experience gained in this field, ASTACE commissioned the British Naval Architect Colin Mudie to design an 80 passenger luxury cruise ship some 250 ft. (76.2 m.) on deck, utilising square rig brought up to date with all the best of the technology of the end of the clipper ship era, onto which has been grafted the practical use of modern materials like aluminium, stainless steel, terylene (dacron) sails and ropes, hydraulic winches and other modern equipment.

Sail training ships have very large crews and their gear is designed to utilise the crew to the fullest, and Colin Mudie has experience in this field, having been the designer of the highly successful small British training brig T.S. ROYALIST and her Indian sister ship VARUNA. He has also been commissioned to design a 165 ft. (50.0 m.) barque as a training ship for the Indian Navy.

Now he has taken on the design of an even larger sailing vessel which has to be operated with a very small crew for financial viability, but which needs to set a considerable sail area in something near a traditional clipper ship configuration to achieve passenger appeal and to provide effective fuel economy. An interesting concept.

As can be seen, a three masted barque rig has been chosen, and your attention is drawn to the following special features:-

a. Tripod masts are shown to reduce windage and rigging maintenance.

b. Near triangular courses (lower square sails) are shown to do away with the labour required to handle the four sheets and four tacks that would be used on a traditional arrangement.

c. All jibs and staysails are roller furling and reefing, but these are all of moderate size, the biggest being 2,300 sq. ft. (213 m^2) and this could (and may) be replaced by two smaller sails. This in a total sail area of almost 28,000 sq. ft. (2,600 m^2).

d. The mizzen has been given three gaffs to split up the sail area. The three lower sails can be brailed into the mast by ropes leading to the deck, while the topsail can be lowered to the deck down a conventional mast track set to one side of the mast to avoid the gaffs.

e. The squaresails may be roller furled inside the yards or, if handled traditionally, they can be bunted and clewed up (like brailing) from the deck which furls them temporarily so that they can be stowed in slow time.

f. All the braces from the two masts would be led to two hydraulic Jarvis winches. These are multiple drum winches so designed to haul in the braces on one side and pay out the appropriate amount on the other side when swinging the yards.

g. Despite the apparent complexity, only four men would be required on deck - at maximum - for tacking, wearing or other manoeuvres, as well as the helmsman and officer-in-charge. With skilled and experienced crew, this could be reduced to two.

h. With the wind dead astern, the vessel may alter course up to forty degrees either side of her course without touching a brace or sheet. No noise or other effect occurs when passing the wind across the stern.

i. Upper sails may be furled easily to reduce the angle of heel as required.

j. With all squaresails furled, the vessel may make good speed to windward under up to 13,000 sq. ft. (1,207 m^2) assisted by the lee engine or both engines.

Altogether this seems an intelligent and practical approach to a carefully considered viable use of commercial sail.

THE GERMAN DESIGN

A scheme is afoot in Germany under Captain Hartmud Schwarz to build a four masted barque rigged passenger vessel 410 ft. (125 m.) on deck. She too will have tripod masts and other labour saving devices, but further details are not available for publication at the present time. Captain Schwarz is also planning to follow his passenger ship with a number of cargo-carrying sailing vessels.

THE AUSTRALIAN DESIGN

In its early stages as yet, there is an idea emanating from Australia to build a 250 ft. (76.2 m.) staysail schooner with the finance coming from the sale of time shares. At least it demonstrates that the thinking about this type of vessel is widespread around the world.

GENERAL OVERALL CONCLUSIONS

For the past one hundred years, and more especially in the last fifty years, the world has more and more come to depend on the relative speed and reliability of motor power, casting off the use of wind power like a worn out overcoat. The financial influence has been strong, with cost of labour rising continuously and the availability of relatively cheap fossil fuel becoming more and more convenient. In smaller craft at first, and later in larger vessels, petrol and diesel engines have provided economical power from smaller and smaller sized units.

In the last ten years a rapid tenfold rise in the price of crude oil and its derivatives - mainly in two violent upward leaps - has encouraged the consideration of alternative sources of power. In ships and fishing craft this has mainly brought to mind a return to sail which had not been abandoned that long previously.

It is contended that initially the best way of re-adopting sail power is to utilise known and tried methods and rigs improved intelligently by the application of modern materials and technology.

With such schemes as a yardstick, it is then appropriate, where theoretical and experimental evidence warrants it, to try out various radical ideas, comparing them as accurately as possible in similar operating conditions to the relatively traditional systems. After a reasonable period - preferably twelve months to cover all seasons - a practical comparison can be made, not only in efficiency, but in capital cost, running expenses, labour attitudes and any other relevant factors.

With respect to the protagonists for wingsails, windmills, kites, dynaships and others of that ilk, it is pointed out that there really is no virtue in constructing and fitting to a ship an expensive, computerised device which produces overall a lesser driving force than a simple seamanlike sail, well designed and built, and suited to the trade for which it is intended.

Progress is fine and should be supported and encouraged, but let us not be humbugged into adopting an untried device merely because it teems with microchips, is constructed of carbon fibre, looks like a refugee from "Star Wars" and thus is "NEW".

In short, the KISS principle is advocated.

BIOGRAPHY OF AUTHOR

The author, born in 1922, entered the Royal Navy at the age of 13½ and attended the Royal Naval College, Dartmouth, where both engineering and sailing formed a large part of the curriculum. An 800 ton non-magnetic brigantine was building in the port at the time, and he was accepted as a crew member and did some sea-time in a cargo-carrying square rigger as training. From 1939-1946 he served at sea in the Royal Navy as an officer in corvettes, frigates and destroyers. He was active in sailing circles in the post-war period and returned actively to square rig in the 1960's, becoming involved in Sail Training for youth. Since 1972 he has been Managing Director of Square

Rigged Services Ltd., Consultants in all aspects of the operation of large sailing vessels, advising on the re-rigging and designing of sailing vessels for sail training and commercial purposes, as well as contributing papers to several International Symposiums on commercial sail and commanding square riggers in Tall Ships Races and other voyages at the present time.

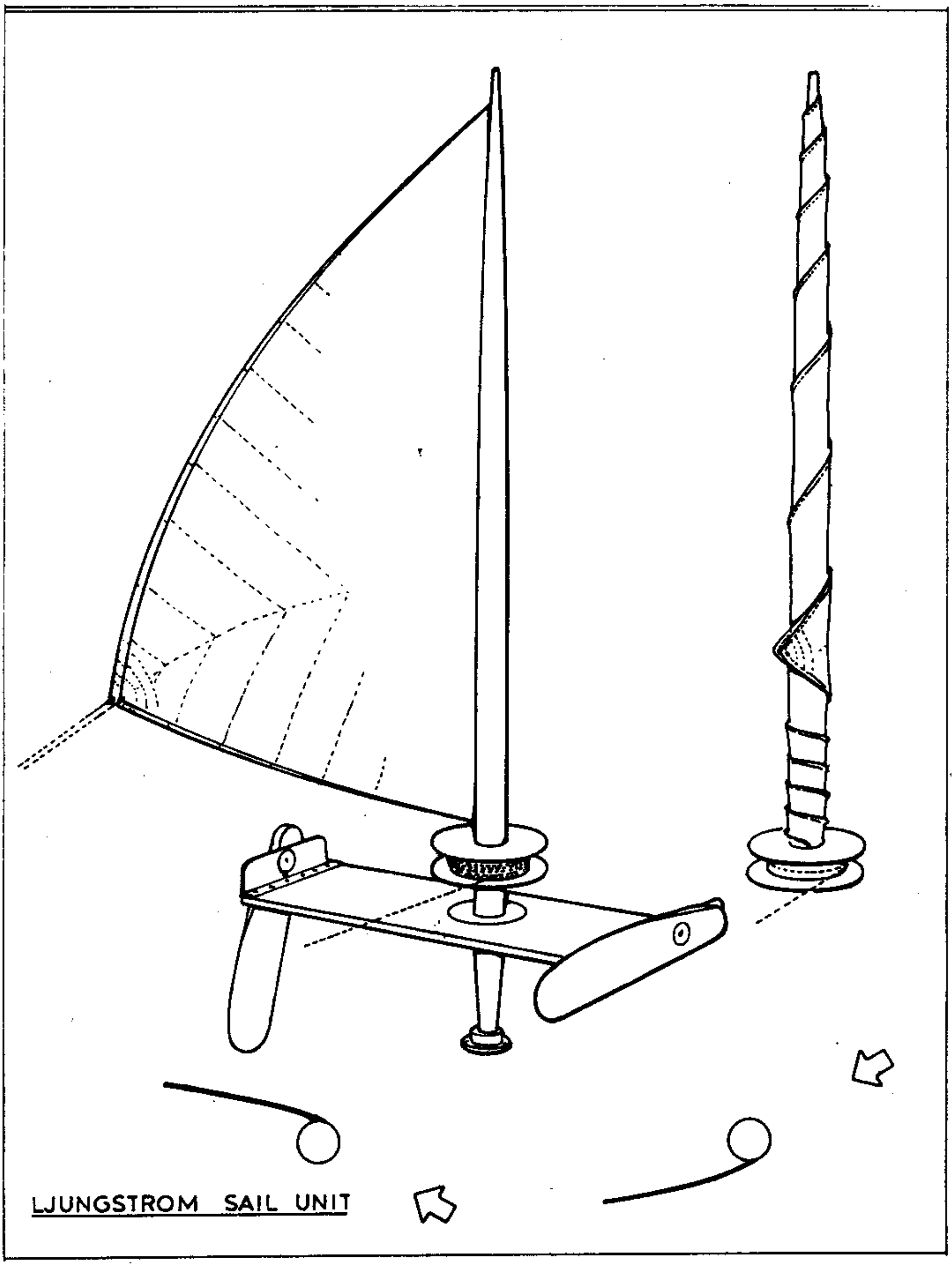

Fig. 1

RIGS FOR SMALL FISHING BOATS.

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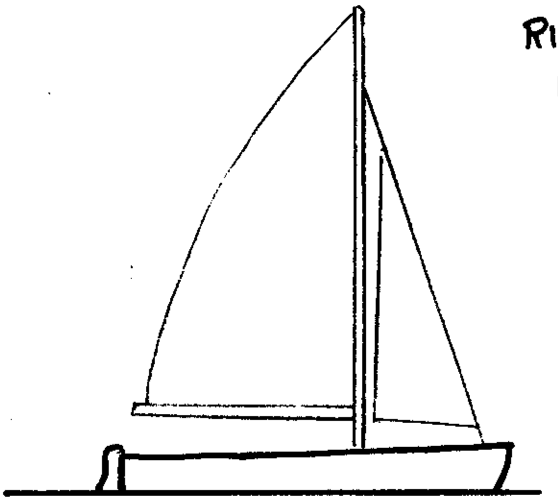
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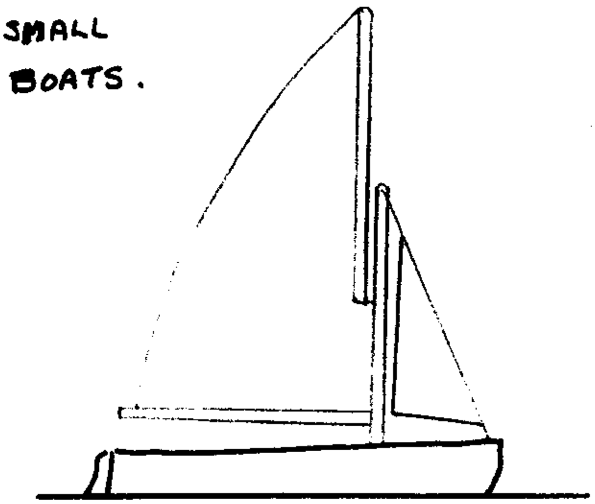
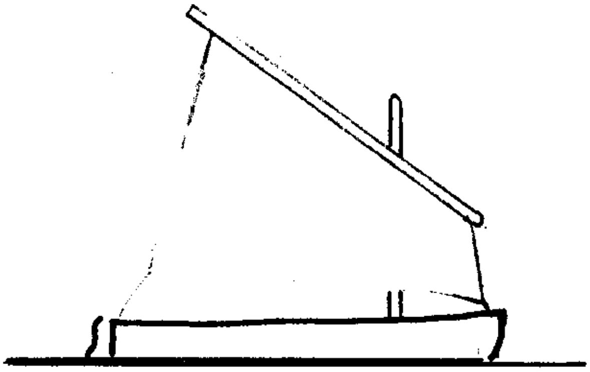
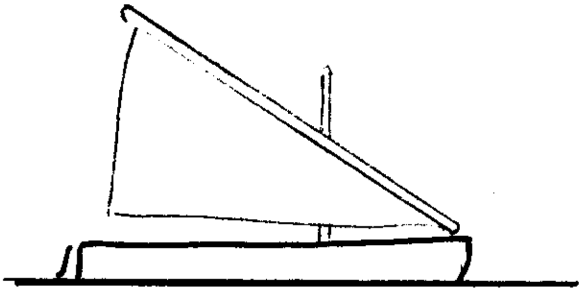

GUNTER LUG


DIPPING LUG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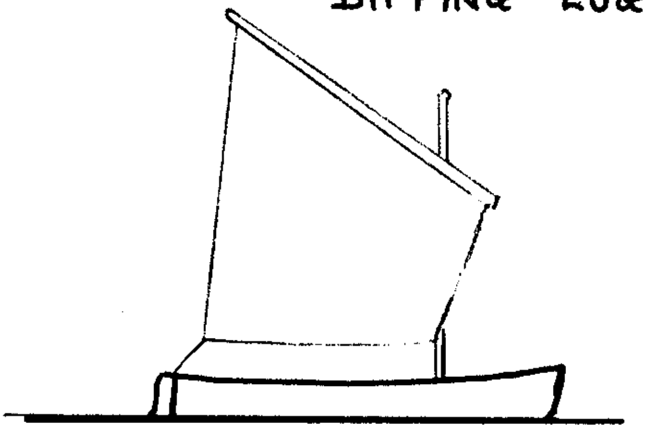
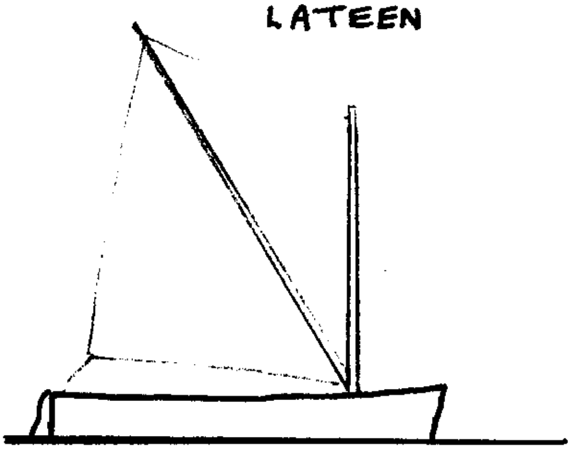
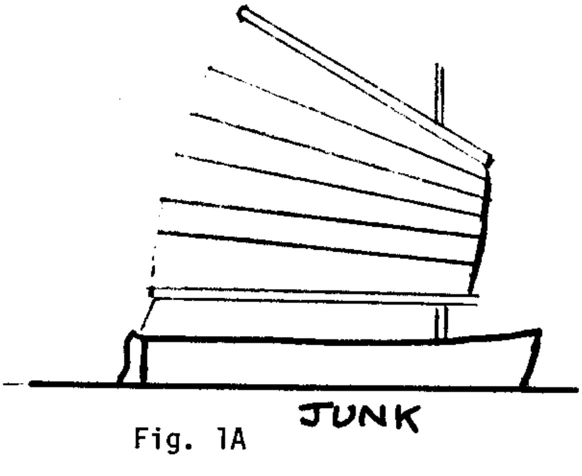

STANDING LUG


SPRITSAIL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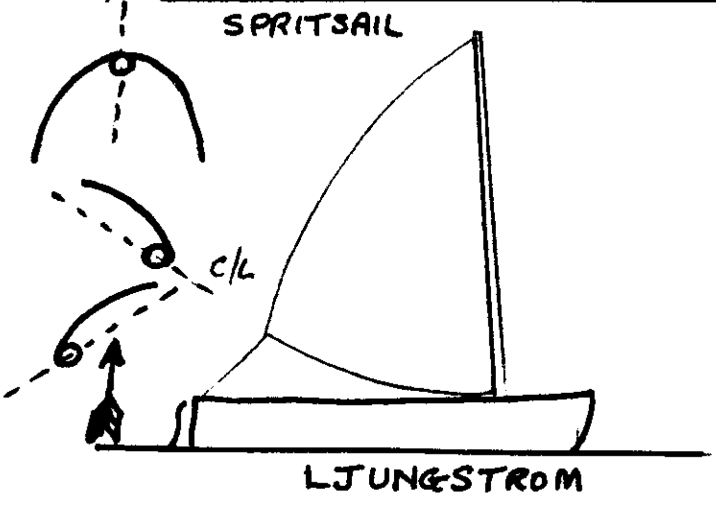
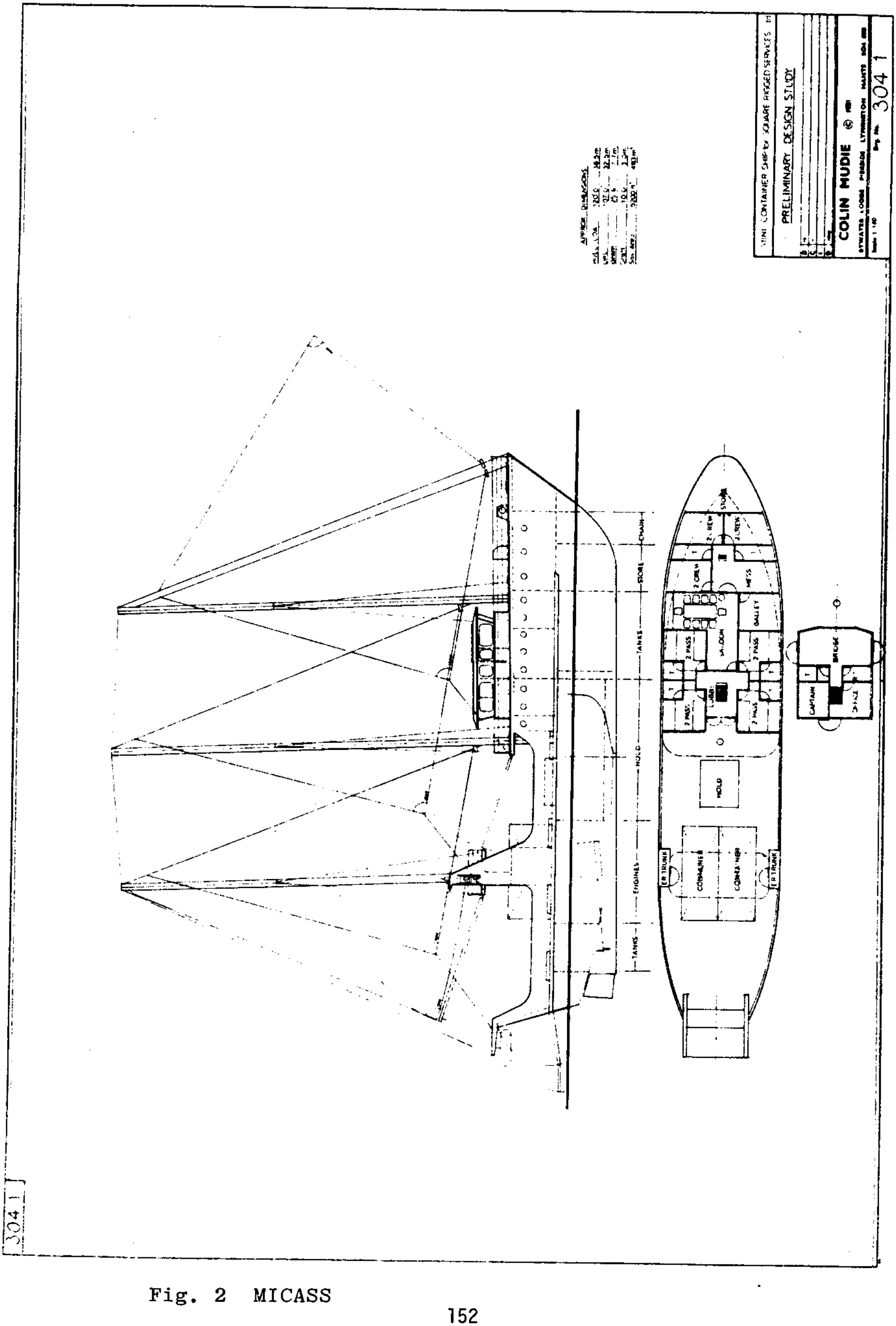


LJUNGSTROM

Fig. 1A


MINI CONTAINER SHIP for SQUARE RIGGED SERVICES
PRELIMINARY DESIGN STUDY
COLIN MUDIE ©
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APPROX. DIMENSIONS
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Fig. 2 MICASS

VESSEL **SHEET**

(c)

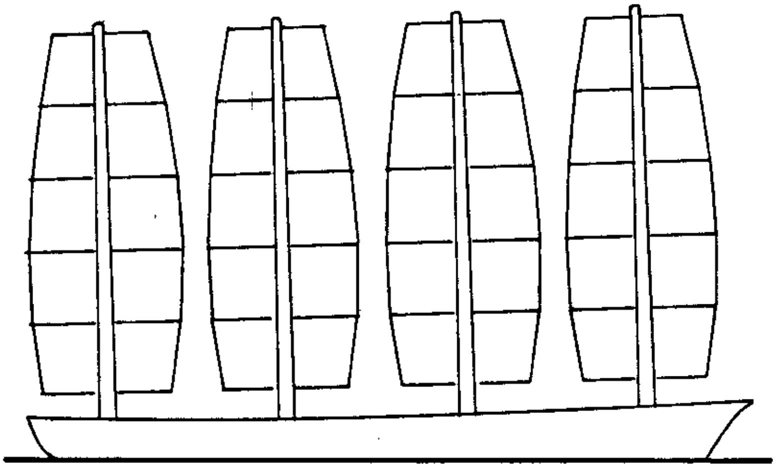

Fig. 3 PROELSS DYNASHIP

VESSEL **SHEET**

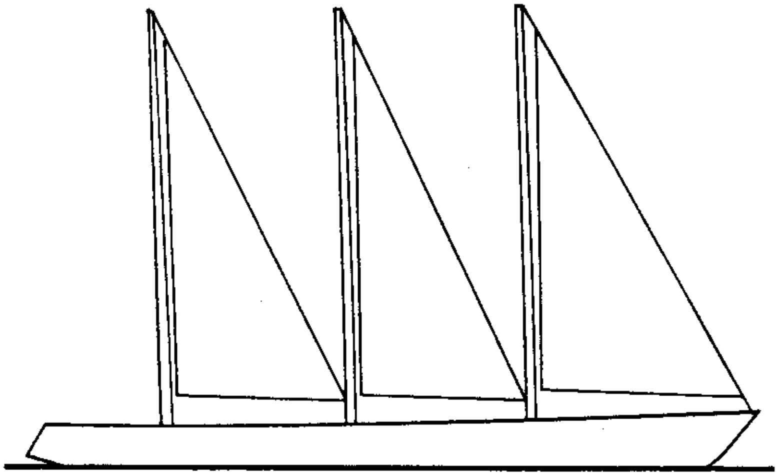

Fig. 4 WARTSILA WIND CRUISER

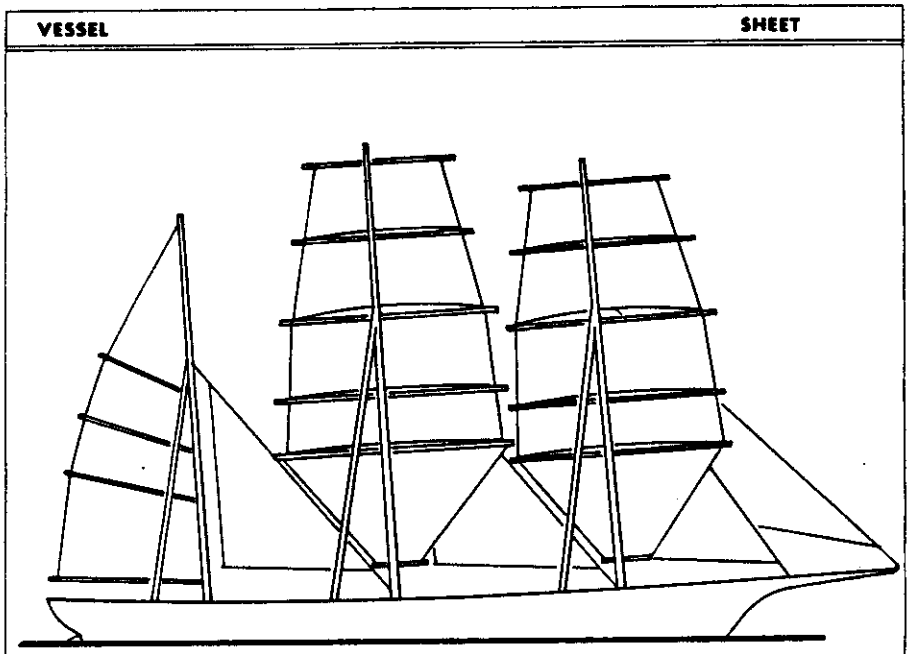

Fig. 5 ASTACE/COLIN MUDIE PASSENGER LINER

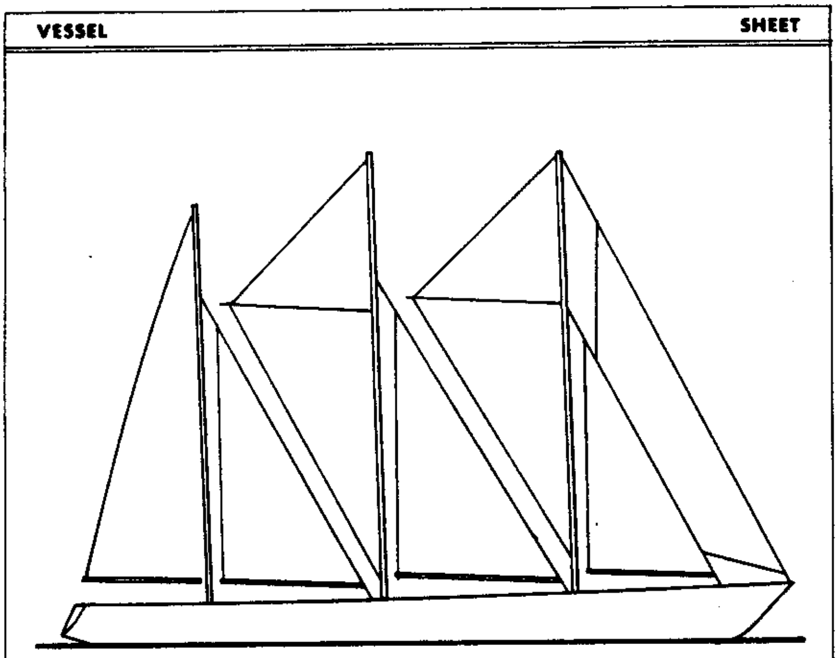

Fig. 6 STAYSAIL SCHOONER

CHARACTERISTICS OF MULTI-HULLED SAIL-ASSISTED WORKING WATERCRAFT: HULL AND PROPULSION SYSTEMS

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Considering the range of the subject, we shall voluntarily restrict ourselves to two points, which we believe are fundamental. We have over the past ten years attempted to form an opinion upon them.

These points are, respectively, pitching of the catamaran and sail propulsion of present working watercraft.

DAMPING OF THE PITCHING OF WORKING CATAMARAN

The various problems due to pitching of catamarans are well known to the users. Let us try to understand the various aspects of this phenomenon.

I. Effects

A catamaran sailing in a formed sea, will experience high amplitude pitching motion. When the frequency of encounter with the waves comes into resonance with the natural pitching frequency of the ship, the fore-part of the hulls may become submerged, or the fore-platform may slap violently, in the case where there is a forward platform. The force of the action obviously depends on the actual speed of the ship, on the pitching period, on the distance between the crests of the waves and on the height of the waves.

This phenomenon has the following effects:

a) considerable slowing down of the ship, each wave producing a violent breaking action.
b) destructive effect on the fore platforms or on the cross beams, which can lead to total failure and loss of the ship. This effect is all the more important since the joining central platform is extended into the front of the hulls.

For example: during a crossing of the Gulf of Gascogne which I made aboard a cruise catamaran four years ago, the platform longitudinals were completely dislocated and the platform began to separate from the hull after five days at sea.

This catamaran was 22m (72 ft.) long and was constructed in plywood with a platform which extended almost to the fore. Moreover, this platform was at about 0,80m (2'7 1/2") above the water. That is very low for a boat of this size.

c) fatigue for the crew.
d) loss of one of the major qualities of a catamaran, i.e. platform stability and the possibility to have a large deck for working space.

II. Causes

Multiple causes are responsible for the pitching action which is more severe than that experienced by other types of ships. We shall try to distinguish the major causes.

a) Fundamental lack of damping; in most instances, the sea is never exactly perpendicular to the direction of the advancing vessel. The same wave will meet the two bows with a lag in time.

Due to this lag time, one hull will be more immersed than the other, with the passage of each wave.

This being said, let us consider that the damping of vertical motion is essentially due to the resistance of the forward part of the hull to this motion.

This resistance is of the type: encounter resistance + frictional resistance.

On a catamaran, the damping of the pitching action, that is the dissipation of the energy of the pendulum equivalent to the entire ship, thereby meaning the two hulls plus a platform, is accomplished by the surface and volume of a single hull. This is precisely where lies the difficulty in principle for the catamaran to damp its own pitching motion.

To this main cause may be added other causes which at times may be very important.

b) The platform being, for obvious reasons of construction, placed low enough in relation to the water line, will hit the wave either from the fore or the aft and set back the ship.

Since the surface provided by the platform is one of the fundamental advantages of the catamarans, the builder often has a tendency to extend the platform towards the ship's extremities, which serves to aggravate the problem.

c) The longitudinal weight distribution, given this platform, is unfavorable, since it is more important at the extremities, than in the case of a single hull. The pitching period S of the ship pendulum is of the form $S = KI$, I being the moment of inertia of the ship pendulum. The farther away the ship's weights will be from the axis of rotation and therefore transferred towards the ends, the larger I will be.

This will have the effect of lengthening this period and increasing its amplitude, thereby increasing the total amount of energy which will be dissipated.

d) Lastly, given the asymmetry of the attack of the wave, pitching will occur along a more or less disgonal axis.

These diagonal motions will generate extra torsion which, in the case of relatively flexible linking structures, may also enter into resonance with the period of pitching or the frequency of the waves.

III. Possible Solutions

a) Increase the damping.

This may be achieved by increasing the volume above the average flotation, thus causing an important deflection to the planking above the waterline. Even more than this deflection, which increases the volume, it is important to slow down the vertical flow.

One effective solution consists in placing a hard chine near the waterline, or better still, a step. Why near the waterline? Because this slowing down must take place from the beginning of the separation from the position of equilibrium of the ship pendulum.

Such a device must be carefully put in place because, in the vertical breaking force, there is nearly always a component of breaking towards the rear, and the damping of the pitching should not result in the end to an increased drag.

b) Reduce the moment of inertia of the hip pendulum.

This reduction implies lightening of the structure both fore and aft, since we cannot diminish the load-carrying capacity either for working craft (fishing boat), or for the payload (freighter) transport vessel.

That implies therefore the necessity to accommodate for the bending and torsion loads acting on the cross beams by placing elements as close as possible to the axis of rotation in pitching (central beam).

Such a design remains perfectly feasible for working vessels, following the example of certain racing boats, and is less expensive to build.

This axis of rotation in pitch is, for all catamarans we have studied up until now, approximately an axis containing the center of gravity of the waterline surface (these are catamarans 8 to 25m in length (26 to 82 ft.).

c) Minimize "returning" effects by decreasing the lift of aft lines.

Such an option must be carefully handled since at a certain speed the drag is considerably increased for fine stern lines. Moreover, too large a fineness limits aft damping.

Finally, and to conclude this paragraph on the pitching of multi-hulls, we are now working on a peculiar device which is a sort of automatic foil which damps the pitching by artificially varying the pitching period of the ship and avoids dangerous resonances between ship pendulum's own period and the frequency of encounter with the waves.

Finally, and as a result of our experience with sail trimarans for offshore racing, we believe that all we have just indicated for catamarans is also partially true for trimarans but to a lesser degree (the relation between catamaran and trimaran necessitates a discussion which cannot be developed in this paper).

THE MEANS OF SAIL-ASSISTED PROPULSION APPROPRIATE TO A CATAMARAN AND ITS MANEUVERING

In the case of sail propulsion, sailing along the wind always remains a problem which is difficult to solve for the following reasons:

a- The problems of pitching are more severe when sailing along the wind, as each pitch of the sea empties the sails.

b- The fact that in the case of a momentarily strong wind, the catamaran, which does not heel, cannot absorb by some heeling the energy of this strong wind, for the boat cannot accelerate instantaneously. This requires a reinforcement of the masts and rigs, as well as of the scantling of the sails, thus increasing the weight in upper regions (topheaviness) thus the moment of inertia, thus the pitching.

The actual course of a sailing catamaran does not exceed 45° from the real wind in the best of cases, that is to say a racing sail boat with a revolving mast and an elaborate sail with batten, an efficient center board surface, aspect ration on the order of 3, and a leeway angle of 2° (testing done aboard the 20m (65 ft. 7 1/2 in.) catamaran "Elf Aquitaine").

In the case of a working vessel with a more classical sail, a furling jib, a normal mast, a sail with a few battens, a center board aspect ratio on the order of 1/3, which is already quite rare for a working catamaran, the course does not go beyond 70 to 75° of the real wind with a leeway of 5° to 7° (tests done aboard the fishing catamaran "Dar Mad") in good sea conditions. (In this case an interesting thing was noted: the fact of setting one of the two motors at approximately quarter speed almost completely eliminates the leeway).

It would appear therefore quite unrealistic to envisage a catamaran working vessel that is entirely or almost so sail powered. To eliminate 150° direction appears to be very penalizing as much for fishing (lobster potting, maneuvering round rocks, retrieving a floating net, etc.) as for the transportation of cargo, due to the suppression of certain possible routes.

What's more, maneuverability in port becomes a real problem, whereas at engine power in the case of a twin engine, a catamaran achieves a 360° turning circle.

Only trimarans may for certain usages (tuna fishing or coastal trawling in the case of small vessels), get along with a low powered motor since their capability along the wind is much better.

On the other hand, on a catamaran the disposable surface and the lateral stability of the platform allow for almost all possible rigging systems.

Our current philosophy on this subject is now decided, following 15 years of experience with the sailing systems on two types of boats which appear in fact quite similar, as paradoxical as that may appear:
--racing single handed sailboats,
--sail assisted working sailboats,
for, in both cases, it appears absolutely indispensible to facilitate the maneuver of the sails to the maximum.

This present philosopy may be stated as follows:

-- one or more masts classically rigged,
-- one or more jibs on rollers,
-- one or more main sails on rollers,
-- reduction of the number of masts in relation to the size of the ship because of the interactions between the two, even with beam wind.

The wing masts coupled with a fully battened mainsail represent real aerodynamic progress and, what's more, the maneuverability of sails is very simple in principle, but for the time being, their reliability is unsufficient for if we wish to have a simplified shroud (only one stay and two back stays), there must be one revolving mast with very large inertia due to the enormous stiffness under sail of working catamarans.

Such a mast is technically feasible, but the current cost is prohibitive (approximately 6 to 8 times more expensive than that of a normally rigged mast).

The masts without shroud, simply implanted "wishbone" style, are equally inconvenient from the point of view of cost, but to a lesser degree than for the revolving masts. Also, their aerodynamic efficiency remains very mediocre.

In conclusion, let us say a word about this stiffness under sail of working catamarans:

-- The maximum lateral stability of a working catamaran is in fact very large when compared to a monohull of the same displacement in loaded condition.
-- What's more and this is one of the extremely interesting peculiarities of this type of ship, the lateral stability increases with the deck load because this stability is of the following form (see apendix).

This feature is extremely interesting for all types of boats which load from the deck (for example, coastal fishing crafts, passenger vessels, etc. ...).

For example, two boats of equal displacement and similar length (this example refers to two working boats which we have effectively studied and for which we have verified the stabilities): a 12 meter (39 ft.), a 12 meter (39 ft.) fishing catamaran.

One of the consequences of this lateral stiffness is the necessity to overdesign all the parts of the sail propulsion system, which is to say:

-- the mast
-- the standing rigging
-- the weight of the sails
-- the running rigging.

The exact calculation of the loads remains difficult because, although the righting moment may fairly well be determined, the sail remains approximately perpendicular to the direction of the force aerodynamic. What is the reduction of these loads due to the instantaneous stretching of the sail material and what is the influence of the air to the top of the sail due to the heeling?

We have been able to determine experimentally that: comparing identical sail surfaces on a catamaran and on a monohull, the supplementary load carried by this rigging leads to an increase of 25 to 30% of the moments of inertia of the mast, of 25 to 30% for the strength of the standing and running rigging, the strength of the sail material increasing a proportion of 15 to 20%.

It is of course obvious that these results obtained from analysis performed on several boats, are not valid unless we consider other boats destined for similar usage, the speed achieved by a catamaran being always larger for a given surface than that achieved by a monohull.

Conclusion

These consideration concerning working multihulls do not pretend to represent a complete study; however, I wish to add that, in spite of the need for the careful elaboration of the means of reducing pitching moment and of the location of the cross beams, the future of service multihulls, whether sail-assisted or motor driven only seems to be assured. Their advantages are real (improved platform stability, greater speed, reduced fuel consumption, improved maneuverability, etc. ...).

However, this type of ship is revolutionary, and requires an extremely rigorous and careful design in order to convince the maritime world (fishing, service and transportation).

Annex 1

HIGH EFFICIENCY SAIL

The necessity to have best efficiency of the sail, with the same speed of wind and with the same surface of sail is very important in first, on the racing boats (vector Fa bigger with the same wind).

The wing sail and the wing mast have been known for a long time, but these were not developed for a long time for two reasons:

1.- The technological difficulties:
    a) the possibility of building wing sail light and with reduced surface area,
    b) building battens strong and light
    c) building a wing mast light and strong enough with a large section.

2.- The problem of racing rules because the progress starts with the racing machines and during sixty years all the racing rules (RORC - CCA - IOR and so on ...) have forbidden all the full battened sails or wing mast or furling mast. Progress has been made only on the rigging materials (Kevlar - rod rigging - and so on ...), the weight of the canvas and alloy masts.

The new success of multihulls races without rules have utilized all the principles of sail and mast, with the only rule: efficiency.

We have particularly studied and installed on racing multihulls two systems of sail:

1.- A wing sail soft and thick (Chapouteau System) with a classic mast (annex 2).
2.- A wing mast with a fully battened sail.

These two systems are very interesting for the direction of apparent wind (25° to 70°):

a) the efficiency is better. The vector FP is 6 to 10% more than with a good classic sail. The efficiency is better for the Chapouteau Sail in more than 15 knots wind and better for the wing mast and the fully battened sail under 15 knots wind;
b) these two systems are also very interesting when the sail is in "flag position" (lifting), specially for the Chapouteau Sail. This quality is interesting for working boats because it needs to reduce the sail area less often;
c) when the boat is running or has the wind on the quarter, the efficiency of the Chapouteau Sail is not pleasant because we cannot modify the belly of the main sail; a fully battened sail is better (but not better than a classic mainsail) and we are obliged to stress the leech to bend the batten.

Conclusions

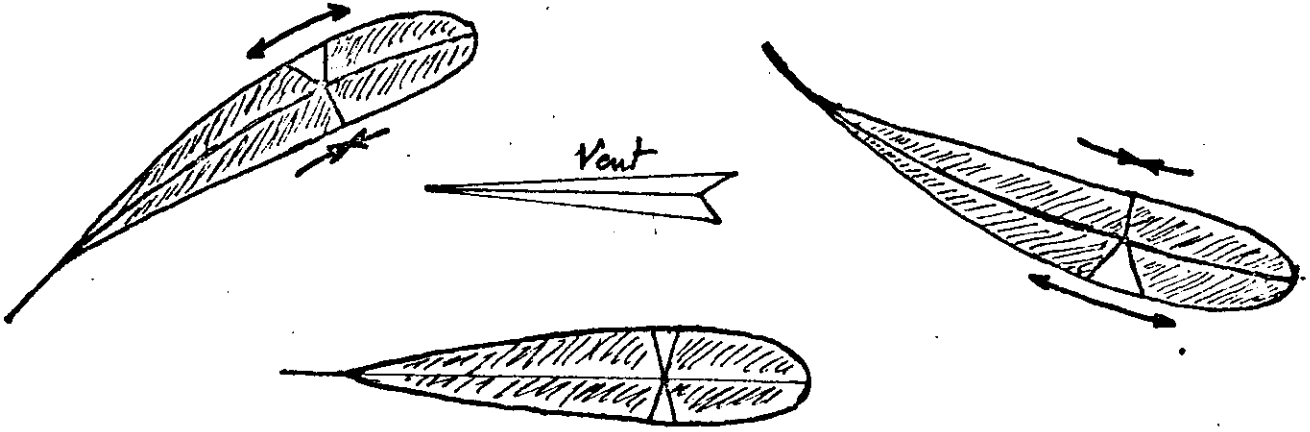
1.- The efficiency of these systems are a reality, but the efficiency is better when the boat is faster, because the boat is almost always on the wind (the new fast multihull racer beat when the wind is free). The sail-assisted working boats are not fast on the wind except with sail and engine.

2.- Now, all these systems are expensive and not so strong because of many parts (sail, mast, batten, bearing) but it is certainly possible to progress and we study now a wing mast with a non expensive building cost.

3.- The possibility of lifting without slatting (put in a flagging position) is very interesting for all fishing boats, because it is not necessary to reduce the area of sail so often (to reef is not easy for a short time).

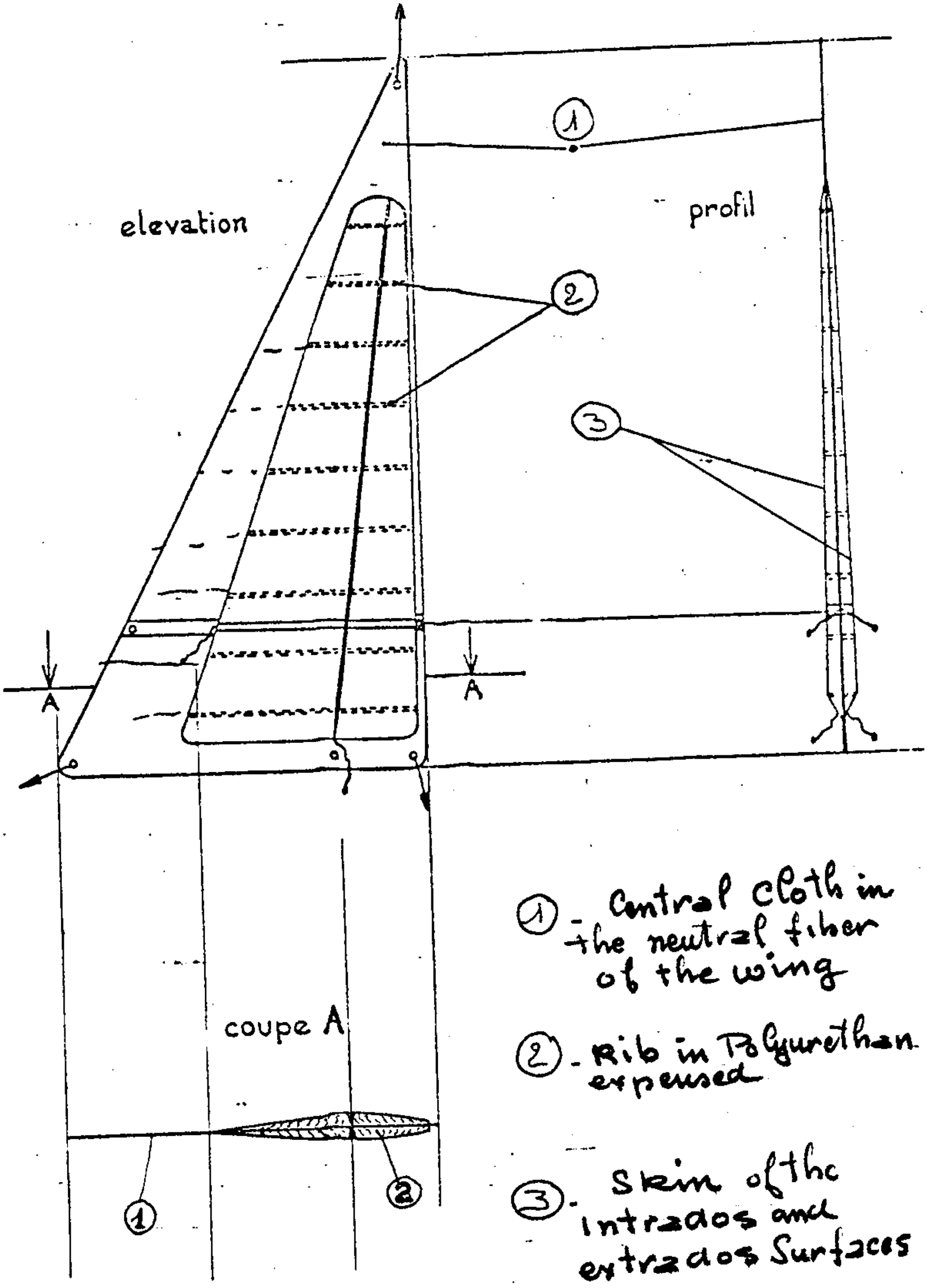
For us, it is very important to study the wing mast more. The thick sail (soft and rigid) although the actual price and the actual strength is not adequate for a working boat actually.

Section of the "Chapouteau Sail"



ANNEX 3

Description of the "Chapouteau Sail"



① - Central cloth in the neutral fiber of the wing

② - Rib in Polyurethan expensed

③ - Skin of the intrados and extrados Surfaces

ANNEX 4

NOTE: Annexes 4 and 5 were translated by the conference organizer, and the author is not responsible for errors in such. JWS

ANALYSIS OF THE CALCULATION OF AVERAGE PRESSURE

The specific mass of air is related to the specific weight and the acceleration of gravity: g.

The mass volume at sea level at a temperature of 15° C.

volumetric mass = 1.225 Kg/m^3 $\gamma = m/g$

$g = 9.81\ m/sec^2$

$\gamma = 0.125\ Kg\text{-}sec^2/m^2$

$P = 0.5\ \gamma \times V^2 \times C3$

27 n. - 13.8 m/sec

$P = o.5 \times 0.125 \times 13.8^2 \times Cz$

Cz = 1 P= 11.9 Kg

22 n. - 10.8 m/sec

$P = 0.5 \times 0.125 \times 10.8^2 \times Cz$

Cz = 1 P = 7.29 Kg

The value of one for Cz has been used in our calculations.

Average Pressure: P = (11.9 + 7.29)/2 = 9.6 Kg

Letting Cz have the value of 1.17 corresponds to placing a flat plate perpendicular to the wind.

For 27 n., P = 13.92 Kg

For 22 n., P = 8.53 Kg

P average = (13.92 + 8.53)/2 = 11.22 Kg.

ANNEX 5

FISHING CATAMARAN OF 11.5 METERS (37.7 ft.)

STUDY OF THE CAPSIZE MOMENT FROM THE SAILS

The capsize moment of the sails is produced by the lateral component of the force resulting from wind pressure on the sail. (See sketch of the sail plan with maximum righting moment).

Let us call Fl this lateral component

Fp is the total lift force

Fa is the forward component

Thus, L is the lever arm of the Fl component.

The sail force capsize moment equation is of the form:

Cv = Fl x L

(This is valid if the craft is horizontal, and less so when heeling, for the force exercised is at maximum when the sails are on the wind; however, let us consider therefore this maximum value.)

CALCULATION OF PRESSURE ON THE SAILS

This pressure, Fp is of the form:

Fp = S x P (unit force)

Pressure per square meter depends on the wind speed.

Let us calculate Fp for a wind of Force 6, assuming (which is already an overestimate) that sails are not reefed before force 6.

At force 6, (27 knots) unit pressure = P = 9.5 Kg/m^2

Thus, Fp = 53 x 9.5 - 503.5 Kg

If one considers that Fl = Fp x 0.9 and L = 6.45 m

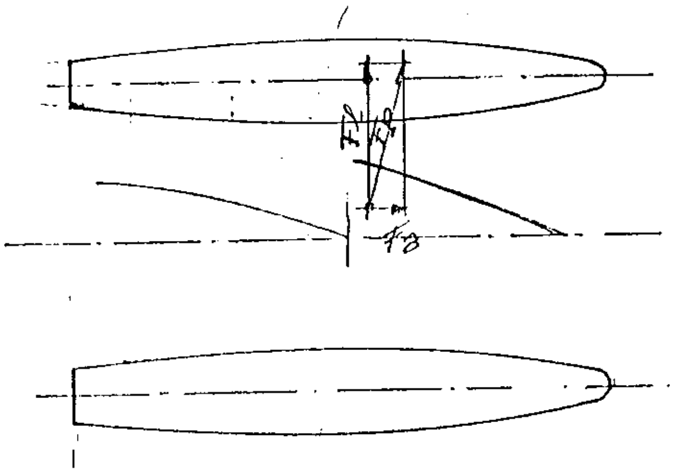
Cv = 503.5 x 0.9 x 6.45 = 2922 m/Kg:

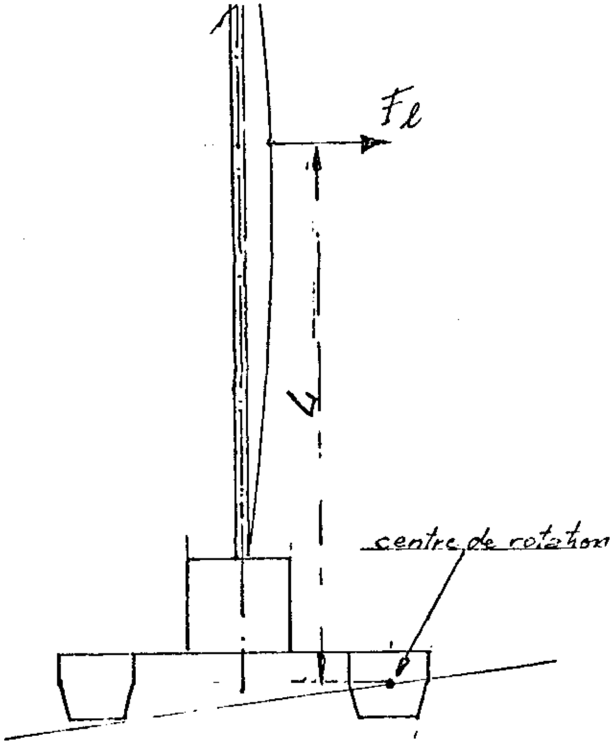
Let us examine the righting moment at 12530 m/Kg:

Cm/Cv = 12530/2922 = 4.28

The maximum righting moment is thus four times the capsize moment from the sails.

ANNEX 6





Catamaran de Peche

Schema des efforts dus aux Voiles

Now, let us determine the wind speed necessary for equilibrium for the maximum righting moment.

Thus, Cmax. = Cv = 53 x Pu x 6.45 x 0.9 = 18596 m/Kg

Pu = 18596/(53 x 6.45 x 0.9) = 60.44 Kg/m^2

A pressure of 60.44 Kg/m corresponds to a wind speed of 60 knots, force 10 to 11 on the Beaufort scale. (If sails have not been reduced they will be torn to pieces by this wind force.)

Moreover, and in every case shown in the firgure, above force 5, even taking into account leeway prevention, the boat will slip to leeward, thus diminishing markedly the heeling moment.

PRELIMINARY FISHING TRIALS IN NEW ENGLAND WATERS OF THE OCEAN PICKUP, A SAIL POWERED TRIMARAN

by

Richard C. Newick, Sherrill B. Smith, and John H. Todd, Ph.D.

Background

Ocean Arks International is a research and communication organization working on ecological development issues. Over the past ten years we have had experience with fishing communities in the Indian Ocean, South Pacific, Caribbean, and the Atlantic coast of northeastern South America. Fisheries development in many countries is at a crisis point. Many tropical nations are losing their access to hard international currencies and are facing bankruptcy. With the decline in economic stability is a concurrent deterioration of the fishery infastructure which is dependent upon supply and technical inputs from the industrial nations. Spare parts, fuel, processing and ice-making equipment, as well as new boats, are in many instances unavailable. International aid programs cannot fill the gap or sustain the infastructures.

The problem is compounded by the inability of many fishermen to revert to traditional vessels and methods. One reason is that many coastal communities no longer have access to rot-resistant and long-lived boat building woods. Even where the woods still exist they are often targeted for export to gain foreign exchange.

Project

Ocean Arks International has embarked upon a long-term project to develop advanced design fishing craft powered by sail. They are designed to be constructed from rapid growing and low value "weed" trees which can be grown to a useful size in a few years. Part of our research involves collaborating with N.A.I.S.A. in Costa Rica in the planting of a wide variety of trees and evaluating their usefulness as wood/epoxy composite construction materials.

Another design objective was to develop a vessel in which fully three-quarters of its costs would be based upon local economic activity and less than twenty-five percent require imported materials.

Three relatively new technologies were selected and combined for the development of fishing vessels. They included:

i. The wood/epoxy saturation technique, or WEST SYSTEM®, developed by the Gougeon Brothers (1). The wood/epoxy composite building materials can produce boats with high strength-to-weight ratios. Modern racing yachts, airplanes, and windmill blades are being built with WEST SYSTEM® methods. The WEST SYSTEM® has the additional advantage of enabling low value and rapid growing trees to be utilized.

ii. Naval architect James Brown, in collaboration with Richard Newick, developed a master mold concept called Constant Camber® which permits the lamination of compound curved plywoods. Hulls of different sizes and shapes can be built from the same mold (2). Constant Camber®

simplifies cold molding methods and is adaptable to construction in rural or remote settings.

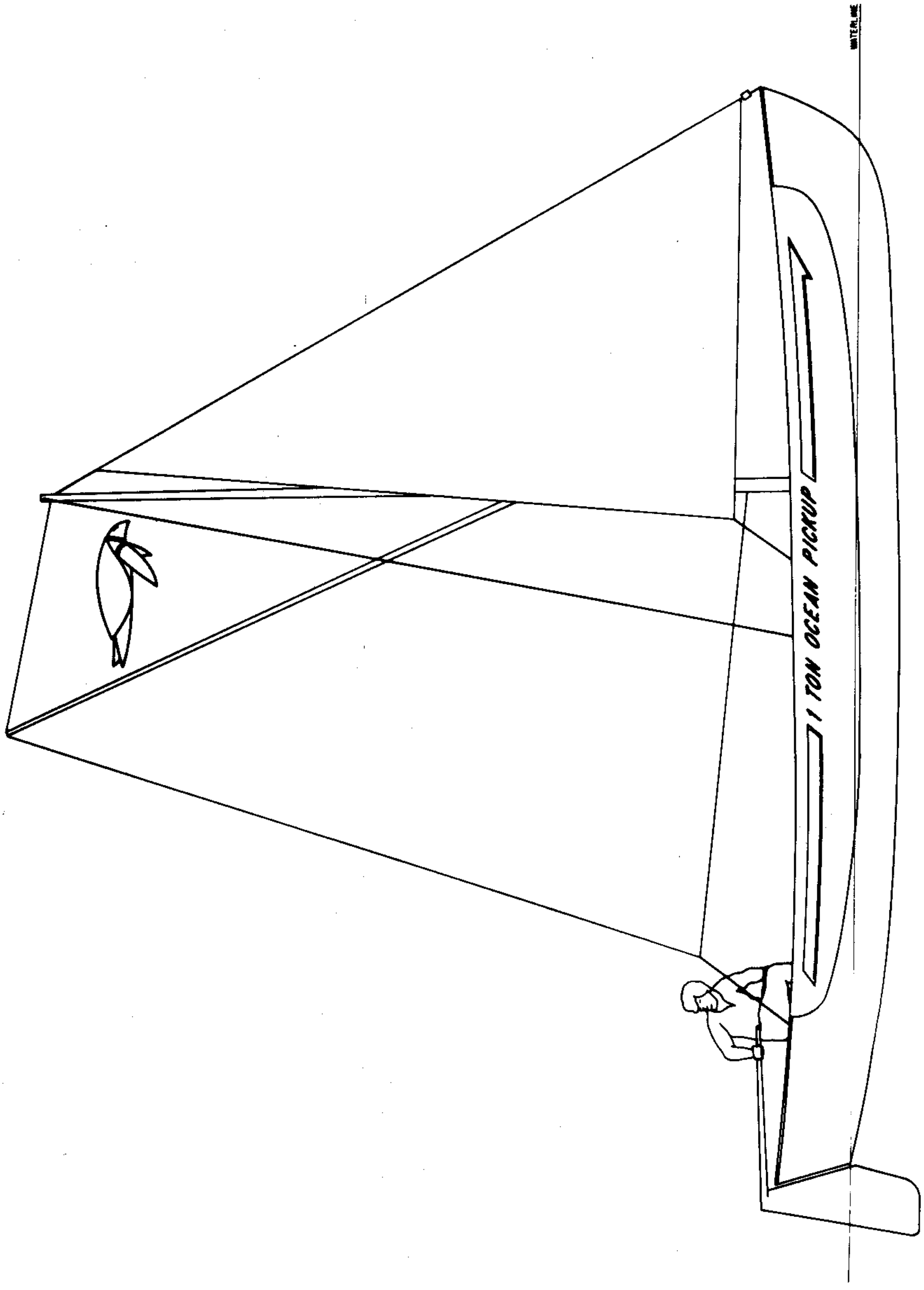
iii. Vacuum bagging allows pressure to be applied over large surfaces during cold molding. Originally an industrial process, it has been detuned to a "backyard" or remote setting scale by John Marples in association with Brown and Newick (3).

The wood/epoxy saturation technique, WEST SYSTEM®, with Constant Camber® cold molding, and vacuum bagging combine well to permit the construction of high performance vessels suitable for commercial fishing.

Design and Construction of the Prototype Ocean Pickup

The design requirements were to develop a multihull specifically adapted to the needs of fishermen who had become accustomed to fast vessels powered by outboards. The vessel was to provide a stable working platform with a large area for fishing gear. It was to have a motoring speed with a 15 hp outboard of 10⁺ knots, and a sailing speed of 12⁺ knots. It was to be seaworthy, beachable, and safe. Ocean Arks International turned to Richard Newick for the design. See Photograph 1 and Drawing 1.

DARWING #1



1 TON OCEAN PICKUP
OCEAN ARKS INTERNATIONAL
DESIGNER, RICHARD NEWICK

Photo 1

Specifications

32' Trimaran Sloop

Length -- 32'
Beam -- 20'-9"
Draft -- 15" hull; 26" rudder; 5' daggerboard
Sail Area -- 335 sq.ft.
Weight -- 2,000 lbs.
Payload -- 3,000 lbs.
(Optional) Outboard Motor -- 5 to 15 hp

Construction materials: Chosen for availability away from industrial centers, ability to be used with simple tools.

2,200 sq.ft. Douglas Fir (or any similar wood) veneer 0.1" thick
11 sheets 3/8" x 4'x8' marine grade fir (or similar) plywood
300 board feet Douglas Fir (or similar) good grade wood
40 gals. epoxy resin for adhesive/coating plus additives
125 yds. 4' wide fiberglass 10 oz. cloth
50 sq.yds. 7 oz. Dacron sailcloth, thread for sewing, grommets
500 ft. 3/8" dia. Dacron and Nylon cordage
Paint, 8 blocks, 26 galvanized steel bolts, non-ferrous staples
4 mil. or 6 mil. polyethylene plastic for vacuum bags

Construction method: [redacted] Constant Camber® mold (curved in two directions) of 1" lumber, coated and glued with epoxy. [redacted] Patterns for hull sides are made of fiberglass (mold and battern materials not listed above).

Assemble three plies of pre-fit and epoxy-coated veneers on mold, hold in place with a few staples until vacuum bag is put on top, sealed at edges and air is exhausted. Epoxy cure takes several hours, work should be done in moderate temperature and humidity.

Coat exterior of panel (after sanding) with fiberglass cloth set in epoxy; epoxy coat interior of panel; trim panel edges to pattern;

Assemble two hull sides, glass taped along keel/stern line inside and outside;

Install transom, bulkheads, sheer stringers, daggerboard trunk, deck beams, deck and sheer rub rail;

Paint, add hardware;

Glue up hollow box spars for connecting structure and mast;

Make rudder and daggerboard.

CONSTRUCTION TIME ABOUT 1,500 MAN-HOURS

Construction method noted above can be further simplified for remote area assembly where electric power is not available or where it is more important to put people to work than to build most efficiently -- substitute nail pressure for vacuum pressure when gluing veneers together on mold.

This method of building can produce long-lived boats. The designer has had commercial sailing craft of similar configuration and materials, with good maintenance, give a useful life of over twenty years in the Caribbean.

Performance and Fishing Gear

The prototype was launched on Martha's Vineyard in November, 1982, and has been sailed off Cape Cod all winter in a variety of wind and sea conditions. It has proven to be fast, maneuverable and seaworthy. It was originally rigged as a sprit sail sloop with a roller reefing jib. The sprit has been replaced by a gaff for greater ease of handling and reefing.

The Ocean Pickup has been rigged for bottom trawling, trolling, trap and hook and line fishing, long lining, and gill netting. All of the gear is handled by hand. Our objective is to have a sail powered research vessel capable of studying a variety of fisheries.

Bottom Trawling:

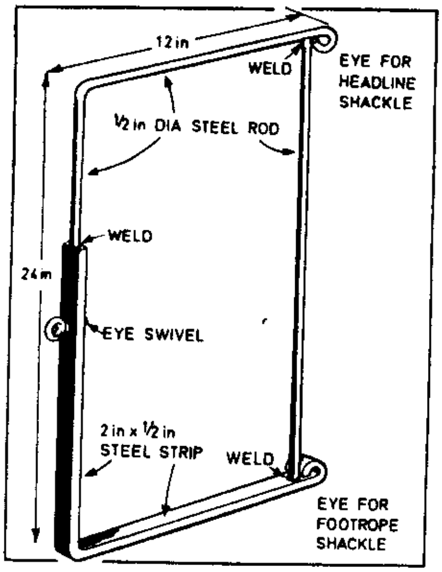
To date our most interesting experiment has been setting and towing a trawl net. In the past trawling was possible for deep keel sail boats only by towing with a long beam to spread the mouth of the net. With 20' between the amas, or outer hulls, of the trimaran, we were able to run the towing warps through blocks hung outboard of the amas and this stern width was sufficient to keep the net spread without a beam or traditional otter boards. The net has a 22' sweep chain and the wing ends were supported with a pair of rectangular danleno frames with skids on the bottom. The danleno design we used was by Harry Buckingham, an English fisherman (Drawing 2). The trawls were made in 5 to 10 fathoms of water, and the boat was able to maintain trawling speeds and adequate maneuverability in 12 - 15 knot winds. Deep water trawling is probably not feasible, unless Ocean Pickups trawl in pairs.

We also experimented with the same trawl net and 12" ~~and~~ by 24" doors. They worked well; however, higher wind speeds of 15^+ knots were required to maintain trawling speeds.

Gill Netting:

Light PVC "H" frames, or "goal posts" have been installed on the aft part of the between-hull working platforms. These are used for setting and hauling gill nets. We have found the large deck space to be a major plus for the design as it permits the carrying of a large quantity of nets and traps.

DRAWING 2



danleno frame

As of this writing -- mid-March -- the Ocean Pickup has not been used for trolling, hook and line, long lining, or pot fishing. However, it appears that the vessel is well suited as a general purpose fishing vessel.

Future

By the time of The International Conference on Sail Assisted Commercial Fishing Vessels, the Ocean Pickup will be undertaking fishing trials in the waters off Guyana in South America. The Ocean Arks International project, sponsored by Guyana Fisheries Limited with the support of the Canadian International Development Agency, will investigate sail power in the shrimp, snapper/grouper, and inshore net fisheries. We will also carry out trials in the by-catch fishery as a buy-back boat returning the incidental fish catch from offshore shrimp trawlers. A preliminary economic evaluation of a larger three-ton payload version of the Ocean Pickup indicates that it would be cost effective as a buy-back vessel in the Guyana shrimp fishery.

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RETROFIT SAIL-ASSIST ON NEW ENGLAND FISHING VESSELS

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ABSTRACT

The New England fishing industry includes many different fishing methods and fishing vessel types. The predominant method however is trawling with vessels ranging from 50 to 90 feet. The MIT Sea Grant Program has conducted a study to determine the feasibility of sail-assist retrofit on vessels from this large class of trawlers.

With the cooperation of vessel owners, preliminary designs were done on several working trawlers. In addition, the potential economic effects, local wind conditions, and compatability with fishing activity were analyzed. Design criteria were developed for the purpose of minimizing cost of installation versus benefits.

The conclusions of the study are that sail assist retrofit is feasible and economically attractive on many New England vessels. The wind patterns and the locations of fishing ports and fishing grounds offer ample opportunity to use winds during steaming. The use of sail-assist during the trawling operation is possible under certain conditions. Further, the benefits of a sail-assist installation -- reduced fuel consumption, reduced vessel motions, better propeller performance and an alternative means to reach port in an emergency -- all begin to accrue even with a minimal sized sail plan.

This paper presents the methodology used in the preliminary design of three retrofit installations. Some of the engineering problems encountered are related along with preliminary cost estimates. Opportunities for sail-assist trawling are discussed.

INTRODUCTION

The sharp increases in oil prices in 1973 and 1978 have prompted consideration and adoption of many energy conservative measures in the U.S. fishing industry, particularly the harvesting sector. The use of more efficient gear and methods, the installation of Kort nozzles or the use of fuel monitors are examples [1].

The use of sail powered or sail assisted fishing vessels has been proposed by many and successfully demonstrated by some [2,3,4]. Generally, the use of wind power is considered only for new construction where steps can be taken to optimize the total design. Concepts proposed for New England fisheries have involved new vessels and often included non-traditional hull types, deck layouts or fishing methods.

Since the New England fleet is considered by many to be overcapitalized and many stocks are subject to vessel quotas, the justification for new construction can be weak. Based on the interest expressed by local fishermen the MIT Sea Grant Marine Advisory Service undertook a study to assess the feasibility of retrofit sail-assist within the present New England fleet.

The project was composed of three parts. First was the gathering of information on fleet composition, fishing patterns and weather. Second was the identification of appropriate vessels with cooperative owners and the preparation of preliminary retrofit sail plans. Finally, these two parts were combined in an effort to determine the feasibility of the specific designs and from there draw general fleetwide conclusions.

THE NEW ENGLAND FISHING FLEET

The New England commercial fishing fleet is composed of a wide variety of vessels ranging from one man open skiffs to 130 foot trawlers. From the standpoint of fish landed, tonnage, and economic importance, two groups must be considered; inshore and offshore. The more than 9,000 downeast type lobster boats are not included in these groups nor in the following discussion.

The offshore fleet numbers around 400 and is characterized by vessels larger than 65' with a crew of between 4 and 10 [5]. These vessels usually fish year round with trips of 3 to 10 days duration. Bottom trawlers, "draggers", predominate but this group includes many large scallopers. Some of the trawlers also engage in midwater trawling or pair trawling. These vessels typically fish out of New Bedford, Boston, Gloucester, Portland or Rockland. They fish the waters of the Gulf of Maine, Stellwagen Bank, Georges Bank, and to the south or east of Nantucket.

Depending upon the availability and price of fish, offshore vessels can steam 100 to 200 miles before setting the nets. Once engaged in fishing, most of the time is spent towing the gear, though if fish are sporadic, steaming can occur throughout the trip. Short spells of bad weather can force heaving-to until the gear can again be safely deployed.

Power plants aboard these offshore vessels are usually high speed diesel engines of 300 to 800 horsepower. They are single screw propulsion with propeller diameter and pitch usually specified for some compromise between steaming and towing conditions. Some vessels, particularly the newer ones, are fitted with Kort nozzles. Variable pitch propellers are rare.

Older vessels in this group are often side trawlers and constructed of wood. The majority of newer vessels are steel stern trawlers with single or double chine hulls. The designs have evolved to minimize acquisition costs while providing increased towing power and hold capacity. Most vessels are owner or family operated. Only recently has there been an increase in larger fleet operations.

The inshore group of vessels ranges from 15 to 65 feet in length; however, since the smaller vessels in this range cannot readily be typified, the portion from 35 to 65 will be discussed. These vessels number over 750, usually have crews of between 2 and 6, and either day fish or have trips of 2 to 5 days duration. They use a variety of gear but again, trawling predominates.

Inshore vessels fish out of all major and minor ports and harbors. Their range of fishing depends upon season and fish availability. Some vessels in this class consistently make 100 to 200 mile transits to favored grounds. Others set their gear just around their homeports. An important method of fishing included in this group is gill netting. Other common techniques are groundfish longlining, scottish seining, purse seining, tub trawling and harpooning.

In spite of their size, these smaller vessels can often be seen well offshore in the worst of weather, lured by the high dockside prices paid during the harsh winter months. Hull forms, power plants, and construction materials vary significantly. They are typically owner operated.

Figure 1 depicts the New England waters and indicates major and minor fishing ports. Also shown are typical steaming patterns of offshore and inshore vessels.

WIND DATA FOR NEW ENGLAND WATERS

The National Weather Service collects daily climatological data from many coastal stations and ships at sea. This data is published in the form of Pilot charts which present monthly average wind speeds and directions covering five degree square regions. There is considerable local knowledge which suggests that significant variations exists within those regional areas, particularly in New England waters.

To quantify this local variation and to obtain data more useful to the present study, wind data was compiled from local Coast Guard reporting stations. Coast Guard weather logs include six observations per day of wind direction and velocity. As a simple but useful technique, the frequency and direction of winds greater than 15 knots were recorded monthly. Data from Gloucester, Scituate, Chatham and the Nantucket Light Ship were obtained. The most complete and useful data were for the year spanning 1980-81 at Gloucester and the Light Ship. Only these data are included here.

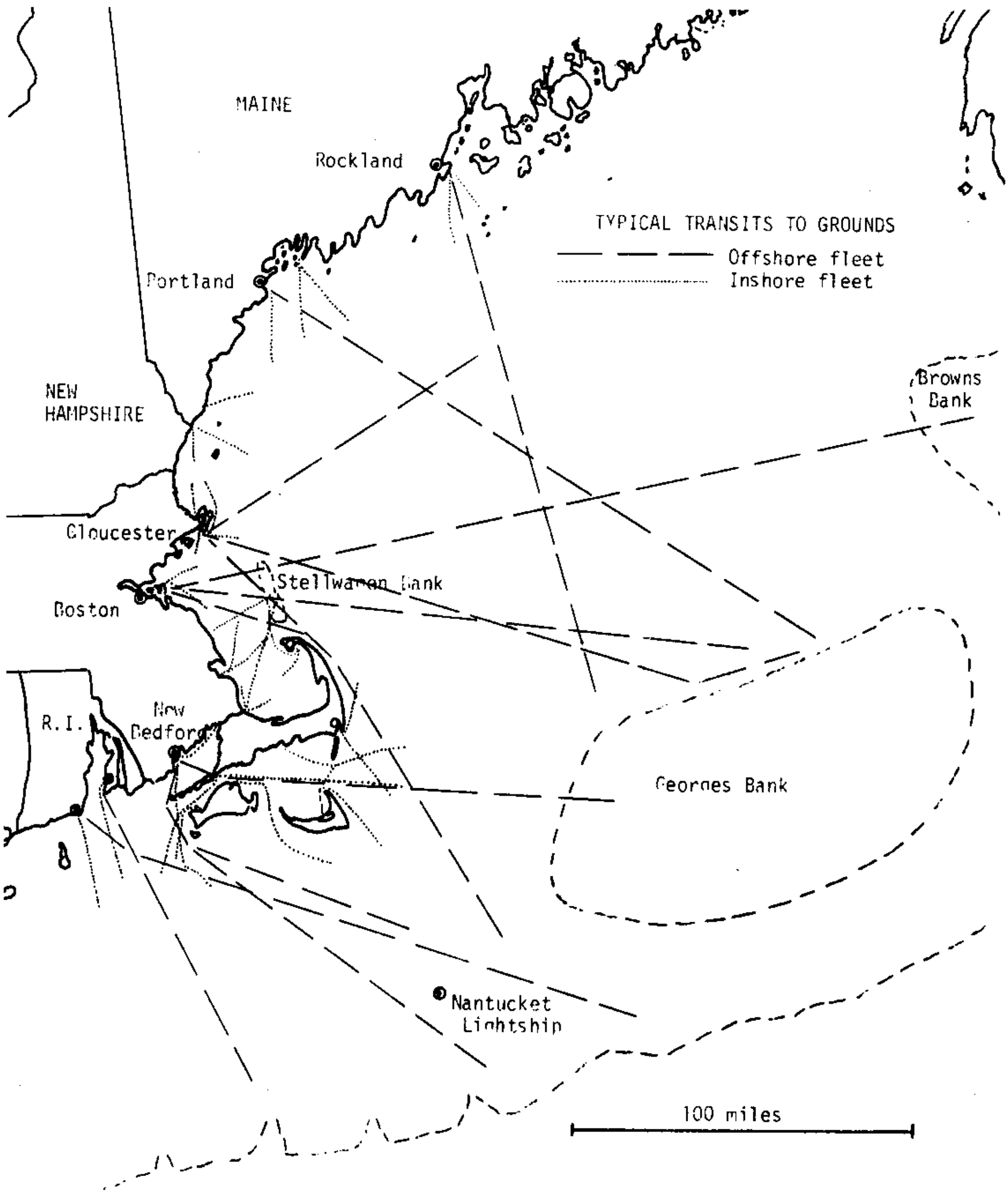

Figure 1. New England fishing grounds showing typical transits for the inshore and offshore fleets

Table 1 is a presentation of the data from the two locations. The months were grouped in threes to reveal seasonal and geographic variations. The trends indicated verify local knowledge and can be used to quantify the percentage of time winds exceed 15 knots and which directions predominate. This information combined with the transits shown in Figure 1 could help determine promising fisheries for consideration of sail-assist during steaming.

		N	NE	E	SE	S	SW	W	NW
Jan. Feb. March	Nantucket	8.6	2.6	3	2.6	4.6	6	12.3	17
	Gloucester	4	1	3	3.3	4	3.3	8.6	9.3
April May June	Nantucket	3.3	4.6	0	2.3	7.3	7.6	3.6	3.3
	Gloucester	0	0	0	3.6	4	4.3	2.6	10
July Aug. Sept.	Nantucket	2.3	1.6	2.3	1.6	5	3.6	0.6	2
	Gloucester	1.3	1	1	3	1.3	2	2.3	2.6
Oct. Nov. Dec.	Nantucket	6.3	3.3	5.3	3	2.6	5	9.6	11
	Gloucester	0	1	3	1.3	9	6.3	11	13.3

Table 1. Frequency per month of wind observations over 15 knots at Gloucester Coast Guard Station and Nantucket Light Ship for various directions. Each occurrence represents a log entry and four hours duration can be assumed.

RETROFIT DESIGN METHODOLOGY

Many factors must be considered when evaluating the potential of sail-assist on existing fishing vessels. All the concerns present in the design of a new sail-assisted vessel exist and are complicated by a few more. Most notable is the fact that the existing boat was designed with probably no consideration for sails or their associated gear. A further complication can be the numerous modifications or additions to the vessel since its design, or simply the lack of any drawings.

At the beginning of the design process, criteria must be established to serve as goals or guidelines to judge the innumerable retrofit possibilities. The following list of criteria was developed and, it is believed, reflects the engineering, economic and attitude realities of the New England fishery.

- A retrofit sail-assist installation must not interfere with the operation of the vessel's fishing gear.
- The operation of the sails must not require additional crew aboard and should preferably be handled under normal watch conditions.

- The sail-assist installation should not diminish the safety of the vessel with respect to stability, storm survivability, or risks to personnel.

- When possible, the hardware associated with the sail installation should be as robust as the normal vessel outfit. The system should be designed with due regard for anticipated level of maintenance, and environmental exposure (particularly icing) and mechanized components should have fail-safe manual backup.

- The sail plan size and level of complexity should maximize the owner's return on investment.

The implications of most of these criteria are clear in that we assume that the vessel is presently an effective fishing platform and any significant deviation from the present methods of gear handling may represent an unacceptable economic risk to the owner. The last criteria has less than obvious implications since the benefits of a sail installation begin to accrue with even the smallest of sail plans. The hoisting and proper setting of a sail has two important effects, the generation of forward thrust and the reduction of vessel motions. The latter effect not only is beneficial from the standpoint of crew comfort and safety on deck but also improves the propulsive efficiency of the propeller due to a smoother incoming flow and possible reduced frequency of cavitation and/or ventilation. Therefore, a sail-assist installation of steadying sail proportions is a valid consideration particularly if such a sail could be set from an existing mast.

Though installation costs and fuel savings both increase with sail area, the relationship varies and the installation cost is complicated by numerous sudden increases such as the extension of an existing mast, the installation of a new mast, the necessity of structural changes, or the addition of ballast.

The total benefits from an installation are often difficult to predict. The dollar benefits from reduced motions are hard to establish. In addition, the resulting improved propulsion coefficient does not lend itself to analysis and is not easily isolated from sail thrust during sea trials. It is suspected that much of the unexplainable synergistic effects of motor sailing could be accounted for by the improved propeller efficiency.

The costs and benefits of a sail-assist installation are very boat-specific. What is an optimum sail plan proportion for one vessel may not correspond to that of another similar sized vessel. An analysis should be performed to reveal maxima in the benefit/cost relation. Figure 2 is a hypothetical example of what such an analysis might reveal. An optimum sized sail plan can result which is far different than might be expected based on conventional sail boat proportions.

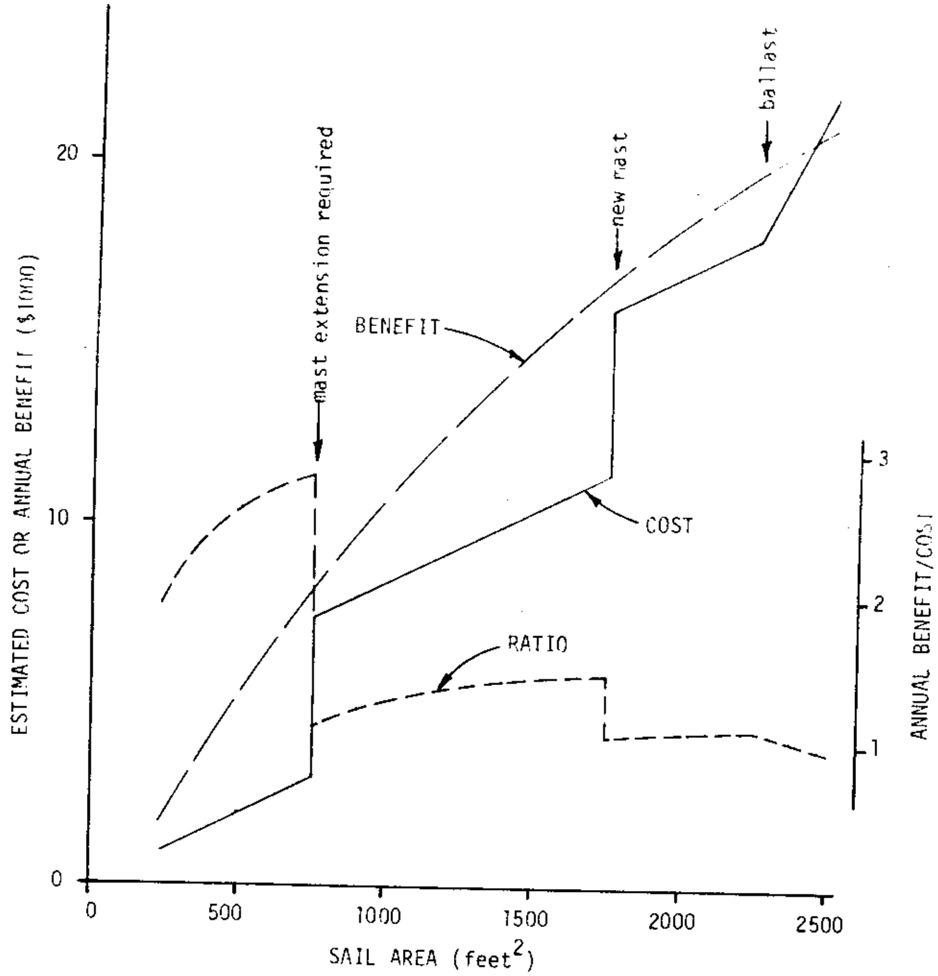

Figure 2. Costs and economic benefits versus sail area for a hypothetical retrofit sail-assist installation.

Intermingled with this optimum size analysis is the design process itself. This includes a thorough understanding of the vessel's present condition, method of fishing, and the constraints imposed by the owner and crew attitudes and capabilities. A complete analysis of the present stability characteristics is required. The soundness of relevant structures must be determined and the power requirements learned for various phases of the vessel's operation.

In the course of this project several interested vessel owners were identified and the retrofit sail-assist design of their vessels will be presented to demonstrate the application of the above methodology.

PRELIMINARY RETROFIT DESIGN - 86 FOOT SIDE TRAWLER

The 86 foot side trawler Vincie-N, out of Gloucester, Massachusetts, is typical of a vanishing breed of wooden vessels built with a hull form reminiscent of her sailing ancestors. Built in Bath, Maine, in 1938, she has been well maintained and is thoroughly sound. Launched with a 128 horsepower direct drive diesel, she now has 410 horsepower installed with a clearly undersized propeller. The original wooden mast has been recently replaced with a robust steel pipe version as shown in Figure 3.

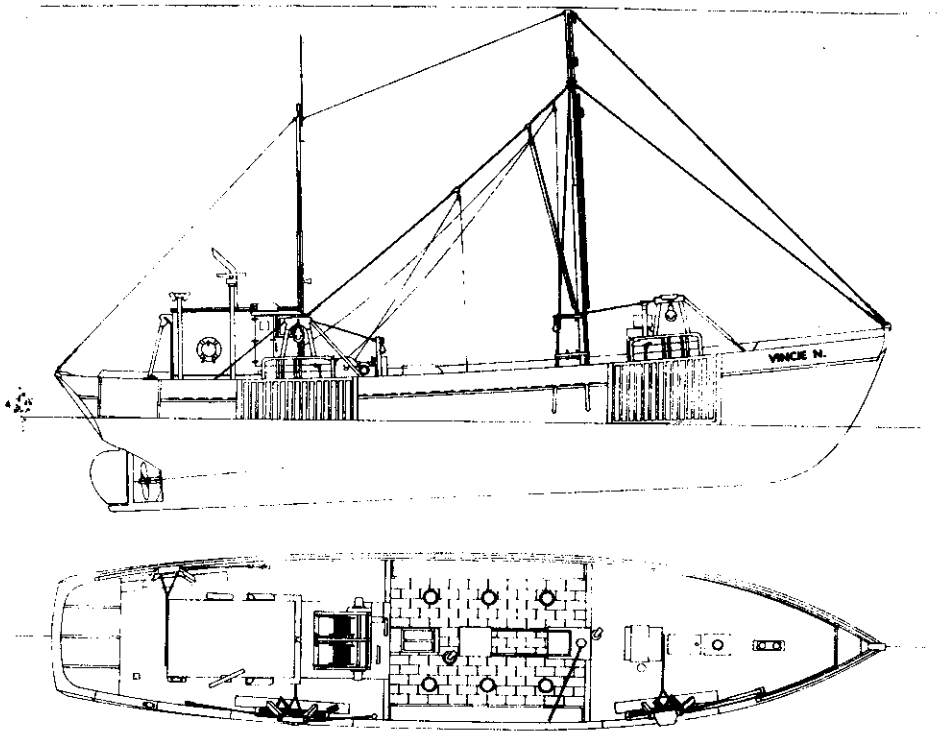

Figure 3. Outboard profile and deck plan of 86' side trawler Vincie N.

Based on the vessel's design and the owner's previous cooperation in several earlier Sea Grant projects, the preliminary design process was begun. There were no drawings of the vessel in existence; therefore to perform the necessary stability calculations, a lines drawing was prepared from measurements and photographs taken during a routine maintenance haul-out. Sectional offsets were measured at four locations approximately at stations 1, 4, 7 and 9. These, combined with profile photographs and detailed views of the stem and stern area were sufficient to generate the lines shown in Figure 4. From the lines, the hydrostatic calculations were performed manually with righting arms determined for heel angles of 15, 30, 45, and 60 degrees, and three different immersions to bracket anticipated loading conditions. The cross curves of stability are shown in Figure 5.

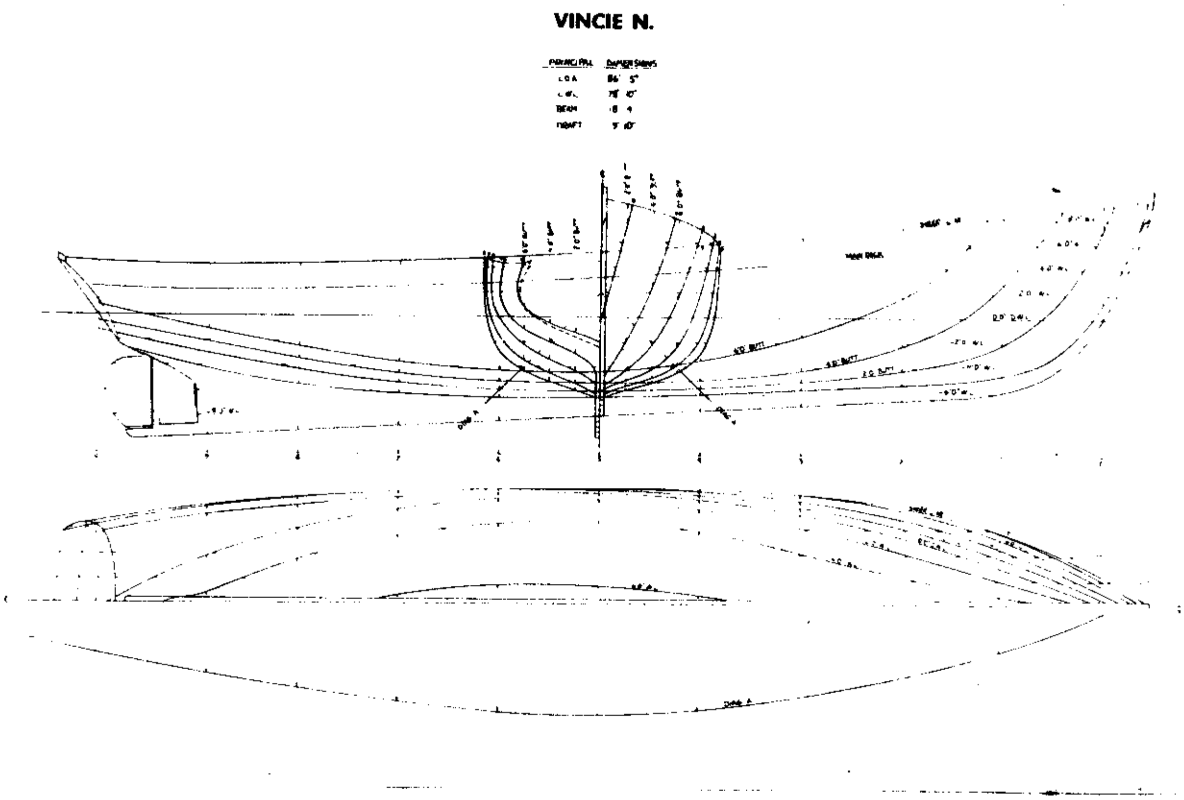

Figure 4. Lines drawing for Vincie N. reconstructed from hull measurements

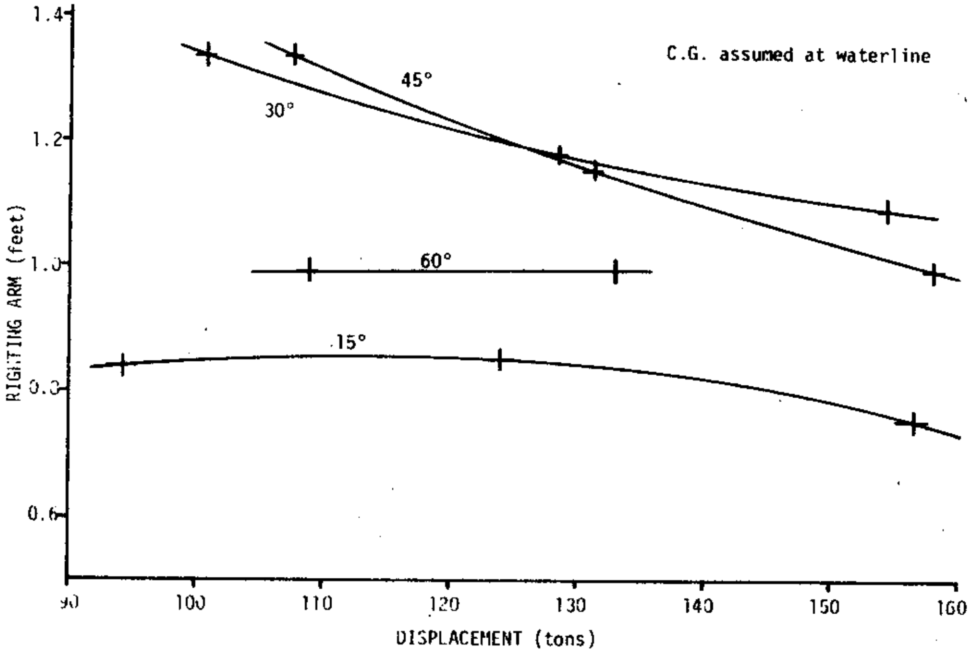

Figure 5. Cross curves of stability for Vincie N.

The effect on static stability of two candidate sail plans was then demonstrated by preparing a righting arm curve for the present condition and with the topside weight of the two installations. (See Figure 6). The location of the vessel's center of gravity was determined by an inclining experiment. The larger of the two sail plans was determined to be the more promising and involved lengthening the existing mast by 24 feet (see figure 7). The details of the proposed mast extension can be found in Appendix I. The 715 square foot mainsail was to be roller furling behind the mast. Due to the bulwarked forward main deck, the 745 squarefoot jib was to be hanked on and handled conventionally. The hoisting gear shown in Figure 3 would be provided with a quick-disconnect at its attachment to the after gallows and swung forward to prevent interference while sailing. Sail plans which involved a mizzen resulted in unjustifiable cost increments due to the present inadequate aftermast and interference with the exhaust and radar installations. The estimated cost for this retrofit is presented in Table 2.

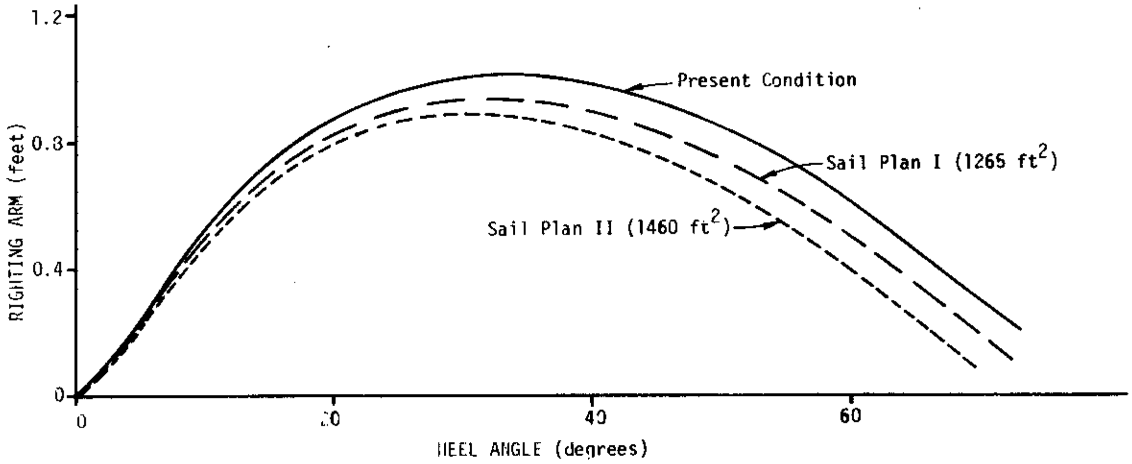

Figure 6. Righting arm for Vincie N. in present condition and with proposed sail-assist installations.

Mast Extension and standing rigging	$ 4,500
Mainsail (new)	2,200
Jib (used)	800
Mainsail furling gear	2,400
Running rigging	1,200
Miscellaneous	600
TOTAL COST	$ 11,700

Table 2. Estimated cost of 1460 square foot retrofit sail-assist installation on the 86 foot side trawler Vincie N.

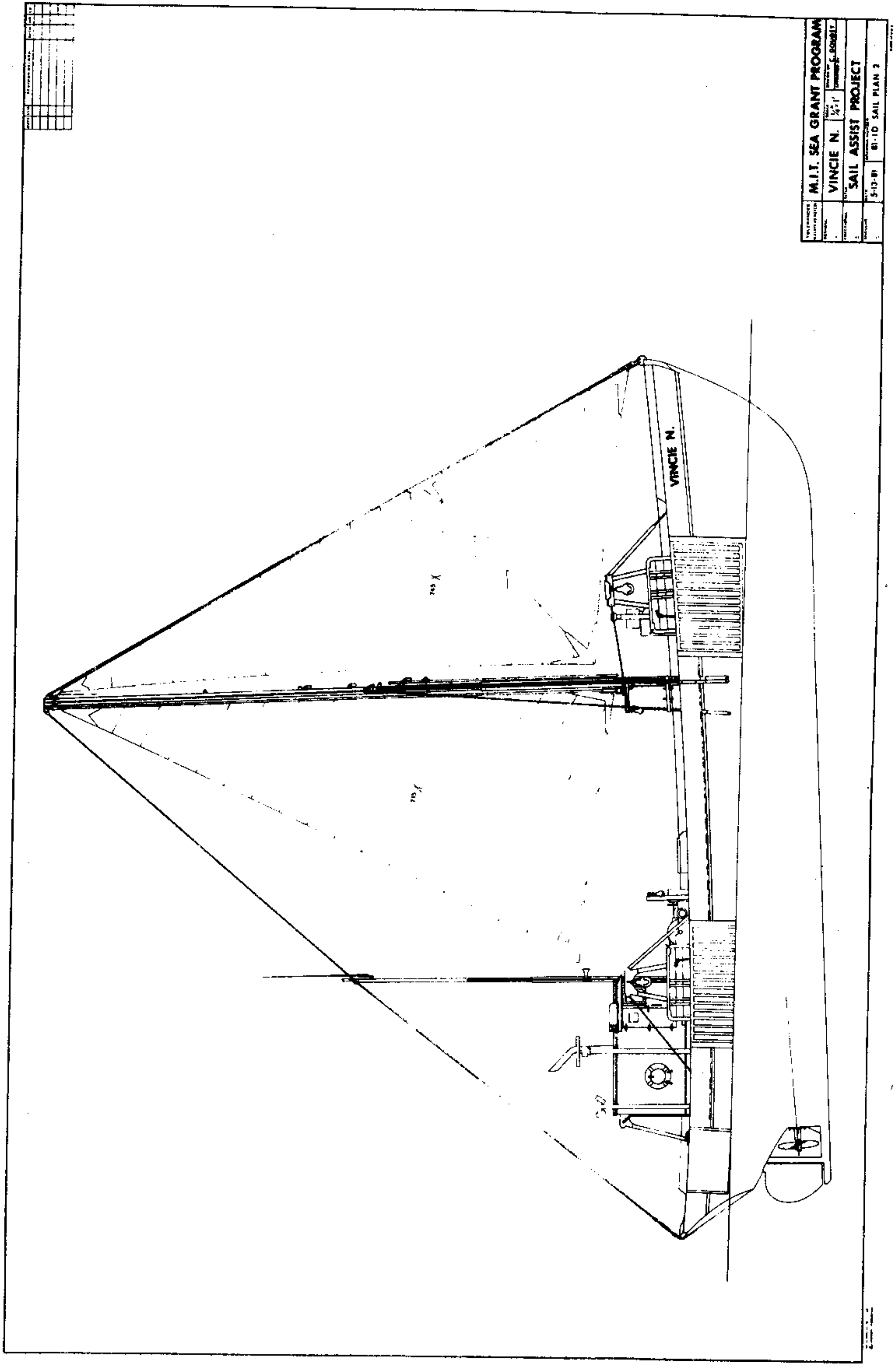

Figure 7. Proposed sail plan for the 86 foot side trawler Vincie N.

To better predict the performance of such a sail plan, a towing experiment was conducted. With the cooperation of the Gloucester Coast Guard Station, the Vincie N. was towed at both powered and unpowered conditions. The speed increase above normal for various Vincie N. throttle settings could be attributed to tow line tension and could later be correlated to forward thrust produced by the proposed sails. Due to a knot meter failure and weather deterioration the powered experiment data was unusable. The resistance and EHP curves are presented in Figure 8. The experimental plan described above could be an effective performance predictor though induced drag from leeway and the effects of heel would not be included.

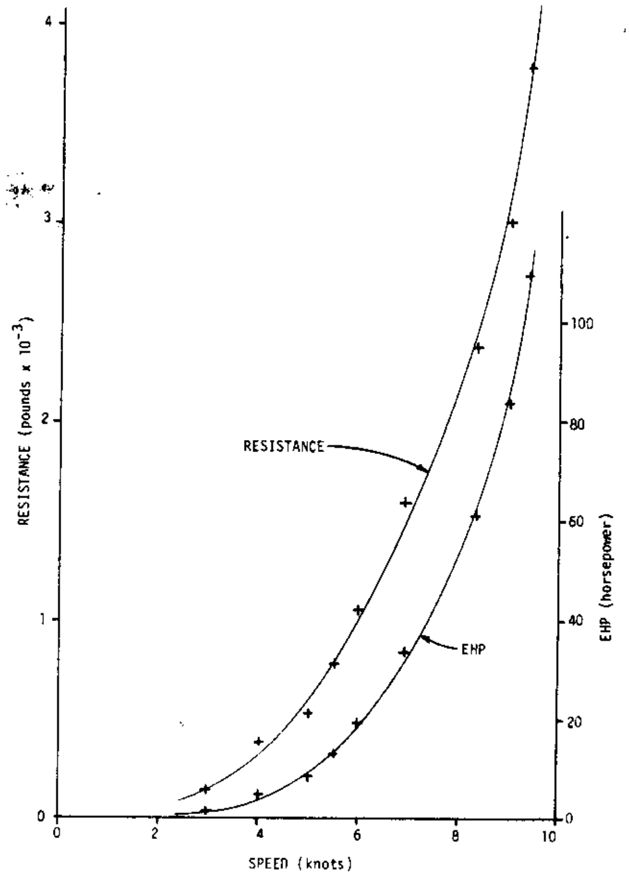

Figure 8. Resistance and EHP versus speed for 86 foot side trawler Vincie N. (from towing experiment)

PRELIMINARY RETROFIT DESIGN - 55 FOOT STERN TRAWLER

The stern trawler Denyle is a Bruno and Stillman 55 foot GRP vessel of which over thirty are in service in New England. She is typical of an even larger class of newer inshore draggers which often fish year round. Equipped with a 375 horsepower diesel, her daily fuel consumption is around 200 gallons. Based on $1.10 per gallon and 190 days per year underway, the annual fuel expenses are $41,800.

The Denyle's pilot house is well forward and she has no mast, using a 12'3" high rigid A-frame aft for hoisting. The lines and construction plans were obtained from the builder and a calculation and an inclining revealed ample stability for carrying sail with a maximum righting arm of 1.67 feet at 28 degrees of heel and over 1.00 feet at 60 degrees.

A retrofit design was prepared using a salvaged 57 foot yacht mast which was available. The 940 square foot sail plan, shown in Figure 9 seems of reasonable proportion but is quite conservative by yacht standards and yields a Dellenbaugh Angle of 3.7 degrees, stiff indeed! Both sails were to be roller furling and sheet to the stern towing frame. Sail trim would be done manually using the capstans on the dual hydraulic main trawl winches. The roller furling was to be hydraulically operated though the commerial availability of such gear was not determined. The vessel was sold before further work could proceed.

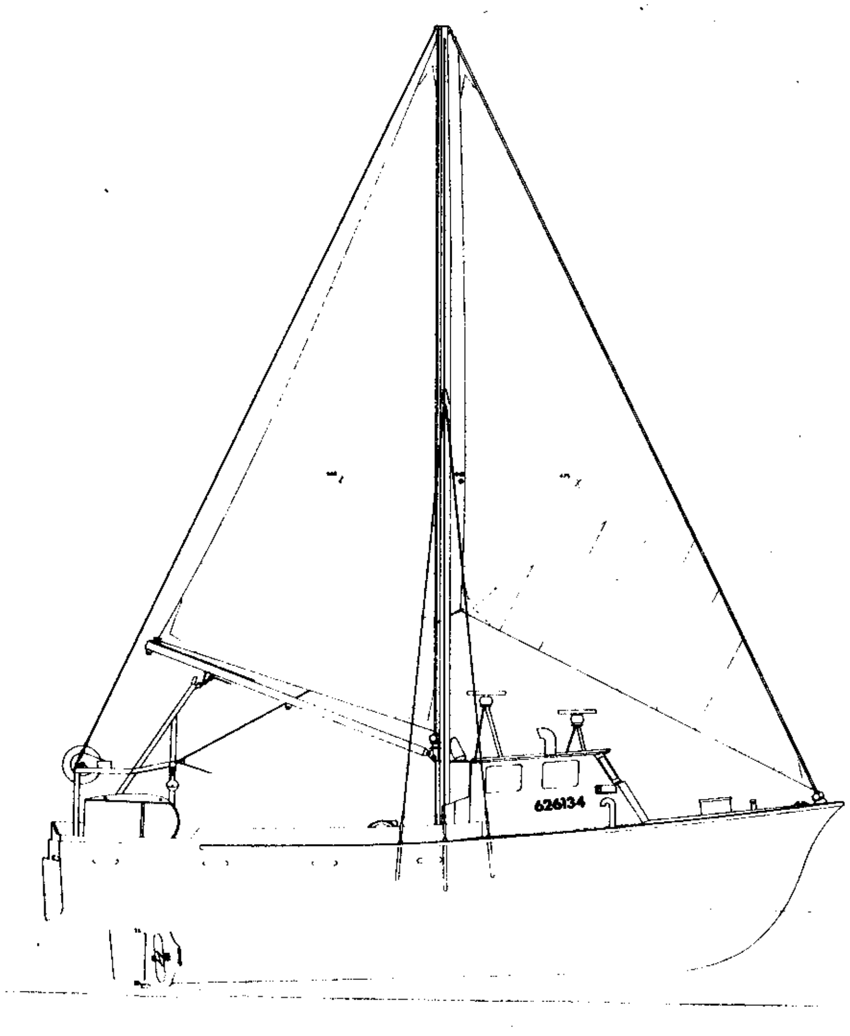

Figure 9. Proposed sail plan for 55 foot stern trawler Denyle.

PRELIMINARY RETROFIT DESIGN - 58 FOOT ST. AUGUSTINE TRAWLER

The 58' Miss Kim is a small dragger out of Scituate that was originally built as a shrimp trawler. She was a latecomer to the project and little has been accomplished in the area of stability analysis or detail retrofit costs. The vessel does however serve as an example of how existing rigging can be integrated into a compatible sail-assist rig.

The aft deck of the Miss Kim is 22 feet long with a myriad of booms, guys, tackles and struts, all essential to the present method of handling the trawl and unloading fish. Without extensive re-rigging and changes in gear handling techniques, setting a sail aft of the present mast would be impossible. Forward of the mast, however, is relatively clear of rigging and obstructions. The use of foresails alone could therefore have merit from both a cost and compatibility criteria. The lower forestay which presently leads to the stem is necessary to ensure the hoisting capacity of the main boom. Its removal would require alternative bracing for the existing portions of the mast or necessitate the leading of the boom topping lift to the top of any mast extension, requiring such an extension to be heavier than needed from a sail carrying standpoint.

A proposed configuration is shown in Figure 9. The lower forestays remain in place and a non-tacking, double rig is supported by a mast extension and dual forestays. The two mast-overlapping jibs are on separate roller furling mechanisms and each is used separately when reaching. Downwind, both jibs can be set.

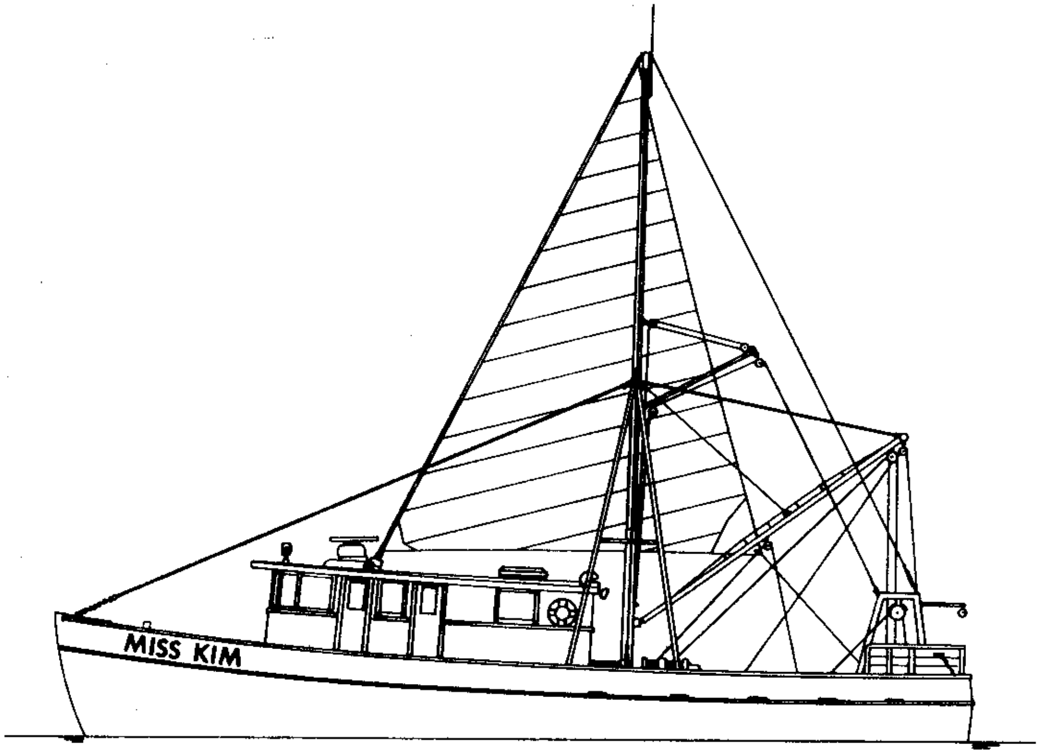

Figure 9. Proposed double headed sail plan for 58 foot stern trawler Miss Kim. Port jib is omitted for clarity.

The owner/operator of this vessel considers downwind trawling an attractive option. For a significant part of the season he fishes hang-free tows where direction does not seem important. He considers tow direction based on prevailing winds to be an acceptable constraint and that an effective means of rapid roller furling would provide the necessary maneuverability should the trawl come upon an obstruction. The size of this rig is yet to be optimized and the possibility of an additional flying jib should be considered. The concept represents a sail-assist installation that could apply to a broad class of fishing vessels.

COMPATIBILITY OF SAIL-ASSIST DURING FISHING OPERATIONS

The New England fishing industry is blessed with highly productive fishing grounds within easy reach of most ports. Transit times to and from these grounds are short in comparison to many other fisheries. The potential of sail-assist would therefore be limited if the only justification was reduced fuel consumption during steaming. This unfortunately is the case in installations proposed for vessels engaged in passive fishing methods. Gill netting, long lining or pot tending often require high control and maneuverability during the setting and hauling of gear. This would discourage the use of sails during those activities except for reduced area, stay sail configurations. In addition, energy consumption during periods of gear tending is generally low.

Trawling, by contrast, is more energy intensive, and fuel consumed by the fishing operation typically dominates. The thrust required to pull the trawl significantly exceeds that required during steaming. For this reason efforts to design sail powered trawlers have had discouraging results [6]. By accepting the obvious limitations, the benefits of sail-assist can be realized within the constraints of practicality and cost effectiveness. During trawling, if the wind and other conditions are favorable, the sail can be used to augment the propeller's thrust and allow an easing back of the throttle. The fuel savings may be fractional but it must be realized that most of time underway is spent trawling. The dollar value of fuel savings can be significant and present more economic justification than a similar installation on a vessel using passive gear. The sail-assist installation proposed for the stern trawler Denyle could produce over 1000 pounds of thrust with the wind astern at 15 knots. That would represent approximately 20 percent of the towing force required. Similar saving in other phases of the vessel's underway operations would result in an annual savings of over $8,000. The expected improvements in propeller efficiency due to reduced vessel motions could make this estimate conservative.

There are other phases of fishing vessel operations which allow unique opportunities for sail-assist. Often during brief periods of bad weather a vessel will stay on the fishing grounds at low power, dogging the wind. This is a more frequent occurrence when the species sought is available only at certain times of day. Under these circumstances comfortable station keeping could be achieved by sail alone. Another example of utility is the case where fishing operations cease but steaming full speed to port would result in arrival before unloading facilities are open. Sailing home under low or no power would be possible.

CONCLUSIONS

Based on the results of the preliminary designs presented above, the concept of retrofit sail-assist seems feasible on a significant portion of New England fishing vessels. The cost effectiveness of such installations is very boat-specific.

Due to the beneficial effects of reduced vessel motions, the economically optimum sail plan for such a retrofit may be far smaller than that required to achieve the speed or towing power presently available from the vessel's engine. The energy intensive nature of trawlers, contrary to popular belief, makes such vessels prime candidates for sail-assist when the type of bottom fished does not present frequent hangs.

The draft, stability, and seaworthiness of most New England trawlers give them good sail carrying potential. The standing and running rigging required to handle the trawl can conflict with conventional sail plans. A moderate sized sail plan, or one uniquely arranged to minimize interference can often be installed at low cost and with reasonable payback.

Due to the traditional nature of the New England fishing industry it is likely that an in-situ demonstration of the compatibility of sail-assist and conventional fishing methods will be necessary before it is considered viable.

ACKNOWLEDGEMENTS

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The cooperation of the fishing vessel owners was essential in conducting this project. Sammy Novello, owner of the Vincie N., Dennis Sweeney and Lyle Chamberlain, owners of the Denyle, and George Adams owner of the Miss Kim deserve our gratitude. The cooperation of the Coast Guard station personnel who willingly provided access to their weather logs is acknowledged. The assistance of Mr. Ham and the Gloucester Coast Guard Station boat crew is greatly appreciated. The cooperaton of Jerome H. Milgram, MIT Professor of Naval Architecture, and Don Mitchell, President of Cruising Design, Inc. is also acknowledged.

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APPENDIX I

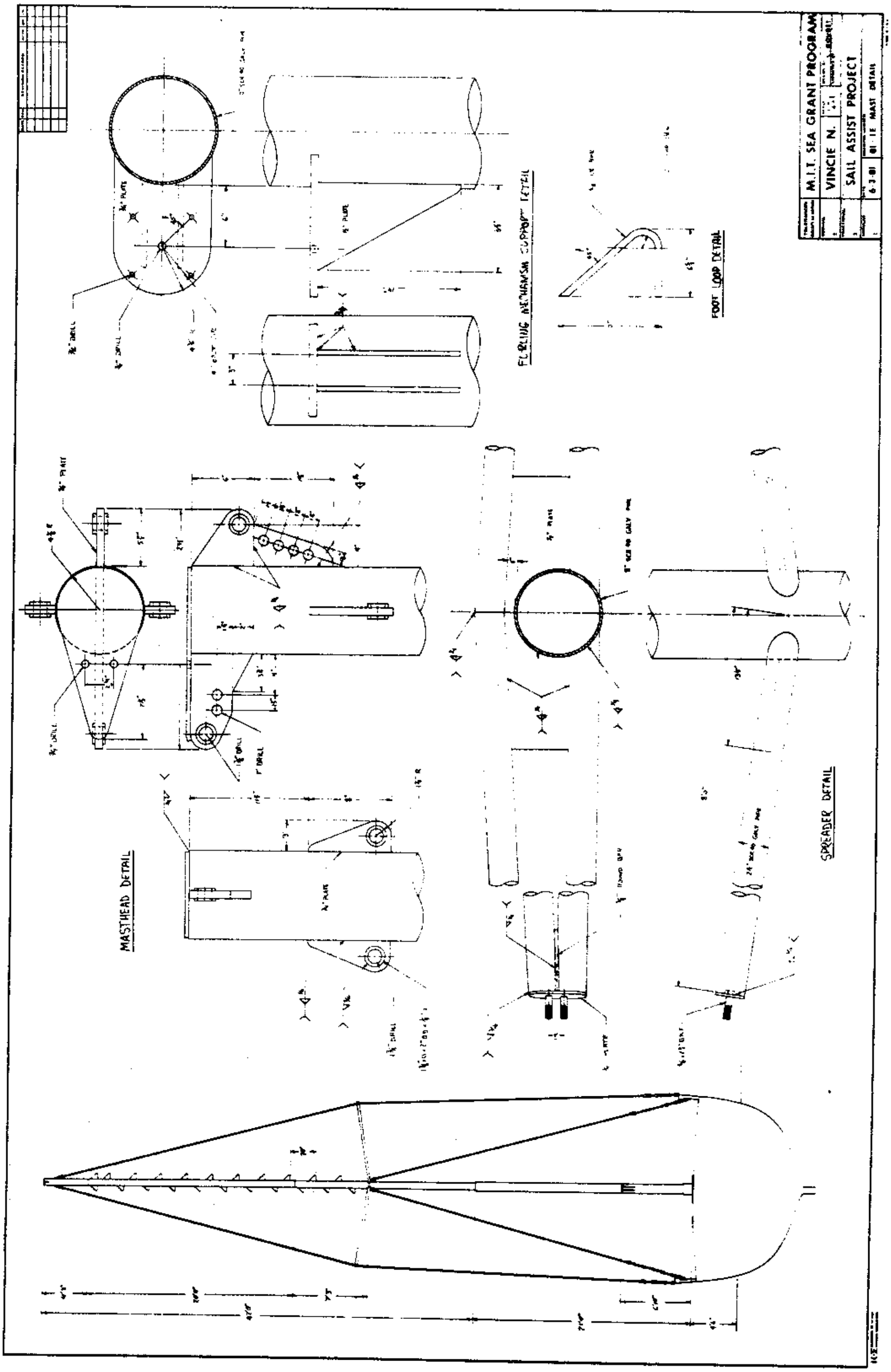

Figure 10. Detail of mast extension for 86 foot side trawler Vincie N.

A PACIFIC ISLANDS FISHING VESSEL

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ABSTRACT

Described is a small sailing catamaran intended for construction by Pacific Islanders without sophisticated tools and facilities. The vessel is 41 feet (12.5 meters) long, 26 feet (7.92 meters) wide. Each hull is four feet (1.2 meters) wide at the sheerline and three feet (.91 meter) wide at the bottom. The hulls are 8 feet (2.44 meters) deep. The hulls draw about 2 feet (.61 meter) when light and four feet (1.2 meters) when heavily loaded. Sail is carried on two masts. An alternative sail plan with four masts is illustrated.

The vessel is specifically designed for deep-sea fishing, for manning by Pacific Islanders.

INTRODUCTION

For two millenia multi-hulled sailing vessels carried almost all of the people, the animals and the cargo in the Pacific and East Indian Oceans. The only exceptions were Asian junks and sampans -- highly developed and efficient carriers. Rarely, however, did these great ships venture the long, deep-sea voyages traversed by the multi-hulls.

With little fear of contradicition it can be said that all of the great voyages, the voyages of discovery and settlement of the thousands of Pacific Islands were exclusively in multi-hulled sailing vessels, created without metal of any kind -- whether for tools or fastenings or hardware.

These remarkable vessels varied greatly in design.

In Melanesia very large three and four-hulled vessels in great fleets rhythmetically plied the wind routes off New Guinea. In shorter voyages marvelously swift proas (1) sailed among the lesser islands.

In Micronesia, those thousands of islands, mostly atolls stretching five thousand miles within the temperate zone of the Pacific, the favored vessel was the outrigger canoe. This form had the advantage of being able to tack or jibe without rerigging and changing the helm to the other end. While very fast, such a vessel is by nature somewhat fragile and limited in size.

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(1) A proa is a slim hull to which is connected by beams athwartships a heavy float. This float os kept out of the water while underway and is always kept to windward. Change in direction is affected by making the stern the bow, moving mast, yard and sail to another mast step and moving the steering oar to the opposite end. The slim hull, with the float or "ama" out of water results in an extremely fast

vessel, but a very temperamental one, requiring a large and efficient crew.

Multi-hulled sailing vessels reached the highest development, however, in Polynesia. Few people realize that Polynesians were regularly making voyages of two and three, even four thousand miles (6400 kilometers) a thousand years before Columbus sailed down-wind from the Azores to the Carribean. Many of the Polynesian voyages regularly required sailing at points of wind which European vessels could not match until the Nineteenth century.

More importantly, these great voyages were not the exception; they were the rule. The wide Pacific was traversed regularly by the Polynesian navigators; great fleets plied annually from the Marquesas to Hawaii, and return, from Tonga to New Zealand and the Samoas. By at least 1200 A.D. the entire Polynesian Triangle had been not only discovered; it had been settled. This is a huge area, stretching more than 5500 miles (8800 kilometers) from New Zealand to Easter Island, and northwest to Hawaii, another 2500 miles (4000 kilometers), back to New Zealand about 4000 miles (6400 kilometers). This is an area far larger than the entire North Atlantic sailed by the Vikings, the Spanish and the Portuguese combined prior to 1450.

There is little doubt that the Micronesians and especially the Polynesians were the greatest navigators, the most expert deep water sailors and probably the greatest ship designers of all the world's history prior to at least the Seventeenth century.

Perhaps, however, due to their great successes in settlement, perhaps due to the excessive toll in resources and manpower these remarkable voyages had exacted, the great voyaging ceased by about 1500. The magnificent voyaging vessels were no longer built and the Polynesian peoples largely lost contact with their cousins in other archipeligos. Their knowledge of navigation slowly dimmed and by the time of the Rediscoveries by the European captains in the Sixteenth, Seventeenth and Eighteenth centuries, the descendants of these formerly the greatest sailors, were amazed at the ability of the Europeans to make such long voyages.

Today there are perhaps ten people in the whole world who possess the remarkable navigational techniques of the ancient Pacific peoples. None of these is Polynesian.

THE POLYNESIAN SAILING VESSEL

What was this instrument of such great Polynesian voyaging?

It was a catamaran. (2)

The hulls were two hollowed-out logs (generally of hardwood - e.g. Koa, a very tough Hawaiian tree with some characteristics of oak and others of Honduras mahogany). Some of the larger catamarans had a plank lashed above the natural sheer of the log (similar to the old log canoes of the Chesapeake region). The lashing holes were waterproofed by tree gums.

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(2) A catamaran (probably derived from the East Coast Indian word "Kattumarans" where thousands of these double-hulled vessels are

still used in close-to-shore fishing) is defined as a vessel having two hulls of roughly equal dimensions connected in parallel by a platform. The hulls are generally very long in ratio to their beam, with relatively low freeboard.

Curved beams mounted athwartships supported a central platform on which was erected a cabin similar to those built on shore.

There were, generally, two masts, each supporting a claw-shaped sail tightly woven of pandus strands.

These catamarans were rarely longer than 75 feet (22.87 meters); hull widths rarely exceeded 4 feet (1.22 meters) Freeboard was low as the auxiliary power for these vessels was provided by paddlers seated in each hull. Watertight integrity was somewhat enahnced by wooden covers fitted over the open hulls when paddlers were not seated in them. The center platform was raised by bowing the beams which connected the hulls.

With a length/beam ratio of at least 15 to 1, these vessels presented considerably less resistance than mono-hulls. As they had no dead ballast, they were lighter than mono-hulls. Thus their required sail area was less. the weight of spars and sails reduced. Their speed, despite the bluntness of entry of hulls was significant, a source of amazement to the European discoverers who saw them underway.

Indeed, these were the fastest deep-water ocean-going sailing vessels in history, at least until the Baltimore Clippers of the early 1800's. Moreover, no other vessel in the world could sail closer to the wind until the development of schooner-rigged vessels of the early 1800's.

The few small voyaging canoes which remained were greatly admired by Captain Cook when he visited the Hawaiian Islands in 1778. The last large fleet of them transported the army of Kamehameha the Great from Hawaii Island to Maui and Oahu in his successful conquest of all the Hawaiian Islands during the opening decade of the last century. Several of the larger catamarans even mounted cannon.

Only two of these great vessels are now known to exist in all of the world - and both of these are recently built replicas.

PRESENT STATUS

I have gone into some detail as to these ancient craft because, I suggest, ignoring the evolutionary creativity of two millenia would be foolishly wasteful.

This does not mean that the conditions which created these vessels still continue to exist -- or that we need have Polynesian kahunas (priests) select with appropriate ceremony the trees to be felled out of which the hulls of modern vessels should be fashioned.

Indeed, Polynesians as a race now evidence only a smallish remnant of their aptitude for the sea. (Fortunately there does appear the beginning of a racial renaissance in this and other ancient aptitudes). For the most part all of the native Pacific

Islanders -- Melanesian, Micronesian and Polynesian -- have seen the world pass them by. They have been the victims of cultures imposed upon them which they neither admire nor comprehend. They are, for the most part, impoverished, bewildered and overwhelmed by the white man's and the Asian's command of science.

The results have been either a superficial integration at the lowest economic levels or a growing isolation in a declining subsistence economy or, what may be worse than either in the long run, a resentment towards all other races leading to an intransigent, even chauvinistic, nationalism. As a people they have lost their self-sufficiency. Many have also lost their pride and their bearings.

FISHING VESSELS

With the exception of New Guinea -- rich in almost all the valuable minerals, New Caledonia -- the second largest source of nickel in all the world, and the phosphate pinnacles -- Nauru and Ocean Island (both nearly mined out), few of the Pacific Islands have any natural resources of any consequence, except one.

Their warm surrounding oceans abound in fish.

Presently, and for a long time, this their only natural resource has been taken by a highly organized scientifically efficient fleets of Japan, Korea, Taiwan and Russia. Steel hulls and diesal engines and all the science which produces such machines has relegated the Pacific Islander to eating from cans the fish which abound off his coasts -- tins filled by Asians and a few Europeans and Americans.

By relearning the arts and skills of fishing beyond his reefs, the Pacific Islander has, I suggest, a greater opportunity to improve his economic and sociological well-being than in any other single effort. He can capitalize his only real natural resource and utilize his historical affinity for the sea. This affinity, though long submerged, can be reawakened. A combination of challenge and opportunity will, I believe, suffice.

But he will need a vessel with which to start.

REQUIREMENTS OF A PACIFIC ISLANDER'S FISHING VESSEL

Unless he will merely substitute masters rather than again become his own, his vessel cannot duplicate those now conducting fishing operations in the Pacific.

Pacific Islanders do not have (with the single exception of Nauru) the capital with which to build great hulls of steel powered with large diesal engines. Nor, even if they did have access to such capital, could they organize it as efficiently as the corporate masters of East Asia, America or Europe.

The fishing projects I envision must confrom to and stimulate basic cultural patterns of the Islanders. Fishing, in other words, must be more than a business; it must involve more than a small segment of the communities; it must in due course permeate the lives of whole villages.

And this can be done, with numerous incidental advantages.

Certain objectives and parameters must be ascertained, stated and advanced.

Among these are:

1. The design of the vessels must be appropriate to the fisheries where they will be used and the crews who will man them. This requires substantial input from these same people.
2. The vessels should be of a design which will permit their being constructed, at least in large measure,in the villages from whence their crews will come.
3. As much of the construction labor, materials and equipment as possible should be provided from the same island or other islands within the archipeligo. This includes sail-making, construction of spars, even some foundry work (marine blacksmithing) and welding. It includes splicing of metal cables, asselbling blocks, even reconditioning engines. These are skills beneficial to the Islanders, skills which they now possess or can learn.
4. Crews both for construction and sea-manning must be trained. While formal, book-oriented education cannot be ignored, most of the training will undoubtedly be by apprenticeship, experience. (Islanders have remarkable memories, a result of their systems of oral preservation of geneologies for many generations before any writing became available).
5. The prototype vessels must be simple in design, without complex curves; they must be adapted to construction in remote areas devoid of sophisticated construction facilities.
6. The design must result in an extremely strong vessel. Despite its name, the Pacific Ocean can become a roaring, raging beast intent on wreaking havoc upon those who put forth upon it.
7. The vessel must be designed to utilize the most easily obtained building materials, stock items wherever possible. The initial class of these vessels should be constructed of hardwood frames, easily bent stringers, plywood skins. Fastenings should be screws and bolts and good glues. Such sophistications as fiberglass, foam cores and the like can follow later.
8. Hull shapes should emphasize ease of construction over exotic efficiency; flat bottoms may well be the rule. Not only are they easier to construct, but they beach more readily and safely. They also permit shallow draft for reef-running. The extra knot or two which a more finely-formed hull might produce is not worth the extra effort and frustrations.
9. Size restraints are those of overall costs and the nature of fishing techniques to be employed.
10. The rig must be simple, strong and powerful enough to drive the vessel at a good speed. Though the hull froms here proposed are not those of racing yachts, they are long and lean, conducive to respectable speeds.
11. Spars and sails should, wherever possible, be standard, interchangeable with other boats. While unstayed masts have many attractive features -- and later may be adopted -- a rather sophisticated spar building technique would be required; the initial spars would be better constructed conventionally -- hollow, glued and screwed and strongly stayed.
12. Hardware should be simple, rugged. Roller reefing, particularly

of headsails, may well be sufficiently foolproff to be warranted. But even that may be an expense unjustified on the first prototypes.

13. These will be deep-sea vessels. Accommodations for adequate crews, including apprentices, must be provided. Such quarters, messing and head facilities will be rather primitive as compared to those required for Western-type vessels. This is an acceptable condition.
14. The vessel must be susceptible of repair and refitting without resort to sophisticated yards. It should be able to be beached for scraping and painting, small enough to be manhandled on rollers.
15. It must be designed to sail reasonably well in all states of loading -- light or burdened. To do this may well require the lateral resistance of centerboards or leeboards.
16. It should have refrigeration, perahps freezing capabilities, depending on the fisheries to be utilized. (On-board refrigeration is more expensive, under the factors in effect, than taking aboard ice upon departure).
17. Adequate fuel and water capacity must be provided.
18. An auxiliary engine is a necessity. A diesel engine is a thing of beauty -- but too expensive and difficult to maintain in the environment here contemplated. A reconditioned automobile or truck engine would be more appropriate, considering all things including the reasonably minimal use for which it is intended.

These are the basic limitations and parameters. The most important of these are simplicity of design, strength, seaworthiness and economy of construction and maintenance. These are not impossible combinations.

THE PROTOTYPE VESSEL

The vessel suggested is shown on Sketches 1 through 7 attached.

It is a catamaran.

This configuration is utilized for many reasons:

a) It conforms to the age-old traditions of those who will build and man it.
b) It permits a hull shape which is easier to construct, having no compound curves or bending which requires a steam box.
c) It is, by reason of its high length to beam ratio, easily driven, whether under sail or power.
d) It has for its size an enormous deck area for fishing gear and crew working.
e) The stability of widely separated hulls provides a working area relatively more level than a mono-hull of equal length.
f) It need carry no ballast in order to maintain a vertical posture under sail.
g) Its wide stance permits a larger sail area to be contained within a lower profile thus lessening the capsizing moment.
h) The catamaran configuration permits the vessel to be readily beached for repairs and maintenance without complex shoring, marine railways and complex infrastructure.
i) Being without ballast the vessel, though somewhat overbuilt for strength, its nevertheless relatively light.
j) Its long flat bottoms provide shoal draft characteristics required to navigate shallow passes over reefs.

The hull shapes are simple.

The typical hull center frames are four feet (1.22 meters) across the top, three feet (.91 meters) at the bottom and eight feet (2.44 meters) deep. One-third of each hull have frames of these identical dimensions. (See Sketch 6)

The hulls are 41' (12.50 meters) long. There is considerable rake to the stems which creates a distinct flare in the bows. The transoms are narrow, less raked, providing less flare in the stern sections. The stem at the sheerline is one foot (.30 meter) higher than the sheer line amidships; however the deck is raised one foot and thus is in line with the stem sheer.

The ratio of hull length to maximum hull width is 10.25 to 1.

The ratio of hull length to bottom beam is 13.67 to 1.

The hulls are separated by a deck which is 26 feet (7.9 meters) wide. Thus at the median waterline there are 19 feet (5.79 meters) between the hulls. I am aware that the ratio of maximum beam to length is more usually 1 to 2 and this vessel's is approximately 1 to 1.58. This increased beam was decided upon for several reasons:

1) The greater separation of the hulls reduces the buildup of of bow V waves within the tunnel, resulting in increased speed.
2) Greater stability under sail is afforded, without undue increase in clumsiness (if, indeed, clumsiness is a result of the greater beam).
3) A larger deck working space is provided, and this is a work boat.
4) An incidental advantage is that the two rudders, thus provided with greater moment, turn the vessel more quickly.

From Sketch 6 showing the midship frame, it is obvious that the hulls are rather deep, 8 feet (2.44 meters) compared to an average beam of 3.5 feet (1.06 meters). The principal reason for this is to raise the bottom of the deck a fair distance above the sea, to provide an adequate tunnel freeboard. One of the problems of relatively small catamarans is that the underside of the deck is lapped by waves. This is not only uncomfortable but slows the vessel considerably.

The deck structure is actually a bridge. The connecting beams rigidly attached at both ends to the tops of the hull frames are skinned on both top and bottom with plywood. These beams are nine inches (22.5 centimeters) on edge, two inches (5 centimeters) thick (and doubled where plywood seams occur). This is a structure of exceptional strength.

There is always a problem with multi-hulls in the twisting motion -- as where the starboard hull's bow dips in one trough and the port hull's stern dips in another. This problem does not appear significant in a boat of these dimensions joined by a deck of this construction. (I am working on a larger, heavier catamaran sailing barge. In that situation the problem does make its appearance and some rather unique diagonal bracing is required.)

The hulls contain the fish holds midships. These holds are separated by watertight bulkheads from the forward and aft sleeping quaters, three (rather narrow) bunks in each hull. Below the fish holds are the fresh water and fuel tanks.

The holds, as earlier mentioned, are refrigerated. In the prototype vessels, the refrigeration units will probably be those removed from old freezers whose cabinets have rusted out on shore. The auxiliary engine operating a generator will be started up from time to time to supply the electricity to maintain the temperatures required. This is all rather crude to fishermen in this audience, but it will suffice -- and it does have the merit of economy. Hopefully from the profits derived from these economies, a more sophisticated system will be able to be installed in the not-far-future.

POWER

Power is primarily by sail, but auxiliary gasoline engine power is also provided.

A catamaran presents numerous possibilities for innovative sailing rigs, far more than mono-hulls of the same length. Most catamarans have been rather traditionally rigged, with one or more masts stepped on the centerline, with shrouds extending from mast to chainplates on the outboard sheer lines of the hulls. Traditional fore and back stays stretch from mastheads to stemheads and stern posts or the beams connecting them.

I have elected to use rather different rigs, for which I have already been criticized and expect further criticism in the future.

Unconventionally they are, perhaps even unlovely in the eyes of everyone but the designer. They do, however, present certain definite advantages in my view.

Sketch 4 depicts the first rig carried. It is, in effect a sloo! and a cutter rig one set farther forward than the other.

This set-up has some advantages and some disadvantages. There is less windshadow on the leeward sails when the wind is abeam than if the masts were equidistantly stepped from the bows. However the boom on the port headsail is unusually long and therefore rather clumsy. It is however designed so that it will clear all the foredeck gear. I cannot claim the rig to be a thing of beauty, with all the booms hung five and one-half feet above the deck. The sails are basically leg-o-mutton, rather old-fashioned when viewed by eyes accustomed to tall, slim Marconi rigs. Theyhave the advantage, however, of supporting a relatively large sail area on relatively short sticks. This vessel can carry full sail when I would be very wary of it if carried on much taller masts and shorter booms.

What I consider a better sail plan was developed for another vessel now being modeled. This is the one shown on Sketch 7. Here the masts <u>are</u> stepped the same distance from the bows. And there are four, rather than two masts. There <u>will</u> be some windshadow. However there are other advantages which I think outweigh this result.

The first is simplicity of staying. For the entire rig, there are two forestays, one backstay and four shrouds plus a center headstay.

The narrowest width of the deck -- the line between the two mast steps -- is 18 feet (5.5 meters)! Very few, if any, vessels 41 feet (12.5 meters) long can boast such unimpeded deck space for the locating of working gear.

The "secret" of all this is, of course, the unconventional spar connecting the mastheads. This beam must, of course, be carefully designed and even more carefully constructed. So designed, constructed and utilized, it completes a series of wide-stanced triangles which would be the delight of any trigonometry student.

As can be observed, a large sail area can be obtained from masts that do not reach very high into the heavens. The rig has the further advantage that, as in no other of which I am cognizant, the booms have an honest 180 degree arc, unimpeded by shrouds which ordinarily attach to chainplates aft of the mast step.

I am also toying with light squaresails, stowed on deck, to be hoisted, yard and all. to the centers of those masthead beams, swinging within that 18 foot void when the wind is from one quarter or the other -- or somewhere in between. And, with only a bit more handling effort, much wider squaresails could be hoisted, with the yard's leading end forward of one mast, aft of the other. Such sails could push this catamaran along at a fair clip in quatering winds.

By this time even the most conservative sailing man acknowledges (sometimes with reluctance) the necessity for an auxiliary engine.

The plan for such engine power on our prototype conforms to this imperative, however, with a difference.

As already mentioned, a reconditioned automobile or truck engine is contmeplated as our motive power. Such engines are cheap, easily repaired; there are relatively abundant spare parts. They produce a lot of horsepower. Admittedly they are not as fuel-efficient as a diesel. But the additional initial cost of the latter will buy many months, indeed many years, of fuel for an automobile engine which is used but a small number of hours each voyage. It is also true that gasoline engines present a fire hazard. But that is no greater a hazard than many other accepted by those who fish hundreds of miles at sea.

In any event the engine is mounted pretty much out in the fresh air -- centered on the deck, well forward of amidships. By a universal joint it is connected to a sahft hung on the underside of the deck. At the aft end of the shaft is the screw. The shaft is lifted, folded up against the bottom of the deck when under sail, greatly reducing propeller drag.

Alternatively a large outboard could be mounted between the stern posts and tilted up when not in use. However big outboards of power commensurate with that of an old V-8 auto engine are very expensive, could not as conveniently operate refrigeration units, are even hungrier for fuel and would require some lowering device, as their legs are never deep enough. In a rough sea they are always in danger of immersion. All in all, an outboard would not be a good alternative.

DECK FISHING GEAR

I am not a commercial fisherman and pretend no competence in its techniques and gear. I have therefore taken the easy road -- showing only sketchily some representative gear. It is my objective to provide a fleet, floating workspace upon which a variety of gear adapted to a variety of fisheries can be placed. I yield to others far more knowledgeable than I the task of selecting the proper gear and properly arranging it aboard.

CONCLUSION

The vessel described, like any other, is a compromise. It has inherent disadvantages which accompany what may be considerable advantages. It represents a first effort to solve a number of problems; by no means is it intended as an end-all and be-all. Experience in its use will, I am sure, demonstrate its errors and its good points, allowing corrections and improvements to be made.

But this I know. It will be far superior in and for the environment for which it is intended than vessels designed for different waters, different conditions and different cultures. As such it may in some small way contribute both to the material well-being of thousands of isolated and alienated human beings -- and it may restore in some measure the memory of greatnesses of the past and produce the inclination for greatness in the future.

February 28, 1983
Honolulu, Hawaii

L.N. Nevels, Jr.

BIOGRAPHY

Luman Norton Nevels, Jr.

Address: 4505 Kahala Avenue, Honolulu, Hawaii 96816. Telephones: (808)737-2235 (808) 734-2885 Telex: 7430269 "Malut"

Born: Portland, Maine 1924 (Iroquois, French, Vermont-Yankee)

Married: Mary Ann Gross of Long Hill, Connecticut (Dutch, German, Swiss, French) 1946

Progeny: Two daughters, one son, five grandshildren

Education:

Public Schools: Portland, Maine; Augusta, Maine

Colleges and Universities:

Bowdoin College	1942-1943, 1946 BA)c.l.) 1946
Bates College	1943, 1944
Cornell University	1944 (V-12, Naval Reserve)
Harvard Law School	1946-1949 LLB;JD 1949
Harvard Business School	1949
Naval School of Justice, Newport, Rhode Island	1951

Professional Career:

Private Law Practice:
1949-1951 Hilo, Hawaii
1953-1955 Wahiawa, Hawaii
1960-1967 Hilo, Hawaii
1967-present Honolulu, Hawaii

Judiciary: Judge of the Third Circuit Court, Territory of Hawaii, 1955-1959
FAA Visiting Judge, Wake Island 1968-1972

Fields of Practice:
International contract; Real estate law; Tax haven law; Civil trials

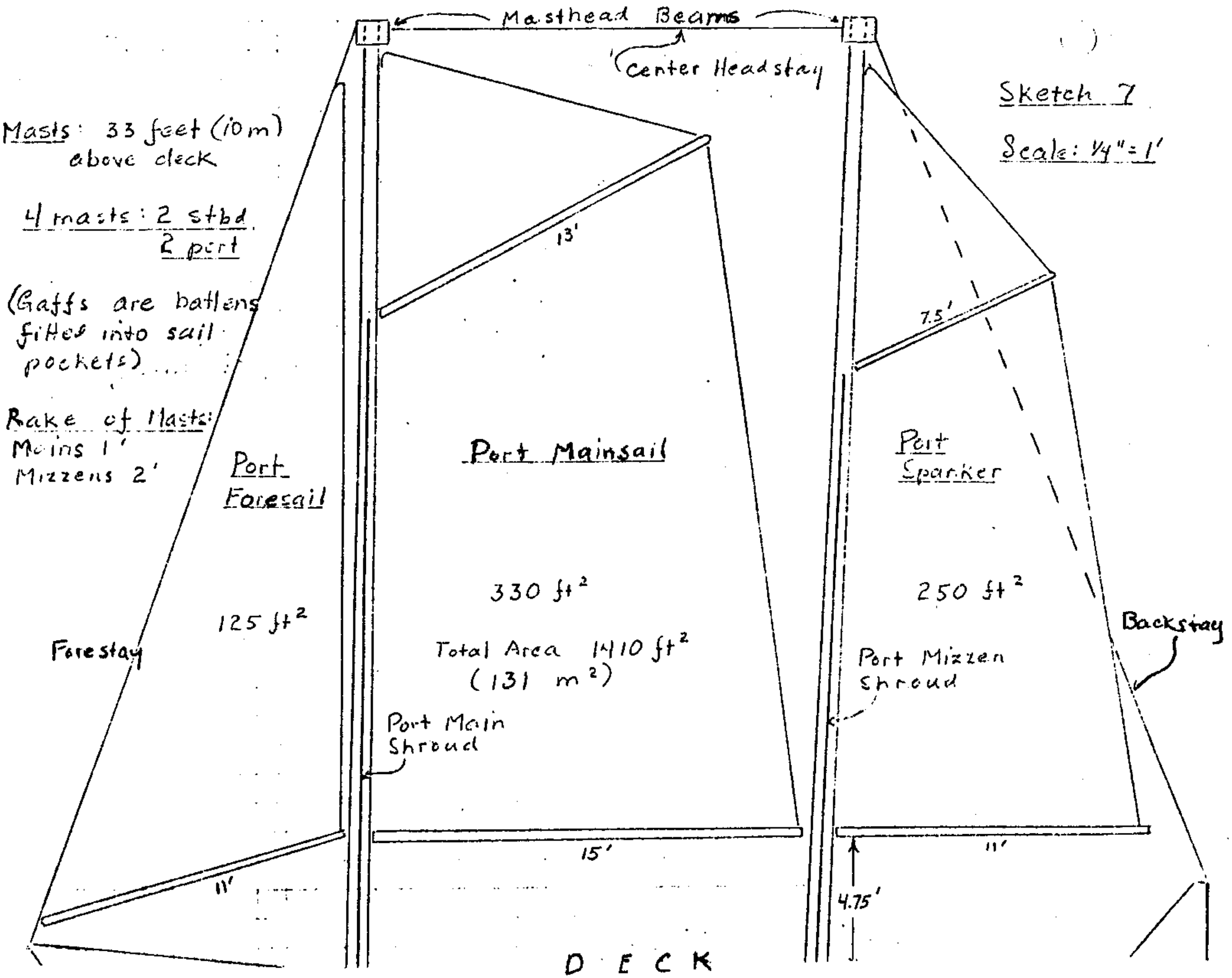
Military Service:
1942 Enlisted, USNR; 1944 Commissioned Ensign USNR; 1944-1946 Deck Officer, Western Pacific (landing Craft); 1946-1949 US Naval Reserve, Boston (Submarines); 1949-1951 US Naval Reserve, Hilo, Hawaii (Intelligence); 1951-1953 Active Duty, Pearl Harbor (Communications Security); 1953-1964 US Naval Reserve (Surface Unit, Hilo, Hawaii); 1964 Retired, LCDR USNR.

Business Interests: Copra, cattle, cacao - South Pacific plantations. Real estate - France, Spain, South Pacific Islands. Trading company - Mogadiscio, Somalia. Mines - US and Central America. Gas wells - Louisiana. Wind turbines - Windfarm operations projected for Hawaii, South Pacific.

Avocations: Design of sailing vessels, light aircraft; design of unconventional weapons systems; private pilot; sailing; military and naval strategy and tactics; and history.

Sketch 7

Scale: 1/4" = 1'



Masts: 33 feet (10 m) above deck

4 masts: 2 stbd
2 port

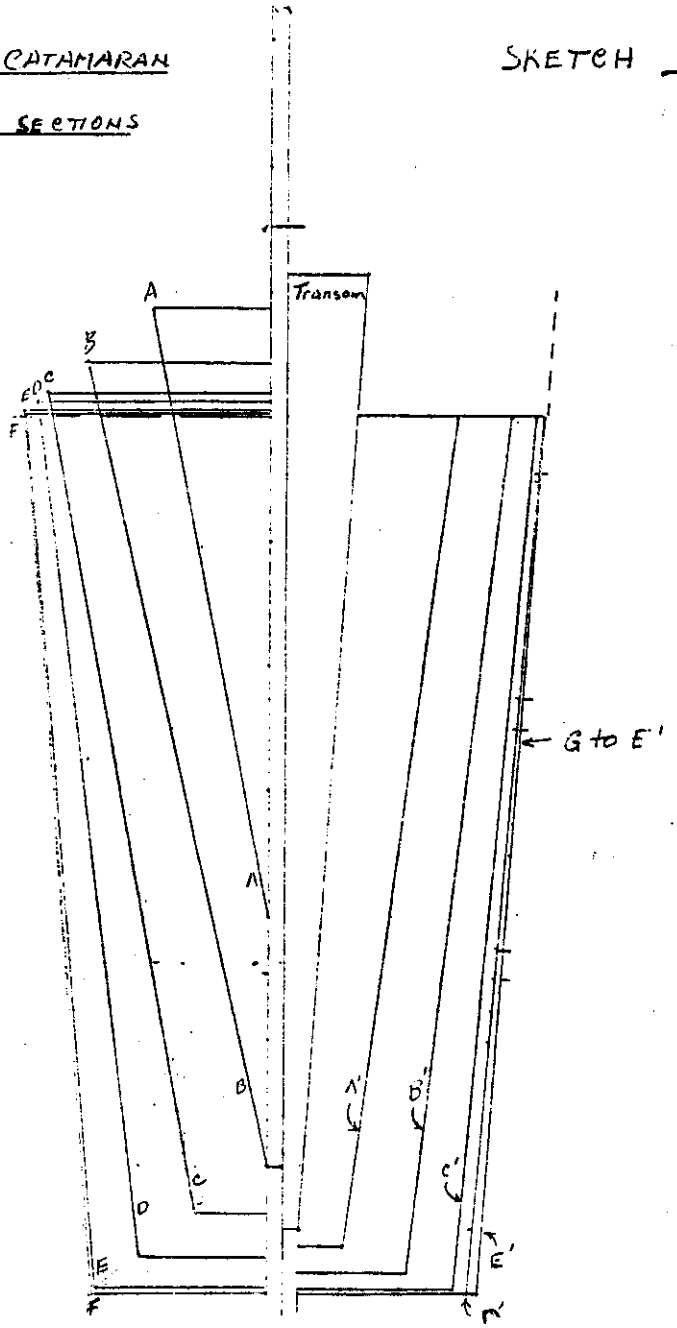
(Gaffs are battens fitted into sail pockets)

Rake of Masts:
Mains 1'
Mizzens 2'

FISHING CATAMARAN

HULL SECTIONS

SKETCH 6

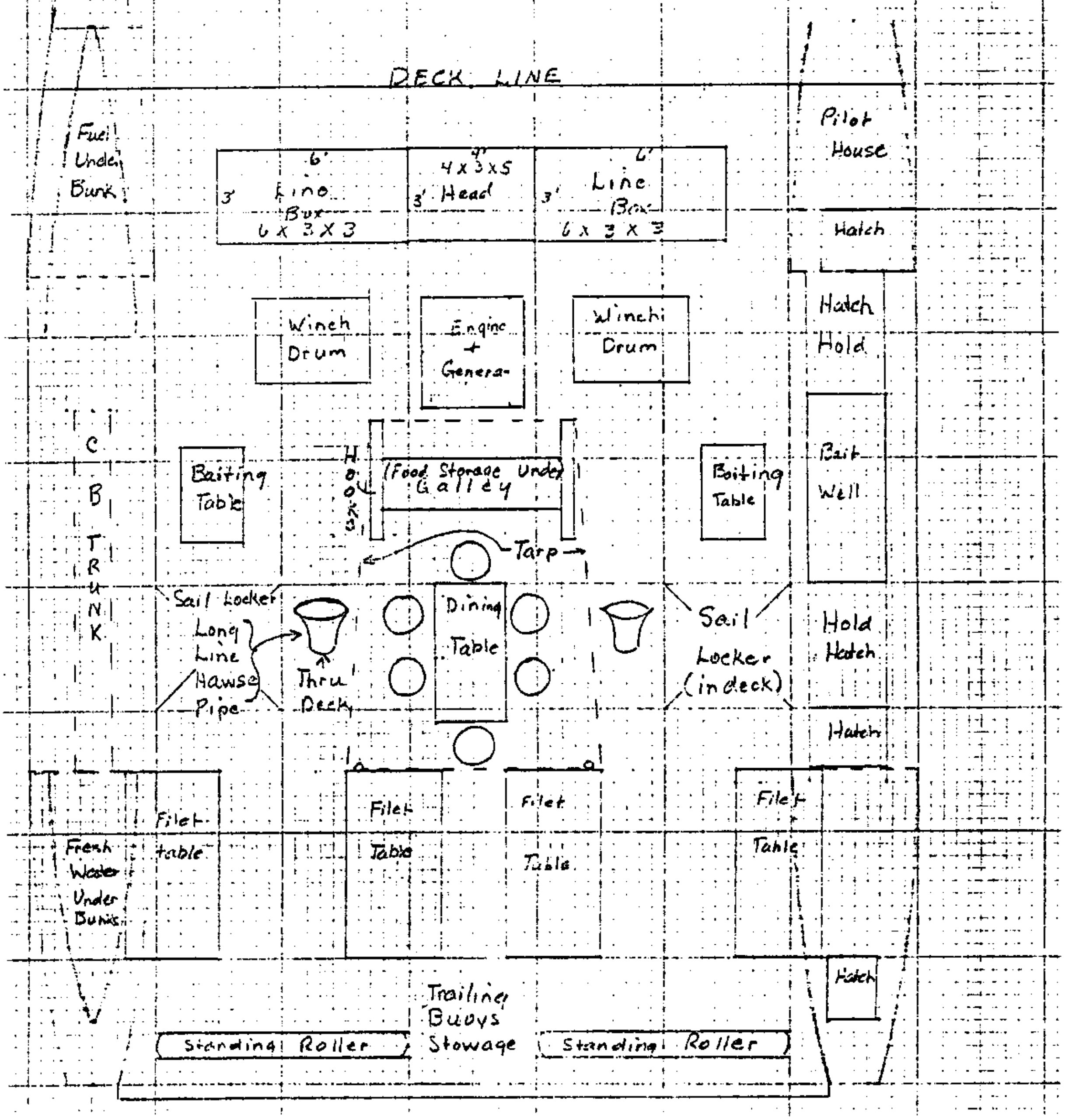


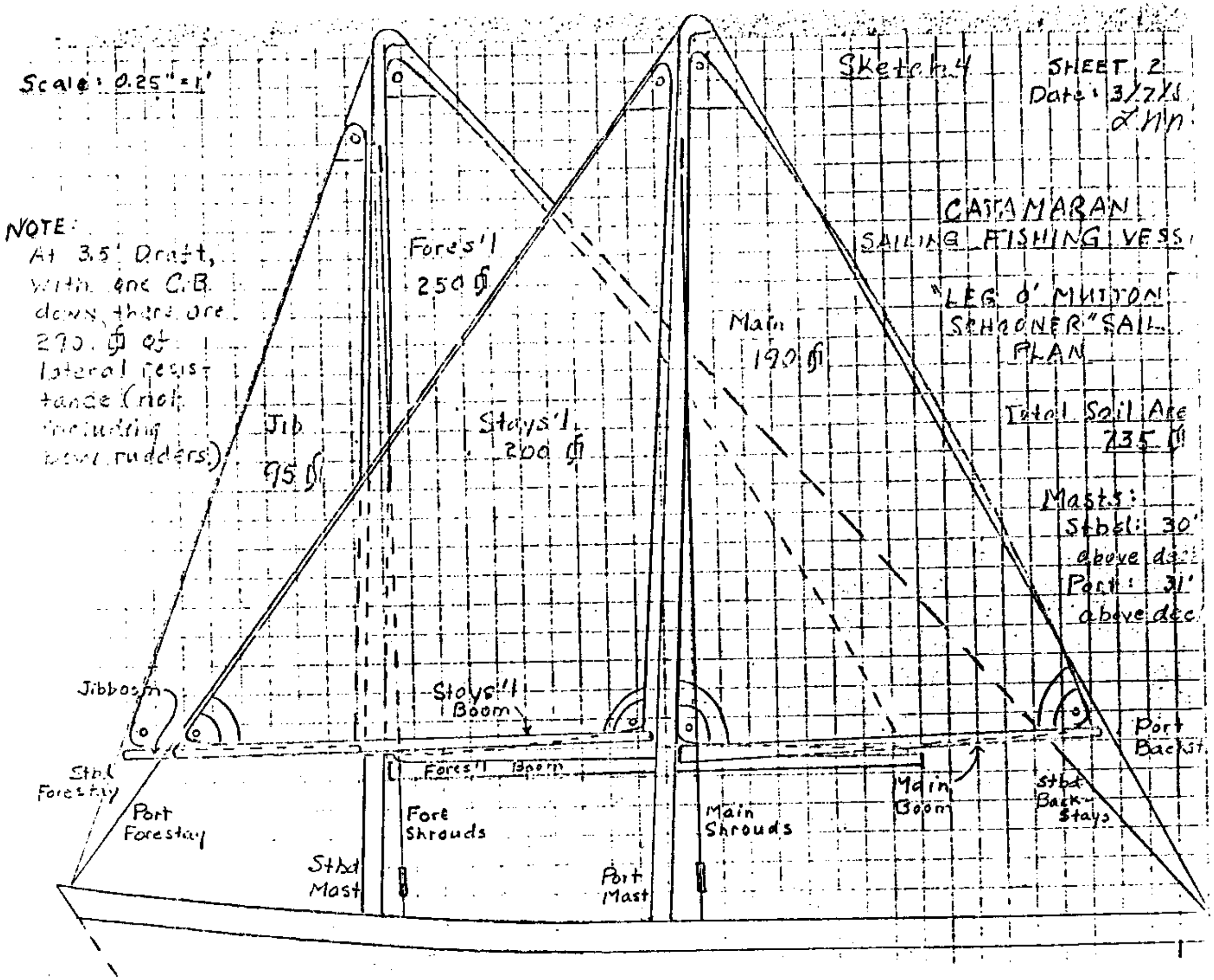
April 17 82

Sketch 5

Deck Arrangement

41' CAT
Sailing Fisherman
(for long line use)

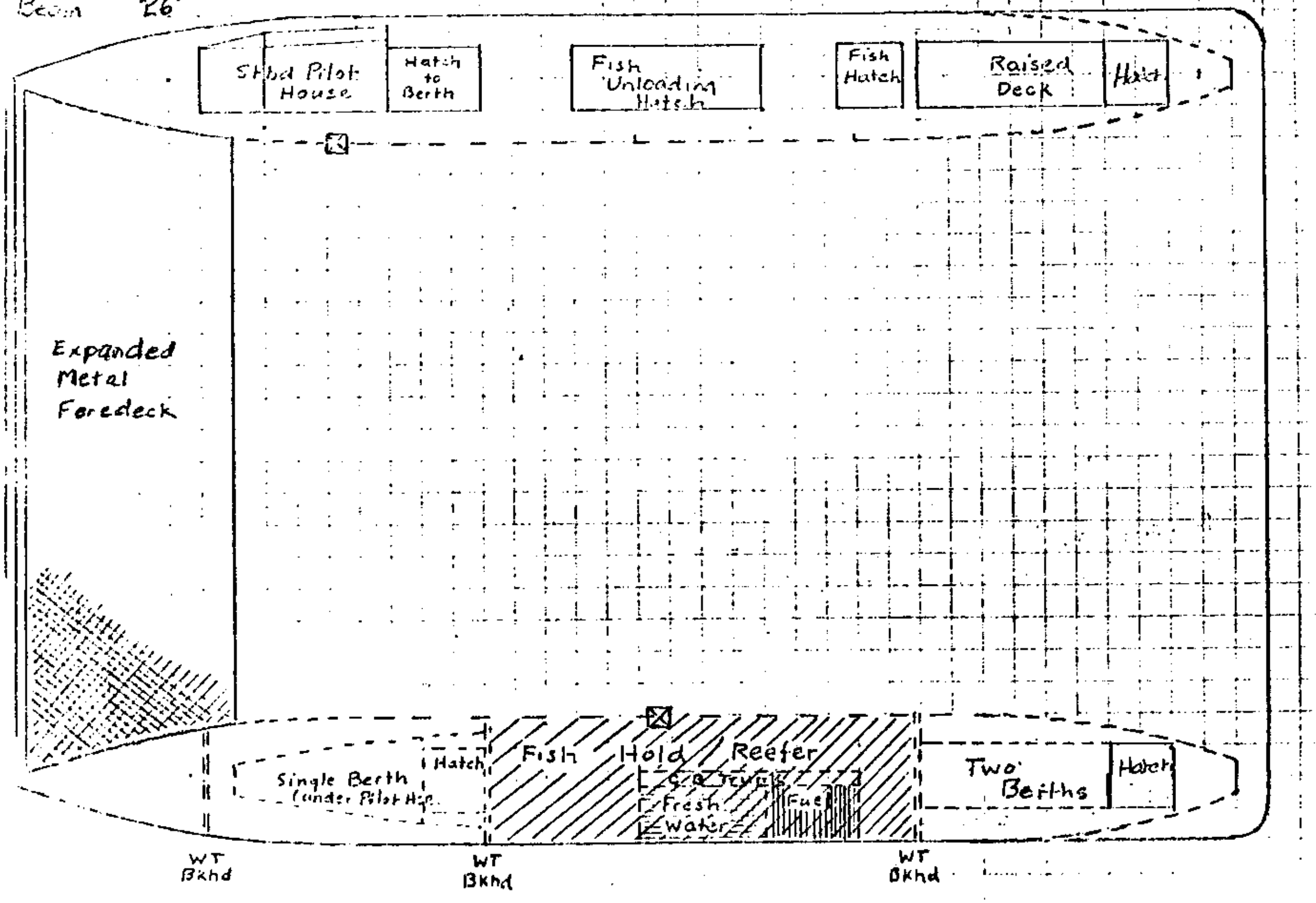


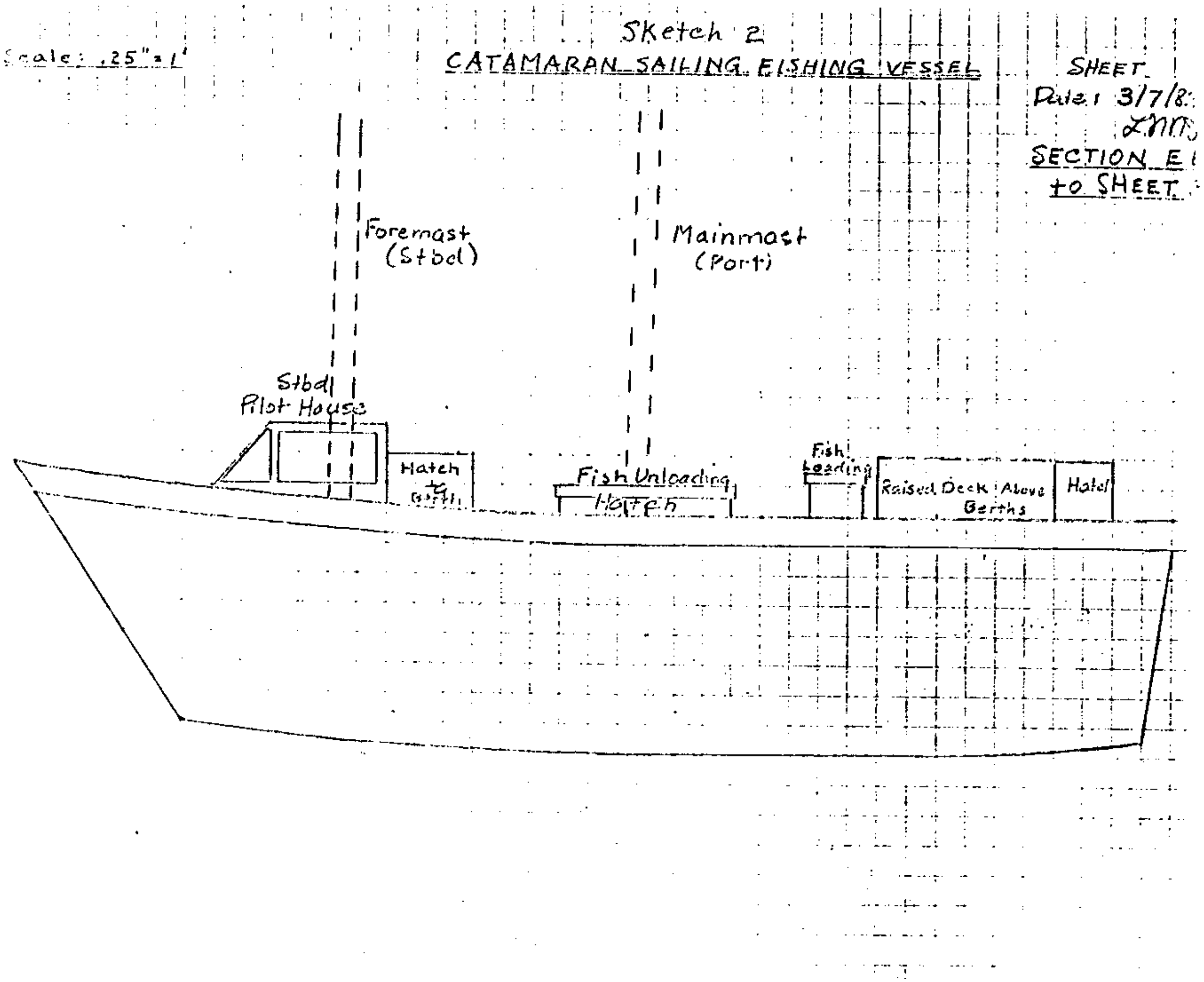

Scale: 0.25" = 1'
Sketch 4
SHEET 2
Date: 3/7/81
LHn
CATAMARAN
SAILING FISHING VESS
"LEG o' MUTTON SCHOONER" SAIL PLAN
Total Sail Are 735 ft²
Masts:
Stbd: 30' above dec
Port: 31' above dec
NOTE:
At 3.5' Draft, with one C.B. down, there are 270 ft² of lateral resistance (not including rudders)
Fores'l 250 ft²
Main 190 ft²
Stays'l 200 ft²
Jib 95 ft²
Jibboom
Stbd Forestay
Port Forestay
Stays'l Boom
Fores'l Boom
Main Boom
Fore Shrouds
Main Shrouds
Stbd Mast
Port Mast
Port Backst.
Stbd Back-Stays

Sketch 3
SCALE: 0.25" = 1'
Length: 41'
Beam 26'

CATAMARAN SAILING FISHING VESSEL
Configuration:

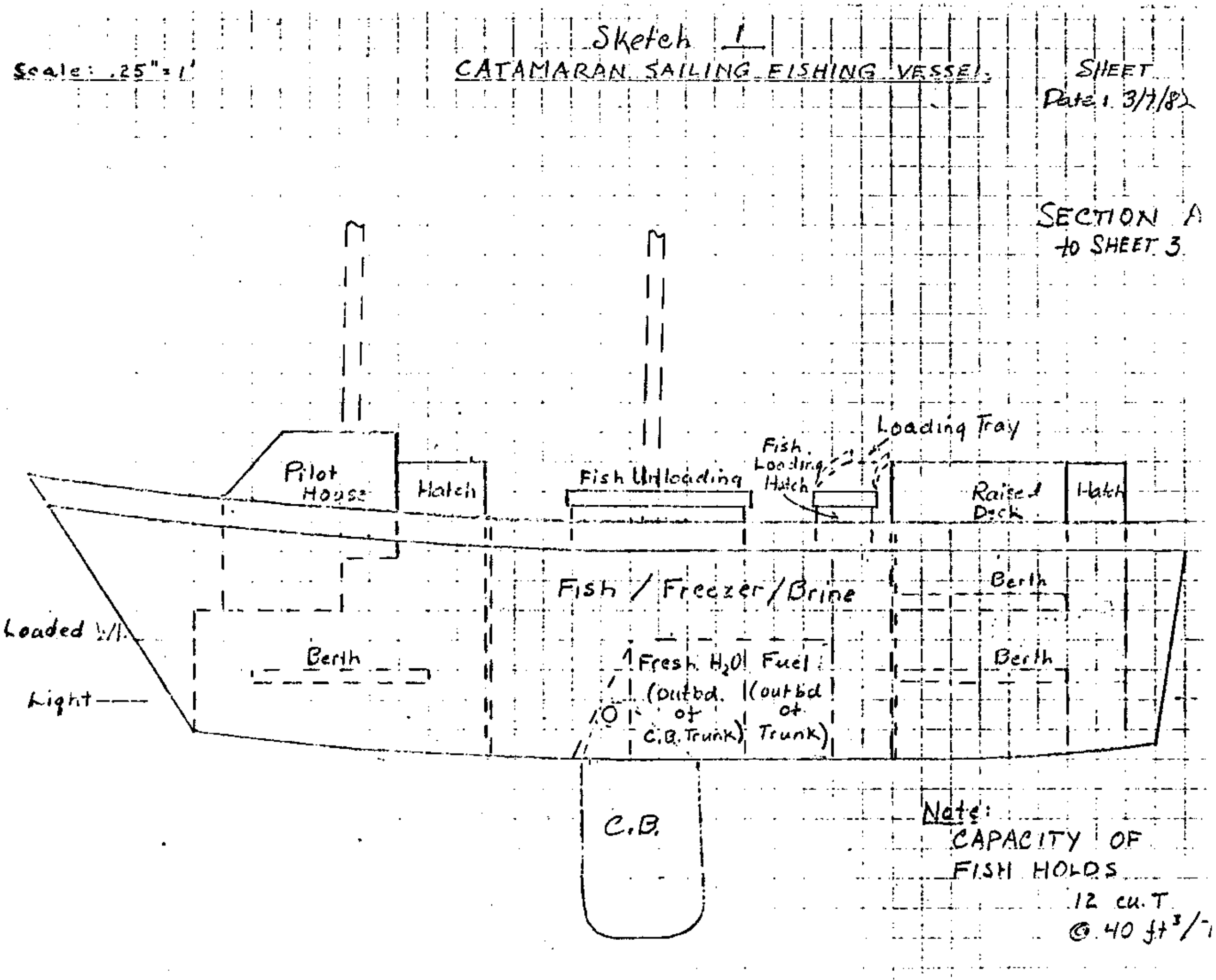
SHEET
Date: 3/7/82





Sketch 2

CATAMARAN SAILING FISHING VESSEL



Sketch 1

CATAMARAN SAILING FISHING VESSEL

Scale: .25" = 1'

SHEET

Date: 3/7/82

SECTION A to SHEET 3

Note: CAPACITY OF FISH HOLDS 12 cu. T @ .40 ft³/

SAIL-ASSISTED FISHING VESSELS FOR GULF OF MEXICO, CARIBBEAN AND NEAR-ATLANTIC WATERS

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University of South Florida
College of Engineering
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May, 1983

ABSTRACT

Described are the results of a series of studies over the past two and one-half years with computer-aided design tools of the problem of retrofitting existing motorized fishing vessels with sails. Clear economic gains in fuel savings up to 30 to 40% are evident in the longline snapper-grouper industry. Cost and fuel savings of only 15% are forecast for the stone crab-lobster boats due to bridge height restrictions and short range to fishing grounds. Minimum cost and fuel savings of 15% and maximum of 30% are anticipated from retrofitted Gulf shrimp trawlers. It is now judged time for industry to manufacture and market retrofit packages for common types of fishing vessels. A family of catamaran conceptual designs is illustrated and the advantages and disadvantages of this hull type discussed. The long time average wind history of the area is described coupled with illustrations of wind encounter on typical fishing routes. Snapper-grouper boats from Florida's West Coast can sail up to 84% of the time, year-round, while shrimpers along the Texas coast can utilize sails up to 91% of the time if the vessels have modern, clean rigs or advanced thrusters capable of sailing close to the wind. The unstayed mast is advocated due to its inherent shock absorbing power by bending and its simplicity and lack of interference with the fishing operation. Sail-assisted vessels have the added advantage of being able to maintain service speed longer in rough seas, as was learned from the MINI LACE experience. Most fishboats and especially Gulf shrimp trawlers are of old design and with no consideration given to today's high fuel prices. Some recommendations for changes in design practices are given including a recommendation that use of lightweight, strong composites be considered to improve the 15% payload-displacement ratio of today's shrimp trawlers and because such has the potential to reduce fuel costs dramatically.

INTRODUCTION

Most of the studies performed to date on retrofitting existing motorized craft with sails were done with computer programs which are discussed in references 1, 3, 14, 18, 36, 37, 38 and 39 coupled with visualization sketches of possible sail plans. Computer programs reside in Prime 750, Tektronix 4051 and Apple II Plus computers at the College of Engineering of the University of South Florida. The basic tool used for most studies is a computer program employing the technique of life cycle costing which takes a series of inputs regarding vessel particulars and specifics on the fishery and the specific fishing operation being studied, and costs these out over a 15 year period, (19), (39), (42). A fundamental input to this program is the long term, average percentage of power supplied by the sails. To obtain this number, the wind history is examined for the particular route (1), hull resistance is estimated and calculated (11), (12), (15), (19), (24), (25), (43), (44), (45), (54), power to carry sail is calculated from stability data (3), (36), (37), visualization sketches are drawn to ascertain whether that amount of sail can be carried without interfering with the fishing operation, and speed of the vessel under sail is computed, (11). The latter is often high enough that the wind strength and direction become the dominant factors in determining percent of power supplied by the sails. The process is an iterative one, in that various combinations of sails are designed to seek a maximum power extraction within the criteria established as outlined in a succeeding section. Until this conference, experimental data for the motorsailing mode and analytical means of predicting speed under power and sail were badly lacking. The papers by Lange and Schenzle (19) and by Satchwell and Mays (34) will certainly help remedy this gap. The Florida Sea Grant/University of South Florida instrumentation program is also intended to provide badly needed data in this area. The paper by Blem and this author addresses this topic.

THE FISHING INDUSTRY IN FLORIDA AND THE GULF OF MEXICO

Florida's fishing industry, as a business enterprise, is 160 years old.(6) In 1975, about one-third of all the fishermen in the coastal states from North Carolina through Texas worked in Florida. The estimated primary economic impact within Florida of commercial fishing in Florida for 1978 was $ 531.7 million plus $ 111 million in incomes generated and not including impact on the retail sector.(5) Others have estimated a figure as high as over $ 1000 million annually as compared to a reported value of the sport fishery at $ 5000 million annually.(10) Gulf of Mexico shrimpers produce more than half of the volume and about 80% of the dollar value of shrimp harvested in the U.S. (35) Using grossly inefficient fishing machines, "dinosaurs, absolute pigs," (41) the typical shrimper spent $ 13,000 on fuel in 1970 and $ 70,000 in 1980. (2), (35) The shrimp industry is second only to the Maine lobster industry in energy inefficiency per unit of protein produced.(46), (47) Only 1.0 to 1.7 pounds of shrimp per gallon of fuel are produced by Gulf shrimpers. (18) The Gulf of Mexico shrimp fishery is discussed in more detail later in this paper.

SOME CRITERIA FOR SAIL-ASSISTED POWER FOR FISHING VESSELS

The following criteria are advanced as necessary for the application of wind-driven thrusters to commercial fishing vessels:

1. Retrofit of existing motorized fishing vessels must show provable, substantial economic gains over those craft without sails. Year-round fuel savings of at least 15 percent from wind power would seem to be a reasonable minimum to judge whether or not to install sails.

2. Sail rigs must be simple to operate, reliable, durable, safe, practical and of low cost. The fisherman's job is to fish. Operation of the fishing vessel is of secondary importance and should take a minimum of his time, attention and skill.

3. Sail rigs must pose a minimum of interference to the fishing operations. Unstayed masts are preferred for this reason and also because they provide an added safety factor. When a strong wind gust strikes, part of the heeling force is absorbed by the spar bending.

4. To minimize crew fatigue and heighten work efficiency, rigs must give minimum angles of heel. The criterion used in these studies was a maximum of 10 degrees of heel in 20 knots of apparent wind.

5. The easiest vessels to retrofit with wind thrusters are those with clean superstructures, low to the waterline, such as snapper-grouper longline boats. This permits sail rigs to be designed for minimum interference with the fishing operation and low enough to maintain stability and minimize heel.

6. Winds must be reasonably consistent in direction and strength with a minimum of calms and at least 10 knots average, long term, year round velocity. Winds of 15 to 20 knots (Force 4 to 5) are preferred. Wind pressure is proportional to the square of wind velocity and power to the cube.

7. Bridge clearance must not interfere with masts. Devices for on board raising and lowering the mast are deemed awkward and an added complexity for most situations. Tabernacles may, however, sometimes be suitable.

8. Range to the fishing location should be sufficiently far and consume a sufficiently high percentage of fuel to justify using sails for a sizeable fraction of the usual full powering time. However, shrimp trawlers in such areas of highly favorable winds as the Texas coast, can certainly profit by using sails to assist in the trawling operation.

9. The rig must be close-winded, i.e. the vessel must be able to sail efficiently at a good turn of speed up to 45 or 50 degrees from the true wind direction. In this case, 90 degrees or one-fourth of the compass rose is denied for sailing as are the periods when dead calms are encountered. Gaff, schooner, ketch and similar rigs are thus ruled out by this criterion since they generally will sail well only up to 60 or more degrees to the true wind, thus increasing the denied area to at least 120 degrees or 33 percent. Without instrumentation, many sailors pinch into the wind and believe their speed to be more than it really is. Sailing closewinded is difficult, and there are occasions while motor sailing when use of sails slows the vessel down rather than adds to the speed. The drag force becomes higher than the side force thus producing negative thrust. In the motor sailing mode, the wind will be forward of the beam most of the time, and the ability to sail to weather is crucial. The marconi (bermudian) rig as optimized by the racing yachts is preferred. Even better would be one of the advanced thrusters as wingsails or perhaps Flettner rotors. Windmills are awkward but provide the unique ability of sailing directly into the wind.

10. Sails are used to supply part of the power for propulsion, and the engine is operating at all times - motor sailing. Even in high winds, the engine will continue to turn the propeller at a few hundred RPM to minimize drag from that source.

The designer has control of criteria 2, 3, 4, 9 and 10 and designs to optimize criterion 1. As concerns retrofit of existing motor vessels, the remainder are out of his hands. Thus, the prospects for retrofit of stone crab-lobster boats in the Florida Keys were assessed as unlikely because of criteria 1, 7 and 8.

SOME DESIGN PROBLEMS IN SAIL RETROFIT

Some particular questions and problems occur when trying to design a sail rig for an existing fishing vessel. These are discussed below.

1. Ballast tradeoff - the lower the center of gravity, the more sail area may be carried, and hence more thrust is available for a given wind strength. However, the heavier the vehicle, the more energy is needed to propel it at a given constant speed. The usual yacht has a ballast to displacement ratio of 33 to 50%. There may be an optimum ballast to displacement ratio for vessels designed from scratch and particularly large ones. Motorized fishing vessels are very heavy for their length with displacement-length ratios of 400 to 600. Moreover, these heavy beasts have a payload to displacement ratio of only 14 to 30%. The length of these vessels limits the amount of efficient sail area which can be carried, and the vessel's stability curve is sufficiently large to handle the usual sail plans devised. Thus, this has not been found to be a problem in the

retrofit case for all vessels examined to date.

2. Center of gravity variation. Fishing vessels are variable displacement craft. As a fishing mission proceeds, fish are caught, adding to the vehicle's weight. However, bait, supplies, water and fuel are consumed, subtracting from the weight. In one fishing vessel studied, the displacement varied from about 100 tons in the light ship condition to 135 tons with 10% consumables and 100% cargo, to 155 tons with half consumables and half cargo, to 180 tons with 100% consumables and no cargo. The center of gravity maximum variation was about eight inches - a significant amount. Trap boats such as are used in the stone crab-lobster fishery and scallopers with a large deck cargo can have an even greater variation. As the center of gravity rises, less sail area can be carried for a constant maximum heel angle. This variation must be taken into account when designing retrofit rigs and the sail handling gear.

3. Lateral plane area. Sailing vessels rely on keels, boards and long narrow hulls to resist drift to leeward - leeway - and to make progress generally to windward. The underwater portion of the hull provides about 20% of this leeway inhibition in modern racing sailing yachts with the keel-rudder or board-rudder combination doing the rest of the work. Although chines are a help in inhibiting leeway, most motorized fishing vessels have poor underwater hull forms for sailing to windward. Lateral plane area could be augmented in retrofit with leeboards and/or a bow board or bow rudder, but measurements are necessary to see if this added complication is really justified.

4. Steering. Sailing vehicles rely on the rudder to develop some hydrodynamic force to resist leeway and for balance. At low speeds, larger rudder areas are required than at high speeds. Thus, sailing vessels usually have much larger rudders than do power craft. This should not be a problem in the retrofit case where constant speed in the motorsailing mode is assumed.

5. In Florida waters, shoal draft is usually a must. This argues against installing deep keels or leeboards.

6. The sail rig must be balanced with respect to the underwater lateral plane to prevent an excessive turning moment being developed either into or away from the wind. This has so far not been a problem.

7. The designer has choices of the usual sloop, ketch or schooner rigs and stayed vs. unstayed masts. The usual stayed mast is a birdcage of complex rigging wires, turnbuckles, toggles, spreaders, etc. which surely can interfere with the fishing operation. In addition, each of these rigging elements is a possible failure point which can lead to dismasting.

8. The prediction of performance while motor sailing is not at all straightforward. Hoisting sails while under power at 6 knots which would provide thrust for a sailing speed of 4 knots in a particular wind situation will not recessarily result in a combined speed of 10 knots. The speed may be somewhat more than the algebraic sum of the two or markedly less in the case where it is impossible to trim the sails for minimum angle of attack and stall results. Recent analytical work by James Mays and Chris Satchwell (34) at this conference which in part implements earlier work by John Letcher (22) plus the experimental work of Lange and Schenzle (23) and Jean Louis Armand, A.Morcheoine and D. Paulet at this conference have shed considerable light on this heretofore obscure problem.

WIND DESCRIPTION GULF OF MEXICO AND NEAR-ATLANTIC

The wind picture for this area is not as good as might be wished, with year-round wind velocities averaging only about 11 knots in the Gulf areas and about a half-knot less on Florida's Atlantic coast. There is a bit more in the winter months and a bit less in the summer. Fortunately, there appears to be enough wind to provide a significant amount of auxiliary thrust. Table 1 shows a sample output of wind data computed from pilot chart information using the computer program of reference (1) which was generously shared with the University of South Florida College of Engineering. Table 2 gives the long term, average winds for the Tampa Bay area on the west coast of Florida. It illustrates a long-term average wind history which would be encountered by a vessel operating between the Tampa Bay area and a fishery 200 nautical miles due west. Table 3 shows average wind conditions on Florida's East Coast – the near-Atlantic.

Table 4 illustrates the winds which would be encountered, on a long term average basis, by a vessel travelling between the Tampa Bay area and a fishery located 200 nautical miles west, westsouthwest and westnorthwest resectively. Wind direction is referenced to the vessel's course to these three sites which are typical travel distances for boats engaged in fishing by long line methods for snapper and grouper from this region. Percentages are calculated on a round trip basis. Two points can be noted from these yearly average figures:

A. At a long term, year round average wind velocity of 11.3 knots, there is sufficient wind blowing from the right directions to justify fully attempting to exploit the wind as a source of auxiliary thrust for fishing boats on these routes.

B. It is important that sail rigs be utilized which are very "close-winded," i.e. which can sail efficiently at angles up to 45 or 50 degrees from the true wind direction. In such cases, the percentage of sailing time is over 80% on all three routes. That would seem to rule out gaff, schooner, ketch and similar rigs and emphasize clean, marconi types or advanced thrusters as wing sails or Flettner rotors. If non-close-winded rigs are chosen, the percentage of possible sailing time drops to around 58 or so percent, i.e. when there will not be headwinds or calms.

Table 5 shows the sailing conditions along the Texas coast where there is a major shrimp fishery. Shrimp boats here, typically sail along the isobaths parallel to shore. One such route was selected for computer analysis and appears here: Galveston to Corpus Christi, Texas and return. Wind conditions are about the same as in the eastern Gulf but the fishing route coincides with optimum wind directions here. Thus a good clean sailing rig can sail over 90% of the time. This drops to 67% if the vessel cannot close reach, i.e. sail up to 45 to 50 degrees from the true wind direction. There is no doubt that sail-assist would materially help this fishery.

Table 1

```
 VOYAGE SUMMARY==>                             MONTH = NOV

GALVESTON......CORPUS.CHRISTI.

                   NUMBER OF LEGS =      2      TOTAL DISTANCE =   285.23
                        VOYAGE TRUE WIND FOURIER COEFFICIENTS
                    PDF     49.25   -0.08 -10.32    0.09   -2.29
                    SPEED   55.95    0.02  -4.54    0.00    0.33

                          DISCRETE TRUE WIND PDF            AVG WIND SPEED
                       BOW                      7.3 %           12.0 KTS
                       CLOSE REACH             25.2 %           13.9 KTS
                       BEAM REACH              33.2 %           16.1 KTS
                       BROAD REACH             25.5 %           13.9 KTS
                       DEAD AFT                 7.3 %           12.0 KTS
                       CALMS                    1.4 %
                       VOYAGE AVERAGE WIND     14.2 KTS     STD DEV   7.5 KTS
```

Table 2

AVERAGE YEAR-ROUND FLORIDA WEST COAST WIND

The following figures are for a 200 nautical mile run due west to a fishing region - usually snapper or grouper - from the Tampa Bay area and return.

Month	Wind Speed (Knots)	Percent Calms
January	13.6 knots	1.3%
February	13.6	1.1%
March	13.3	1.5
April	12.2	1.7
May	9.9	3.4
June	8.5	5.9
July	7.9	7.5
August	8.2	7.2
September	10.6	3.6
October	12.0	2.0
November	12.8	1.7
December	13.1	1.5

See Table 4 for year-round averages.

Table 3

AVERAGE YEAR-ROUND FLORIDA EAST COAST WIND

The following figures are for a 425 nautical mile run from Miami to Cape Canaveral to Daytona Beach to Miami.

Month	Wind Speed (Knots)	Percent Calms
January	12.5 Knots	1.5%
February	12.7	1.2
March	12.4	1.8
April	11.4	1.9
May	9.5	3.5
June	8.2	5.8
July	7.8	6.7
August	7.9	7.0
September	10.1	4.0
October	11.7	2.3
November	12.3	1.5
December	12.3	1.3

On a long-term, yearly average basis, on this route the average wind velocity encountered is 10.7 knots. If the vessel can close reach, she can sail 86% of the time, if not, 62%.

Table 4

SAILING CONDITIONS OUT OF TAMPA BAY AREA

YEAR-ROUND AVERAGES

Wind Direction Relative To Course	West Percent of Time	West-SouthWest Percent of Time	West-NorthWest Percent of Time
Bow	14.7%	9.4%	13.9%
Close Reach	23.1%	25.2%	25.1%
Beam Reach	21.2%	27.3%	19.0%
Broad Reach	23.1%	25.3%	25.1%
Aft	17.7%	9.5%	13.8%
Calms	3.2%	3.2%	3.2%
% Sailing if Can Close Reach:	82.1%	87.3%	82.9%
% Sailing if Cannot Close Reach:	59.0	62.1	57.8

On a yearly average, over all three courses, a vessel which can close reach (sail up to 45 degrees from the true wind direction) will be able to sail 84.1% of the time. One which cannot sail this close to the wind will be able to sail 59.6% of the time. The year-round average wind speed is 11.3 knots.

Table 5

SAILING CONDITIONS ON TEXAS COAST

MAY TO NOVEMBER

The following figures pertain to a round trip 330 nautical mile run between Galveston and Corpus Christi, Texas on a typical shrimp boat fishing mission.

Bow Wind	6.5% of time
Close Reach	24.1%
Beam Reach	36.2%
Broad Reach	24.6%
Aft	6.6%
Calms	1.9%

The monthly wind speed averages are: May: 11.4 knots; August: 9.0 knots: November: 14.2 knots for an average in this seven month period of 11.5 knots. If the vessel can close reach, it can utilize sails 91.6% of the time, if not, this figure drops to 67.5%.

RETROFIT OF SNAPPER-GROUPER BOATS

Figure 1 shows an example of this type of vessel. There are about 200 of these craft on Florida's West Coast, and they are typical of boats used in many longline fisheries in the world. Average length is about 44 feet (13.4 m.). They are usually fitted with four to six power reels and travel on the average 18 times per year some 200 miles to the fishing grounds and average some 800 miles per trip. A wind heel criterion of ten degrees in 20 knots of apparent wind with sails sheeted flat was applied together with stability data taken from drawings, by inclining experiments or by estimate from taking off hull lines. As is so often sadly the case, for many boats studied, reliable displacement figures were not available. Figures 2 and 3 show conceptual visualization sketches of possible sail rigs for two such vessels whose sail areas were determined by the wind heel criterion. It is encouraging to find that in all cases studied, reasonable "leads" and sail area to weight ratios were obtained. The sketches emphasize the need to study each individual craft being considered for retrofit and the role that superstructure height plays in limiting sail area.(36)(37)

The life cycle cost analysis of this vessel as described in References 19 and 37 is given in Appendix A together with a brief explanation of this economic tool. This particular analysis does not consider mortgage payments, presently payable at ruinous rates and shows a fuel savings of 168,000 gallons amounting to some $ 356,000 (assuming a 10% fuel inflation rate) over a 15 year period if sails and the wind account for 40% of the power used. The 40% figure was arrived at by assuming that sails were used 84% of the time (see Table 4) x 50% (for going to and from the fishing grounds) with a bit of fuel being expended to turn the propeller over one or two hundred RPM. Alternatively, some credit can be given for sail-assist while moving between fishing sites.

The cost of retrofit is estimated at about $10,000 to $12,000 for this vessel, and this cost is forecast to be recovered at the end of the first year of operation. It now appears to be time for an enterprising manufacturer to offer retrofit gear for this industry.

The above figures are most conservative. In fact, an enterprising fisherman, willing to use sails more of the time can likely increase these fuel savings.

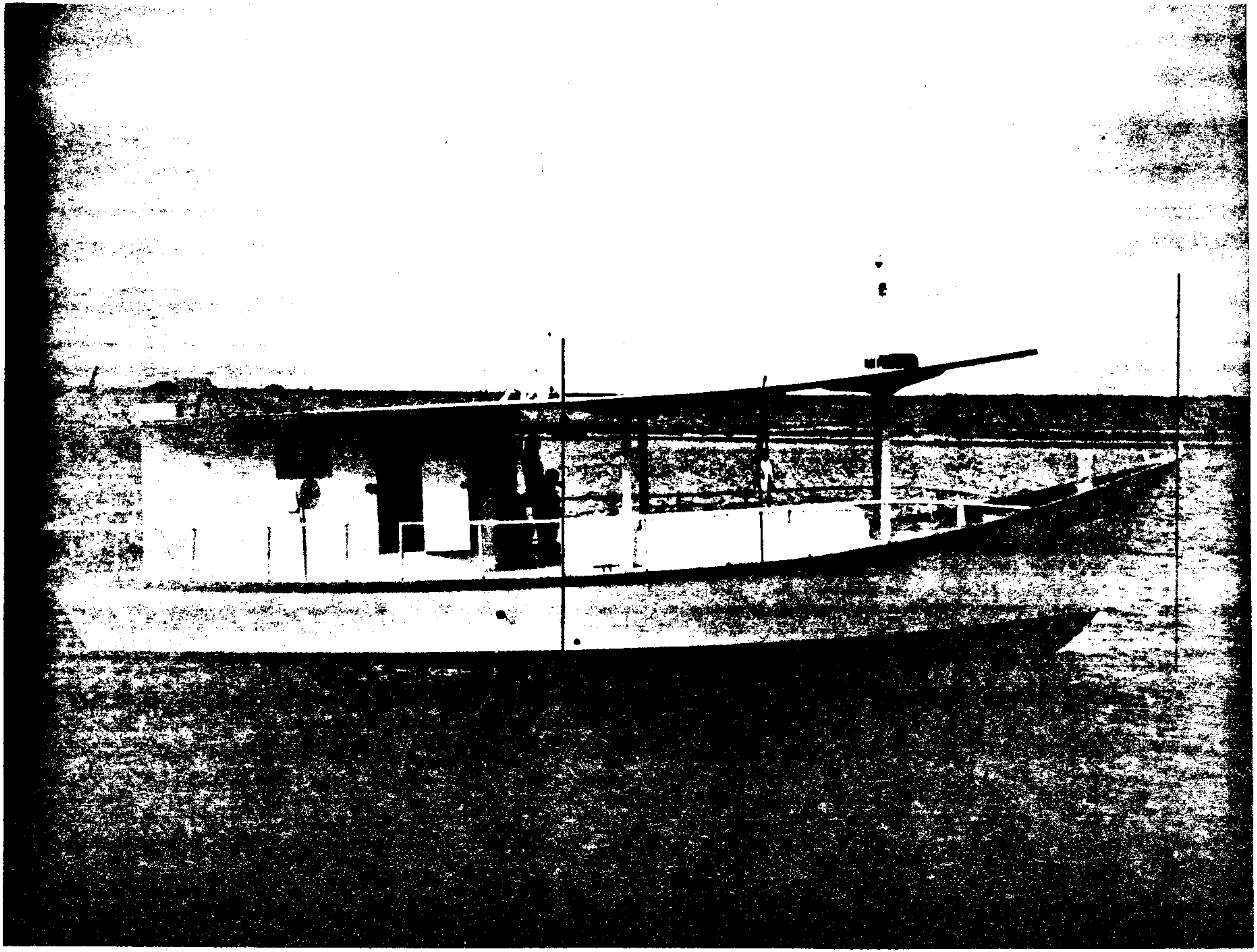
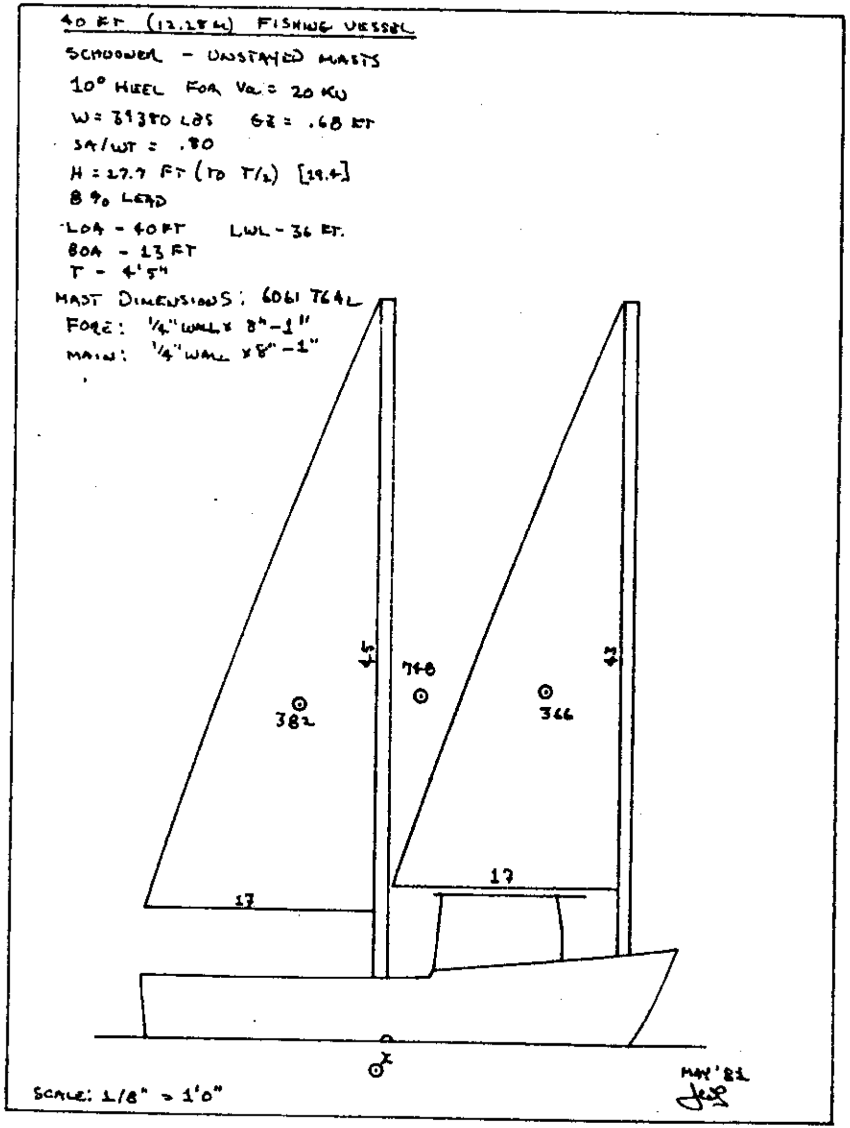


Figure 1


40 FT (12.2 M) FISHING VESSEL

SCHOONER - UNSTAYED MASTS

10° HEEL FOR V_A = 20 KN

W = 31380 LBS GZ = .68 FT

SA/WT = .80

H = 27.7 FT (TO T/2) [29.4]

8 % LEAD

LOA - 40 FT LWL - 36 FT.

BOA - 13 FT

T - 4'5"

MAST DIMENSIONS: 6061 T6 AL

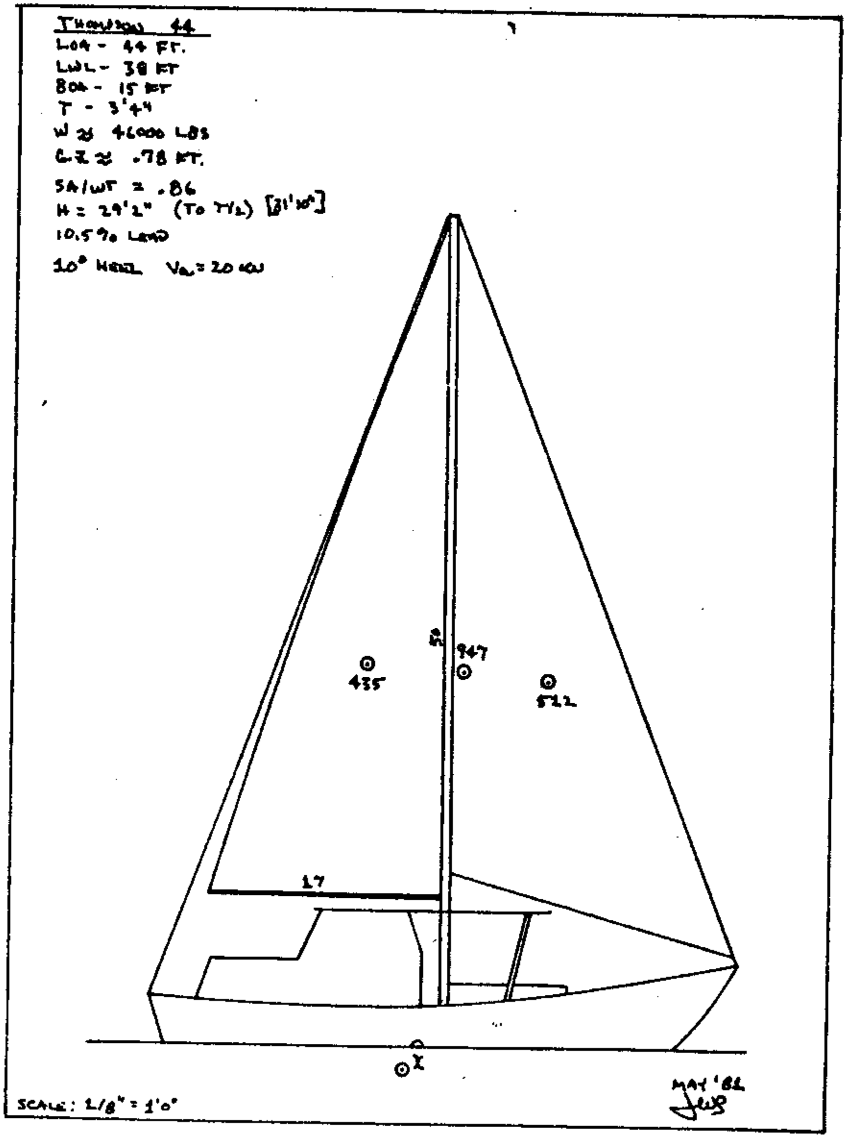
FORE: 1/4" WALL x 8"-1"

MAIN: 1/4" WALL x 8"-1"

SCALE: 1/8" = 1'0"

MAY '82

Fig 3


THOMPSON 44

LOA - 44 FT.

LWL - 38 FT

BOA - 15 FT

T - 3'4"

W ≈ 46000 LBS

GZ ≈ .78 FT.

SA/WT = .86

H = 29'2" (TO T/2) [31'10"]

10.5 % LEAD

10° HEEL V_A = 20 KN

SCALE: 1/8" = 1'0"

MAY '82

Fig 2

RETROFIT OF STONE CRAB - LOBSTER BOATS

There are approximately 1000 of these craft ranging in length from 23 to 66 feet (7 - 20 m.) in the Florida Keys, and similar craft operate out of other parts of Florida and in other sections of the United States and the Caribbean. Monroe County, which encompasses all of the Florida Keys, is the leading seafood producing county in Florida. During the 15 years from 1964 to 1978, landings of fish and shellfish in Monroe County ranged from 21.8 to 29.6 million pounds which recently represented 17.5% of Florida's total. Dockside value was at 31% of Florida's total at $ 28.3 million. Key West is a major port and in 1978 ranked 40th in landings and 17th in value of landings in the U.S.A. Monroe County is also the leading commercial boat owning county in Florida. In 1978, 11.1% of Florida's commercial craft were located here - some 2749 vessels. (7)(8)(9) There are numerous small-scale fish boat building operations, fish trap builders and other ancillary businesses.

Monroe County, which encompasses all of the Florida Keys, is the leading seafood producing county in Florida, and its relative contribution to Florida's landings and dockside value of seafood is increasing. During the 15 years from 1964 to 1978, landings of fish and shellfish in Monroe County ranged from 21.8 to 29.6 million pounds which recently represented some 17.5% of Florida's total. Dockside value was at 31% of Florida's total in 1978 at $ 28.3 million. Key West is a major port and ranked 40th in landings and 17th in value of landings in the U.S.A. in 1978. Monroe County is the leading commercial boat owning county.In 1978 11.1% of Florida's commercial craft were located here - some 2749 vessels.(4)(6) There are numerous small-scale fish boat building operations, fish trap builders and other ancillary businesses.

Monroe County is the leading seafood producing county in Florida. 11.1% of Florida's commercial boats were registered here in 1977 to 1978 - 24,805 craft.(9) In 1974, approximately 70% of Florida landings of spiny lobsters were made in Monroe County. At that time, depreciation was the greatest expenditure, accounting for 43.7% of the total. Traps lost and fuel ranked second and third in costs in that year.(26) In 1979, of the variable costs - excluding depreciation - crew wages and shares represented the greatest expenditure, cost of traps second, fuel third and bait a close runnerup to fuel.(27) In 1981, it is likely that fuel costs moved to first place.

Each $100 of spiny lobsters sold generated sales in other industries of $47.65 and incomes of $52.35 in 1975.(26) In 1979, 6.3 million pounds of spiny lobster were landed in the United States valued at $12.8 million. Florida was the leading producer at 5.95 million pounds for a dockside value of $11.71 million. In Florida, the value of the spiny lobster catch is second only to that of salt water shrimp.(27) Firms in Monroe County account for 80 to 90 percent of Florida spiny lobster landings in recent years.(28)

Most lobster boats are operated as combination vessels and also set traps for stone crabs and long line for various species. Stone crabs are considered a secondary fishery. The 1972 to 1975 average annual catch in Florida for stone crabs was 2.28 million pounds valued at $1.71 million.

TYPICAL STONE CRAB-LOBSTER FISHING OPERATION

Typically, lobsters are caught in an average 11.2 hour work day consisting of 8.3 hours fishing time, 2.3 hours running to and from the fishing grounds and 0.6 hours in unloading time. Running and fishing times per day increase with boat size. Average lobster catch is 16.5 pounds per trap per season and 157.5 pounds per trip, and both increase markedly with size of vessel.(27)

The owner of CARCHARODON leaves in the early morning and cruises to the lobster grounds at reduced speed -15 knots at 1500 RPM - taking some three hours to arrive at the trap site. He fishes for six hours and returns by darkness. His vessel is operated 125 to 150 days per year. He also catches some 300 pounds of grouper per year to supplement the income from this vessel. This boat hauls 3000 traps and average fuel consumption per eight month period is 4200 to 5000 gallons including generator consumption. This represents about 4% of his gross dockside sales - an unusually low figure. Average fuel use probably approaches 15-20% while that for the Florida snapper-grouper industry is about 30% and for shrimpers is approximately 50%.

LOBSTER FISH BOATS

The following figures are taken from a 1978-79 survey. The average lobster fishing craft in the Florida Keys is 36.0 feet (11 m.) in length overall. Average engine size was 258 horsepower and ranged from 101 to 600 horsepower. Eighty percent of the engines used diesel fuel. 90% of the hulls were of fiberglass. Average boat age was 5.3 years. Average engine age was 3.2 years.(27)

Three stone crab-lobster boats were examined in this study. These are of the larger sizes ranging from CARCHARODON at 37 ft. 10 in. length overall to 66 ft. (11.5 - 20.1 m.) Two are shown in Figures 4 and 5. As is usually the case, the displacement of two of these craft are unknown and had to be estimated as was the displacement-length ratio. An impromptu inclining experiment was performed on CARCHARODON with the aid of Mr. Fisher, marine agent for Monroe County, but was unsuccessful. Hence the metacentric height -GM had to be estimated from that of similar craft. These data were available on one of the craft from hull lines drawings thanks to the courtesy of Mr. Arthur R.Wycoff, NA. A photograph of CARCHARODON is shown in Figure 4. The 53 foot (16.1 m.) length overall by 20 foot (6.1 m.) beam DAWN is shown in Figure 5.

The 46 ft. 11 in. (14.3 m.) and 66 foot (20.1 m.) boats are typical of those which used to fish for lobster in Bahamian waters. In 1975, the Bahamian government banned foreign lobster fishing, and landings from domestic waters increased.(28)

ECONOMICS OF SAIL-ASSISTED POWER

Appendix B gives an economic analysis of the lobster operation with CARCHARODON using the computer-aided technique and life cycle costing method described in References (19) and (32). This should only be taken as approximate, since the factors pertaining to multiple use or combination fishing were not taken into account. Predicted fuel savings are estimated to be on the order of 15% with fuel cost savings of almost $ 14,000 over a 15 year period. A more complete study of conventional, powered vessels for the 1978-79 season gives an average gross revenue of $ 40,912 and net of $ 14,880 per boat per year.(27)

PROSPECT FOR SAIL-ASSIST RETROFIT FOR STONE CRAB-LOBSTER BOATS

In the Florida Keys, southeast winds prevail with a year-round average of approximately 11 knots. This is sufficient to provide a meaningful measure of wind-assisted propulsion. Superstructures are relatively clean. However, range to the fishing ground is so short that major fuel savings are unlikely. Another problem is of bridge height. Most of the boats of this type must either traverse non-opening bridges or travel unreasonably far out of the way to get to the fishing grounds. In the case of CARCHARODON, a figure of 15% sail power was derived. It is assumed that sails will only be used to get to and from the fishing grounds (75% of engine useage), good winds will obtain 50% of the time, and throttling back on the engine will save some 40% of the fuel during operation.

Bridge clearances average only about 20 or so feet. (6.1 m.) Thus, there are only two possibilities for most boats in this fishery: accept the complication, cost and extra maintenance of hinged masts in tabernacles or travel by longer routes under bridges which have reasonable clearances. Figure 6 shows a sample sail plan for retrofitting one of these craft.

Figure 4

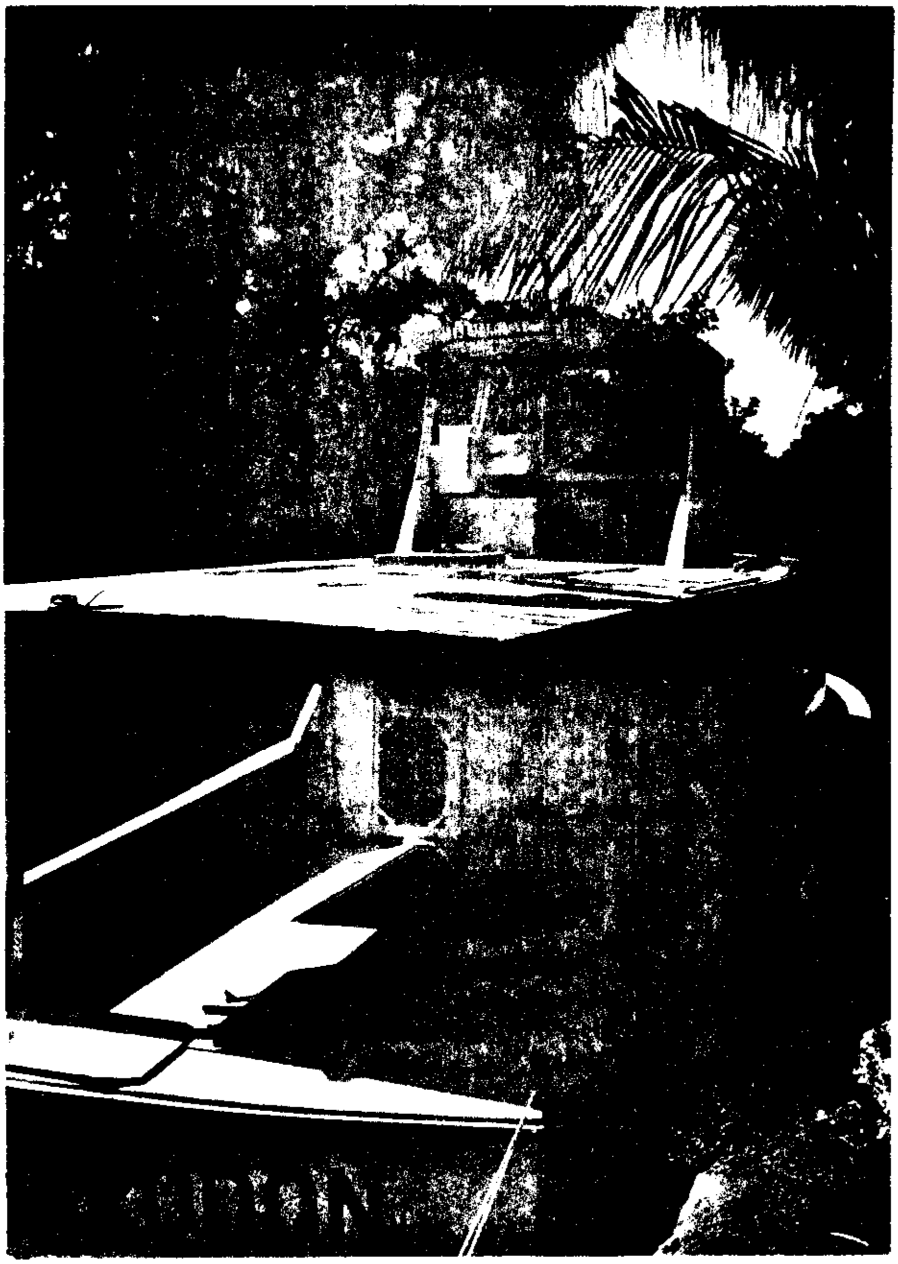
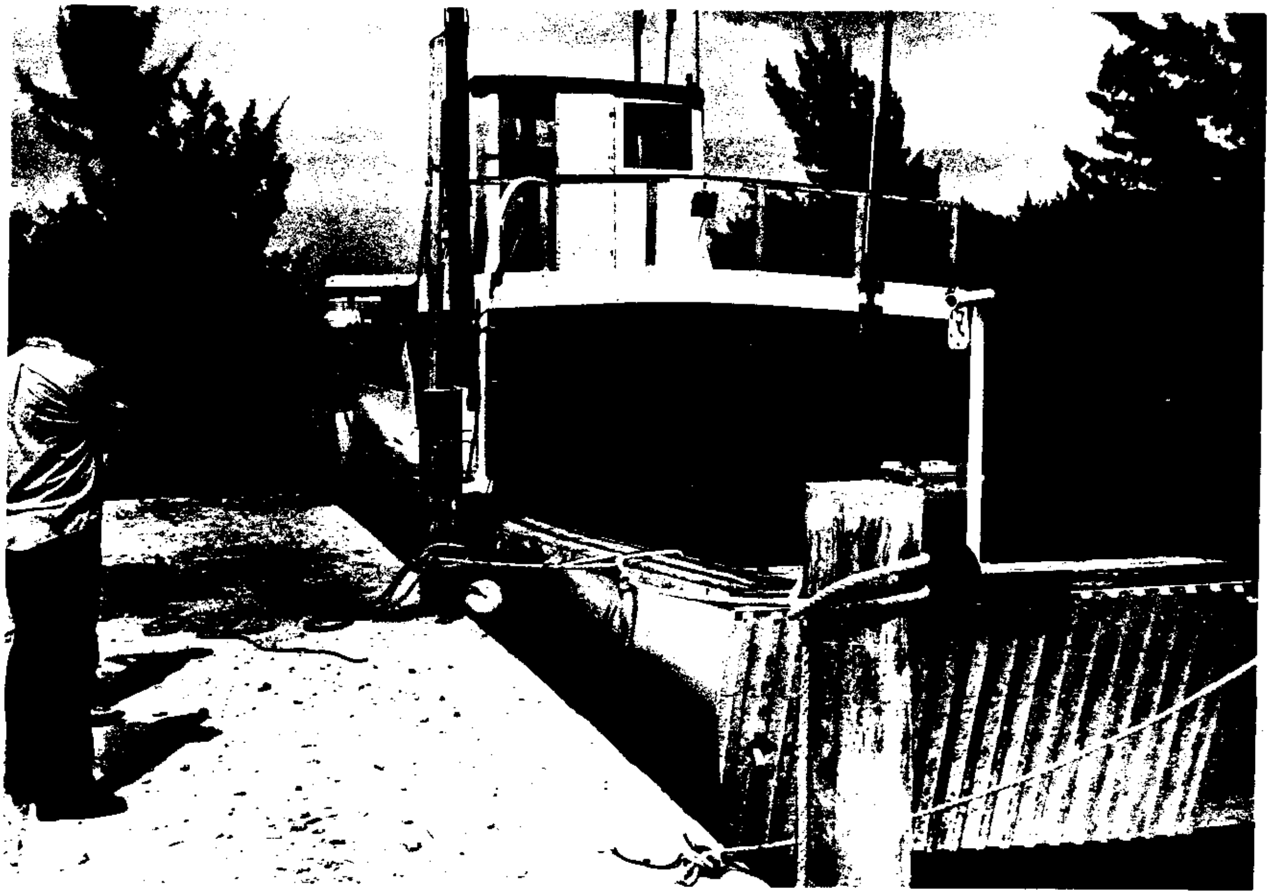


Figure 5



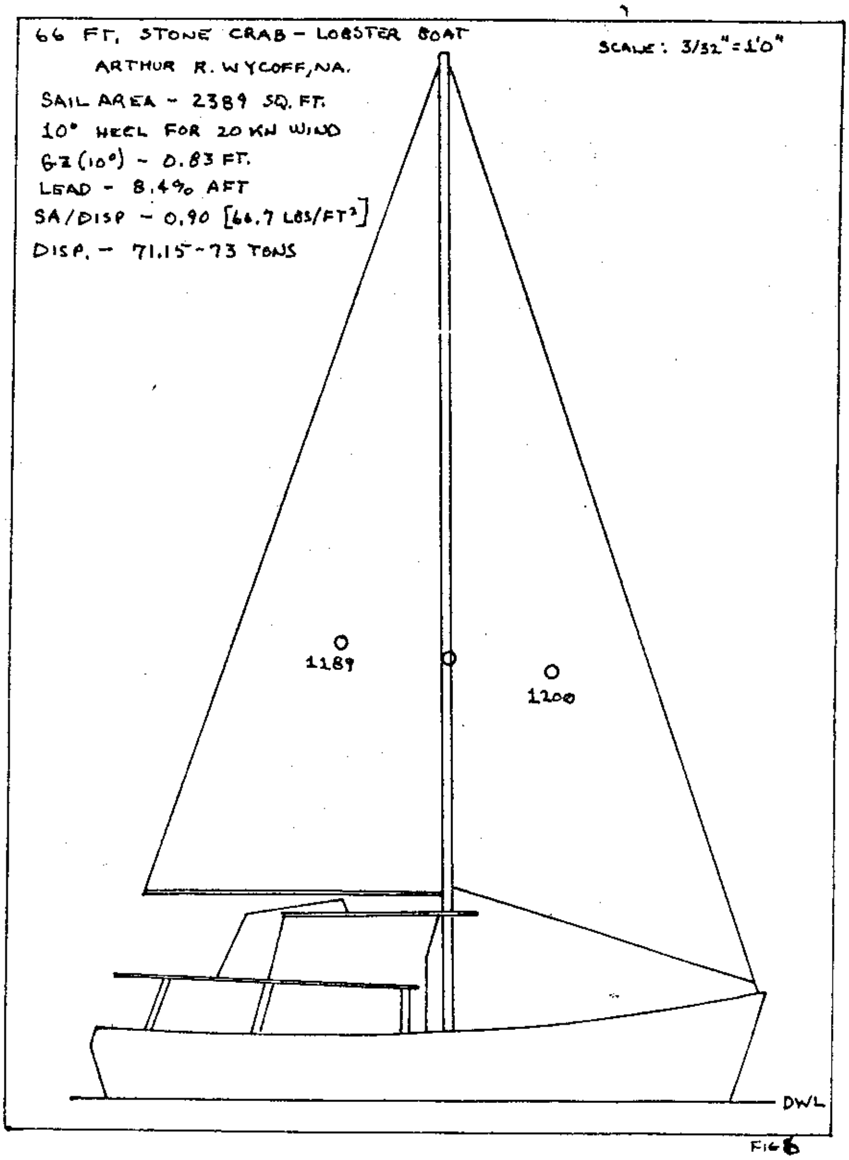

66 FT. STONE CRAB - LOBSTER BOAT
ARTHUR R. WYCOFF, NA.
SCALE: 3/32" = 1'0"
SAIL AREA - 2389 SQ. FT.
10° HEEL FOR 20 KN WIND
GZ (10°) - 0.83 FT.
LEAD - 8.4% AFT
SA/DISP - 0.90 [66.7 LBS/FT²]
DISP. - 71.15 - 73 TONS
1189
1200
DWL

FIG 6

RETROFIT POSSIBILITIES FOR GULF SHRIMP TRAWLERS

Shrimp continues to be the most valuable seafood product landed in the U.S.(52) As was mentioned earlier, the Gulf shrimp fishery is an important one which produces 80% of the dollar value of shrimp harvested in the U.S.(35) At the second time it uses grossly inefficient fishing machines, "dinosaurs - absolute pigs," in producing only 1.0 to 1.7 pounds of shrimp per gallon of fuel.(41)(21) Since 1973, annual fuel costs for shrimp boats have gone from $ 10,000 to $ 12,000 to $ 80,000 to $ 100,000 per boat.(2) Fuel and oil account for 40 - 54% of the total operating cost for vessels over 50 ft. (15 m.) The Gulf shrimp fleet consumes 33% of the diesel fuel used by the U.S. fishing industry.(46) A 68 foot (20.7 m.) shrimper with a 365 hp diesel engine consumes 50,000 gallons of fuel per year.(42)

In the past each vessel prospected independently. Fleet operators now use the strategy of sending only one boat out to locate shrimp and advise the others. Independent operators do not travel to different fishing areas as much as they used to. If no shrimp are found, they anchor and wait. There are more frequent drydockings and bottom cleaning and painting. Fuel consumption is not the number one goal - increased earnings is. Very few have changed their operations to reduce fuel consumption. 100% of the installed power is used during fishing, and reduced power is used only when free running, and then not often.(21)

FUEL SAVING METHODS FOR SHRIMPERS

The author of Reference (46) states that good fuel management techniques can save the individual boat owner as much as 15% of his fuel bill.(2) Surely, the use of lightweight, strong composite sandwich construction with protection against holing by high impact point loads would be another way in which new vessels could be more efficient. The enormously heavy present-day shrimp boats which can carry only 15% or less of their weight in fish have no place in this fuel expensive economy. Nevertheless, many of these very expensive behemoths exist and it is necessary to examine all possible ways in which fuel and hence money can be conserved with the vessels presently in service. The author of Reference (21) has many sound ideas for reducing fuel useage of shrimp boats. A major problem facing anyone trying to seek remedies for the excessive fuel consumption of slabs (shrimp trawlers in excess of about 75 ft. -22.9 m.) is well stated by the author of the excellent Reference 21: "Not one vessel operator knew the displacement of his vessel. No loading or stability data was provided for any vessel visited." Knowledge of the displacement is of fundamental importance in any redesign, repowering, sizing of a sail rig and any other fuel economy measures.

MORTGAGE AND INSURANCE FOR SHRIMPERS

Another enemy of the fisherman is extraordinaly high mortgage interest rates. One owner held mortgages on his three boats of nine, 11 and 15% and many can barely afford to make the interest payments each month without reducing the loan principal.(20) In a 1978 survey, only three of 37 fishermen interviewed had insurance policies on their small boats. The average expense was $ 2200 per year. Ten of 48 in the medium category (51-65 ft. 15.5-19.8 m.) had insurance at an average annual premium of $3675. 37 of 44 in the large category had insurance policies, probably because this is usually required by lending institutions.(31)

SHRIMP VESSEL CHARACTERISTICS

The trend in the last two decades has been toward larger and more powerful vessels. For boats 55 ft. (16.8 m.) or less, 61% have engines of 100 to 200 hp; 55-65 ft.(16.8-19.8 m.) 32% have engines of 100 to 200 hp, 30% 200-300 hp, 31% 300-400 hp; 65-75 ft.(19.8-22.9 m.) 71% 300-400 hp; 75 ft.(22.9 m.) 28% 300-400 hp, 24% 400-500 hp, 15% 500-600 hp, 24% greater than 700 hp.(46) In a survey of 1982 64 shrimp trawlers abuilding in Alabama, Florida, Louisiana, Mississippi and Texas 27% were 85 ft. (25.9 m.) in length, 27% were 75 ft. (22.9 m.), 8% were 78 ft.(23.8 m.), 9% were 70 ft.(21.3 m.) and 6% were 68 ft. (20.7 m.) for a total of 77%.(53) In 1978, Florida had 1729 registered shrimp boats, of which 32% were 40-64 ft. (12.2-19.5 m.) in length and 26% were over 65 ft. (19.8 m.) (7)

SHRIMP TRAWLER ROUTES

Major shrimp fisheries are located along the Atlantic coast of Florida, near the Dry Tortugas off Key West, Florida, and along the coasts of Mississippi, Alabama, Louisiana and very especially Texas. Figure 7 shows a map of the Texas coast with the isobaths plotted along which the shrimpers trawl. In Mississippi and Alabama, the smaller shrimp trawlers work primarily inside the barrier islands. Medium size vessels work from June to December from the barrier islands to several miles offshore. Frequently the slabs work distant waters to the Mississsippi River to Texas. From February to April, they shrimp offshore or in the Tortugas-Key West area. The situation is similar for shrimp trawlers registered in other states on the Gulf and as far north as North Carolina. Of 20 vessels surveyed in 1980 to 1981, the average total number of annual trips was 119 and trip length varied from six hours to 17 days. Time spent going between fishing grounds and ports ranged from 31% for trips of two days maximum to 15.6% for a seven day trip. A typical trip was 255 hours (10.6 days). Time spent going to and from port amounted to 11 to 14% of the time away from dock and 14 to 27% of total fuel useage was accounted for. 51% of the time away from dock was spent trawling which used

70% of the fuel.(46) Vessels typically trawl nets at 2.8 to 3.2 knots with 3.0 most common.(21) Figure 8, also taken from Reference 4, is another map of the Texas coast with annual shrimp catches plotted.

SAILING SHRIMP TRAWLERS

To the best of the writer's knowledge, no-one has used sail-assist to help alleviate the woes of the large fleet of shrimp trawlers fishing Gulfof Mexico waters. A model of one such was made by Florida builder Oscar Ewing in a bid for its use in Bangladesh where fuel costs $4 to $6 per gallon.(48)(49) A twin running rig has been designed but never implemented.(24)

Reference 4 is an excellent master's degree thesis from a student at Texas A&M (1976). He compared a 72 foot (21.9 m.) 340 hp diesel trawler and a 78 ft. (23.8 m.) sailing trawler with 3468 sq.ft. (322 sq.m.) of sail and a 120 hp engine. His calculations showed the sail-assist vessel using 37% of the power with 40% less fuel consumption than the conventional craft. However, the catch was 68 to 72% of that of the motor trawler. His sail-associated costs were 8.8% of the total vessel cost.

SAIL-ASSISTED RETROFIT SHRIMPERS

Table 5 illustrates the sailing conditions on the Texas coast from May to November. Figure 9 gives annual average wind speeds. Shrimpers typically fish along the isobaths, parallel to the coast. A series of computer runs (1) were made along the route between Galveston and Corpus Christi and return. The average wind speed in this time period was 11.5 knots, and a vessel on this route would expect on the long term average to encounter headwinds and calms only 8.4% percent of the time. This would seem ideal for sail-assist in a major shrimp fishery. The numbers are similar for the major Dry Tortugas shrimp fishery.

Brown estimated 40% fuel savings by comparing a new sail-assist vessel with an existing motor trawler.(4) The author of this paper initially estimated fuel savings on the order of 30% and perhaps more from retrofitted shrimp trawlers on such routes. When Lange and Schenzle's manuscript became available describing experiments with the retrofitted North Sea Trawler KFK FREDDY (23), their data were reduced and compared with a hypothetical typical motorized Gulf trawler equipped with a retrofit sail rig of 2640 sq.ft.(245 sq.m.) and 2240 sq.ft.(208 sq.m.) for running only. It is believed that this is the type of rig which Colin Ratsey had much earlier designed. (29). Table 5 gives the particulars of the two vessels. By using a typical Cummins engine power and fuel set of curves (56) for the heavy duty condition, an estimate was made that in the case of Lange and Schenzle, rougly 19 percent of the fuel was saved and in the case of the retrofitted Gulf shrimper 15%.

The principal reason for the difference is that average winds are much higher in the North Sea than in the Gulf. No credit was given to the Gulf vessel for the highly favorable direction of winds in the usual Gulf shrimping areas. Also, no credit was given to the sail-assist vessel being able to maintain service speed in rough conditions far longer than conventional craft due to the steadying effect of the sails. In addition, the assumption made for the KFK FREDDY was that rough sea allowance was on the order of 25% added resistance. That surely is not the case in the usual relatively mild climate of the Gulf of Mexico. It is interesting to note that data for the KFK FREDDY implies that at a wind speed of 12 knots, 71 sq.ft.(6.6 sq.m.) of sail area is equivalent to one horsepower.

Although the unique shrimp fishery has not yet been completely modelled in the computer, for shrimp trawlers off the Texas coast, it is this author's opinion that fuel savings of up to 30% are possible for retrofitted boats if operated with sails up at all times except during calms, headwinds and storms. A twin running rig for assistance during most of the trawling operation seems highly adviseable as recommended by Colin Ratsey. (29) With fuel bills for slabs reaching $100,000 per year, even a 15% savings is $15,000 annually. Figures 10 and 11 show typical Gulf shrimp trawlers at dockside. One possible rig envisaged is to add a 23 foot (7 m.) section to the top of the king post to extend the mast to a height of 60 ft. A furling headsail would be installed with a foot of 38 feet (11.6 m.) and an area of 700 sq.ft.(65 sq.m.). The 28 ft. (8.5 m.) net booms would be used as mainsail booms for a pair of main sails of just over 500 sq.ft. (46.5 sq.m.) each. Approximate sailing speeds for the twin sails running and for sailing on other points are given in Appendix C.

It is estimated that cost of retrofitting the 76 foot hypothetical trawler with a conventional sail rig will be between $12,000 and $18,000 and that these costs will be recovered in approximately one year.

Table 5

PARTICULARS OF TWO SAIL-ASSISTED VESSELS

	KFK "FREDDY" Ref.(19)	Typical Shrimper Used as Comparison
LOA:	79 ft. (24.1 m.)	76 ft. (23.2 m.)
LWL or LBP:	67.5 ft. (20.6 m.)	69.2 ft. (21.1 m.)
Displacement:	120 tons	136-179 tons*
Engine HP:	150(?)	320 HP
Cruising HP:	108	195
Cruising RPM:	1800	1800
Cruising Speed:	9 knots	10 knots
Sail Area:	1937 sq.ft. (180 sq.m.)	2640 sq.ft. (2240 running) (208-245 sq.m.)
Sail Area/$\nabla^{2/3}$	8.3	7.6 - 9.1
ΔP **	27 hp (25%)	37 hp(19%)
Fuel Savings	19% est.	15% est.

Vessel Speed Under Sail Only
Propeller Free to Turn

Running	6.8 knots	3.1 knots ***
Reaching	8.6 knots	5.3 knots ***

Notes:

* Depending on loading condition.

** Motorsailing increment. Amount horsepower can be reduced due to thrust from wind in sails.

*** For wind speed of 20 knots for the FREDDY and 11.3 knots for the hypothetical vessel.

The above data and estimates were determined by using references: 1, 4, 14, 23, 44, 46, 56 and 57.

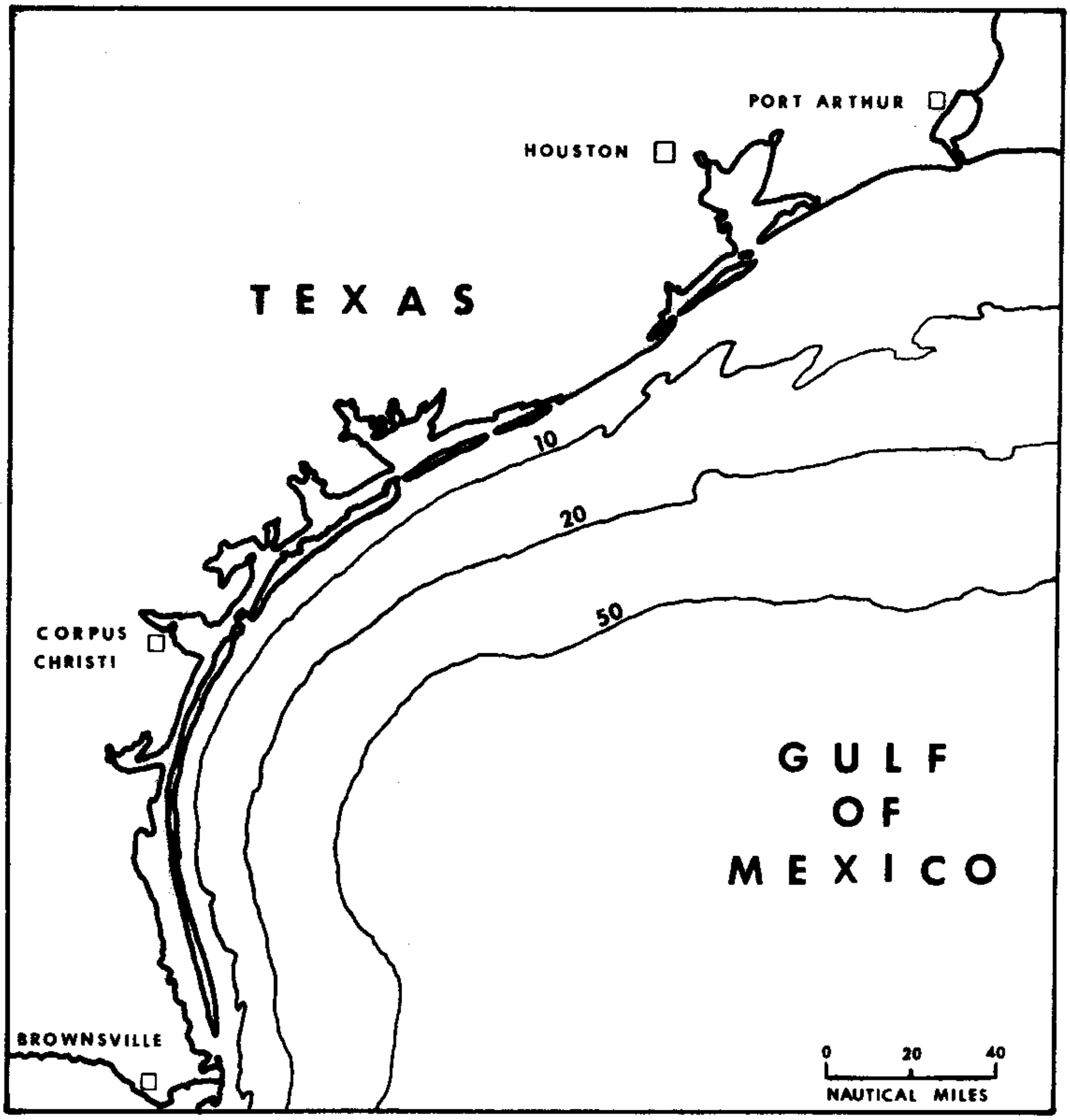


Figure 7 Isobath Map. Depths in fathoms.

Taken from Reference 4

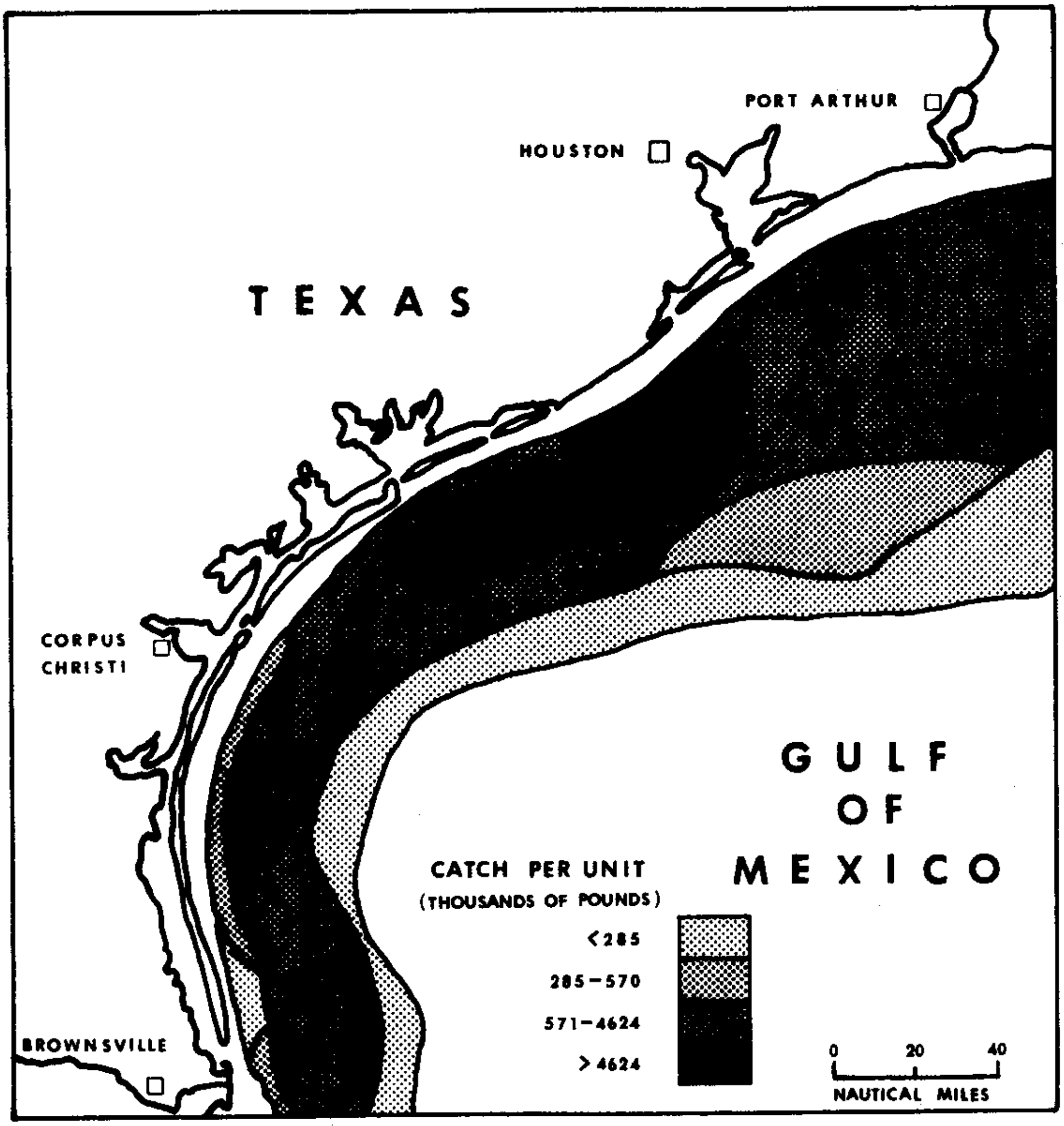


Figure [illegible] Annual catch of all shrimp. Modified after Osborn, Maghan, and Drummond.

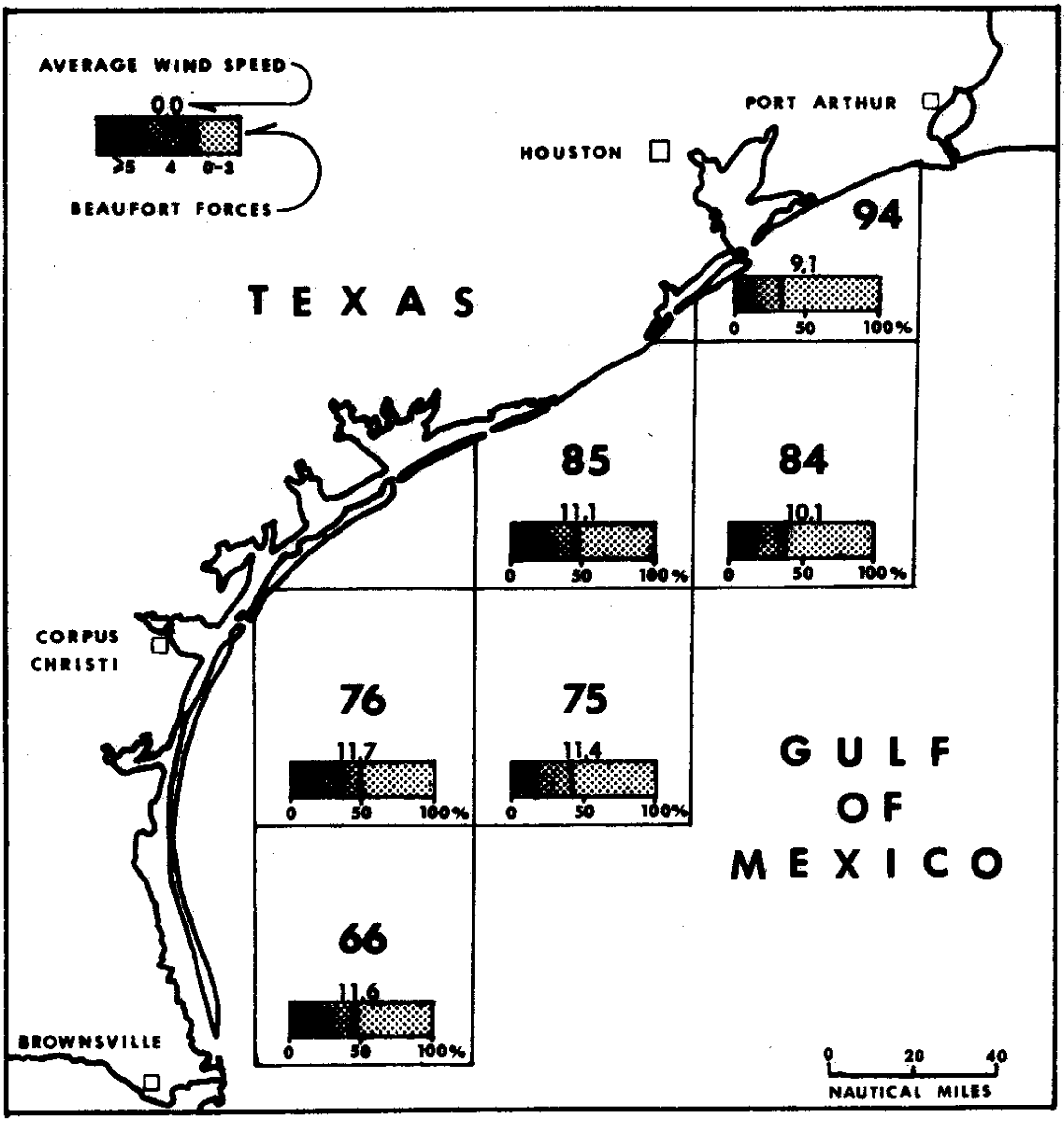
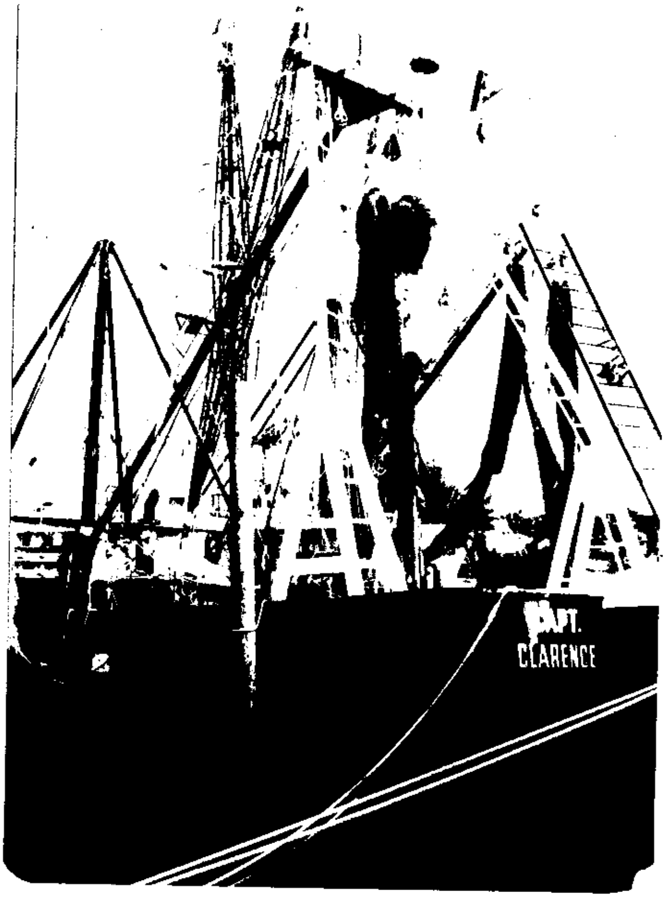


Figure 9 One-degree Marsden Squares with average annual wind speed in knots and bar graph of annual percentages of Beaufort wind forces 5 and over, 4, and 0-3.

Figure 10



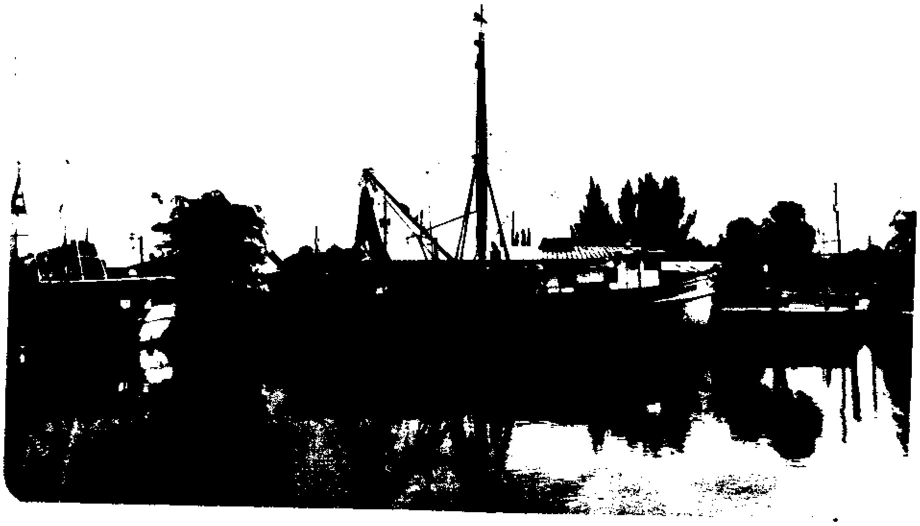


Figure 11

CATAMARAN COMMERCIAL FISHING BOATS

Catamarans have long intrigued naval architects as potential work boats. With the recent explosion in fuel prices, that interest is higher than ever. The reason is quite simple: long, slender hulls require far fewer horsepower to propel through the water than short, fat ones. Figure 12 shows a comparison of two resistance curves. The upper curve is typical of those for heavy shrimp boats and the lower for catamaran hulls. Catamarans have many advantages and one major disadvantage: they are more stable upside down than rightside up. However, most, if not all Gulf fishing boats would founder if knocked down 180 degrees in the water. The catamaran can be designed to float and provide a survival platform albeit an uncomfortable one.

A family of proposed designs for Gulf waters was designed in the conceptual sense last year by this author. Plans for four geosims were outlined and are shown in Figures 13 through 17. Particulars for the four designs are given in Table 7.

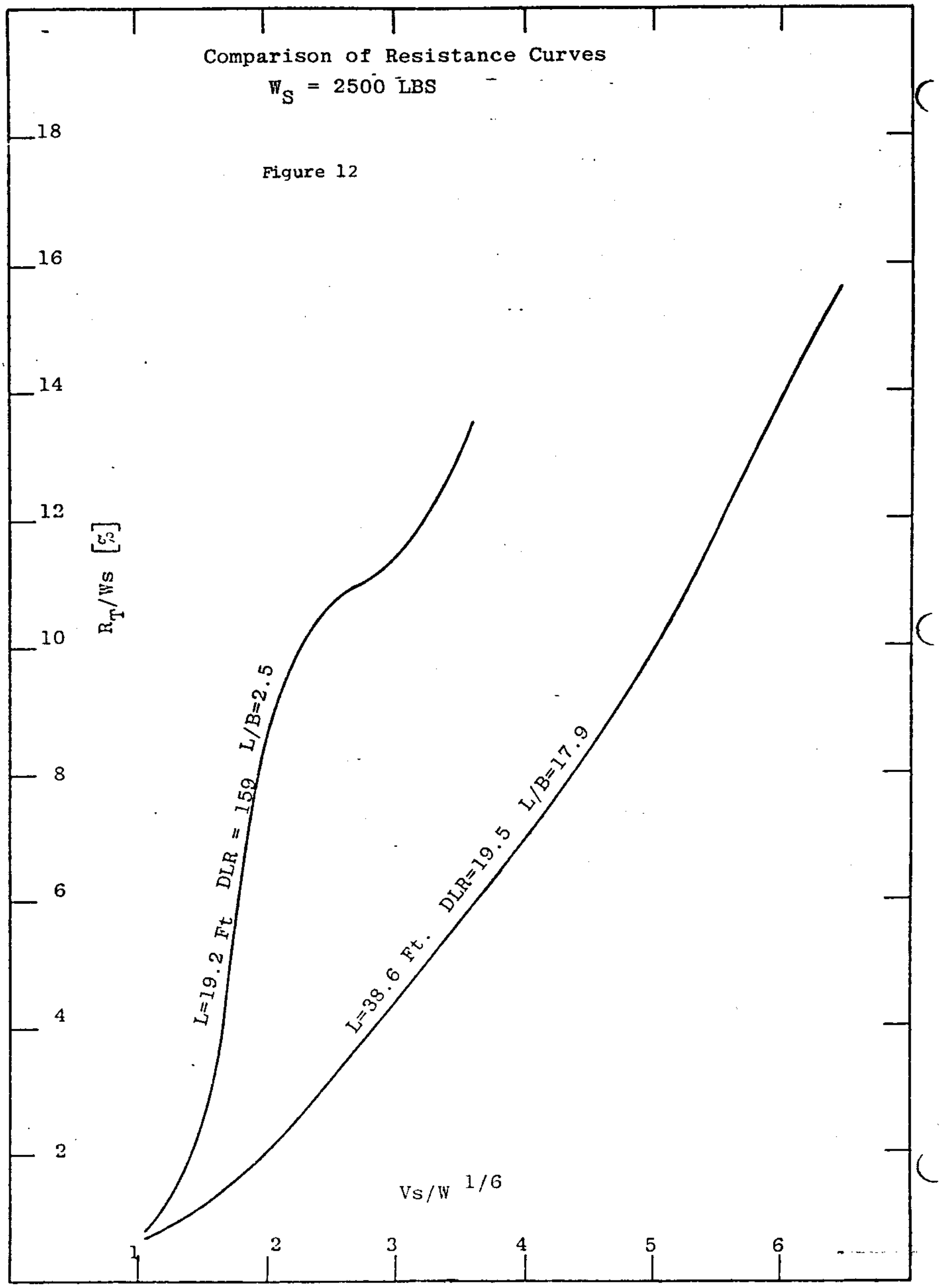
Table 7

CATAMARAN SAILING FISHING VESSELS

LOA	LWL	OAB	DISPL.	Payload	Hull Draft
23 ft.	21 ft.	13 ft.	4500 lbs.	1.0 tons	1.75 ft.
29	26	15	8500	2.0	2.17
36	33	18-20	15400	4.0	2.75
46	42	25	31724	8.0	3.49

Notes: LOA is length overall
LWL is length on waterline
OAB is overall beam
DISPL. is displacement
Payload is total weight fish plus ice
Draft is to profile not keel or skeg

Prismatic Coefficient: 0.57
Displacement-Length Ratio: 191 to 217
Length to Beam Ratio on WL: 5.1
Longitudinal center of buoyancy: 60% aft
Hull topside flare: 23% of waterline beam



Comparison of Resistance Curves

W_S = 2500 LBS

Figure 12

Figure 13

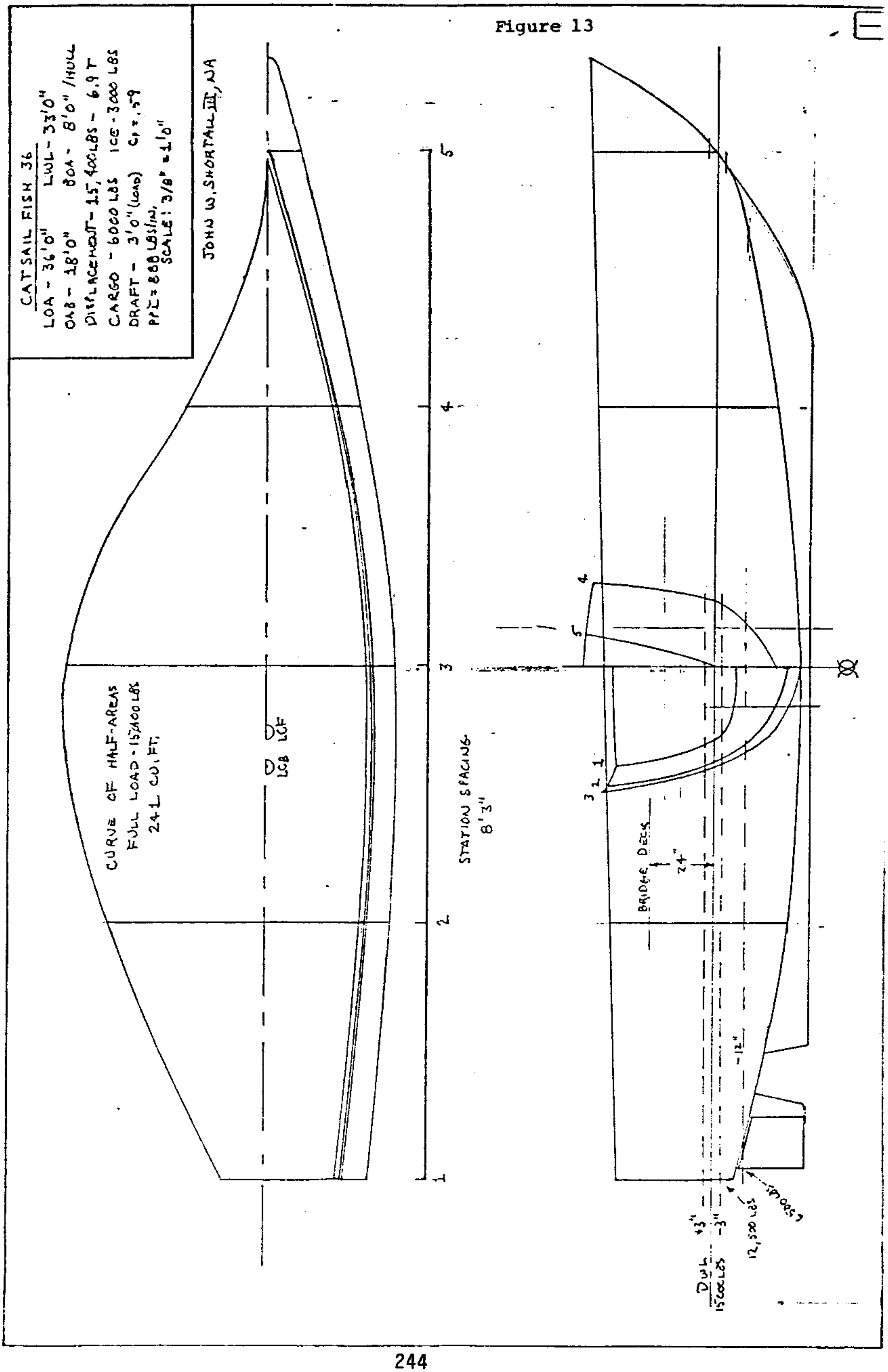

CATSAIL FISH 36
LOA - 36'0"
LWL - 33'0"
OAB - 18'0"
BOA - 8'0" /HULL
DISPLACEMENT - 15,400 LBS - 6.9 T
CARGO - 6000 LBS
ICE - 3000 LBS
DRAFT - 3'0" (LOAD)
C_P = .59
PPI = 888 LBS/IN.
SCALE: 3/8" = 1'0"
JOHN W. SHORTALL III, NA
CURVE OF HALF-AREAS
FULL LOAD - 15,400 LBS
241 CU. FT.
LCB
LCF
STATION SPACING
8'3"
1
2
3
4
5
BRIDGE DECK
24"
-12"
DWL
15,400 LBS
+3"
-3"
12,500 LBS
18,300 LBS

Figure 14

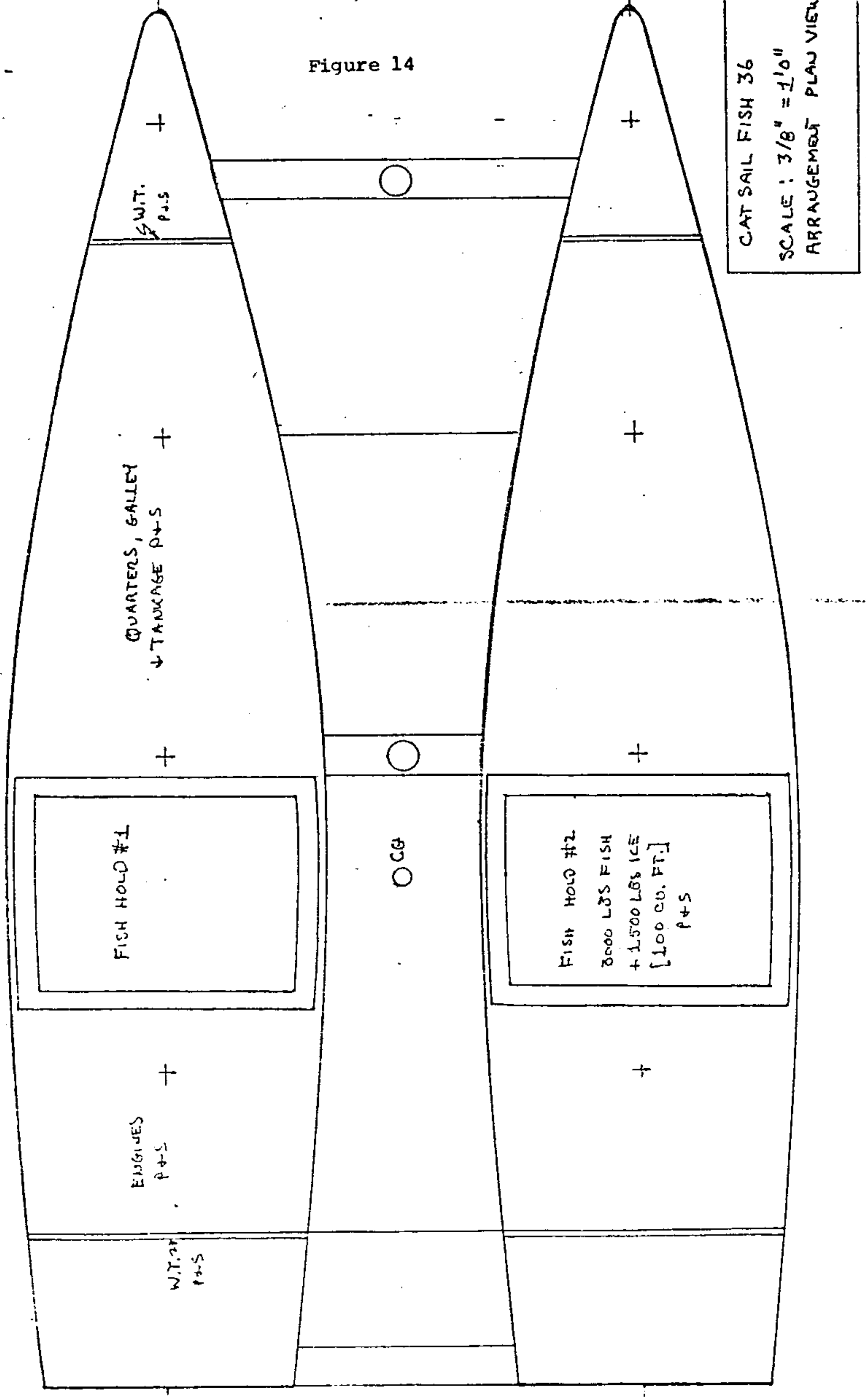

CAT SAIL FISH 36
SCALE : 3/8" = 1'0"
ARRANGEMENT PLAN VIEW
W.T. P+S
QUARTERS, GALLEY + TANKAGE P+S
FISH HOLD #1
CG
FISH HOLD #2
3000 LBS FISH
+ 1,500 LBS ICE
[100 CU. FT.]
P+S
ENGINES P+S
W.T. P+S

Figure 15

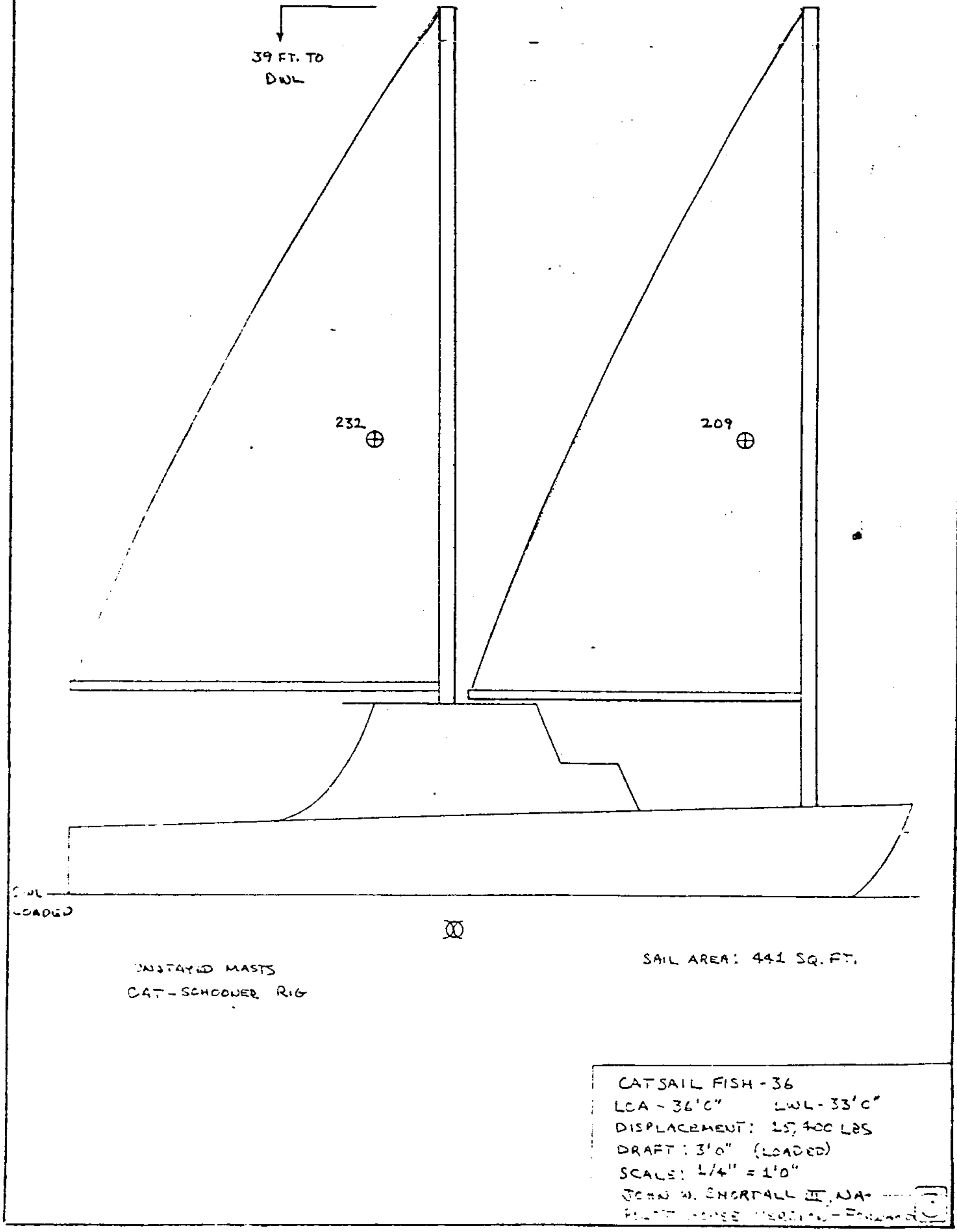

39 FT. TO DWL
232
209
DWL LOADED
UNSTAYED MASTS
CAT-SCHOONER RIG
SAIL AREA: 441 SQ. FT.
CATSAIL FISH - 36
LOA - 36'0"
LWL - 33'0"
DISPLACEMENT: 15,400 LBS
DRAFT: 3'0" (LOADED)
SCALE: 1/4" = 1'0"
JOHN W. SHORTALL III, NA
PILOT HOUSE MODIFIED - FORWARD

Figure 16

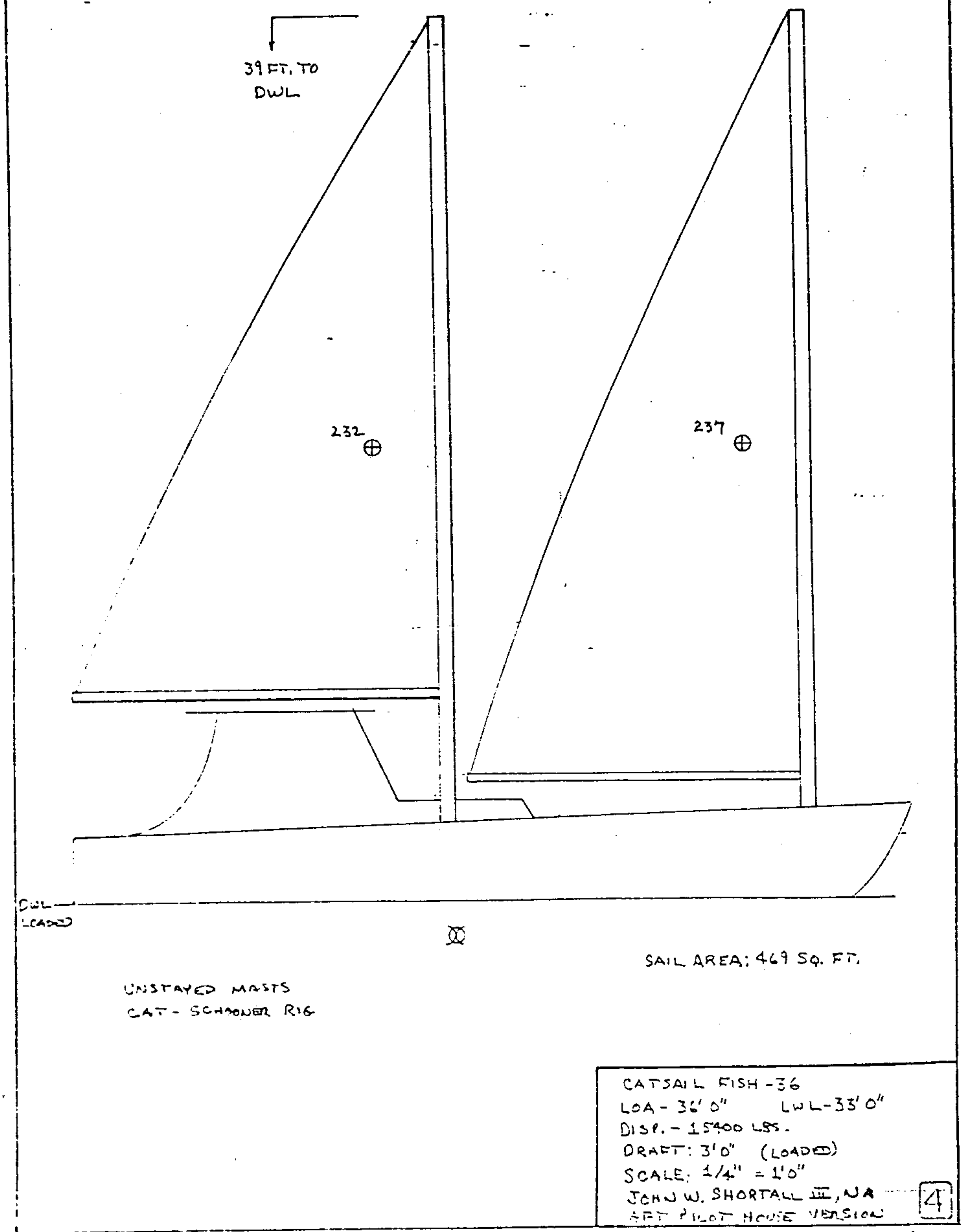
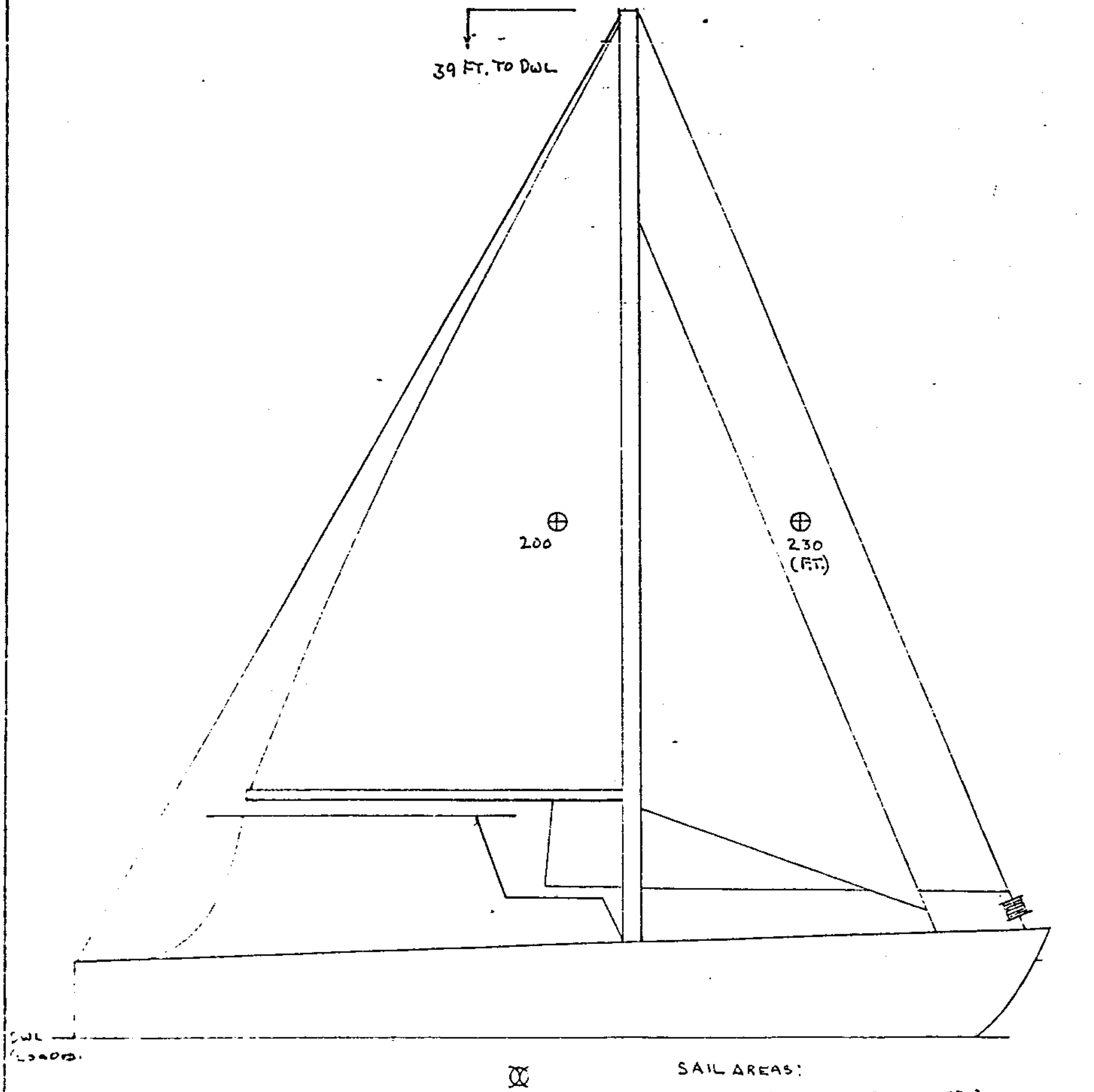

39 FT. TO DWL
232
237
DWL LOADED
SAIL AREA: 469 SQ. FT.
UNSTAYED MASTS
CAT - SCHOONER RIG
CATSAIL FISH -36
LOA - 36' 0" LWL - 33' 0"
DISP. - 15400 LBS.
DRAFT: 3' 0" (LOADED)
SCALE: 1/4" = 1' 0"
JOHN W. SHORTALL III, NA
AFT PILOT HOUSE VERSION
4

Figure 17



STAYED MAST - CUTTER RIG

SAIL AREAS:

MAIN:	200 SQ. FT.	562 TOTAL
JIB:	116	
GENOA:	246	
FORE A:	230	

CATSAIL FISH-36
LOA - 36' 0"   LWL - 33' 0"
DISP. - 15400 LBS.
DRAFT: 3' 0" (LOADED)
SCALE: 1/4" = 1' 0"
JOHN W. SHORTALL III, NA
STAYED MAST VERSION

5

CONCLUSIONS

1. Direction and strengths of winds in the Gulf and near-Atlantic area are sufficient to provide marked assist to commercial sailing fishing vessels. Long term, year-round average is a bit over 11 knots in most areas.

2. Economic gains of up to 30 to 40% seem possible by retrofitting conventional snapper-grouper boats with sails.

3. For the stone crab-lobster fishery fuel savings of only 15% are forecast unless the fisherman is willing to put up with mast lowering mechanisms such as tabernacles.

4. Fuel cost savings of at least 15% are possible for retrofitted shrimp trawlers with benefits possibly as high as 30%. This is particularly true for the Texas coast shrimp fishery area.

5. For new designs for both one and two man day fishing boats as well as larger vessels, the sail-equipped catamaran configuration offers decided cost and fuel savings advantages.

6. In other areas of the world where 20 knot or so trade winds blow constantly, the fuel and cost savings can be considerably more than the figures forecast here for the Gulf of Mexico-Near Atlantic areas.

7. Other wind thrusters, as wing sails and possibly Flettner rotors and windmills, should be seriously considered, research on these high thrust wind thrusters should be carried out. For a given thruster area, increases in thrust may be as much as 2.4 to 10 times that of conventional soft sails for a given wind strength. Rotors would seem to be ideal for fish boats and offer the very minimum of interference with the vessel's operation.

8. Designers and builders of fish boats should in this author's opinions junk all previous designs and start over. The present designs appeared to work in an era when diesel fuel cost 20 cents per gallon. We now know how to design vessels in very light weight composite plastics to reduce non-paying weight to a minimum and are learning more all the time in this field, chiefly from the aircraft industry. Designers should pay attention to the aerodynamics of commercial craft to minimize wind resistance. e.g. Trawlers should be designed to carry all top hamper slung low on deck.

9. It now seems time for private industry to step in and market retrofit rigs for common types of vessels.

10. It is recommended that designers give strong consideration to using the unstayed mast in sail rigs for commercial fishing vessels.

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BIOGRAPHY

The author is a practising naval architect and teaches that subject plus computer-aided design/yacht design as well as such mechanical engineering courses as: computer-aided design:CAD of structures, CAD-machine design, CAD-senior and graduate project design, CAD-stress analysis and similar topics. He is a member of SNAME as well as a member of SNAME Panel H13 on sailing vessel and sailing yacht research, chairman of the papers committee of SNAME Southeast, and the 1983-84 nominee for Chairman of the Southeast Section of SNAME. He is also a member of: Society of Small Craft Designers, Royal Institution of Naval Architects, American Society of Mechanical Engineers, IEEE Computer Society, Ocean Engineering Society, American Physical Society and American Association for the Advancement of Science. He spent three years as an officer in the U.S.Maritime Service and Merchant Marine on ocean-going ships and four seasons on Great Lakes vessels. He has sailed small boats and yachts since 1943.

APPENDICES

APPENDIX A - LIFE CYCLE COSTING DATA FOR SAIL-ASSISTED SNAPPER-GROUPER VESSELS

The life cycle costing method is described briefly in Reference 42. It is a standard method for engineering economic analysis when deciding whether to purchase capital equipment. Its basic premise is that the present value of money must always be taken into account in any economic forecast where investment of such is the question. One definition of present worth is that money which has to be invested today to have funds in the future to meet all expenses, and all costs are reduced to the common basis of present worth. In more usual terms, the purchaser of a fishing vessel, as the purchaser of any piece of capital equipment, must decide whether that investment will pay more and how much more than investing the money in stocks, money market funds or indeed any moneymaking enterprise. He then can himself weigh the risks and decide intuitively which course to take. Most fishermen who do not have mortgaged boats fail to take into account the income their vessel represents if it were sold and that money invested, when figuring their net annual returns. A sample output for the case of retrofitting a snapper-grouper boat is given on the next page.

SNAPPER - GROUPER BOAT - LIFE CYCLE COSTING

SAILING FISHING VESSEL CHARACTERISTICS

LENGTH OVERALL= 44 FT.
DISPLACEMENT= 20.5 TONS
SAILS INSTALLED IN YEAR: 0
PERCENT SAIL POWER= 40%
SAIL AREA= 947 SQ.FT.
MAST HEIGHT= 56 FT.

FUEL SAVINGS

TOTAL FUEL CONSUMED IF SAIL HAD NOT BEEN INSTALLED= 420000 GALLONS

TOTAL FUEL CONSUMED= 252000 GALLONS.
TOTAL FUEL SAVED= 168000 GALLONS.

SAIL RETROFIT ONE-TIME COST= $ 10841

SNAPPER - GROUPER BOAT

LIFE CYCLE COSTING OVER VESSEL LIFETIME

YEAR	FUEL	
	COST	SAVINGS
1	28000	11200
2	30800	12320
3	33880	13552
4	37268	14907
5	40995	16398
6	45094	18038
7	49604	19841
8	54564	21826
9	60020	24008
10	66023	26409
11	72625	29050
12	79887	31955
13	87876	35150
14	96664	38665
15	106330	42532
SUM:	$ 889,629	$ 355,852

```
FISHING VESSEL ECONOMIC PARAMETERS

1. COST OF FISHING VESSEL,$/TON: 4100
2. ENGINE REPLACEMENT COST, $: 5000
3. ENGINE REBUILD COST, $: 2000
4. COST OF SAILS, $/SQ.FT.: 3
5. COST MAST & RIGGING, $/FT.: 125
6. COST SUPPORT STRUCTURE, $: 1000
7. SALVAGE VALUE VESSEL, % OF COST: 10
8. VESSEL LIFETIME, YEARS: 15
9. FUEL COSTS, $/GAL.: 1
10. COMMO+NAVIG.GEAR COST, $: 11000
11. DOWN PAYMENT, %: 10
12. MORTGAGE RATE, %: 8
13. MORTGAGE TERM, YEARS: 15
14. GENERAL INFLATION RATE, %: 6
15. FUEL INFLATION RATE, %: 10
16. DISCOUNT RATE, %: 8
17. INSURANCE & MAINTENANCE, %: 5
```

```
THE FOLLOWING ARE OPERATIONAL DEFAULT
VALUES AND DESCRIBE ANNUAL OPERATING
CHARACTERISTICS OF THE SAILING FISHING
VESSEL FOR LIFE CYCLE COST ANALYSIS
1. RANGE TO FISHING SITE <MILES>: 400
2. AMOUNT ICE USED PER TRIP <LBS.>: 3000
3. DURATION OF TRIP <DAYS>: 14
4. NUMBER OF ANNUAL TRIPS: 18
5. SPEC.FUEL.CONSUMPT.<GAL/HP-HR>: .05
6. VESSEL CRUISING SPEED <KNOTS>: 9
7. CATCH VALUE <$/LB.>: 1.1
8. AVERAGE CATCH SIZE <LBS.>: 3000
9. ICE COST <$/LB.>: .0175
10. ENGINE SIZE <HP.>: 350
11. VESSEL LENGTH <FT.>: 44
12. VESSEL DISPLACEMENT <TONS>: 20.5
13. YEAR SAILS INSTALLED (YEAR END): 0
14. PERCENT OF SAIL POWER: 40
15. SAIL AREA <SQ.FT.>: 947
16. MAST HEIGHT <FT.>: 56
```

APPENDIX B

STONE CRAB – LOBSTER BOAT

LIFE CYCLE COSTING – 15 YEARS

YEAR	FUEL	
	COST	SAVINGS
1	2880	432
2	3168	475
3	3485	523
4	3833	575
5	4217	632
6	4638	696
7	5102	765
8	5612	842
9	6174	926
10	6791	1019
11	7470	1120
12	8217	1233
13	9039	1356
14	9943	1491
15	10937	1491
SUM:	$ 91,505	$ 13,726

SAILING FISHING VESSEL CHARACTERISTICS

LENGTH OVERALL= 37.83 FT.
DISPLACEMENT= 16.3 TONS
SAILS INSTALLED IN YEAR: 0
PERCENT SAIL POWER= 15%
SAIL AREA= 548 SQ.FT.
MAST HEIGHT= 52 FT.

FUEL SAVINGS

TOTAL FUEL CONSUMED IF SAIL HAD NOT BEEN INSTALLED= 43200 GALLONS

TOTAL FUEL CONSUMED= 36720 GALLONS.
TOTAL FUEL SAVED= 6480 GALLONS.

SAIL RETROFIT ONE-TIME COST= $ 9144

APPENDIX C - PERFORMANCE PREDICTION SUMMARIES

76 FT. SHRIMPER

Displacement: 156.3 tons

Sail Area: 2640 sq.ft.

Prismatic Coefficient: 0.575

True Wind Velocity: 11.3 knots

CASE I

Angle to True Wind: 90 degrees (beam reach)

Angle to Apparent Wind: 65 degrees

Hull Resistance: 1152 lbs.

Heel Angle: 2 degrees

Boat Speed: 5.3 knots

CASE II

Sail Area: 2240 sq.ft.

Angle to True Wind: 180 degrees (running)

Heel Angle: 0

Hull Resistance: 408 lbs.

Boat Speed: 3.1 knots

THOMPSON 44 SNAPPER-GROUPER BOAT

Displacement: 46,000 lbs.

Prismatic Coefficient: 0.575

Resistance: 419 lbs.

Angle to True Wind: 90 degrees

Angle to Apparent Wind: 61 degrees

Heel Angle: 3.3 degrees

Boat Speed: 6.4 knots

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LINEARIZED PERFORMANCE ANALYSIS OF SAILING AND MOTOR-SAILING

by

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NOMENCLATURE:

AR	aspect ratio: a measure of the slenderness of a wing planform
C_L	lift coefficient: see introduction
C_D	drag coefficient: see introduction
C_{DO}	parasitic drag coefficient: indicates drag caused by rate of loss of linear momentum of a fluid
C_{Di}	induced drag coefficient: indicates drag due to tip vortex generation
C_{ep}	effective power coefficient: indicates fuel-saving benefit of rig/keel combination
C_{er}	effective drive coefficient: indicates net thrust from rig/keel combination
D	distance along track
F_H	heeling force from rig
F_R	driving force from rig
F_S	side force from keel
L	lift
P	constant: indicates power-dependent ship operating costs
R_i	induced resistance: associated with formation of tip vortex on keel
R_{DK}	parasitic resistance: associated with rate of loss of linear momentum as the sea flows around the keel
R_T	upright resistance: water resistance of upright hull, without keel
SFC	specific fuel consumption of engine engine power/unit time
Tr	net propeller thrust
V	speed (see section on suffixes also)
a	ratio of ship speed/true wind speed
c	wing chord: the streamwise dimension of a wing

K	induced drag factor: a constant in the drag equation - its value depends on the span loading of a wing	
pdf	probability density of wind strength and direction	
x	longitudinal axis of a ship	
y	lateral axis of a ship	see Appendix
z	vertical axis of a ship	
c	ship resistance constant: indicates upright ship water resistance	
Θ	angular variable for wind statistical data (=0 North)	
∇	volumetric displacement of a ship	
ϕ	angle of heel	
β	apparent wind angle: angle between course sailed and vector sum of true wind velocity and air velocity arising from ship motion -(see Figure 1)	
γ	true wind angle: angle between course sailed and true wind direction - (See Figure 1)	
γ_0	half tacking angle: the true wind angle used when tacking	
ρ	density: used with suffixes a or s to denote air or sea	
η_T	transmission efficiency from engine to propeller quasi propulsive efficiency: accounts for both	
η_D	propeller efficiency and adverse hydrodynamic interaction between propeller and hull	

Suffix:

A	apparent
a	air
e	effective
f	fuel
L	linearized
P	power
R	drive
S	ship or sea (note however that F denotes ship sideforce)
T	true
K	keel

1. INTRODUCTION

Analysis of a sailing or motor-sailing vessel is acknowledged to be a difficult problem involving many variables. It is both complex and nonlinear, making it difficult for naval architects to quantify the potential benefits of propelling a ship with some type of rig/keel combination. The aim of this paper is to present a simplified analysis to quantify the benefits of windship propulsion. Simplification is done via nondimensional analysis, separation of slight from extreme nonlinearities and the introduction of new coefficients describing the net propulsive and fuel-saving benefits of a rig/hull/keel combination. Methods are shown that combine statistical weather data with rig/hull/keel data to arrive at an expected voyage time (under sail alone) or expected fuel saving under motor sail (assuming ship speed fixed).

Both sea and air fluid flow problems are based on axes defined relative to the course sailed. This choice of coordinate system eliminates leeway angles as variables in the algebra and implies that "apparent" wind angles are relative to the course sailed and not the ship center line. Conventional definitions of lift and drag coefficients are used in the analysis:

$$L = 1/2 \rho V^2 S C_L$$

$$D = 1/2 \rho V^2 S C_D$$

where L is the aerodynamic lift force, D is the aerodynamic drag force. Other variables are defined under Nomenclature.

Simple wing theory gives the drag coefficient in terms of the lift coefficient.

$$C_D = C_{DO} + \frac{KC_L{}^2}{\pi AR}$$

There are very few areas of powered-ship design which could not be changed by the introduction of some form of wind assistance, and this paper does not presume to rigorously explore every aspect of the problem. The analytical development is deliberately kept simple, both as a means of examining the problem as a whole and because fairly conservative expectations of accuracy are appropriate to any performance calculations involving wind power.

The word "linearized" has a number of implications for both this paper and the wider problem. For this paper, it means that an analysis will be attempted for an essentially linear lifting problem where there is no separation involved in the lifting process. This implies that both rig and keel will consist of "wing" devices.

However, some separation may be admitted for drag generation in downwind sailing, which can come out in the algebra as an increase in C_{DO}.

Main conclusions are:

- It is possible to define nondimensional coefficients which describe the performance of some rig/keel combination and which depend mostly on only two variables.

- Conservative calculation of expected sailing-ship voyage times can be found by combining weather statistical data with rig/keel performance data.

- Tacking criteria for motor-sailers are given;' the method of deriviation may be used equally well to define other tacking criteria appropriate to some other consideration, such as minimum fuel usage or minimum operating cost.

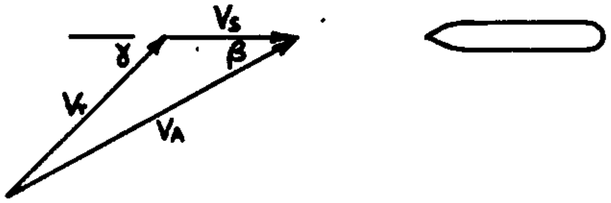
- Expected fuel savings for a motor-sailer, with a fixed ship speed, can be found by combining weather statistical data with rig/keel/engine/hull data. Strategies other than fixed speed can be adopted to obtain greater savings using similar methods.

2. BACKGROUND CONSIDERATIONS

2.1 Wind Velocity Triangle - Basic Results

A wind velocity triangle is constructed, appropriate to wind velocity components approaching a ship.

Figure 1. Wind Velocity Triangle



V_S, V_A and β can be measured and the cosine rule may be applied to obtain:

$$V_T^2 = V_S^2 + V_A^2 - 2V_SV_A\cos\beta \qquad 1.$$

$$V_T = \sqrt{V_S^2 + V_A^2 - 2V_SV_A\cos\beta} \qquad (0 \leqslant \beta \leqslant \pi)$$

The sine rule can be used to obtain:

$$\frac{V_T}{\sin\beta} = \frac{V_A}{\sin\gamma} \qquad 2.$$

$$\text{or} \qquad \gamma = \sin^{-1}(V_A\sin\beta/V_T)$$

Alternatively, V_A and β can be found from V_T and γ via

$$V_A = \sqrt{V_S^2 + V_T^2 + 2V_SV_T\cos\gamma} \qquad 3.$$

and

$$\beta = \sin^{-1}(V_T\sin\gamma/V_A) \qquad 4.$$

(3) and (4) may be combined to obtain:

$$\sin\beta = \frac{V_T \sin\gamma}{V_S^2 + V_T^2 + 2 V_S V_T \cos\gamma} \qquad 5.$$

(1) and (3) may be combined to obtain:

$$\cos\beta = \frac{V_S + V_T \cos\gamma}{V_S^2 + V_T^2 + 2 V_S V_T \cos\gamma} \qquad 6.$$

In reality, wind speed is a function of height, so that β is a function of height, $\beta = \beta\ (z)$. There are compensating corrections that can be applied, correct to the order of our approximations.

2.2 Ship Resistance

Ship upright water resistance may be obtained from:

$$R_T = \textcircled{C} \frac{\pi \rho_S V_S^2 \nabla^{1/3}}{250} \qquad 7.$$

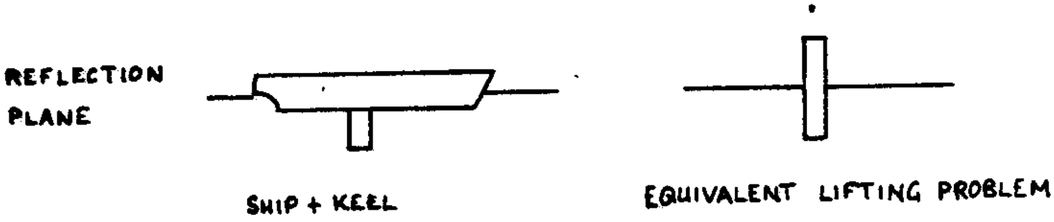
In addition to (7), additional upright resistance may normally be expected from the action of wind and waves. Relative to R_T this is known to be small for light to moderate winds and calm seas. Consequently, this additional resistance will be ignored as far as the present analysis is concerned, implying a limitation on its validity in respect to ship speed predictions in heavy weather.

Moderate heeling, without sideforce, is known to have very little effect on ship resistance and will be ignored. However, heeling is known to increase the resistance due to sideforce and this effect could at some stage be taken into account. For larger ships, heeling is less a factor as with increasing linear dimension (e.g., length) the heeling moment increases by the third power of the length scale factor while the restoring moment increases by the fourth power.

Production of sideforce leads to a large increase in ship resistance due to induced drag. The nature of this increase varies, depending on how the ship sideforce (F_S) is produced. A ship hull is a low aspect lifting surface and produces compensating sideforce relatively inefficiently. Elaborate keels, commonplace on sailing vessels, are needed to generate lift in windward conditions. However, sail assisted vessels operating at or near a service speed will be able to generate significant sideforce by virtue of the speed of the fluid. Obviously practical considerations generally will encourage the avoidance of extra appendages. Experience on large sailing vessels of a half a century ago found that the addition of a skeg or a bar keel was often sufficient to reduce leeway to an acceptable amount.

An alternative is to use some form of keel, ideally having a smooth surface, deep draft and carefully designed planform. Analysis of such a keel may be achieved by means of an "equivalent keel" concept as described by Kerwin (1978).

Figure 2. Equivalent Keel Concept



To analyze the keel lift (or sideforce), standard methods may be applied to the equivalent lifting problem to obtain:

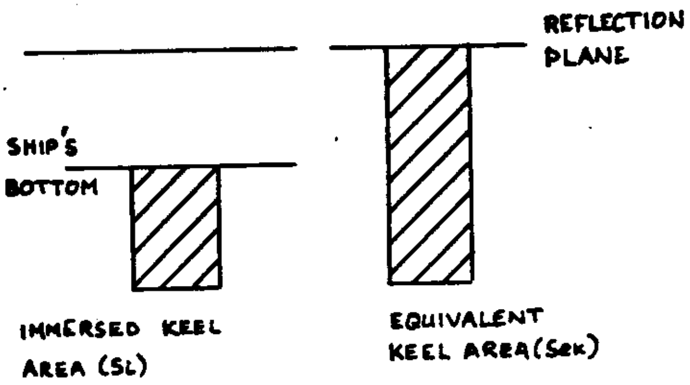
$$F_S = C_{Lk} \, \tfrac{1}{2} \rho_s V_S^2 S_{ek} \qquad 8.$$

$$AR_{ek} = \frac{2s^2}{S_{ek}} \qquad 9.$$

$$R_i = \frac{k_k C_{Lk}^2}{\pi AR_{ek}} \cdot \tfrac{1}{2} \rho_s V_S^2 S_{ek} \qquad 10.$$

The parasitic drag of the keel can be accounted for by means of an equivalent keel parasitic drag coefficient C_{DOEK}. This consists of the keel parasitic drag coefficient (C_{DOK}) scaled by the ratio of the immersed to equivalent keel areas as shown in Figure 3.

Figure 3. Immersed and Equivalent Keel Areas



The parasitic resistance of a keel may be obtained as:

$$R_{DK} = C_{DOEK} \cdot \tfrac{1}{2} \rho_S V_S^2 S_{EK} \qquad 11.$$

A few words about the implications of equations (8-11) are appropriate before continuing.

Some assessment of F_S and V_S is needed to ensure C_{LK} has a reasonable value and the keel does not stall. The incidence or camber of the keel is conventionally fixed relative to the hull. In this case the keel area will be sized to keep hull leeway angles from causing significant drag increases due to separation of the hull flow.

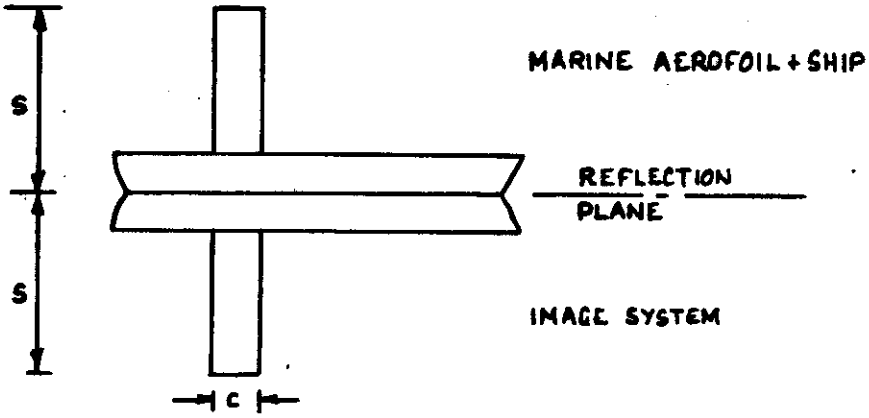
However, it should be possible to engineer a rotatable keel whose incidence or camber can be varied relative to the hull to produce sideforce at zero ship leeway angle and allow reductions in the keel area and hence resistance. Such arrangements have been tried in the past and caused steering problems, but there do not appear to be insurmountable difficulties for the future. Our observations about the practicality of such devices still apply, however.

The implication of equation 11 is that deeper draft keels or faster ship speeds result in less induced resistance. One consequence of this is that when motor-sailing to windward, the F_S/R_i ratio of the hull is improved, implying that pure sail experience sometimes inadequately represents the efficacy of motor-sail performance.

2.3 Marine Aerofoil Forces

The aerodynamic loads produced by a sail-rig can be extremely difficult to analyze, particularly if a lifting membrane (soft sail) is used as the major component. In the case of a wing-sail, circulation control or similar device, analysis is possible via lifting line or lifing surface methods. The essential aerodynamic problem is to model the marine aerofoil and hull above waterline together with an image system. In the case of a rig, where overall height is much greater than deck height, the reflection plane may be taken as the sea, giving an aerodynamic problem as shown in Figure 4.

Figure 4. Marine Aerofoil Aerodynamic Model



Analysis of this type of problem can be achieved by standard methods (Bergeson et al,1981) with forces as described by:

$$L = C_{Lr} \cdot \tfrac{1}{2} \rho_a V_A^2 S_{er} \qquad 12.$$

$$D = C_{Dr} \cdot \tfrac{1}{2} \rho_a V_A^2 S_{er} \qquad 13.$$

$$= \left[C_{Doer} + k_r \cdot \frac{C_{Lr}^2}{\pi AR_{er}} \right] \cdot \tfrac{1}{2} \rho_a V_A^2 S_{er} \qquad 14.$$

C_{DOER} is an equivalent profile drag coefficient for the rig, calculated by taking C_{DOR} and scaling by the ratio of the "exposed" area of rig above the hull and the area of rig when projected down to the waterline.

From Figure 4,

$$S_{er} = s.c \qquad 15.$$

$$A_{er} = 2s^2/S_{er} \qquad 16.$$

and Kr is an induced drag factor dependent on rig span loading only.

Equation (3) may be used in conjunction with (12) and (14) to obtain rig forces:

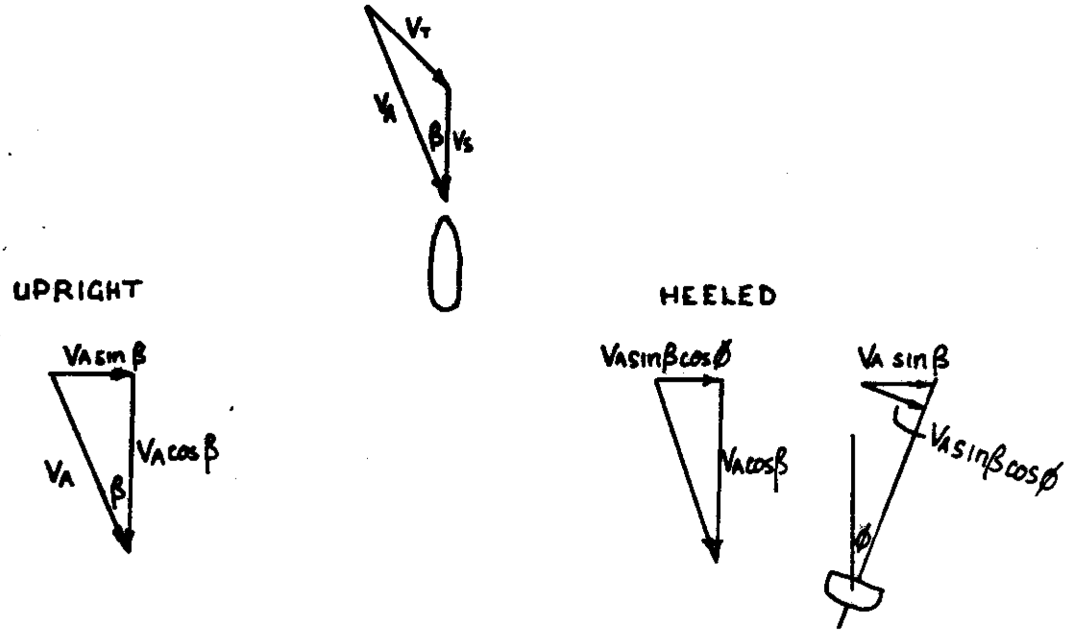
$$L = C_{Lr}.\tfrac{1}{2}\rho_a.(V_s^2+V_T^2+2V_sV_T\cos\gamma).S_{er} \qquad 17.$$

$$D = \left[C_{Doer} + k_r.\frac{C_{Lr}^2}{\pi AR_{er}}\right].\tfrac{1}{2}.\rho_a.(V_s^2+V_T^2+2V_sV_T\cos\gamma).S_{er} \qquad 18.$$

Some of the implications of (17) and (18) need to be appreciated at this stage. For windward sailing, a reasonable L/D ratio is required, implying that span loading should be looked at closely. An elliptical loading maximizes L/D; however, it may not be fully appropriate for a ship going to windward. This depends on the windward ability of the hull and many other factors. A good L/D ratio can also be achieved by increasing rig height which is reflected in (18) by an increase in ARer. This can also cause excessive heeling moments and stall the upper parts of a rig when a ship is rolling, resulting in a reduction in speed. The latter effect can be noticed with very small vessels in rough water but may not be too important for ships.

When reaching, the essential requirement is to maximize lift, and when running, to maximize drag. As with multiple keels, the basic forms of (17) and (18) can still be used to describe multiple aerofoils, and again some re-definition of Aer, Ser and Kr will be needed. When a vessel heels, there is a change in both the geometry of the force balance and the effective apparent wind angle β, as shown in Figure 5.

Figure 5. Wind Velocity Triangle Changes Due to Heeling



This treatment of heeling is rather like that of an aircraft wing with dihedral, where an assumption is made that velocity components in the spanwise direction have no effect on the pressure distribution.

From Figure 5, the effective apparent wind angle is changed as a consequence of heeling and is now given by:

$$\beta_e = \tan^{-1}\{\sin\beta\cos\phi/\cos\beta\}$$

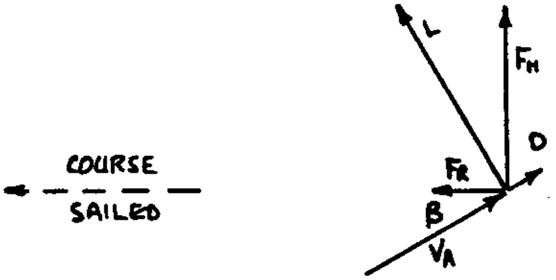
$$= \tan^{-1}\{\tan\beta\cos\phi\} \qquad 19.$$

The importance of (19) is that it allows heeling to be removed from subsequent analysis since every problem involving it can now be related to an equivalent unheeled problem once βe or γe is calculated.

2.4 Balance of Force on Sailing Ship

Rig and hull forces are in balance when a sailing ship moves through the sea/air at constant relative speeds. This equilibrium case is the only one to be considered and as a first step, attention is drawn to the problem of resolving rig lift and drag into a driving force F_R and heeling force F_H. Figure 6 illustrates the rig forces.

Figure 6. Rig Forces



Forces may be resolved as:

$$F_R = L\sin\beta - D\cos\beta$$

$$F_H = L\cos\beta + D\sin\beta$$

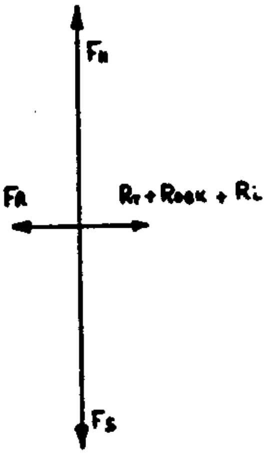
Using (5) and (6) and nondimensional coefficients,

$$F_R = \tfrac{1}{2}\rho_a S_{er}\sqrt{V_S^2 + V_T^2 + 2V_S V_T\cos\gamma}\,.\left(C_{LR}\,V_T\sin\gamma - C_{Dr}\left[V_S + V_T\cos\gamma\right]\right) \qquad 20.$$

$$F_H = \tfrac{1}{2}\rho_a S_{er}\sqrt{V_S^2 + V_T^2 + 2V_S V_T\cos\gamma}\,.\left(C_{LR}.\left[V_S + V_T\cos\gamma\right] + C_{Dr}.\,V_T\sin\gamma\right) \qquad 21.$$

The hull forces are a sideforce (F_S) together with upright, keel parasitic and induced resistance (R_T, R_{OEK} & R_i). This balance of forces is shown in Figure 7.

Figure 7. Balance of forces on sailing ship.



For the equilibrium case considered, clearly:

$$F_R = R_T + R_{deck} + R_i \tag{22.}$$

$$F_H = F_S \tag{23.}$$

If motor-sailing is being considered, a net thrust (T_R) from the propeller is included in (22) to obtain the general form:

$$T_R + F_R = R_T + R_{deck} + R_i \tag{24.}$$

3. SIMPLIFICATION AND SOLUTION OF SAILING SHIP PERFORMANCE EQUATIONS

The objective of this section is to explain both the solution of sailing ship performance equations and concepts which seem useful for extensions to existing theory. Before proceeding, it is wise to review the assumptions made so far. These may be summarized:

- vertical wind velocity gradient effects ignored
- air drag on hull and wave resistance ignored
- hull resistance due to heeling ignored
- effects of heeling on rig forces can be accounted for separately
- residuary resistance coefficient is essentially constant in the speed range of sail assisted vessels

We recombine equations (20), (7) and (10) to rewrite the sailing vessel thrust/drag relationship.

$$\tfrac{1}{2}\rho_a S_{er}\sqrt{V_S^2+V_T^2+2V_SV_T\cos\gamma}\,.\,(C_{Lr}.V_T\sin\gamma - C_{Dr}[V_S+V_T\cos\gamma])$$

$$= \text{©}.\frac{\pi.\rho_s.V_S^2.\nabla^{2/3}}{250} + \left(C_{Doek} + \frac{k_K.C_{LK}^2}{\pi AR_{ek}}\right).\tfrac{1}{2}\rho_s V_S^2 S_{ek} \qquad 25.$$

Now if (25) is divided by $1/2\,\rho_a V_T^2 S_{er}$ and a non-dimensional speed ratio parameter introduced as:

$$a = V_S/V_T \qquad 26.$$

then (25) becomes:

$$\sqrt{a^2+1+2a\cos\gamma}\,.(C_{Lr}.\sin\gamma - C_{Dr}[a+\cos\gamma])$$

$$= \text{©}\,\frac{.\pi.\rho_s.a^2.\nabla^{2/3}}{\rho_a.S_{er}.125} + \left(C_{Doek} + \frac{k_K.C_{LK}^2}{\pi.AR_{ek}}\right)\frac{\rho_s}{\rho_a}\frac{S_{ek}.a^2}{S_{er}} \qquad 27.$$

Hence the two variables V_S and V_T have now been replaced by a single variable - a. The implications will be discussed later. C_{LK} now needs to be related to F_H. Using (8), (21), and (23):

$$C_{LK} = \frac{\frac{1}{2}\rho_a S_{er} \sqrt{V_s^2 + V_T^2 + 2V_sV_T\cos\gamma}\,\left(C_{Lr}\left[V_s + V_T\cos\gamma\right] + C_{Dr}.V_T\sin\gamma\right)}{\frac{1}{2}\rho_s V_s^2 S_{ek}}$$

$$= \frac{\rho_a . S_{er} . \sqrt{a^2 + 1 + 2a\cos\gamma} . \left(C_{Lr}\left[a + \cos\gamma\right] + C_{Dr}.\sin\gamma\right)}{\rho_s . S_{ek} . a^2} \qquad 28.$$

Substituting (28) into (27) gives:

$$\sqrt{a^2+1+2a\cos\gamma}.\left(C_{Lr}.\sin\gamma - C_{Dr}\left[a+\cos\gamma\right]\right)$$

$$= \copyright . \pi . \frac{\rho_s . a^2 . \nabla^{2/3}}{\rho_a . S_{er} . 125} + C_{DOEK} . \frac{\rho_s}{\rho_a} . \frac{S_{ek}}{S_{er}} . a^2$$

$$+ k_K . \frac{\left(a^2+1+2a\cos\gamma\right).\left(C_{Lr}.\left[a+\cos\gamma\right]+C_{Dr}.\sin\gamma\right)^2 . \rho_a . S_{er}}{\pi . AR_{EK} . \rho_s . S_{ek} . a^2} \qquad 29.$$

This equation is of similar form to that derived by Letcher (1982) in the nondimensionalization and the inclusion of keel parasitic drag term. Equation (29) is nonlinear in a and γ. Other variables either depend on a and γ or are substantially constant. One exception is ©. This will be substantially constant at low-ship speeds, and so for these speeds it is possible to conclude that the ratio of ship speed to true wind speed will also be constant for a given true wind angle, γ.

In practice, (29) can be easily solved with a root-finding numerical technique, and a typical performance polar is shown in Figure 8.

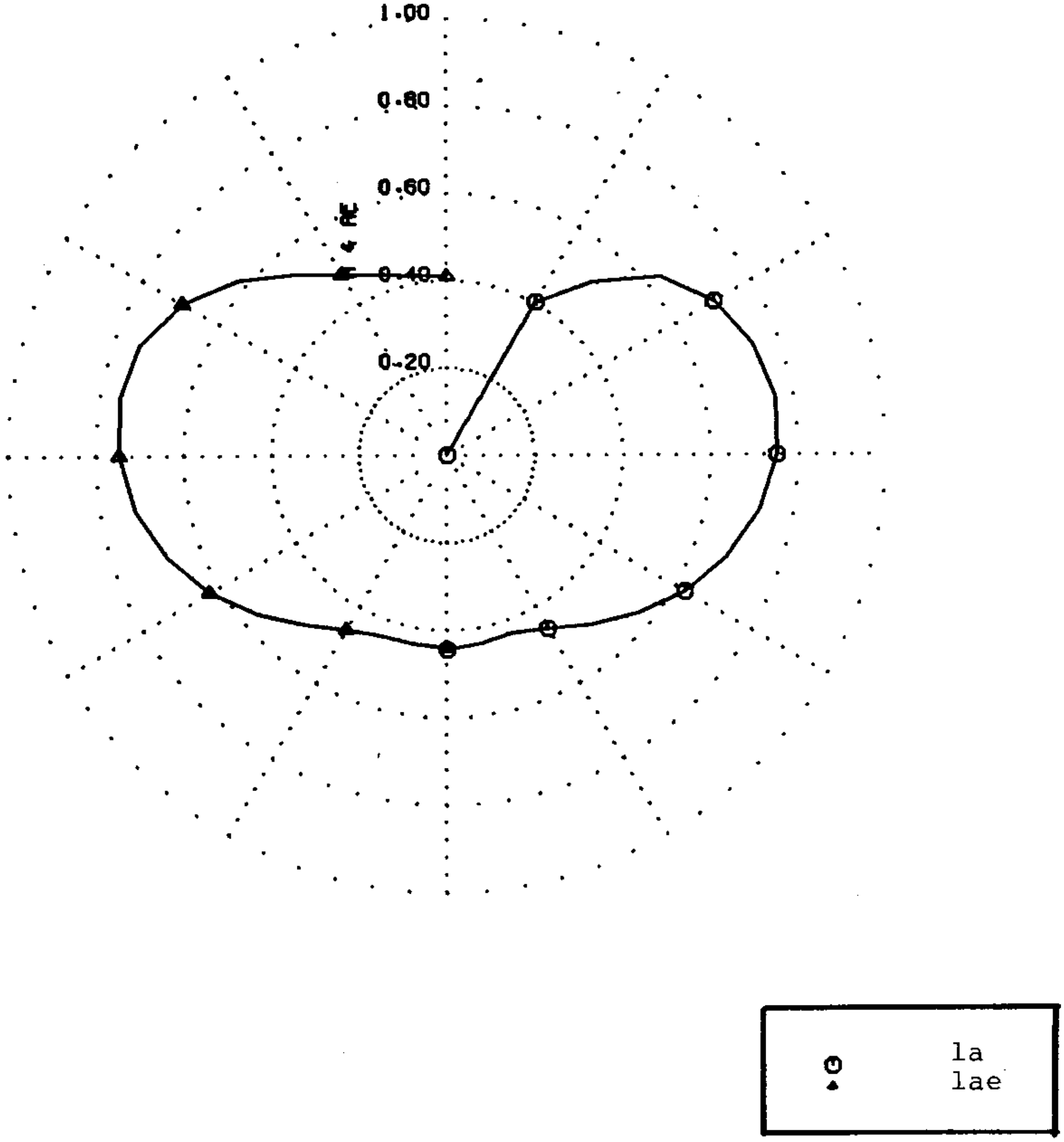


Figure 8. Performance Polar for Fishing Boat

The motor-sailing case may be solved in a similar way, although in this instance a specific, rather than generalized answer will be obtained. One concept which is important for future work in motor-sailing is the idea of the net beneficial effect of the rig.

As before, a given rig/keel combination lends itself to nondimensional analysis and the following coefficients may be defined:

effective drive coeffecent $$C_{er} = \frac{F_R - R_i - R_{ok}}{\frac{1}{2}\rho_a V_T^2 S_{er}} = C_{er}(a,\gamma) \qquad 30.$$

effective power coefficient $$C_{ep} = \frac{(F_R - R_i - R_{ok}).V_s}{\frac{1}{2}\rho_a V_T^3 S_{er}} = C_{ep}(a,\gamma) \qquad 31.$$

The effective drive and power coefficients may be used either as yard sticks for the evaluation of rig/keel combinations or as a means of tabulating data applicable to superficially more complex problems.

Equation (29) may be decomposed and used with (30) and (31) to obtain:

$$C_{er} = \sqrt{a^2+1+2a\cos\gamma}\,.(C_{Lr}.\sin\gamma - C_{Dr}[a+\cos\gamma])$$

$$- C_{D0ek}.\frac{\rho_s}{\rho_a}\frac{S_{ek}}{S_{er}}.a^2$$

$$- k_K.\frac{(a^2+1+2a\cos\gamma)(C_{LR}.[a+\cos\gamma] + C_{Dr}.\sin\gamma)^2.\rho_a.S_{er}}{\pi.AR_{ek}.\rho_s.S_{ek}.a^2} \qquad 32.$$

and

$$C_{ep} = a.C_{er} \qquad 33.$$

It is important to note that the values of C_{er} and C_{ep} are independent of many of the simplifications and assumptions made to describe hull resistance;' in particular the absence of © is particularly gratifying as it is very difficult to assess.

Having said that it must be realized that this level of analysis has ignored problems such as: multiple mast aerodynamics, heavily loaded lifting surfaces, nonlinear hull induced drag effects and the windage effects on side force and hence induced drag.

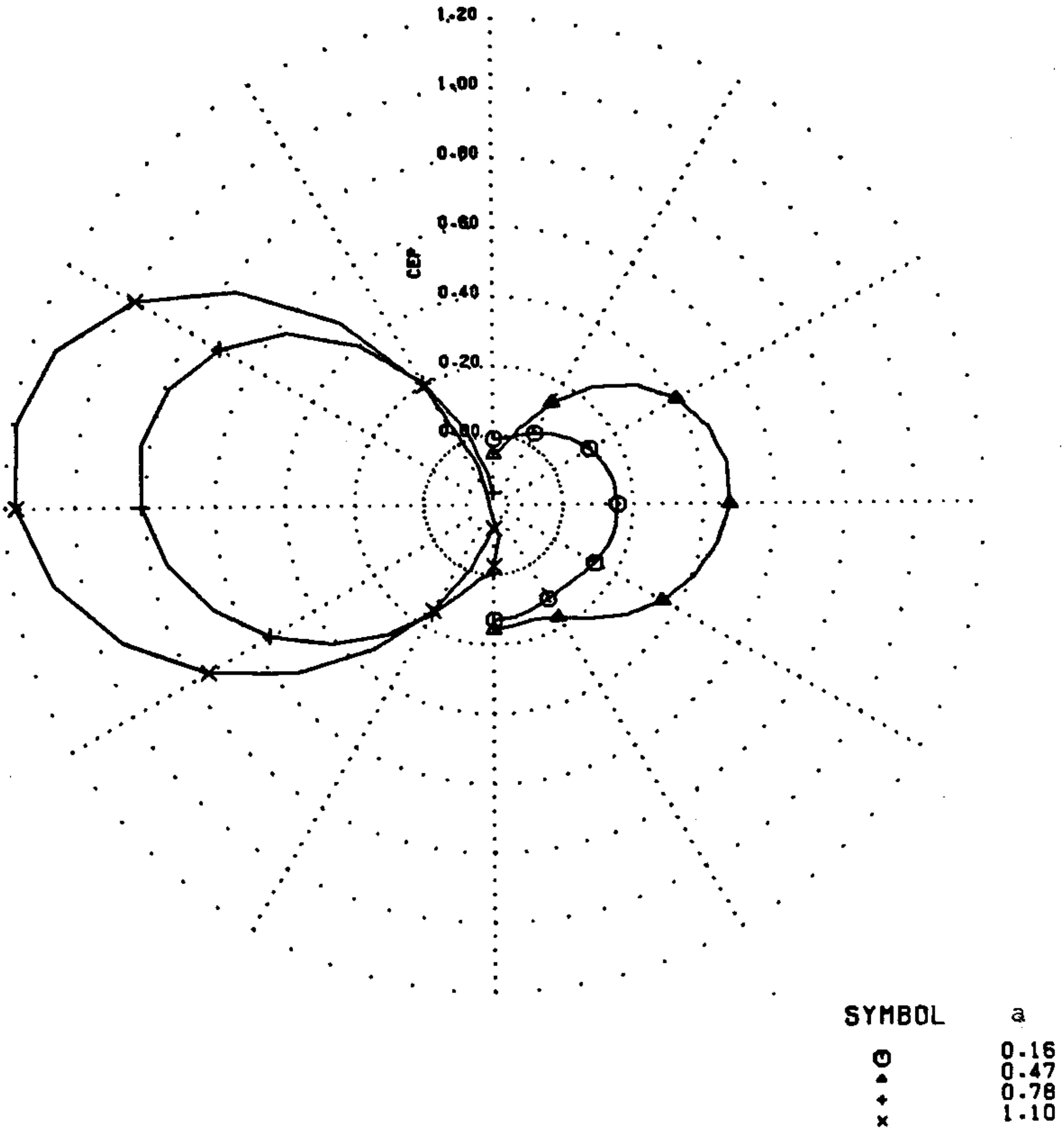


Figure 9. Effective Power Polar - Fishing Boat

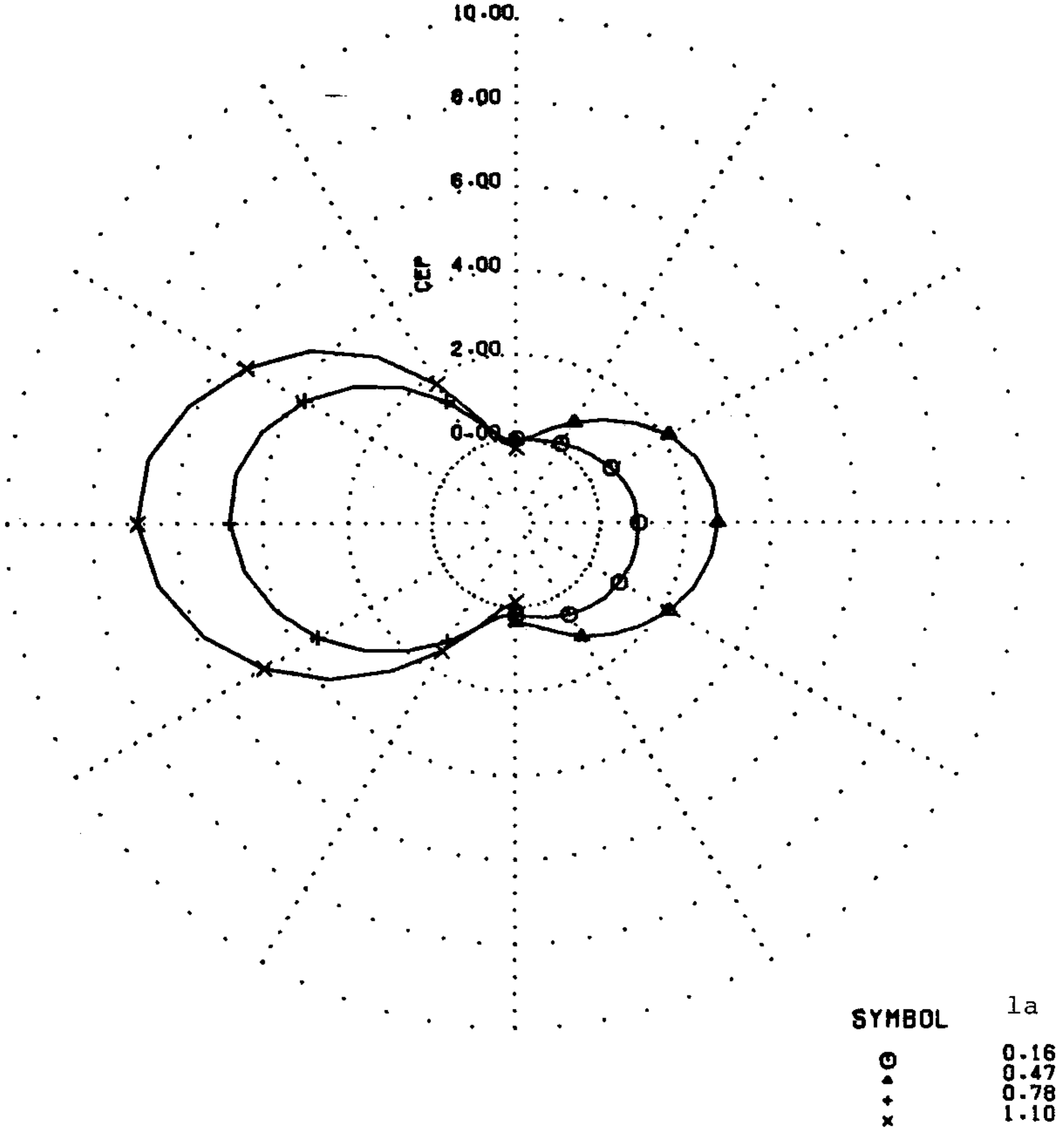


Figure 10. Effective Power Polar - General Cargo Ship

In the motor-sailing mode, power can be varied to maximize either the fuel-saving or speed-enhancing benefits of the rig/keel.

The implications of treating the problem in this way should not go unnoticed. Effective drive and power coefficients can be readily used by naval architects to relate familiar upright ship resistance data to rig/keel data.

In practical use, C_{er} is defined for some rig/keel combination as a function of a and γ. To calculate sailing-ship speed, the equation:

$$C_{er}(a,\gamma) \cdot \tfrac{1}{2}\rho_a \cdot S_{er} \cdot V_T = \copyright \cdot \frac{\pi \cdot \rho_s \cdot V_s^2 \cdot \nabla^{2/3}}{250} \qquad 34.$$

must be solved. This is simply another form of (29) and may be solved in the same way. The form shown in (34) allows details of promising rig/keel combinations to be computed, stored on file and used as required with different hull forms. As mentioned above, knowledge of © for different hull forms as a function of speed is not often readily accessible.

The power coefficient may be used to assist with the calculation of fuel savings as follows:

Effective power from rig = $C_{ep}(a,\gamma) \cdot \tfrac{1}{2}\rho_a V_T^3 \cdot S_{er}$ 35.

Power required from engine to deliver the same effective power to hull = $\dfrac{C_{ep}(a,\gamma) \cdot \tfrac{1}{2}\rho_a V_T^3 \cdot S_{er}}{\eta_T \eta_D}$ 36.

Fuel saved = $SFC \cdot TIME \cdot \dfrac{C_{ep}(a,\gamma) \cdot \tfrac{1}{2}\rho_a V_T^3 \cdot S_{er}}{\eta_T \eta_D}$ 37.

This assumes that all effective power delivered can be profitably used; more will be made of this point later.

4. CALCULATION OF VOYAGE TIMES AND FUEL SAVINGS

The time a sailing vessel takes on a voyage depends essentially on winds, waves and currents it encounters and the actions of the crew. Fuel saved by a motor-sailer depends on the same parameters. Climatology can be used to obtain a probability density of having a wind speed and direction at a geographical location at a time of year. Knowing these probability densities, it then becomes possible to compute either an expected voyage time--under sail alone or an expected fuel saving using a known ship speed. The word "expected" is used in its mathematical sense: i.e., the sum of the products of the probabilities times the value in question.

From the ship owner's point of view, these calculations should indicate both the possible utilization of a pure sailing vessel and the potential economic benefits of a motor-sailer. Obviously, these figures relate to longer periods than individual voyages but should be quite adequate to decide whether the benefits of wind power are sufficient to justify further consideration.

The climatology we use for our calculations was obtained on computer tape from the National Climatic Center in Asheville, North Carolina and is the same information as plotted as wind roses on the Pilot Charts as depicted in Figure 11.

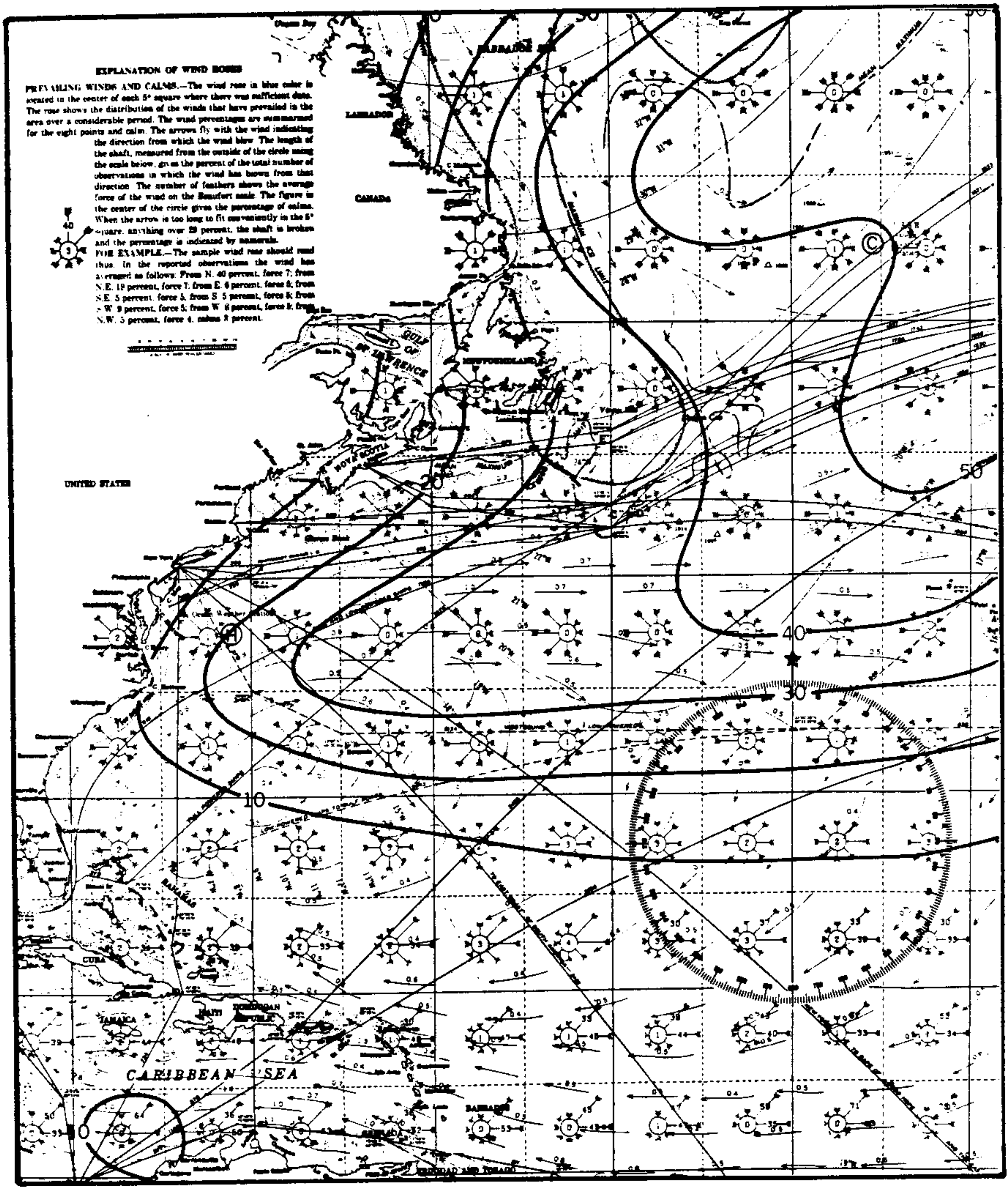
A probability density function (pdf) is defined such that:

$$\int_0^\infty \int_0^{2\pi} pdf(V_T, \theta)\, d\theta\, dV_T = 1 \qquad 38.$$

It needs also to be understood that:

pdf=pdf $(V_T : \theta$: geographical location, time of year) 39.

Equation (39) is combined with a ship performance polar to calculate an expected speed made good along some intended track. The form of this performance polar is split into two parts. Firstly, if (29) is solved for a constant θ, then a solution is obtained as $a(\gamma)$. This does not account for tacking, and so a new "effective" solution to (29) is sought to account for this. Reference is now made to Figure 12.



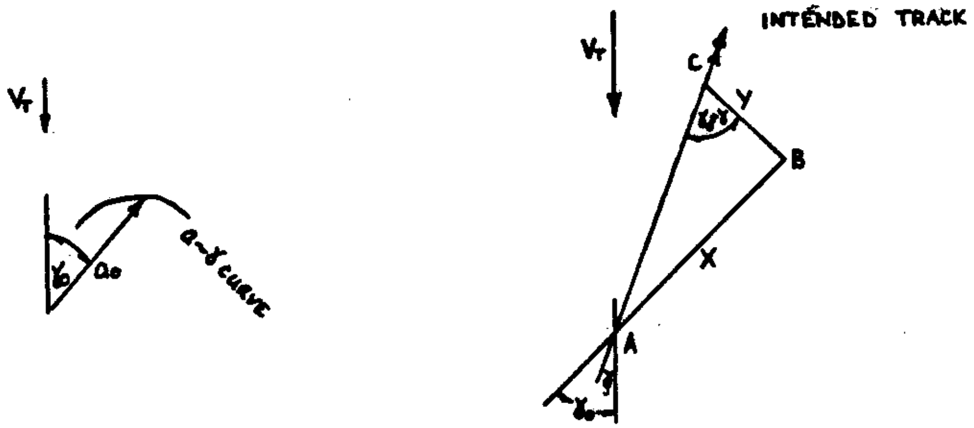
EXPLANATION OF WIND ROSES

PREVAILING WINDS AND CALMS.—The wind rose in blue color is located in the center of each 5° square where there was sufficient data. The rose shows the distribution of the winds that have prevailed in the area over a considerable period. The wind percentages are summarized for the eight points and calm. The arrows fly with the wind indicating the direction from which the wind blew. The length of the shaft, measured from the outside of the circle using the scale below, gives the percent of the total number of observations in which the wind has blown from that direction. The number of feathers shows the average force of the wind on the Beaufort scale. The figure in the center of the circle gives the percentage of calms. When the arrow is too long to fit conveniently in the 5° square, anything over 29 percent, the shaft is broken and the percentage is indicated by numerals.

FOR EXAMPLE.—The sample wind rose should read thus. In the reported observations the wind has averaged as follows: From N. 40 percent, force 7; from N.E. 19 percent, force 7; from E. 6 percent, force 6; from S.E. 5 percent, force 5; from S. 5 percent, force 6; from S.W. 9 percent, force 5; from W. 8 percent, force 6; from N.W. 5 percent, force 4, calms 3 percent.

Figure 11. Wind Roses on Pilot Chart (Northwest Atlantic)

Figure 12. Implications of Tacking



It is required to go from A to C. This is done via route A, B, C at speed ratio a_o, actual distance travelled is X + Y and distance made good is $X\cos(\gamma_o-\gamma)$ + $Y\cos(\gamma_o+\gamma)$. The effective speed ratio along the intended track is therefore:

$$a_e = a_o \cdot \frac{X\cos(\gamma_o-\gamma) + Y\cos(\gamma_o+\gamma)}{X+Y}$$

since $X\sin(\gamma_o-\gamma) = Y\sin(\gamma_o+\gamma)$

$$a_e = a_o \cdot \frac{\sin(\gamma_o+\gamma)\cos(\gamma_o-\gamma) + \cos(\gamma_o-\gamma).\sin(\gamma_o-\gamma)}{\sin(\gamma_o-\gamma)+\sin(\gamma_o+\gamma)}$$

$$a_e = a_o \cdot \frac{\sin 2\gamma_o}{2\sin\gamma_o\cos\gamma}$$

$$a_e = a_o \cdot \frac{\cos\gamma_o}{\cos\gamma} \qquad \text{for } |\gamma| < |\gamma_o| \qquad 40.$$

The solution to (29) may now be combined with (40) to produce an "effective" linearized speed ratio polar, $a_{el}(\gamma)$, suitable for use with (38). See Figure 8.

Calculation of voyage time can now proceed by relating γ, the true wind angle relative to track and the wind direction θ, relative to true north. If θ_1 defines the required track, then:

$$\gamma = \min\{|\theta-\theta_1|,\ 2\pi-|\theta-\theta_1|\} \qquad 44.$$

The expected ship speed (V_{PS}) may be found by combining (38), (41) and (44) to obtain:

$$V_{ps} = \int_0^{\infty}\int_0^{2\pi} V_T \; q_t(\gamma) \;\; pdf(\gamma, V_T)\, d\gamma\, dV_T \qquad 45.$$

Another way of approaching the tacking question which requires less mathematical manipulation and offers more insight into the issue is to recognize that any speed polar can be converted into an "effective" speed polar by choosing the maximum of i) the speed polar value itself at a given angle (γ) or ii) that value of a (or V_s) at the intersection of the radial line from the zero speed origin with a line drawn between any two points on the "ordinary" speed polar. Thus for windward sailing if we draw a line tangent to the speed polar at maximum speed points (port and starboard tacks), that line intersects the dead-to-windward case at the maximum speed made good point.

In auxiliary sail propulsion cases often occur where the minimum speed is not dead to windward but at some angle, say, broad off the bow. This would be brought about by the increased side force on the hull due large top hamper and freeboard, resulting in a significant increase in induced hull drag. This method of making the speed polar"convex" is easily adapted to a computer and guarantees the proper "effective" polar.

Conventional ship economics leads to the concept of an "economical ship speed" where the cost of burning extra fuel outweighs any economic advantage arising from increased utilization of the ship and her crew. It is possible to pursue this theme with a motor sailer, i.e. combine (37),(38) and (44), calculate time from an integral along the track of the reciprocal of "economic ship speed" to obtain:

$$\text{expected fuel saving} = \int_0^{D}\int_0^{\infty}\int_0^{2\pi} \frac{pdf(V_T,\theta).\,Cep(V_T,\theta).\,\frac{1}{2}\rho_a V_T^3 S_{er}.SFC.}{V_s \eta_T \eta_D}\, d\theta\, dV_T\, dD \qquad 46.$$

There are several drawbacks associated with (46). First and foremost is that it is based on a fixed-ship speed rather than average voyage time. If ship speed is allowed to vary, then greater advantage may be taken of the wind. Secondly, it over-estimates the fuel savings in extreme weather, and a limit should be placed on the effective power that can be delivered. Thirdly, implications behind the efficiency terms η_T and η_D require some comment. With a fixed-ship speed policy, the motor-sailer needs either a controllable-pitch or self-pitching propeller to maximize fuel saving, as power to be delivered by the engine is very variable. A multiple-engine installation and possibly a gearbox may be used to guarantee the delivery of the required amount of effective power at a reasonable SFC. All of these refinements are present in some new ships and frequently justified by fuel savings they produce in their own right. For a motor-sailer, they are much more desirable and should also be less expensive as the installed engine power should be reduced. It might also be noted that a low-speed, direct-drive diesel coupled to a single fixed-pitch propeller may be used, but that the fixed ship speed policy would be very difficult to implement. Instead, a policy of operating the engine within a fixed economical power range and allowing the ship speed to vary around an acceptable mean, might be the best bet.

Clearly, the operation of a motor-sailer needs to be examined with much more care if the fuel-saving potential of the wind is to be properly utilized. Fuel-saving depends on the effective power delivered by the wind, time and the engine/transmission/propeller efficiency. Criteria are needed to decide whether or not to tack and if so, through what angle so as to develop more realistic "equivalent" C_{ep} curves for all possible headings. Once these are obtained, expected fuel savings can be estimated on a sounder basis than the form shown in (46).

Firstly, however, reference is again made to Figure 12 with a view to finding a speed required during a tacking manoeuvre (V_{S2}) to equate to an equivalent speed made good (V_{S1}).

Time taken to steaming directly from A to C $= \dfrac{X\cos(\gamma_0 - \gamma) + Y\cos(\gamma_0 + \gamma)}{V_{S1}}$ 47.

Time taken to motor-sail route A-B-C $= \dfrac{X+Y}{V_{S2}}$ 48.

Equations (47) and (48) must clearly be equal if the tacking manoeuver is to be a fair comparison with the direct route under power alone. Equating them gives rise to the expression:

$$V_{S2} = V_{S1} \cdot \frac{\cos\gamma}{\cos\gamma_0} \qquad 49.$$

The tacking angle (γ_0) depends essentially on what use the rig is being put to. If costs are to be minimized, then an objective function is set up which expresses cost and γ_0 varied until a minimum is found. For the present however, γ_0 will be found from minimum fuel usage.

The vessels used for examples in the computation of expected sailing speeds and fuel savings were 1.) a motor-sailing fishing vessel and 2.) a general cargo vessel. The fishing vessel is comparable to a design by Monk and built by Skookum Marine. It is 10.4 m over all with a displacement of approximately 17,600 lbs. For purposes of motor sailing we assumed it would be driven at 7 knots under combined sail and power. The general cargo vessel is similar to the SD14, a well known design of 14,000 tonnes deadweight and a speed of 14 kts. She was assumed to be fitted with a rig of 1,200 square meters.

The speed polar of Figure 8 shows fishing boat speed both with and without tacking. Since we have linearized the problem and have non-dimensionalized vessel speed V_s by true wind speed V_t to get a, there is only one curve to be plotted. As discussed above, this representation is valid at low to moderate wind and ship speeds.

The power polars of Figures 9 and 10 for both the fishing boat and cargo ship depict the results of equation (33). Note that the origin represents a power loss of $C_{ep} = -.2$, thus for high values of a, both vessels show a net power loss (cost) attributable to the rig. Notice the large increase in net power delivered from beam winds.

The two vessels were "sailed" on typical routes for the purpose of observing the results of equations (45) and (46). The fishing boat was assumed to go from Tampa to 29N 92W to 22N 95W and return to Tampa (the "Gulf Route"). The cargo ship travelled a fictitious route from Tampa to Key West to the Northeast Providence Channel direct to Southampton and return via Bahamas - Key West.

The probability values, $pdf(\theta,V_t)$, of the encountered wind speed and direction relative to the ship's bow were derived from the Pilot Chart wind probabilities, $pdf(\theta)$, the Pilot Chart average wind speeds and application of equation (44). The distribution of wind speed for a given angle $a(\gamma)$ (or V_T) was given by a two parameter Weibull function where the parameters are set by the mean wind speed and standard deviation of wind speed, both numbers from the National Climatic Center Pilot Chart data tape.

The Pilot Chart Climatological data are given uniquely for each 5 degree Marsden Square. As the vessel proceeds along its track, it traverses different Marsden Squares. A computer program was written that keeps track of the wind statistics along the ship's passage. Equations (45) and (46) were also programmed to give the expected passage speed and expected net fuel savings due to sail assist along the route.

Figure 13 is an example of computer output of that program for the fishing boat on the "Gulf Route". The ship speed was the expected ship speed given by Equation (45) assuming no auxiliary power was used. The fuel saved was determined by (46) assuming a fixed speed strategy of 7 knots. The program was run for each of the twelve months.

The general cargo ship was run on the "Southampton Route" for each of the twelve months. Equation (45) was not utilized as it would only be in exceptional cases that some sort of motor propulsion would not be used. The fuel savings in tonnes per voyage is tabulated in Table 1 along with the mean wind speed encountered along the voyage. Notice that as the wind speed varies so, of course, does the net fuel savings.

For both the fishing boat and the cargo ship it was assumed conservatively that the rigs would not be used in true wind speeds in excess of 36 knots. The choice of a rig design wind speed is economic (Bergeson et al). Since the probability of wind speed diminishes rapidly at higher wind speeds, there is little to be gained in designing a rig for power extraction at very high winds due to the greatly added capital cost of a stronger rig.

```
                       VOYAGE WEATHER AND PERFORMANCE RESULTS

                          GULF ROUTE                   FISHING BOAT           JAN

  ------------------------------------------------------------------------------------------------

  LEG =  1 FROM   27.00,  83.00 TO  29.00,  92.00
         COURSE =   264  DISTANCE = 491.5
                                                      N   NE    E    SE    S    SW    W    NW  ALMS  STD DEV   AVG
              AVG WIND DIRECTION PDF (%)            16.4 15.8 19.4 16.5 10.2  4.2  5.4 10.8   1.3
              AVG WIND SPEED (KTS)                  15.5 14.0 13.1 12.4 12.2 12.2 15.4 17.1            7.0    13.8

              SHIP SPEED =    5.58 KTS          FUEL SAVED =      83.30 KG
  ------------------------------------------------------------------------------------------------

  LEG =  2 FROM   29.00,  92.00 TO  22.00,  95.00
         COURSE =   201  DISTANCE = 450.2
                                                      N   NE    E    SE    S    SW    W    NW  ALMS  STD DEV   AVG
              AVG WIND DIRECTION PDF (%)            17.4 17.5 20.3 18.7 10.2  3.0  3.2  8.0   1.7
              AVG WIND SPEED (KTS)                  16.3 13.7 12.3 12.3 11.7  9.5 12.4 16.5            7.0    13.2

              SHIP SPEED =    5.56 KTS          FUEL SAVED =      77.51 KG
  ------------------------------------------------------------------------------------------------

  LEG =  3 FROM   22.00,  95.00 TO  27.00,  83.00
         COURSE =    65  DISTANCE = 720.1
                                                      N   NE    E    SE    S    SW    W    NW  ALMS  STD DEV   AVG
              AVG WIND DIRECTION PDF (%)            16.0 19.1 24.4 17.5  7.0  2.4  3.7  8.4   1.4
              AVG WIND SPEED (KTS)                  15.2 12.9 12.2 12.0 11.3  9.9 12.2 16.0            6.8    12.8

              SHIP SPEED =    5.35 KTS          FUEL SAVED =     113.48 KG
  ------------------------------------------------------------------------------------------------


                  VOYAGE SUMMARY:
              NUMBER OF LEGS =     3      TOTAL DISTANCE =  1661.86      MONTH = JAN        SHIP = FISHING BOAT
                     DISCRETE TRUE WIND PDF          AVG WIND SPEEDS
                 BOW                   13.0 %            13.1 KTS
                 CLOSE REACH           27.3 %            13.1 KTS
                 BEAM REACH            24.7 %            13.7 KTS
                 BROAD REACH           21.7 %            13.3 KTS
                 DEAD AFT              11.8 %            12.3 KTS
                 CALMS                  1.4 %
                 VOYAGE AVERAGE WIND   13.0 KTS   STD DEV   6.9 KTS

                  VOYAGE AVERAGE SHIP SPEED  5.47 KTS        (SAIL ONLY)
                  VOYAGE FUEL SAVINGS        274.  KG        (MOTOR SAILING  AT CONSTANT SPEED OF  7.0 KTS)
```

Figure 13. Computer Output for Fishing Boat on Gulf Route (January)

Table 1. Monthly Performance Statistics

	Fishing Boat (Gulf Route)			General Cargo Vessel (Southampton Route)	
Month	Boat Speed (kts)	Fuel Saved (tonnes)	Average Wind Speed (kts)	Fuel Saved (tonnes)	Average Wind Speed (kts)
January	5.47	.274	13.0	366.7	18.6
February	5.46	.270	13.0	365.9	18.6
March	5.40	.262	12.8	343.4	17.4
April	5.13	.233	12.1	307.6	15.6
May	4.49	.183	10.3	248.5	13.4
June	3.89	.145	9.1	215.4	11.9
July	3.45	.115	8.0	192.6	10.9
August	3.44	.116	8.1	203.1	11.5
September	4.56	.205	10.9	258.1	13.6
October	5.05	.237	11.7	310.0	15.7
November	5.27	.253	12.5	340.6	17.2
December	5.36	.261	12.7	359.0	18.1

5. SUMMARY

We have presented a simplified approach for the analysis of sail assisted vessels. If we assume vessels operate the majority of the time in moderate wind conditions and at low Froude number, then sailing ship speed is essentially linear in wind speed for a given angle of wind off the bow. Thus a single speed polar $a = a(\gamma)$ or $ae = ae(\gamma)$, with tacking, can be used to describe sail-only performance.

Of perhaps greater interest, as it bears upon the economics, is the net thrust C_{er} or net power C_{ep} attributable to the existence of the sailing rig under different wind conditions. C_{ep} embodies the added parasitic drag of the rig and added keel as well as thrust of the rig and the aerodynamically induced drag of the rig and hydrodynamically induced drag of the hull-keel as a lifting surface.

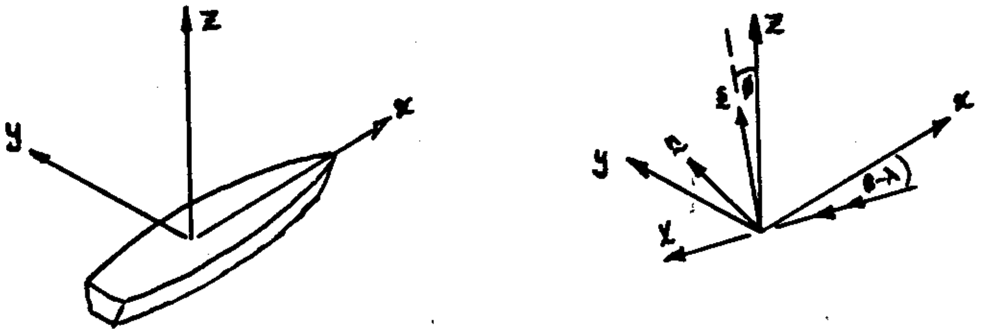
These equations were combined with Pilot Chart Climatology to see the fuel saving results over a hypothetical route in the Gulf of Mexico for a sail assisted fishing boat. Similar results were obtained for a general cargo ship with a sail assist rig on passages between Tampa and Southampton. The expected fuel savings were tabulated for each month showing the impact of time of year on the rig related fuel savings.

APPENDIX I

Calculations Involving Heeling

Heeling is defined as an angular displacement about an axis parallel to a ship's center line passing through its center of gravity. A body axis system is needed to resolve lift and drag into sideforce and longitudinal forces, see Figure AI.

Figure AI. Body Axis System for Heeling Calculations



Unit vectors $\underset{\sim}{v}$, $\underset{\sim}{n}$ and $\underset{\sim}{s}$ describe the apparent wind direction, lift direction and marine aerofoil orientation. These vectors are defined relative to x,y,z, axes as:

$$\underset{\sim}{v} = \begin{Bmatrix} -\cos(\beta-\lambda) \\ \sin(\beta-\lambda) \\ 0 \end{Bmatrix} \qquad \underset{\sim}{s} = \begin{Bmatrix} 0 \\ \sin\phi \\ \cos\phi \end{Bmatrix} \qquad \underset{\sim}{n} = \underset{\sim}{v} \times \underset{\sim}{s} = \begin{Bmatrix} \sin(\beta-\lambda)\cos\phi \\ \cos(\beta-\lambda)\cos\phi \\ -\cos(\beta-\lambda)\sin\phi \end{Bmatrix}$$

Force coefficients Cx and Cy relative to body axes are therefore:

$$C_x = C_L . \sin(\beta-\lambda)\cos\phi - C_D . \cos(\beta-\lambda)$$

$$C_Y = C_L . \cos(\beta-\lambda)\cos\phi + C_D . \sin(\beta-\lambda)$$

These expressions are useful for ship-motion and stability calculations. For performance calculations, coefficients C_R and C_H relative to the course sailed are found from:

$$C_R = C_X \cos\lambda + C_Y \sin\lambda$$
$$= C_L \cos\phi \{\cos\lambda \sin(\beta-\lambda) + \sin\lambda \cos(\beta-\lambda)\}$$
$$+ C_D . \{-\cos\lambda \cos(\beta-\lambda) + \sin\lambda \sin(\beta-\lambda)\}$$
$$= C_L \cos\phi \sin\beta - C_D \cos\beta$$

$$C_H = -C_X \sin\lambda + C_Y \cos\lambda$$
$$= C_L \cos\phi \{-\sin\lambda \sin(\beta-\lambda) + \cos\lambda \cos(\beta-\lambda)\}$$
$$+ C_D \{\sin\lambda \cos(\beta-\lambda) + \cos\lambda \sin(\beta-\lambda)\}$$
$$= C_L \cos\phi \cos\beta + C_D \sin\beta$$

Heeling therefore erodes both drive and sideforce coefficients as a direct consequence of geometry, before any account is taken of its effect on C_L and C_D. For some future wind powered ship design, it is probable that for windward sailing, where heeling is important, that $C_L >> C_D$ and $\phi < 15°$. Assuming $C_L/C_D = 10$, $\beta = 30°$ and $\phi = 15°$, then C_R will be reduced by 4% and C_H by 3%. Since it appears likely that the aerodynamic effects of heeling can be related to changes in V_A and β, similar corrections are sought for the geometric effects.

Writing:

$$C_H = \left(1 - \frac{\Delta V_g}{V_A}\right)^2 . \{C_L \cos(\beta - \delta_g) + C_D \sin(\beta - \delta_g)\} = C_L \cos\beta \cos\phi + C_D \sin\beta$$
$$C_R = \left(1 - \frac{\Delta V_g}{V_A}\right)^2 . \{C_L \sin(\beta - \delta_g) - C_D \cos(\beta - \delta_g)\} = C_L \sin\beta \cos\phi - C_D \cos\beta$$

allows the geometric effects of heeling to be interpreted in terms of a correction δ to β and ΔV to V_A. The corrections are found from a root-finding technique and are small. For the windward case of $C_L/C_D = 10$, $\beta = 30°$, $\phi = 15°$, $\delta_g = .22°$, $\Delta V_g = .017V_A$

Aerodynamic effects of heeling are accounted for in a similar way using correction terms δ_c and ΔV_c. Reference to Figure 5 shows:

$$\delta_c = \beta - \tan^{-1}\{\tan\beta . \cos\phi\}$$
$$\Delta V_c = V_A\left(1 - \sqrt{\cos^2\beta + \sin^2\beta \cos^2\phi}\right)$$

The heeled case can now be defined in terms of an equivalent unheeled problem having an equivalent apparent wind angle, (β_e) given by: $\beta_e = \beta - \delta_g - \delta_c$

and an equivalent apparent wind velocity (V_{Ae}) given by:

$$V_{Ae} = V_A - \Delta V_g - \Delta V_c$$

For many purposes, equivalent true wind angle (γ_e) and speed (V_{Te}) need to be used as input data. These may be found from:

$$V_{Te} = \sqrt{V_s^2 + V_{Ae}^2 - 2 V_s V_{Ae} \cos\beta_e}$$

$$\gamma_e = \sin^{-1}\left(V_{Ae} \sin\beta_e / V_{Te}\right)$$

which are essentially equations (1) and (2) with the e suffix attached.

ACKNOWLEDGEMENT

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SAFETY AND STABILITY CONSIDERATIONS FOR SAIL ASSISTED FISHING VESSELS

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ABSTRACT

The U. S. fishing fleet has suffered many accidents due to poor vessel stability. The magnitude and seriousness of these casualties are discussed. Since the U. S. Government has few rules for the safety of fishing vessels, some suggestions for better stability are set forth. For sail assisted fishing vessels the existing stability criteria used for regulated passenger and freight sailing vessels is presented. With the right considerations this method of assessing sail vessel stability could be applied to sailing or sail assisted fishing vessels. Some pertinent characteristics of sail vessels that meet the existing criteria are presented in tabular form. A sail assisted fishing vessel is checked against the sailing vessel stability criteria used for U. S. commercial vessels.

INTRODUCTION

Safety and stability of fishing vessels are very much entwined. Casualty data for the years 1972 through 1979 show an ever increasing number of vessels lost and deaths on fishing vessels attributed to foundering, flooding, and capsizing. In fact, the data shows that these types of accidents were the major source of casualties for vessels in this class. (2)

In the years 1978 and 1979, 144 people lost their lives in the three major casualty categories mentioned. Fires and explosions, groundings, collisions, and material failures contributed to the deaths of only 22 people over this same period. 169 vessels were lost to the first three categories while only 135 were lost in the last four. This translates to 85 people killed for every 100 vessels lost in a foundering, flooding, or capsizing accident, while only 16 died in fire and explosions, groundings, collisions, and material failures. (2) The latest statistics released for fiscal year 1980 indicate that the trend is continuing: of 60 people killed on fishing vessels, 44 were lost in foundering, capsizing, and flooding accidents. Clearly these types of casualties should be a focus of concern for those involved with improving fishing vessel safety. (5)

DISCUSSION

What is being done to reduce the high cost of these losses and the high death rate? The regulatory attitude in the U. S. has not changed for many years. Fishing vessels are classed as "uninspected commercial vessels". They are regulated under the Motorboat Act of 1940 (MBA-40) which is directed primarily at recreational motorboat safety. This Act limits regulatory authority to those few items specifically set forth in the Act. This feature has made it difficult to adopt technological advances that have developed over the last 40 years to uninspected commercial vessels. The result of this law, as applied to commercial fishing vessels,has been to produce out-of-date and inadequate rules. Enforcement of the law is even more difficult since a vessel must be underway to be boarded and checked for compliance. (3)

In spite of the regulatory constraints, the Coast Guard and other Federal agencies have published a number of articles and circulars for use by the commercial fishing industry. Some of these are:

(1) Casualty statistics published annually in the Proceedings of the Marine Safety Council, usually in the February edition.

(2) Articles in the Proceedings discussing lessons gathered from the casualty data. In the February, 1982 edition, there was an article on stability problems associated with certain type of fishing vessels. In particular, problems with the East coast clam and scallop vessels and Alaska crabbing vessels were discussed. (4)

(3) The Coast Guard publishes circulars called Navigation and Vessel Inspection Circulars (NVIC's) which recommend safe practices for the marine industry. Those pertaining to commercial fishing vessels are:

(a) NVIC 3-76: Stability of Fishing Vessels, With IMO Recommendations for Intact Stability of Fishing Vessels.

(b) NVIC 4-82: Uninspected Commercial Vessel Safety.

(c) NVIC 17-82: Intact Stability of Small Vessels; Recommendations.

Of these circulars, the first is probably most useful since it addresses most aspects of fishing vessel stability from initial GM to safe operating procedures to preserve stability.

Except for the problem of how to assess the stability of small vessels, i.e., those less than 79 feet (24.1 meters) long, there is enough literature available to assist the motor propelled fleet in ensuring sufficient stability. Additionally, even though the academic question of how to determine the safe stability of a small vessel is still unanswered, some of the practical recommendations available will apply to a great number of small vessels.

What stability recommendations are available to fishermen who want to rig their vessels with sail? There exists some sail vessel stability criteria that could be applied to sail assisted or sailing fishing vessels. The Coast Guard has used it for a number of years to evaluate the stability of commercial passenger and freight carrying sailing vessels. The development of this criteria was set forth in a paper presented in Washington, D.C. before the Chesapeake Section of the Society of Naval Architects and Marine Engineers on 2 March 1966. (1) The same criteria was published for comment in the Federal Register.

The Coast Guard has consolidated its various stability regulations into a new Subchapter S. The current regulations are scattered throughout various parts of Title 46 and 33 of the Code of Federal Regulations and are often difficult to locate as well as being redundant. Other rules such as sailing vessel stability appear for the first time as proposed rules for public comment. The sailing vessel and other stability rules were previously issued as Policy Statements and Interpretations. (8)

The proposed sailing vessel rules appear in Appendix A. For the person designing a sail assisted or just plain sailing fishing vessel, these criteria could be used to evaluate its stability. However, since the majority of fishing vessels are uninspected commercial vessels, it is not mandatory that they comply with these criteria.

Since the regulations only tell you how to do the calculations, a discussion of the criteria is helpful and might persuade some people to use them. The method used is a full range stability analysis evaluating three factors that affect sailing vessels: (1)

(1) The first factor evaluated is initial stability of the vessel to sail comfortably and safely in normal weather. As shown in the Appendix, this factor is evaluated by the equation:

$$\frac{1000\ (W)\ (HZA)}{(A)\ (H)} = \text{FACTOR}$$

(2) The second factor evaluated is the ability of the vessel to resist gust and squall conditions without rolling to the point where water enters the hull. The equation used to evaluate this factor is:

$$\frac{1000\ (W)\ (HZB)}{(A)\ (H)} = \text{FACTOR}$$

(3) The third factor checks the ability of the vessel to survive in extremis: A knockdown or a capsize: This factor is checked by the following equation:

$$\frac{1000\ (W)\ (HZC)}{(A)\ (H)} = \text{FACTOR}$$

The first factor was developed from a static or steady wind condition. The righting arm of the vessel over a range of heel is compared with a heeling arm due to wind acting over the same range. The righting arm is defined as $GZ_\theta = f_1\theta$ and heeling arm as $HZ_\theta = f_2\theta$. If the heeling arm is applied slowly, equilibrium is reached at θ_1 where $f_1\theta = f_2\theta$. This is taken as the response of the vessel to a steady wind condition.

The second and third factors use an energy balance between heeling arm curve and righting arm curve. The vessel will roll until the energy added to the system by the heeling arm acting over a range of heel is equal to the energy absorbed by the rolling of the vessel. At θ_2 or when

$$\int_{0}^{\theta_n} f_1\theta \, d\theta = \int_{0}^{\theta_n} f_2\theta \, d\theta$$

these energies are equal and the vessel will reach maximum roll. Figure 1 illustrates this full range analysis.

There are a number of factors that affect the righting arm curve. Those that should be considered are listed below:

(1) Use the worst case, usually the highest vertical center of gravity.

(2) The curve is generally developed at light operating condition.

(3) Low tankage for consumables or other items that would lower KG should be assumed empty or possibly 10% with slack surface.

(4) A number of normal operating conditions should be evaluated to find the worst case.

(5) Buoyancy credit can be given for a tight superstructure.

(6) Careful note must be taken of heel angle where water can enter the hull through doors, hatches, ports, and companionways. If the deck arrangement is assymetrical, the worst case is considered.

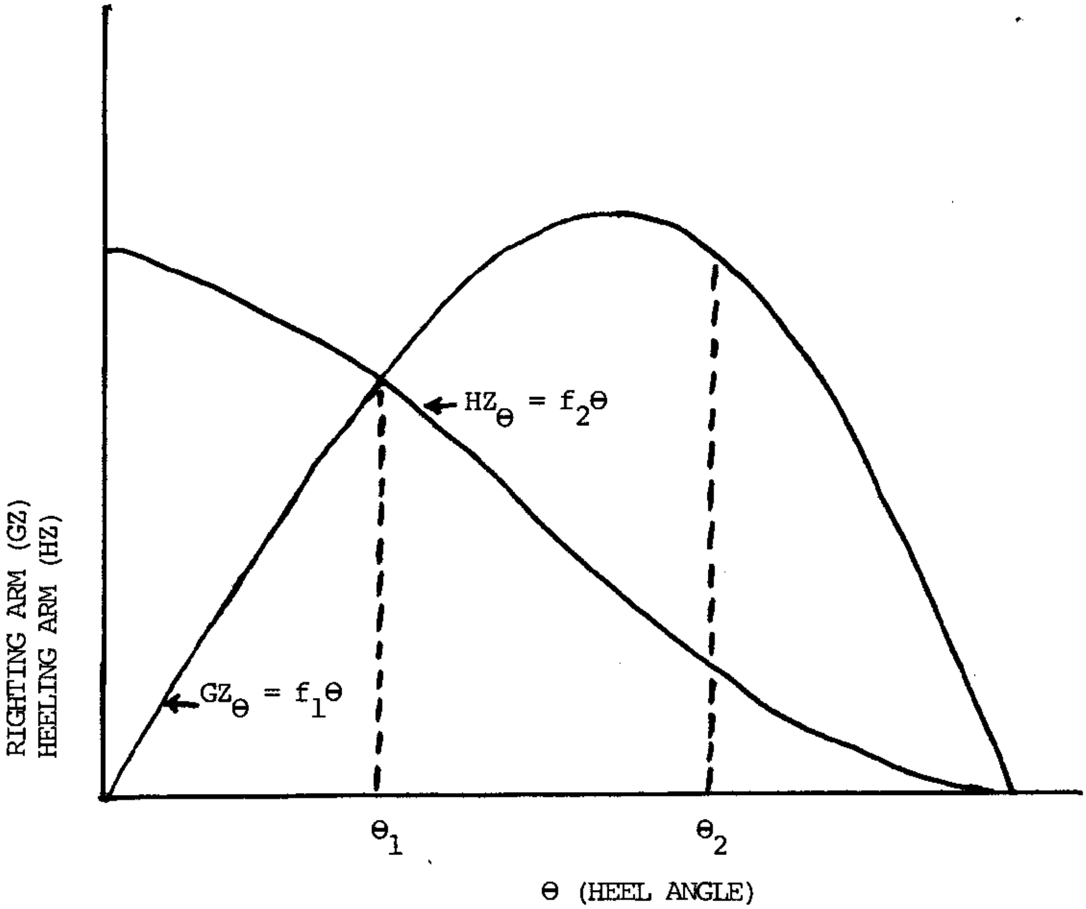
(7) Trim with heel must be evaluated. This must be accounted for when correcting the righting arm curve.

(8) The curve should be developed to at least 90 degrees. If the vessel has a range of stability in excess of 90 degrees, the curve is developed to the limit of the positive range or 120 degrees, whichever is less.

(9) When developing the righting arm curve for fishing vessels, their unique operating conditions should be considered. If the catch is carried on deck, this case must be considered. Other conditions such as suspended fish loads, ice accumulation, shifting cargo, and effect of free liquids all must be considered. It is impossible to predict what the worst case for each type of vessel will be without careful evaluation. NVIC 3-76 and NVIC 17-82 offer guidance for developing some fishing vessel operating conditions.

When considering the effect of the wind, it is a beam wind acting on the entire area of the vessel above water. All sails are considered trimmed flat. As the vessel heels, both the projected area exposed to the wind and the arm at which the wind force acts decrease as the cosine of the heel angle. This establishes the equations for the heeling arm curve as $HZ = HZ_{(A,B,C)} COS^2 (T)$. $HZ_{(A,B,C)}$ is the heeling arm at zero degrees of heel for the various factors. HZ is the heeling arm and T is the angle of heel.

The evaluation of the three factors are based on heel angles of the vessel. The first factor for steady heel uses the heel angle at the deck edge, since most sailors will heel a vessel to deck edge under normal sailing conditions. For the second factor, the downflood angle or 60 degrees is used. This is the point where water could enter the hull if the vessel is hit unexpectedly with strong gusts of a squall. The 60 degrees limit is taken as a maximum since at this angle cabin gear and



BASIC PRINCIPLES OF FULL RANGE
STABILITY ANALYSIS

FIG. 1

other inside ballast starts to come loose. The third factor or knockdown goes to 90 degrees but never more than 120 degrees. If the range of positive stability is less than 90 degrees, the area under the righting arm curve is considered as a "negative area" in obtaining the balance. If the range of positive stability exceeds 90 degrees, the additional area up to the limit of positive stability, but never over 120 degrees, is included. The heeling arm is considered as zero past 90 degrees. The full knockdown case assumes the vessel can withstand a knockdown without downflooding. This assumption is based on the belief that a full knockdown often occurs when the vessel is secured for heavy weather with all deck openings closed. (1)

After the three cases are checked, the resulting numbers must equal or exceed the stability worth numerals shown in Appendix A. For fishing vessels, the numbers for vessels on exposed waters would be the most appropriate.

Although other methods of evaluating sailing vessel stability exist, they depend on initial response to assumed wind pressure. (1) It is felt the full range analysis set forth in the proposed rulemaking is a simple, straight forward, and comprehensive method for checking sail assisted or sail powered fishing vessel stability.

However, a note of caution when using this criteria. It was originally developed for sailing vessels in the commercial passenger trade and for vessels with cargo securely stowed on deck or within the holds. A fishing vessel with a shifting cargo on deck (fish catch) or suspended loads (nets suspended from outriggers) or towing nets will require that these conditions be considered along with the sail criteria. NVIC 3-76 and NVIC 17-82 provide some guidance for considering these effects.

APPLICATIONS

The criteria for sailing vessels as it appears in the proposed rules has been used to evaluate many commercial sailing vessels subject to Coast Guard regulation. A summary of their characteristics is shown in Figure 2. All are monohull vessels that were given stability tests to determine lightship data, i.e., location of vertical and longitudinal center of gravity and lightship displacement.

A 38 foot (11.6 meters) fishing vessel of recent design was given a stability check to see if it satisfied the existing Coast Guard sail vessel stability criteria. A side profile and particulars of the vessel are shown in Figure 3. Since the vessel was not given a stability test, assumed values for the vertical center of gravity were used. The vessel was evaluated at a full load displacement of 14 long tons (14.2 metric tons) and draft of 2.89 feet (.88 meters) measured from the baseline.

The first case evaluated the vessel as designed with a deck edge immersion angle of 8.0 degrees and downflood angle of 15.4 degrees. The point of downflooding was taken as the door sills on the side of the pilot house. The vertical centers of gravity (VCG's) were taken from 2.0 to 4.0 feet (.61 to 1.22 meters) above the baseline.

FIGURE 2

COMMERCIAL SAILING VESSEL DATA

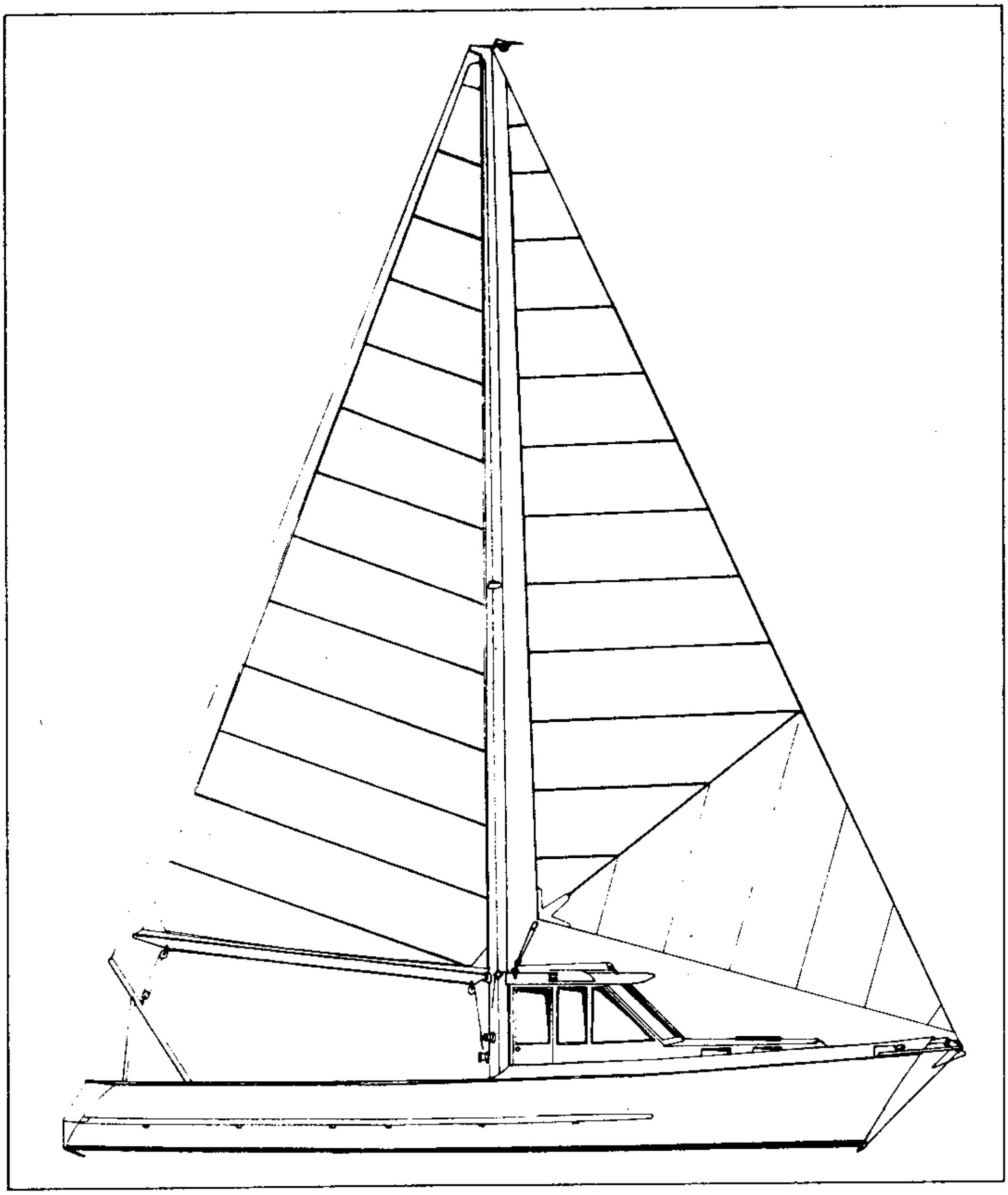
VESSEL	LENGTH ON THE WATER LINE FEET (METERS)	MAX. BEAM FEET (METERS)	DEPTH FEET (METERS)	SAIL AREA FEET^2 (METERS^2)	LIGHTSHIP (INCL. BALLAST) LONG TONS (METRIC TONS)	FIXED BALLAST		TYPE RIG	SERVICE/ROUTE
						WEIGHT LONG TONS (METRIC TONS)	%OF LIGHT SHIP		
1	65.0 (19.8)	21.0 (6.4)	9.3 (2.83)	3020 (280.56)	75.0 (76.2)	20.0 (20.32)	26.7	SCHOONER 2 MASTS	PASSENGER/ OCEANS
2	53.3 (16.25)	18.75 (5.72)	13.6 (4.15)	2114.0 (196.39)	62.0 (63)	17.9 (18.19)	28.9	SCHOONER 2 MASTS	PASSENGER/ OCEANS
3	52.0 (15.85)	15.25 (4.65)	10.2 (3.11)	1914.0* (177.81)* 1556.0 (142.69)	29.45 (29.92)	8.73 (8.87)	30.0	SCHOONER 2 MASTS	CARGO AND PASSENGER/ PARTIALLY PROTECTED**
4	55.0 (16.76)	18.67 (5.69)	10.48 (3.19)	1632.0 (151.61)	35.4 (35.97)	8.04 (8.17)	22.6	SLOOP*** SINGLE MAST	PASSENGER/ OCEANS
5	60.0 (18.29)	21.0 (6.4)	8.83 (2.69)	2277.0 (211.53)	50.85 (51.66)	22.32 (22.68)	43.9	SCHOONER 2 MASTS	PASSENGER/ OCEANS

* WITH CARGO HOLD EMPTY TO 4.5 LONG TONS (4.57 METRIC TONS), 1556.0 SQUARE FEET (142.69 SQUARE METERS) OF SAIL MAY BE CARRIED.
WITH 4.5 LONG TONS (4.57 METRIC TONS) TO FULL LOAD, 1914.0 SQUARE FEET (177.81 SQUARE METERS) OF SAIL MAY BE CARRIED.

** CARGO CAPACITY IS 13½ LONG TONS (13.72 METRIC TONS).

*** FOR OCEAN SERVICE SAILS MUST BE REEFED.

38' SAIL ASSIST



38 FOOT (11.6 METER) SAIL ASSISTED FISHING VESSEL

FIG. 3

LENGTH OVERALL (LOA)	37.5 FT (11.43) M
LENGTH WATER LINE (LWL)	33.3 FT (10.15) M
BEAM	13.0 FT (3.96) M
DRAFT	5.0 FT (1.52) M
FISH HOLD	6,500 POUNDS (2,948.4) KG
SAIL AREA	734 FT. SQ. (68.19) M^2
LIGHTSHIP DISPLACEMENT	22,500 POUNDS (10,206.0) KG
BALLAST (LEAD)*	7,000 POUNDS (3,175.2) KG
*% OF LIGHTSHIP	31%

The second case evaluated assumed a modification to the vessel. The doors were moved as far inboard as possible so that the downflooding angle was 22.2 degrees.

For case 3, the downflood angle was increased to the maximum allowed or 60 degrees. The doors would have to be removed to achieve this and entrance to the pilot house provided through a hatch.

Table 1 shows the results of the three cases investigated. VCG is in feet (meters) above the baseline and the factors are in tons/square foot (metric tons/square meter).

	CASE 1			CASE 2	CASE 3
VCG FT (M)	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 2	FACTOR 2
2.0 (.61)	.587 (6.42)	.528 (5.78)	3.47 (37.96)	.733 (8.02)	1.765 (19.31)
2.5 (.76)	.525 (5.74)	.470 (5.14)	2.632 (28.79)	.646 (7.07)	1.468 (16.06)
3.0 (.91)	.462 (5.05)	.411 (4.50)	1.793 (19.62)	.558 (6.10)	1.171 (12.81)
3.5 (1.07)	.400 (4.38)	.353 (3.86)	1.064 (11.64)	.471 (5.15)	.875 (9.57)
4.0 (1.22)	.338 (3.70)	.294 (3.22)	.491 (5.37)	.380 (4.16)	.650 (7.11)

ANALYSIS OF SAIL ASSISTED FISHING VESSEL

TABLE 1

For ocean service the resulting numerals must be equal to or exceed:

		English Units	Metric Units
Factor 1	-	1.5	16.4
Factor 2	-	1.7	18.6
Factor 3	-	1.9	20.8

The results show that this vessel has excellent ability to survive in extremis. With some modifications, it's ability to avoid downflooding could be improved. Factor 1 could be improved through the modification of the freeing ports or by raising the main deck. If the freeing ports were modified to act as one way ports, i.e., only let water out and not in, the deck edge immersion angle would be increased. The ability of the existing design to reef her sails is also a great asset since decreasing the sail area increases the resulting stability numerals.

This vessel has been in service for quite some time and has not suffered any casualties. She has operated in severe weather and seen substantial beam winds with her sails set and trimmed flat. From all reports she withstood this test without any harm. She was not designed to meet the

Coast Guard proposed sail vessel criteria although with some changes it seems the existing design could be modified to meet all the criteria. With her ability to roller reef her sails, it seems that one of the most viable alternatives would be to correlate the amount of sail carried with wind velocity. Operational instructions for the crew could advise them when to reef their sails and how much sail they could safely carry.

In conclusion, it should be pointed out that the sailing vessel stability criteria discussed was developed to check commercial passenger and freight vessels using sails. Before attempting to apply these criteria to sail or sail assisted fishing vessels, the stability problems unique to fishing vessels must be incorporated. For example, a vessel with a load of fish on deck that could shift poses a unique problem. The shifting problem would have to be solved or a safety factor incorporated into the criteria to allow for the shifting cargo.

Anyone interested in evaluating the stability of fishing vessels should obtain a copy of the paper on the sail vessel stability criteria and copies of the Navigation and Vessel Inspection Circulars 17-82, 3-76, and 4-82. The paper "On the Stability of Sailing Vessels" can be obtained from the Society of Naval Architects and Marine Engineers, One World Trade Center, Suite 1369, New York, New York, 10048. The NVIC's can be obtained by writing to the address shown for them in the references.

The opinions expressed in this paper are those of the author and do not necessarily reflect those of the United States Coast Guard.

ACKNOWLEDGEMENTS

I would like to thank the following people for their cooperation which made this paper possible.

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Rob LADD, Naval Architect, and Chief Designer with Skye Marine Corporation, Fort Lauderdale, Florida. Rob supplied the specifications and plans of the 38 foot sail assisted fishing vessel as well as factual accounts of how the vessel was performing.

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APPENDIX A

PROPOSED RULES FOR SAIL OR SAIL ASSISTED VESSELS FROM FEDERAL REGISTER OF THURSDAY, AUGUST 12, 1982 - VOL. 47, NO. 156

Subpart E—Weather Criteria

§ 170.160 Specific applicability.

This subpart applies to each vessel except—

(a) A passenger vessel, other than a vessel the stability of which is questioned by the OCMI, that—

(1) Is less than 100 gross tons;

(2) Is less than 19.8 meters LOD measured over the weather deck; and

(3) Carries 49 or less passengers.

(b) A tank vessel, other than a vessel the stability of which is questioned by the OCMI, that only carries a product listed in § 30.25-1 of this chapter and that is—

(1) Less than 150 gross tons; or

(2) A tank barge that operates only in river or lakes, bays, and sounds service.

(c) A tank barge that carries a product listed in Table 151.01-10(b) of this chapter.

(d) A mobile offshore drilling unit.

(e) A vessel that performs the test required by § 171.030(c) of this subchapter.

(f) A barge that complies with the requirements in § 174.020 of this subchapter.

§ 170.170 Calculations required.

(a) Each vessel must be shown by design calculations to have a metacentric height (GM) that is equal to or greater than the following in each condition of loading and operation:

$$GM > \frac{PAH}{W \tan (T)}$$

where—

P = .055 + $(L/1309)^2$ metric tons/m^2 . . . for ocean service, Great Lakes winter service, or service on exposed waters.

P = .038 + $(L/1309)^2$ metric tons/m^2 . . . for Great Lakes summer service or service on partially protected waters.

P = .028 + $(L/1309)^2$ metric tons/^{2} . . . for service on protected waters.

L = LBP in meters.

A = projected lateral area in square meters of the portion of the vessel above the waterline.

H = the vertical distance in meters from the center of A to the center of the underwater lateral area or approximately to the one-half draft point.

W = displacement in metric tons.

T = 14 degrees or the angle of heel at which one-half the freeboard to the deck edge is immersed, whichever is less.

(b) If approved by the Commander (mmt), a larger value of T may be used for a vessel with a discontinuous weather deck of abnormal sheer.

(c) When doing the calculations required by paragraph (a) of this section for a sailing vessel or auxiliary sailing vessel, the vessel must be assumed—

(1) To be under bare poles; or

(2) If the vessel has no auxiliary propulsion, to have storm sails set and trimmed flat.

(d) The criteria specified in this section are generally limited in application to flush deck, mechanically powered vessels of ordinary proportions and form that carry cargo below the main deck. On other types of vessels, the Commander (mmt) requires calculations in addition to those in paragraph (a) of this section. On a vessel under 100 meters in length, other than a tugboat or a towboat, the requirements in § 170.173 are applied. Additional intact stability requirements for tugboats and towboats are included in Part 174 of this subchapter.

§ 170.173 Criteria for vessels of unusual proportion and form.

(a) If required by the Commander (mmt), each vessel less than 100 meters LLL, other than a tugboat or towboat, must be shown by design calculations to comply with—

(1) Paragraph (b) or (c) of this section if the maximum righting arm occurs at an angle of heel less than or equal to 30 degrees; or

(2) Paragraph (b) of this section if the maximum righting arm occurs at an angle of heel greater than 30 degrees.

(b) Each vessel must have—

(1) An initial metacentric height (GM) of at least 0.15 meters;

(2) A maximum righting arm (GZ) of at least 0.20 meters at an angle of heel equal to or greater than 30 degrees;

(3) A maximum righting arm that occurs at an angle of heel not less than 25 degrees;

(4) An area under each righting arm curve of at least 3.15 meter-degrees up to an angle of heel of 30 degrees;

(5) An area under each righting arm curve of at least 5.15 meter-degrees up to an angle of heel of 40 degrees or the downflooding angle, whichever is less; and

(6) An area under each righting arm curve between the angles of 30 degrees and 40 degrees, or between 30 degrees and the downflooding angle if this angle is less than 40 degrees, of not less than 1.72 meter-degrees.

(c) Each vessel must have—

(1) An initial metacentric height (GM) of at least 0.15 meters;

(2) A maximum righting arm that occurs at an angle of heel not less than 15 degrees;

(3) An area under each righting arm curve of at least 5.15 meter-degrees up to an angle of heel of 40 degrees or the downflooding angle, whichever is less;

(4) An area under each righting arm curve between the angles of 30 degrees and 40 degrees, or between 30 degrees and the downflooding angle if this angle is less than 40 degrees, of not less than 1.72 meter-degrees; and

(5) An area under each righting arm curve up to the angle of maximum righting arm of not less than the area determined by the following equation:

$$A = K1 + K2 (X - Y)$$

where—

A = area in meter-degrees.

K1 = 3.15 meter-degrees.

K2 = 0.001 meter degrees/degree.

X = 30 degrees.

Y = angle of maximum righting arm, degrees.

(d) For the purpose of demonstrating compliance with paragraphs (b) and (c) of this section, at each angle of heel a vessel's righting arm is calculated after the vessel is permitted to trim free until the trimming moment is zero.

Subpart B—Small Vessels

§ 171.020 Specific applicability.

(a) Except as provided in paragraph (b) of this section, this subpart applies to each vessel that is less than 100 gross tons, less than 19.8 meters LOD measured over the weather deck, and carries 150 or less passengers.

(b) This subpart does not apply to a vessel described in paragraph (a) of this section that carries more than 12 passengers on an international voyage.

§ 171.030 Intact stability requirements for a mechanically propelled or a nonself-propelled vessel.

(a) This section applies to each vessel, except a sailing vessel or an auxiliary sailing vessel, that—

(1) Carries more than 49 passengers;

(2) The stability of which is questioned by the OCMI; or

(3) Is permitted an increased passenger allowance by § 176.01–25(b) of this chapter.

(b) Each vessel must—

(1) Comply with § 171.050 and § 170.170 of this subchapter; or

(2) Perform the test in paragraph (d) of this section in the presence of the OCMI.

(c) Each vessel must be in the following condition when the test in paragraph (d) is performed:

(1) The construction of the vessel must be complete in all respects.

(2) Ballast, if necessary, must be solid and must be on board and in place.

(3) Fuel and water tanks must be approximately three-quarters full.

(4) The weight of passengers and other loads must be onboard and distributed so as to provide normal operating trim and to simulate the vertical center of gravity causing the least stable condition that is likely to occur in service. The number of passengers used in determining the total passenger weight must not be more than the maximum number permitted by § 176.01–25 of this chapter.

(5) If a vessel has non-return closures on cockpit scuppers or on weather deck drains, the closures must be kept open during the test.

(d) Each vessel must not exceed the limitations in paragraph (e) of this section, when subjected to the greater of the following heeling moments:

$$Mp = WB/6$$

or

$$Mw = PAH$$

where—

Mp = Passenger heeling moment in kilogram-meters.

W = the total passenger weight in kilograms. (Assume 63.5 kg per passenger on protected waters when passenger load consists of men, women, and children. Assume 72.6 kg per passenger all other times.)

B = The maximum transverse distance that is accessible to the passengers, in meters.

Mw = Wind heeling moment in kilogram-meters.

P = A wind pressure of—(i) 36.6 kg/m^2 for operation in protected waters; (ii) 48.8 kg/m^2 for operation in partially protected waters; and (iii) 73.2 kg/m^2 for operation in exposed waters.

A = Area, in square meters, of the projected lateral surface of the vessel above the waterline (this surface includes each projected area of the hull, superstructure and area bounded by railings and structural canopies).

H = Height, in meters, to the center of area (A) above the waterline.

(e) Each vessel must not exceed the following limits of heel when doing the test in paragraph (d) of this section:

(1) *On a flush deck or well deck vessel,* no more than one half the freeboard may be immersed, except that, on a well deck vessel that operates on protected waters and has scuppers, the full freeboard may be immersed if the full freeboard is not more than one quarter of the distance from the waterline to the gunwale.

(2) *On a cockpit boat,* the maximum allowable immersion is calculated from the following equation:

(i) On exposed waters—

$$i = \frac{f(2L - 1.5L')}{4L}$$

(ii) On protected or partially protected waters—

$$i = \frac{f(2L - L')}{4L}$$

where—

i = maximum allowable immersion in meters.

f = freeboard in meters.

L = LOD, measured over the weather deck, in meters.

L' = length of cockpit in meters.

(3) *On an open boat,* no more than one-quarter of the freeboard may be immersed.

(4) In no case may the angle of heel exceed 14 degrees.

(f) The limits of heel must be measured at—

(1) the point of minimum freeboard, or;

(2) at a point three quarters of the vessel's length from the bow if the point of minimum freeboard is aft of this point.

(g) Each ferry must also be tested in a manner acceptable to the OCMI to determine whether the trim or heel during loading or unloading will submerge the deck edge. A ferry passes this test if the deck edge is not submerged during loading or unloading.

(h) When demonstrating compliance with paragraph (e) of this section, the freeboard must be measured as follows:

(1) *For a flush deck or well deck vessel,* the freeboard must be measured to the top of the weatherdeck at the side of the vessel.

(2) *For a vessel with a cockpit or for an open boat,* the freeboard must be measured to the top of the gunwale.

§ 171.035 Intact stability requirements for a sailing vessel or an auxiliary sailing vessel.

(a) Except as provided in paragraph (b) of this section, each of the following sailing vessels and auxiliary sailing vessels must meet the intact stability standards of § 171.055 and § 170.170 of this subchapter:

(1) A vessel to be operated in exposed waters.

(2) A vessel to be operated during non-daylight hours.

(3) A vessel of unusual type or rig.

(4) A vessel that carries more than 49 passengers.

(b) A catamaran must meet the intact stability requirements of § 171.057 and § 170.170 of this subchapter.

(c) Each sailing vessel and auxiliary sailing vessel not listed in paragraph (a) or (b) of this section must comply with the requirements in paragraphs (d) through (j).

(d) Each vessel must remain afloat when flooded or capsized.

(e) Each vessel must have suitable hand holds or other means to allow a person to cling to the vessel in the event of a capsizing.

(f) Each vessel operating in partially protected waters must have a self-bailing cockpit.

(g) The OCMI determines whether the vessel has adequate stability for protected waters or partially protected waters. When making this determination, the analysis techniques of paragraphs (h) or (i) are used unless the OCMI determines that other analysis techniques are more appropriate.

(h) Operational tests may be performed to assure that the vessel shows satisfactory handling characteristics under sail.

(i) The simplified stability test of § 171.030 may be used. The heeling moment used for this test must be the greater of the following:

(1) Passenger heeling moment from § 171.030.

(2) Wind heeling moment from § 171.030 under bare poles, or, if the vessel has no auxiliary power, with storm sails set.

(3) Wind heeling moment calculated from the following equation:

$$M_w = PAH$$

where—

M_w = wind heeling moment in kilogram-meters.
A = the windage area of the vessel in square meters with all sail set and trimmed flat.
H = the distance in meters from the center of the windage area to the waterline.
P = 4.9 for both protected and partially protected waters.

(j) Additional or different stability requirements may be needed for a broad, shallow draft vessel with little or no ballast outside the hull. The additional requirements, if needed, will be prescribed by the appropriate Commander (mmt).

Subpart C—Large Vessels

§ 171.045 Specific applicability.

This subpart applies to each vessel that fits into any one of the following categories:

(a) Greater than 100 gross tons.

(b) Greater than 19.8 meters in length.

(c) Carries more than 12 passengers on an international voyage.

(d) Carries more than 150 passengers.

(e) The stability of which is questioned by the OCMI.

§ 171.050 Intact stability requirements for a mechanically propelled or nonself-propelled vessel.

Each vessel must be shown by design calculations to have a metacentric height (GM) in meters in each condition of loading and operation, that is not less than the value given by the following equation:

$$GM = \frac{Nb}{23.6\ W \tan(T)}$$

where—

N = number of passengers.

W = displacement of the vessel in metric tons.

T = 14 degrees or the angle of heel at which the deck edge is first submerged, whichever is less.

b = distance in meters from the centerline of the vessel to the geometric center of the passenger deck on one side of the centerline.

§ 171.055 Intact stability requirements for a monohull sailing vessel or a monohull auxiliary sailing vessel.

(a) Except as specified in paragraph (b) of this section, each monohull sailing vessel and auxiliary sailing vessel must be shown by design calculations to meet the stability requirements in this section.

(b) Additional or different stability requirements may be needed for a vessel of unusual form, proportion, or rig. The additional requirements, if needed, will be prescribed by the Commandant.

(c) Each vessel must have positive righting arms in each condition of loading and operation from—

(1) 0 to at least 70 degrees of heel for service on protected or partially protected waters; and

(2) 0 to at least 90 degrees of heel for service on exposed waters.

(d) Each vessel must be designed to satisfy the following equations:

(1) For a vessel in service on protected or partially protected waters—

$$\frac{1000(W)HZA}{(A)(H)} > 10.9 \text{ (metric tons/sq. meter)}$$

$$\frac{1000(W)HZB}{(A)(H)} > 12.0 \text{ (metric tons/sq. meter)}$$

$$\frac{1000(W)HZC}{(A)(H)} > 13.7 \text{ (metric tons/sq. meter)}$$

(2) For a vessel on exposed waters—

$$\frac{1000(W)HZA}{(A)(H)} > 16.4 \text{ (metric tons/sq. meter)}$$

$$\frac{1000(W)HZB}{(A)(H)} > 18.6 \text{ (metric tons/sq. meter)}$$

$$\frac{1000(W)HZC}{(A)(H)} > 20.8 \text{ (metric tons/sq. meter)}$$

where—

HZA, HZB and HZC are calculated in the manner specified in paragraph (e) or (f) of this section in meters.

A = the projected lateral area in square meters of the portion of the vessel above the waterline computed with all sail set and trimmed flat, except that 100% of the fore triangle area may be used in lieu of the area of the individual headsails when determining A if the total area of the headsails exceeds the fore triangle area.

H = the vertical distance in meters from the center of A to the center of the underwater lateral area or approximately to the one-half draft point.

W = the displacement of the vessel in metric tons.

(e) Except as provided in paragraph (f) of this section, HZA, HZB, and HZC must be determined as follows for each condition of loading and operation:

(1) Plot the righting arm curve on Graphs 171.055 (b), (c), and (d) or (e).

(2) If the angle at which the maximum righting arm occurs is less than 35 degrees, the righting arm curve must be truncated as shown on Graph 171.055(a).

(3) Plot an assumed heeling arm curve on Graph 171.055(b) that satisfies the followings:

(i) The assumed heeling arm curve must be defined by the equation—

$$HZ = HZA \cos^{2}(T)$$

where—

HZ = heeling arm.

HZA = heeling arm at 0 degrees of heel.

T = angle of heel.

(ii) The first intercept shown on Graph 171.055(b) must occur at the angle of heel corresponding to the angle at which deck edge immersion first occurs.

(4) Plot an assumed heeling arm curve on Graph 171.055(c) that satisfies the following conditions:

(i) The assumed heeling arm curve must be defined by the equation—

$$HZ = HZB \cos^{2}(T)$$

where—

HZ = heeling arm.

HZA = heeling arm at 0 degrees of heel.

T = angle of heel.

(ii) The area under the assumed heeling arm curve between O degrees and the downflooding angle or 60 degrees, whichever is less, must be equal to the area under the righting arm curve between the same limiting angles.

(5) Plot an assumed heeling arm curve on Graph 171.055(d) or (e) that satisfies the following conditions:

(i) The assumed heeling arm curve must be defined by—

$$HZ = HZC \cos^{2}(T)$$

where—

HZ = heeling arm.

HZA = heeling arm at 0 degrees of heel.

T = angle of heel.

(ii) The area under the assumed heeling arm curve between the angles of 0 and 90 degrees must be equal to the area under the righting arm curve between 0 degrees and—

(A) 90 degrees if the righting arms are positive to an angle less than or equal to 90 degrees; or

(B) the largest angle corresponding to a positive righting arm but no more than 120 degrees if the righting arms are positive to an angle greater than 90 degrees.

(6) The values of HZA, HZB, and HZC are read directly from Graphs 171.055(b), (c), and (d) or (e).

(f) For the purpose of this section, the downflooding angle means the static angle from the intersection of the vessel's centerline and waterline in calm water to the first opening that cannot be rapidly closed watertight.

(g) HZB and, if the righting arms are positive to an angle of 90 degrees or greater, HZC may be computed from the following equation:

$$HZB \text{ (or } HZC) = \frac{I}{((T/2) + 14.3 \sin 2T)}$$

where—

I = the area under the righting arm curve to—

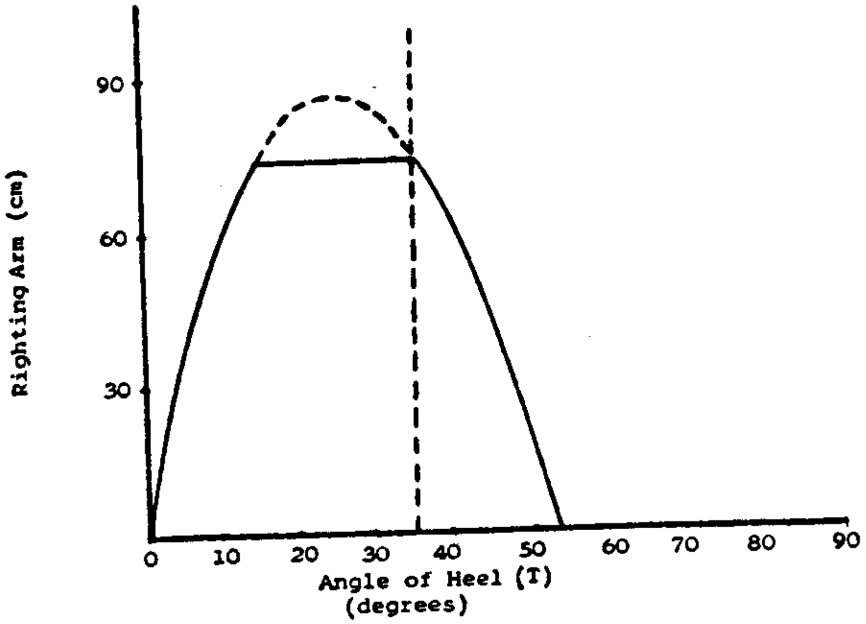
(1) the downflooding angle or 60 degrees, whichever is less, when computing HZB;

or (2) 90 degrees or more but no more than 120 degrees when computing HZC.

T = the downflooding angle or 60 degrees, whichever is less, when computing HZB or 90 degrees when computing HZC.

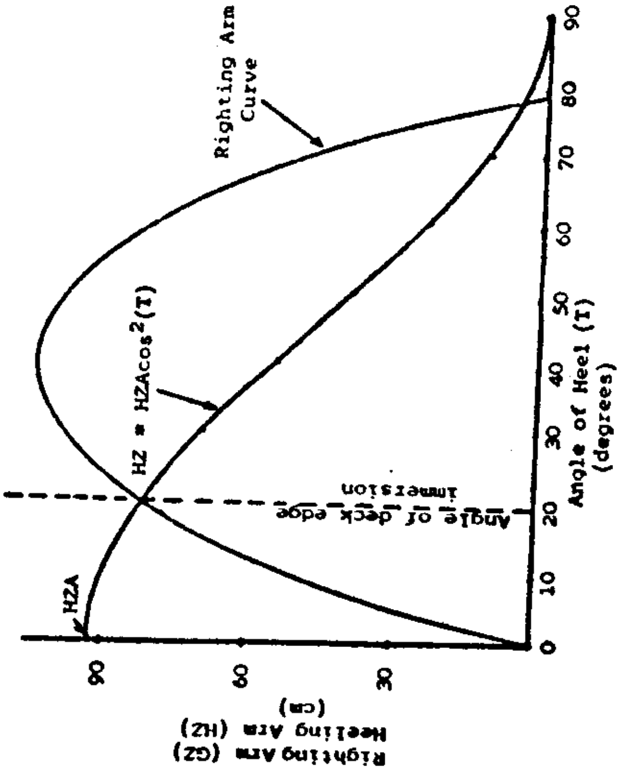
GRAPH 171.055(a)

Truncation of Righting Arm Curve if Maximum Righting Arm Occurs at an Angle of Heel Less Than 35 Degrees



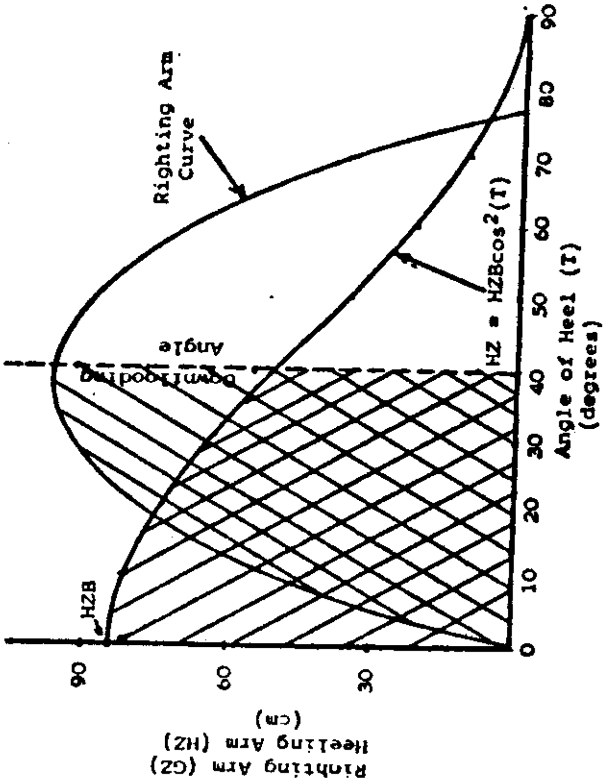
GRAPH 171.055(b)

First Intercept Occurs at the Angle at Which Deck Edge Immersion First Occurs



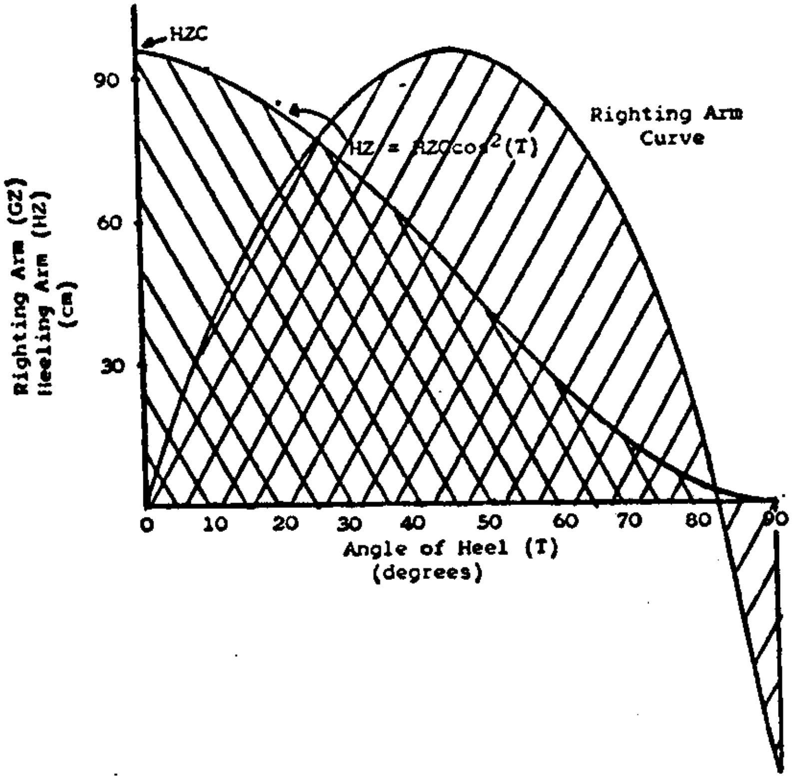
GRAPH 171.055(c)

Shaded Areas are Balanced to the Downflooding Angle



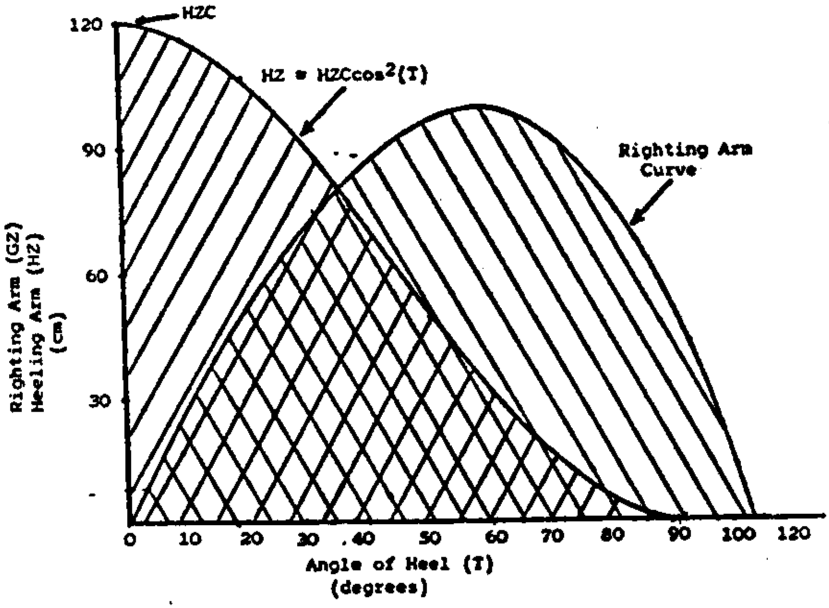
GRAPH 171.055(d)

Righting Arm Curve is not Positive to 90 Degrees and Negative Area is Included



GRAPH 171.055(e)

Righting Arm Curve is Positive Beyond 90 Degrees



BILLING CODE 4910-14-C

§ 171.957 Intact stability requirements for a sailing catamaran.

(a) A sailing catamaran that operates on protected and partially protected waters must be designed to satisfy the following:

$$\frac{0.6(W)B}{2(As)(Hm)} > 10.9 \text{ metric tons/m}^2.$$

where—

B = the distance between hull centerlines in meters.

As = sail area in square meters.

Hm = the mast height above the deck in meters.

W = the combined displacement of both hulls in metric tons.

(b) A sailing catamaran that operates on exposed waters must be designed to satisfy the following equation:

$$\frac{0.6(W)B}{2(As)(Hm)} > 16.4 \text{ metric tons/m}^2.$$

where—

B = the distance between hull centerlines in meters.

As = sail area in square meters.

Hm = the mast height above the deck in meters.

W = the combined displacement of both hulls in metric tons.

BIOGRAPHY

Commander, U. S. Coast Guard. Executive Officer, Marine Safety Office, Jacksonville, Florida. Graduated: U. S. Coast Guard Academy, 1964 with B.S. in Engineering. Graduated: Massachusetts Institute of Technology, 1972 with M.S. in Naval Architecture and Marine Engineering.

TITLE: "LOW COST, MICRO-PROCESSOR BASED POWER CONVERSION INSTRUMENTATION APPLICABLE TO SAIL-ASSISTED COMMERCIAL FISHING VESSELS"

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ABSTRACT

Power conversion instrumentation, until the last two decades, has been a luxury only reserved for ship sea trials and model testing. This was primarily due to the instrumentations inherent fragility and the time required to gather and interpret the data. Digital technology, because of its inherent simplicity, reliability and low cost in terms of functional performance, has allowed the development of highly compact and reliable power conversion instrumentation. This instrumentation is easy to read, and, without distracting from the vessel operators' normal sequence of duties, will allow the operator to carefully manage the balance of energy input from wind and fossil fuel in accomplishing a given task. Basic sensor catagories are considered, e.g., thrust, torque, shaft rotation, fuel flow, vessel water speed, and vessel land speed, and the value derived therefrom when used to enhance the profitability of a sail assisted commercial fishing vessel. Examples of the use of instrumentation on commercial vessels of various classes without the benefit of sail assistance will be given, as well as an application on an in use sailing fisheries research vessel alternatively powered by a controllable pitch propeller and diesel engine propulsion system.

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INTRODUCTION:

Fuel and Power Management Instrumentation (or PROPULSION MANAGEMENT SYSTEMS of varying classes depending on the degree of sensor complexity and vertical integration of information), as priority equipment on board commercial vessels, has grown significantly in the last five years. Design life of the various measuring elements has been improving, as well as the scope of the measurement systems in their application to myriad types of vessels. Increases in fishing catches and reductions in operating costs with constant or improving revenue dollars has resulted in "word-of-mouth" publicity enlarging the sales of this type of equipment. Fuel and power instrumentation is becomming increasingly important in the economic survival of marine commerce, as it gives a greater degree of precision by which the vessel operator may discriminate the relationship between what the vessel is doing vs. the financial goals that he is after. The PROPULSION MANAGEMENT INSTRUMENT, known by product classes as "Fuel Management System", "Power Management System", "Performance Monitoring System" and other titles, is a clustering of instruments, read-out systems and data gathering systems. This process, to be a true management tool, must include a data reduction means.

The title of the device generally gives emphasis to the MANNER by which the sensors are prioritized and the data flow organized. A device which is called a "MANAGEMENT SYSTEM" is designed to aid in the making of judgements on resources which expensing is highly variable and of significant interest. These devices are glanced at occasionally when mounted as a wheelhouse instrument, and the power utilization controls are set using the data given, set policies or correct equipment based on the summary data derived therefrom. A device which is called a "MONITORING SYSTEM" is designed to gather data dumbly and watch for a dangerous condition, e.g., an alarm system, and operate relatively unattended. Fuel and power management functions are generally added as an afterthought, and because of the omnibus nature of the electronics involved, system size and complexity often predicates inadequate use of propulsion management functions.

PROPULSION MANAGEMENT SYSTEM instrumentation generally comprises several classes of devices that input into calculating electronics. The inputing instrumentation deals with energy conversion, and hense deals with such simple elements as time, motion, volume and pressure. Propulsion management systems deal with the systematic gathering of various types of power conversion instrumentation, the presentation of that data and varying degrees of data reduction (supplier dependent).

These electronic systems have grown out of an industry trend toward tighter system packaging over "gauge" read-out type systems, wherein a sensor feeds directly into a simple indicator. These systems occupy significant area in a wheelhouse or engine room environment, and are much more difficult to treat as a collection of information than if the system is tightly grouped with the read-outs of concern located in such a way that they may be directly (visually) compared. Since the creation of microprocessor based systems in the 1960's, packaging costs on computers have come down to the point where "gauge" type systems can no longer compete in electronic read-out type systems if more than three inputs are present (assumes $ 950.00 per instrument including sensor) or where rate information is to be presented. The advantages in terms of additional time saving information availed as a result of the decision to go with computer based information systems is the subject of the paper.

A number of important ratios and percent change terms are displayed to the operator, depending on the system, such as engine fuel burned (g.p.h.), hydraulic or water speed efficiency (g.p. water mile), transportation efficiency (g.p. land or bottom mile), engine conversion efficiency (hp. per gallon per hour) and, if a thrust measurement device is available, lbs. thrust per ft. lb. of torque, thrust hp. per gal. per hour and thrust hp. per engine hp. We will herein evaluate the merits of various power relative sensor inputs, in order of relative economic importance. These are evaluated based on first cost, cost of installation, cost of maintenance over a 10,000 hour continuous use inspection, calibration and repair interval and the speed with which the investment may be recovered. The sensor systems, with what M.S.E. calls PHASE I ELECTRONICS (vessel mounted instrumentation and direct read-out electronics, e.g., no bulk data storage, reduction and statistical evaluation and report writing capabilities), occur in several instrument classes, these being FUEL FLOW, SHAFT R.P.M. (or engine r.p.m.), TORQUE, WATER SPEED AND LAND SPEED. THRUST would also come under this consideration. However, as we currently understand marine instrumentation technology, the installation of thrust instrumentation has the lowest installed cost benefit ratio of the aforementioned.

INSTRUMENTATION CLASSES AND COSTS:

Fuel Flow:

Fuel flow systems are broken down into two basic measurement strategies: a) SENSOR-IN/SENSOR OUT on the engine fuel rail and b) FUEL RECIRCULATION SYSTEMS.

SENSOR-IN/SENSOR OUT systems, as the name implies, measures fuel into an engine and the fuel leaving it. Two sensors are used which must be specially matched and corrected to handle the various changing conditions that happen across an engine fuel rail system. The measurement system relies on the differencing of the two sensor flows for the resultant (fuel consumption rate) flow.

The meters must take into account viscosity changes due to increasing temperature of the fuel, fuel temperature expansion (from 60 degree F. ref.) and density changes due to the introduction of combustion gas, air and boiled volatiles as the fuel goes through engine fuel system. The meters must also be tolerant to the various forms of contaminants introduced by the engine.

FUEL RECIRCULATION systems return, essentially, the unburned fuel returned by the engine that would normally flow back to the day tank. As a result of this processing, the system must incorporate fail safes and the fluid handling properties inherent in the much larger day tank holding system, e.g., sludge holding, particulate settling, degassing and heat rejection.

In the above systems, many different types of meter systems are employed. Because of the high accuracy required over a broad flow range, two basic classes of flow sensors are usually employed, these being TURBINE and POSITIVE DISPLACEMENT meter systems. Turbine meters are kinetic energy devises, while positive diplacement meters are volume capturing devices. These meters are expressed as a dichotomy, when in reality meters are designed with properties similar to both types ranging from fully open to fully sealed in approach. Fully sealed meters are relatively immune to viscosity effects, e.g., the thicker the fluid, the less they slip. However, pressure drop across the measuring elements increase. Turbine meters are sensitive to viscosity changes, but suffer little in pressure drop with increasing fluid viscosity.

A true tightly sealing P. D. type measuring system will block the flow in a fuel line in the jambed condition. A turbine meter system will generally not. However, a pressure relieving bypass valve or other means can be incorporated so circumvent this design problem. M. S. E. fuel flow meters are of the P. D. type but, unlike most P. D. meters, WILL PASS A SIGNIFICANT PERCENTAGE OF RATED FLOW IN THE JAMBED CONDITION with only a few p.s.i. drop. The M.S.E. meter has its measuring elements labyrinth sealed, and an obstruction will cause the rotor system to "hydroplane" in the measuring chamber and enlarge the rotor to measuring chamber clearances.

Fuel Recirculation, when properly done, yields greatest accuracy at the least possible cost. It is also the most difficult to apply correctly and, although a broad spectrum approach, must be carefully analyzed before installation. The three basic classes of RECIRCULATION systems are a) simple loop b) tuned and baffled chamber type, and c) tuned and baffled chamber with heat exchanging. M.S.E. has been a leading pioneer in systems development of SENSOR IN-SENSOR OUT as well as the last two types of RECIRCULATIONS SYSTEM types mentioned above (b and c).

In the design of FUEL RECIRCULATION sensor systems, the high turn down ratios (20:1 between idle to full load, 10:1 in gear idle to full load typically) required of the fuel sensor, along with the low pressure drop, only specially designed positive displacement flow sensors have proven adequate for long term measurement applications at 1% maximum error over engine flow range or less.

Turbine type meters are popular in SENSOR-IN/ SENSOR OUT applications because of apparently low turn down ratios in the fuel rail flows in many applications. However, closer look at what goes on in an engine fuel system can reveal sources of gross error in practical application. Because of large changes in Reynolds numbers (100 to 100,000) across the fuel rail due to engine heat thinning the fuel oil (10:1 kinematic) and the significant change between input and output flows, (5:1 to 100:1 turn down) as well as the introduction of air, soot and combustion gases into the return fuel flow (from a variety of sources), large errors can result, particularly at engine idle. Careful calibration of the two sensors with each other regardless of flow, viscosity and temperature must be made to assure error tracking at large flows.

Costs of turbine meters can range from several dollars to over $ 1,000.00 ea. with "temperature correction". Positive displacement meter systems can run from as little as less than $ 100.00 (with mechanical registers) to several thousand dollars each depending on flow application and sensitivity. This is for a bare meter that will be, unless carefully matched into an integrated system, unsuitable to marginal in even short term application. Most direct reading meters cannot take the corrosive nature of a marine environment or the broad range of vibration and shock sources found on a vessel. An electronic pulser or signal output reading system is the information source of choice. A maximum of 1% error over the engine fuel consumption flow range for a minimum of 10,000 service hours is necessary for even the beginning of a fuel management program.

Shaft R.P.M.:

Propeller shaft counters and engine r.p.m. systems are generally of four types: a) mechanical cable driven, b) d.c. generator drive, c) flywheel tooth generator or counter and d) proximity detection devices.

Mechanical drive systems use a cable driven off a rotating element of the engine. This cable is interlocked with a spring loaded pointer by a low torque magnetic clutch. Eddy currents resulting from the rotation of the magnet(s) with respect to the steel clutch cup cause an increasing clutch drag proportional to r.p.m., and thereby yielding increasing readings. The device is generally reliable and cheap, but only of the most general character in terms of precision. 5% error with another 5% to 7% bounce is common, making unsuitable for most power management instrumentation functions.

D.C. generator systems produce a voltage proportional to r.p.m. These systems are generally used on medium and low speed engines. Because of their structural complexity, failure is by in large vibration induced. Accuracy problems similar to mechanical tachometers are the common case, however less reading hunting is observed.

Gear tooth type tachometer pick-ups are generally magnets wound with a coil. Passing of a moving ferrous material in front of the coil and causing the magnetic field lines in and around the coil to move causes the generation of a voltage. When this is done by a gear tooth, the moving tooth causes a voltage proportional to the peripheral speed of the flywheel, and can therefore, when rectified, drive a calibrated voltmeter. This can be used to drive a voltage sensitive read-out device, or the sine wave converted to a square wave suitable for driving a counter reset by a timing flip-flop. A displaying device would then read out shaft r.p.m.

Proximity sensor devices sense the presence or absense of metal. Unlike the gear tooth type tachometer pick-up, the signals have to be of much longer duration to be "recognized" and an output from the probe generated. This type of system, although frequently more difficult to install, has a direct digital output which is compatible with most computer applications. The system, because of its its triggering characteristics (some use "Hall Effect" devices), has no low speed threshold, and except for overspeed (target time to short to be recognized), computer timing round-off define slow rotation error limits, or jitter, on consecutive rotation updates (round-off errors cancel themselves out over time).

"Gear Tooth" and "Proximity" systems are the cheapest to install, and are nearly equally reliable when properly designed. D has the advantage of detecting extremely low shaft r.p.m., allowing the possibility of a vessel to anchor and monitor strong surface currents through the free wheeling of the propeller shaft (usually not practical unless gear train can be decoupled from propeller shaft and shaft can be "dithered" to reduce seal and bearing break-away torque).

As an add on to a fuel management system, an excellent tachometer can be included for as little as a few hundred dollars. Accuracy to within one shaft revolution allows its use, in conjunction with fuel flow instrumentation, as an effective power measurement device with good repeatability, making it an important inexpensive tool to both fishing vessels, work boats and motor ships alike. This system explores the logarithmic change in propeller power demand against engine R.P.M. with small changes in propeller slip.

The use of a torsion meter converts the vessel into a floating dynamometer stand, allowing the vessel operator to tune his engine for optimal fuel conversion performance. Data gathering and processing from reliable information derived therefrom aids in the identification of engine problems and potential damaging conditions, as well as following declining trends useful in the scheduling of maintenance.

Torque:

Torque is generally sensed by the twist in the propeller shaft over a unit shaft length. Measurement techniques involve using strain gauges, L.V.D. Transformers, magnetic tape with impressed signals and more recently (M.S.E.) high speed time measurement.

Strain gauges are resistance devices that when integrated into an A.C. or D.C. "bridge" type circuit, yield a change in output voltage with respect to displacement. Individual gauges are highly sensitive to temperature changes and require extreme care in design and mounting. Caution should be taken in bonding methods as well as mechanical maintenance.

Linear Variable Differential Transformers are high resolution position detecting transducers. These devices are usually hooked up in a A.C. bridge circuit. The mechanical mounting techniques have to be carefully developed to avoid inherent instability due to vibrations and lateral accelerations (e.g., centifugal accelerations). This is due to the L.V.D.T. containing a plunger which must be moved axially with respect to a solenoid type coil.

The above devices require that electricity be passed onto the shaft, with consequential reduction in accuracy (resistance of the brushes or losses due to transformation in radio transfer of signals.

Magnetic Tape devices which use magnetized tape with impressed signals thereon (such as "1,000" signals per revolution "glued" onto the shaft) are in effect simulated "gear" teeth which can be picked up by magnetic pick-ups or magnetic tape reading heads. These devices use the change in phase angle between the "teeth" of one of the "sprockets" and another "sprocket" some distance away along the shaft axis. By examining the distances between the signal "zero cross-over" point from an initial "in-phase" starting condition, the sine wave signals are converted to a voltage that is proportional to transmitted torque plus or minus long rotating shaft skew. Due to the sensitive nature of the pick-up heads, mechanical vibration from various sources can effect readings (e.g., the "racking" of the hull in response to engine torque pulsations). The electronics, due to the many conversion stages, have error introduced at each analog conversion level. Further, care must be taken in the use of signal pick-up materials to insure stability of mechanical interface and the integrity of the reading gap. Further, because of the reading of very low voltage levels with tape type air gap systems, great care must be taken to shield the system from stray electromagnetic radiation.

High speed time measurement systems offer the greatest promise for time series' engine power measurements and long term accuracy because of its fundamental simplicity, and its low first cost (from a few thousand dollars) compared to other systems (from $ 15,000 to $ 50,000) for marine applications. This type of instrumentation was developed by M.S.E. using high speed computer based technology. A tube assembly is attached to the shaft to gather a unit displacement of the shaft along a distance onto one reading plane. The computer, in "observing" two or more pins rotating with the shaft, times the time T1 the shaft takes to rotate one revolution, and the amount of time T2 it takes for the initializing pin (attached to one end of the shaft) and the interval pin (attached to the tube which is anchored some distance away) to pass.

This fraction has subtracted from it the initial or calibration readings, and is expressed as the numerator in a fraction wherein the denominator is the peak corrected fractional range of the instrument. This resultant is then multiplied by a "K" factor to yield TORQUE and with r.p.m. multiplied by a constant, horsepower. Torque multiplied by revolutions and a "T" factor yield horsepower hours.

The advantages of this patent pending system is that 1) no electricity is passed onto the shaft, 2) the signals are digital in character and subject only to "round-off" errors and, 3) because of its simplicity, high accuracy over long periods between recalibration is easily accomplished. Because of the instruments fully digital character, periodic recalibration can be done in a few minutes with computer aided techniques, versus several hours on other systems utilizing manual methods.

Water Speed:

The simplest and often most easily understood log are the propeller and paddle wheel speed sensors. For shallow draft vessels or vessels that operate in silty water, the latter is superior depending on the manufacturer and materials. This type of device is usually several hundred dollars in cost. Cleaning should be frequent, as fouling effects measurement accuracy.

Current mechanical water speed indicators are traction devices that utilize a paddle wheel or propeller of unit blade pitch operating in the boundry layer flow of the vessel. Usually a magnet is mounted in a balanced relation in the impeller or propeller, and the poles of the magnet(s) pass alternately in front of a highly sensitive coil of wire, producing a low amplitude signal. This signal is boosted by an amplifier/filter network and passed to the reading system.

Magnetic logs are the next up in cost, ranging from several hundred dollars to over $ 12,000. Computer grade equipment can be purchased for several thousand dollars, with the advantage that the instrument has a higher tolerance to fouling, is harder to "knock of the boat" and does not wear out with contact with sand and suspended silt in the water. These devices use a series of coils and a stepwise alternating frequency exciting current, whereon the alternating magnetic field creates a current flow between a set of pick-up pins on the target surface. These devices, like the mechanical logs, operate within the boundry layer of the vessel, dependent on their location and degree of standoff with respect to the hull.

Doppler shift devices are available for costs as low as $ 750.00 to as high as $ 45,000. Since Doppler Shift relys on a change in sound frequency external to the hull in order to measure speed, the power of the device as well as the units descrimination qualities are important to accuracy. There is a significant correlation between cost and log accuracy; the greater.the units energy output, the better the units fidelity in terms of frequency discrimination and interpretation relative to background radiation from many sources.

A Doppler shift speed log uses a sound wave beamed out and focused on a water mass some distance from the hull as the current reference. Sound is reflected back from this mass by particulates in the water, and the resulting frequency shift (hense the name "Doppler") is used to calculate the vessel speed. Since this device focuses on a water target some distance from the vessel, repeatability can be distorted due to changes in surface currents under the vessel, and from the gathering of signals reflected from submerged objects (such as schools of fish).

Depending on the research application, years of good data can be gathered with the simplest of sensors. Caution and scrutiny must be taken in purchasing "sophisticated" equipment at an unusually low price, unless the source is well understood. One low cost nonhull penetrating doppler shift meter we tested gave readings proportional to boat speed with about .5 to .8 knot offset due to background wave noise. Once the vessel engines were started (the boat earlier was in a towed condition), little correlation with actual vessel speed could be found. INSTRUMENT SIMPLICITY, WHEREVER POSSIBLE, SHOULD BE ENCOURAGED.

Care should be taken in placing the respective sensor and in its calibration. Propeller, paddle wheel and "flush" magnetic logs operate in a hull boundry layer of variable distributed velocity with respect to the true hull water speed. "Sword" type magnetic logs and doppler shift logs measure water velocity at varying distances away from the hull depending on design. In all cases, careful calibration over the water speed range of interest must be made. Also, the limitations of the sensors data gathering techniques must be thoroughly understood.

Land Speed:

A number of useful methods of land speed measurement include steaming two ways across a known set of points, taking land fixes with navigation devices (Loran 'C', Radar, R.D.F., Satelite Navigation, etc.) and taking a bottom track with a doppler shift speed sensor. Each type of land speed measurement strategy has its own range of uncertainty that is variable by time of day, type of equipment used and range of distance between sightings.

The cheapest sensing system, with broadest application, is to use a quality LORAN C device with land speed output. Unfortunately, drifting of the Loran lines can cause erronious speed readings under some conditions. M.S.E. has recently introduced a "smart" interface card between the NAVSCANtm and the Loran RS 232 C speed output port, thus allowing the NAVSCAN to display a speed reading that is highly stable and does not contain the majority of "trash" readings that are often averaged into the speed reading. Also, the NAVSCANtm, when using the LORAN C input for vessel speed and when equipted with the data recording option, records not only the NAVSCAN data, but also vessel position.

Thrust:

Thrust is the push exerted against the vessel to perform work. Thrust horsepower is what pushes the vessel forward as a result of the engine converting fuel to energy via the propeller. Effective thrust horsepower is how the vessel converts engine thrust to vessel speed, e.g., tow rope horsepower. Thrust is generally a measurement of pressure exerted by the propeller against a thrusting surface, such as the thrust bearing in the gear of the engine. Engine horsepower to thrust conversion is most important in Controllable Pitch Propeller applications, and on sea trials with new propellers, and monitoring changes in condition over time. A THRUST meter system will start at about $ 5,000.

Read-Out Systems:

If the sensors are the heart of a PROPULSION MANAGEMENT SYSTEM, then the read out electronics is its first form of thought. Without a good electronics system that is easy to use, easy to understand and is specifically engineered to gather and smooth sensor data for easy interpretation, the sensors information would become useless. Because of diesel injector governor hunting in response to changing power demand, and fluctuations in the power requirement of the vessel in response to waves, wind buffeting and tugging gear, a well designed variable averageing system, e.g., A VARIABLE TIME BASE AVERAGER, is necessary to get accurate and repeatable measurement (the whole point of instrumenting your vessel).

The organization of the displays are important, as they determine the priority, the speed and the accuracy that the user can obtain and utilize the information. Poorly presented data will result in user frustration, operator error and lost potential. Electronic read-out systems run generally from a few hundred dollars per sensor input, to over several thousand dollars per data point.

Data Tagging Systems:

At some point in the life of an instrument user, hard copy records are of interest to compare results. These records, in order to be significant, must be identified or classified to enhance your later under standing as to why more fuel was burned on one run than another, why one fuel burn curve relative to vessel speed is different from another, why one operator behaves differently from another.

A DATA TAGGING SYSTEM allows the equipment operator to input, via a code or number, the type of tow he has, his destination, and even weather variables. This relieves the tedium of having to later gather this type of data off the vessel log and hand key or enter this data into a data reduction scheme. With M.S.E. equipment, this is done by pressing a single button and rolling up a number from zero to 99. The operations people or the captain decides as to what these numbers will mean, and these meanings or code definitions are later entered into the data reduction software. Data TAGGING is now a special feature available through special purchase programs in conjunction with PARTICIPATING research groups such as the COOPERATIVE EXTENSION SERVICE, MISSISSIPPI SEA GRANT PROGRAM at Biloxi, Mississippi.

Data Gathering Systems:

Manual data gathering systems are subject to interpretation and transcription errors, as well as being subject to loss. On computer based PROPULSION MANAGEMENT EQUIPMENT, such as many Fuel Management Systems, data is collected and printed on a slip of paper, or on wide computer paper by a dot matrix printer. Unfortunately, these techniques require collection and storage of the paper, interpretation of data and hand keying of the data into a data reducing computer system or the reduction of the data by hand.

A more satisfying method of data collection is by magnetic tape, and the passing of the tape data into a data tape reader for DIRECT FEEDING INTO A DATA REDUCTION COMPUTER. This feature can be available for as little as $ 1,500 from some suppliers depending on the number of data gathering features. The data recorder may be moved from vessel to vessel in a fleet of boats. Each data tape can contain up to a months worth of data, depending on the data collection frequency required by the operator. The DATA TAPE that M.S.E. uses is typically a high quality C-60, C-90 or C-120 casset recording tape of good music recording qualities (such as RADIO SHACK "gold" quality tapes).

Data Reduction Systems:

Once data has been "tagged" and gathered, it should be reduced into some meaningful form. The most expensive aspect of most research efforts is the actual gathering, classifying, reduction and summarizing of data. In the M. S. E. system, the data on magnetic tape is dropped into an M.S.E. data decoder, which is then fed into a small desk top computer, such as a RADIO SHACK Model 2 or Model 12, or an I.B.M. Personnal Computer (the Radio Shack Model 12 has, at this time, the best storage for the $). The data can then be reduced by software of your own design (what the NAVSCAN data format looks like is provided at negligible charge, e.g., is supplied with our data recorder and decoder).

You may also purchase generic research specific statistical software at several stages ranging in price, depending on the supplier and use features, from several hundred dollars to over $ 10,000. The lower cost software will do decoding, listings, general summary statistics, histograms and simple regressions. The more moderate programs include time series, multiple plots, multiple regression, correlation analysis, NORM plots, transformation functions, DIRECT COMPARISON functions and automation.

Data reduction programming, at nominal cost, frees the vessel operator and researcher to be active in creative enquiry, the design of experiments and the interpretation of summarized research. Data summarizations and reports useful to a variety of operations and specific needs are easily obtainable, such as fuel use, tax summaries, cost distributions against product classes and customers, and costing against vessels in a matter of hours instead of man weeks or months of labor. He can then transfer the results to the better management of existing resources and work forward in the pursuit of more advanced methods and equipment.

System Packaging:

Frequently prepackaged instrumentation systems are available focused on the needs of a particular market. These systems will contain the required sensors, junction boxes, power supply, electronic sensor data interfaces and the read-out system. Some manufacturers provide paper tape data output, while others provide tractor feed printers and/or magnetic tape storage. These systems, depending on manufacturer, complexity and accuracy, can range in cost from about $ 1,500.00 to hundreds of thousands of dollars. Through GROUP purchases, in dealing with instrumentation within the scope of this paper, high confidence simple fuel management systems complete comprising fuel flow system, connecting junction box, power supply and read-out system can start at $ 2,500.00. ("C" system). Systems with a data gathering add on capability, capable of high resolution presentation of speed, r.p.m. and fuel fuel flow data start at less than $ 4,000 for a single engine ("B-104" system) and $ 6,000 for twin engine. Special conditions of purchase exist, and the above systems would be acceptable to most engines under 1,500 hp. each. Larger engines demand a different set of installation and instrumentation considerations, and the system increased cost is approximately proportional to the ratio of the horsepower increase above the $ 1,500 hp.

Data recording with LORAN C DISCRIMINATION /INTERFACE CARD could add another $ 2,500 plus onto system cost, but would be well worth it, e.g., relieve the crew and line management of clerical work. The data recorder may be moved from boat to boat, thereby distributing the data sampling costs over many vessels. The DATA DECODER SYSTEM is another necessary item, as with M.S.E. tape systems, a non-standard system of coding is used to increase the data tape recording devices electromagnetic immunity to stray high energy electromagnetic fields found in normal commercial vessel environments. Such a device is worth another thousand dollars, and its cost may be distributed against hundreds of vessels and thousands of reports.

The above inputs direct read out as rate information on a PROPULSION MANAGEMENT SYSTEM, as well as by key power conversion ratios. It is by the collection and progressive reduction of data that trends involving time and other factors may be viewed. These would otherwise be obscured by vague memory.

Historically, as the customer gains a better understanding of the conversion of fuel into revenue in his economic system, he generates more significant and detailed questions about the short and long term operation of the vessel. Questions such as best boat speed under different tow and water conditions graduated into questions about equipment effectiveness, change in efficiency with respect to time since last overhaul or haul out and planning of maintenance taking into account projected market conditions. Slowly the answer to the questions rely less on "hunches" and more on direct observation, market feedback and increasing levels of planning. This happened primarily with increasing levels of pilot discression, through evaluation of crews using instrumentation versus those which did not, their fuel savings, and more refined techniques were being developed using the talents of wheelhouse crew as well as shore based management, e.g., an interlocking talent rather than talent competition. "Style" then becomes proceedure with repeatability defined by judgement and instrumentation, and can be passed on to other crews through training.

Manual collection of data and summarization has since developed into tape data logging and computerized data reduction. Because of the boom in low cost micro-processor based personal computer technology, and the introduction of cheap mass storage technology, such as double density "Floppy" disk drives and "Winchester" hard disk drives, once tedious and for the most part boring work involving the logging of numbers, summarizing and transfering these numbers to supplimentary sheets, and the utilization of manual statistics techniques in reducing data to numbers of interest CAN BE VIRTUALLY ELIMINATED, thus allowing captains, crew members and shore stationed managers to use refined and well understood scientific methods in the studying of phenomena, with little or no teaching in the underlying detailed mathematical theory or the mechanics of what is happening. The captain, crewmember or manager can discover in a gross sense the meaning of: 1) a particular number, 2) how the ranging of this variable can effect his operation, 3) and what are his modalities of judgement for altering this condition to bring this variable to a number within his range of interest. Such variables as horsepower hours per gallon or barrel would be of interest of fuel for a steam plant or diesel engine, gallons or barrels of fuel per land (bottom) mile for the motorship, tow boat and dragging fishing vessel,and gallons per mile water for long distance steaming vessels, midwater and surface trawling fishing vessels and motor sailing vessels.

A management approach to causes, through the use of relavent tools for exploring a systems sensitivity to a particular action, may almost always be used in obtaining a better result. This results in better profits through better understanding, e.g., more knowlegeable resource use and consequentially higher production efficiency. This usually boils down to greater bottom line profits per unit time.

Vessel response to sea conditions and how this changes with time have always been very important questions. In response to customer application, demands have lead to cascades of further questions, resulting in the development of increasingly lower cost information summarization systems with generic data gathering and processing characteristics. Such a system not only presents sensor data, "averaged" to best suit sea conditions, but also allows the operator to "label" or tag the data collectioned by the data recorder. This tagging, by a number or code from 0 to 99, gives the data significance in terms of type of net rig being dragged, or number and loading of barges being towed, going with or against the current and the type and magnetude of other forces which might effect the operation of the vessel wherein direct sensing is not available or applicable. This data is then sorted by tagging code, then plotted by the specific variables of interest. These plots typed by code can then be over plotted and compared, or compared by calculations and proportional measurement, and reduced to table form as an aid in reports development. This can be done by highly trained specialists, and reports drawn from the data bases presented and explained to the end user.

M.S.E. has made available a system known as Automated Data Retrieval and Evaluation System, or A.D.R.E.S. This is a software package that runs on most personnal computers with a minimum of 64 K. RAM and 475 K. (on 8" floppy or hard disk) mass data storage. A.D.R.E.S. is a microcomputer software package designed to reduce large amounts of data (records) recorded on magnetic tape into listings, data summaries, graphs and comparatory reports (see tables 1 through 5).

A.D.R.E.S. has the capacity to REMEMBER the sequence of data reduction steps that was used in developing sets of graphs, tables, key ratios of discoveries and expressions of results. This rememberance is given a name and can be recalled to do the IDENTICAL series of analytical steps, use the same ranges in plotting, graphing, table generation and the development of key ratios. A unique COMPARE command allows the side-by-side comparison of various trips, trip facets, operator variables, equipment or other variables which are defined by sensor class (up to 20) and code (0 to 99). The graphics package in the program plots one system against the other and clearly identifies visually and by magnitude the differences. Thus, an operator can enlist the aid of a qualified marine consultant, such as a NAVAL ARCHITECT, or the help of one of many federally financed SEA GRANT programs wherein significant experience is available, as well as other groups. These people have in depth research experience and are highly developed in areas of DISCOVERY and EXPERIMENT DESIGN, as well as data evaluation. A.D.R.E.S. allows these groups to "set the stage" and generate ongoing automated comparisons and evaluations, thereby reducing the cost of vessel and operations analysis by an order of magnitude (as desk top computers reduced the cost of small business tax processing by a factor of 10).

This evolution has been the result of application demands and customer SPECIFICATION, e.g., a field of instruments that have grown out of the needs and desires of the user. It is by the hands and the knowledge of the human operator that energy is invested in our social welfare, and in a larger context, in the very uncertain future of our survival as a species on this planet.

APPLICATIONS:

M.S.E. has instrumented many vessels with fuel management systems designed to meet specific operational goals. The following covers but a few basic systems and their application. These systems were broken down into four basic wheelhouse mounted configurations, each type yielding progressively more information.

A few applications are shown in figures 1 through 36. I will herein describe how the particular customers operation utilizes the computers output. Please keep in mind that over thirty configurations have been developed to satisfy customer needs. A few basic designs which have been proven the most usefull are presented and discussed here. New designs are constantly being developed to suit customer emerging applications. Please note that the systems are provided with one, two and three displays. On the side of each display panel is a series of information titles and to its left a light. Each time the mode button is pushed, the next lower light next to the respective display lights up and that particular piece of information is indicated. Although here is shown only up to 3 modes (nine separate pieces of information), M.S.E. can provide up to 5 modes and three fuel classes, for a total of 45 separate pieces of information being available at a touch of a button. This computer system is approximately five inches high, eight inches wide, and four and a half inches deep, and weighs only six pounds (about the size of a small citizens band receiver).

FISHING VESSELS UNDER 100 TON:

Perhaps the most vital information a skipper can have in a trawling or dragging operation is gallons per hour (Gal./Hr. or G.P.H.). The "C" unit has a single display, and assumes the vessel has an operational tachometer. "Gallons per Hour" is displayed, as well as registers, or "modes", are supplied for "trip fuel", "fuel remaining" and "trip engine hours". What is interesting is that effective producers in Singleton Fleets have altered basic established fishing notions. Instead of trawling at full power with the intent of maximizing apparent bottom covered, they have readjusted their rig to tow at lower speeds and use their fuel flow measurement systems as a reliable measurement system to indicate net loading. George Sandsburg once of Singleton Fleets vessel number 23 (Cat. 3408) said "I moved the tickler back and slowed down from 1,800 to 1,500 r.p.m. Cut down by 6 to 7 g.p.h., from 19 to 13 g.p.h. with same production.". Captain John Richardson of Singleton Fleets of Singleton Fleets number 46 (Cat. 3412) said "tow now at 14.8 to 15.2 g.p.h. at 1,400 r.p.m., 16.5 g.p.h. with load". Towing at "1,500 r.p.m. requires 18 to 19 g.p.h." Captain John Richardson's "Desco" vessel, running "empty", burns 17 g.p.h. at 1,650 r.p.m., 15 g.p.h. at 1,600 r.p.m. and 13 g.p.h. at 1,500 r.p.m. Captain Jones of Singleton Fleets number 7 uses a "Texas Drop Tickler" on his rig. His sentiments about the system are (typical of the seasoned fisherman at Singleton Fleets) "working with that machine I have come out better". As Ben Bohanan of Singleton Fleets number 18 said "I can set my towing hp. by this computer. I can tell how my net is loaded, and I save fuel". (See figs. 1 thru 3)

Captains who want a greater grasp of the subtle shifts in the operation of their equipment have evolved the "D" unit or dual display unit. Like the "C" unit, only one g.p.h. register is indicated. However, gallons per hour information is displayed IN PARALLEL with some other pieces of data. Commonly, g.p.h. is displayed with engine r.p.m. information of great precision, usually with one revolution per minute maximum error.

It has been found by captains such as Roy Toomer ("Draggin Wagon" of Coral Shrimp) that r.p.m. and gallons per hour (in a gross sense) may behave dependently; but during a tow, r.p.m. will shift up and down with response to the condition over which the net is dragged. The captain can "see" when the net runs into mud, or goes over rocks, and can adjust his rig accordingly, thereby saving his gear. Roy now tows at 12 g.p.h. with four nets, formerly at 19 g.p.h. "in the corner". When the net is loading, Roy Toomer observed an eight to ten r.p.m. decrease while increasing his fuel consumption .5 to one g.p.h. What does Roy say about his fuel management system? He is "delighted with it". Roy also keeps track of trip fuel and fuel remaining. Although he does not correct for auxiliary fuel burned or diesel fuel used as a cleaner, he is accurate to about "50 gallons in 4,000". Other major fleets who have "D" systems have reported similar results.

Frequently, in researching dragging equipment, direct observation and verbal data transfer becomes unsatisfactory. The analysis tasks require larger data bases and greater care in their manipulation and analysis. Shrimping vessels such as the SHAA ISDAN, operated by Captain John Strothenkey, gather data directly via an RS 232C port into a desk top computer for later analysis on board. The REVA ROSE, owned by Captain Tommy Schultz, gathers data on his net and fisheries research on a magnetic tape, "tagged" by an M.S.E. data tagging selector switch (0 to 9 code range plus "A" and "B", giving 20 codes) and can select fuel management system data scan times of every 9 minutes or 100 scans an hour. He also has a selector for "RECORD NOW" via a button, for recording peaks and other transient phenonina. (See figs. 4 thru 12)

Special research using on-board fuel management information is being conducted by a number of SEA GRANT programs. Of particular note is that research conducted by MISSISSIPPI STATE UNIV. , under the direction of Dr. C. David Veal. His experiment design concerning various aspects of the fishing industry is internationally reknown. He can be contacted at:

Mississippi State University
Sea Grant Advisory Service
4646 West Beach Blvd
Suite 1E
Biloxi, Miss. 39531

attn: Dr. C. David Veal
(601) 388-4710

Manual data gathering methods become tedious and, because of the energy lost in manipulating data rather than evaluation and interpretation, many ideas are lost. Adequate instrumentation and supportive data gathering can aid in answering otherwise obscure questions.

WORK BOATS, LARGE FISHING VESSELS AND SHIPS:

Where a significant percentage of vessel time is spent motoring to the area of operations, a "D" (dual display) or "B" (three display) unit will be used with a "knot" speed indicator. The advantage with viewing three key parameters simultaneously is that the vessel operator can adjust the three key variables in operating a vessel in parallel.

The "B" units can be found on long haul vessels such as the tug ALAPUL (now the "Portland") of Washington Tug and Barge, and tuna vessels such as the CAROLINE M (230', 1,800 ton) powered by a large single main engine, such as 16 and 20 cylinder E.M.D.'s. A captain with the aid of knots information, can discern the effects of slowing the engine R.P.M. by a few turns, and can view in parallel display an often remarkable change in gallons per hour (or more importantly, in gallons per mile). This impact, as covered elsewhere, can change due to many factors. On fleet repetitive trip runs, data storage is often necessary, as much of the vessel's performance is dictated by a company mandate, with variance authority due to sea, tow, and vessel conditions given to the captain and the engineer.

Prior to the the NAVSCANtm units installation, the ALAPUL towed at 800 engine r.p.m. She now tows at 780 engine r.p.m. with no apparent impact on scheduling. Because of the complex information gathering, processing and report writing necessary to satisfy Washington Tug and Barge's precise information requirements, M.S.E. has automated and implemented an ongoing and expanding fuel management information processing technology to meet their requirements. In multi engine units, such as Bunge Towings 'A102', the system is used to monitor 3 each. 16 cylinder E.M.D. engines health; and "balance" engine power through precise R.P.M. matching, injector sizing, wheel pitch refining, power setting, etc. Through pilot use of the NAVSCANtm, in the vessels usual transit between Cairo and New Orleans, power planning caused a 6 hour change in transit time (operation dynimics constant), "resulting savings in fuel averaged $8,000.00 (per trip) and simular reduction in engine and machinery wear was noted." Many vessels require the utilization of a multiple totalizing fuel measurement system. An "A" type unit, or multiple engine systems, answer this requirement. The 'A104' is used on long haul operations where part of the haul is in a waterway subject to a fuel tax (on fuel which is burned by the propulsion engines). The entire trip fuel burned by main engines is titled "trip fuel", and that which is burned by the drive engines along a certain waterway is called "leg fuel". Also, data such as is common on the 'B' units is found on the 'A'. Data gathering and A.D.R.E.S. data reduction is almost mandatory on long term fleet utilization of this type of equipment.

The NORDIC MONARCH (150', twin 398 CATS) burned 100+ gallons per hour operating at "recommended" power settings. His fuel bill in the spring 1981 for his 1980 crabbing year was over $90,000. Installing an 'A104' gave the owner-skipper Arny Rassmussen a better insight into his vessel power penalties from design and sea trial figures, and caused him to change his operating speed from "14 to 12 knots and from 100 to 30 G.P.H." The system is a valuable maintenance aid and has been working flawlessly in the Bering Sea. (See figs. 17 thru 22)

The owner-skipper of the crabber HUNTRESS, Dick Goodwin, utilizes a B-105 single engine system with a generator G.P.H. He sets his motoring power with the instrument, and utilizes gen. G.P.H. to plan his loading on his two large G.M.C. generators for the best power output per gallon of fuel consumed.

Dr. Edward Schallenburger of the Honolulu, Hawaii based motor-sailer research vessel FERESA uses his single engine B-106 for judging speed penalties due to weather, current, course, and mission time constraints. He then balances the sail to optimize "free energy" from the sail and adjusts the controllable pitch propeller on his Detroit 4-71 engine to optimize power output per gallon of fuel through his Hundested "VP-4" C.P. propeller, e.g., fuel consumed per hour at selected speed and optimizes gallons per mile. The instrument is used to judge power requirements of fishing equipment being researched, as well as in experiment cost accounting. A significant percentage of the vessels income is derived from "trapping" fish for collectors, and for use as food. Dr. Schallenburger feels that a fuel management system is the "only realistic way to manage fuel in a small boat" of his type, and is mandatory in order to "optimize the use of the propeller". The NAVSCANtm allows the engine r.p.m. and the pitch to be set "just right", although the "range of appropriate pitch is very, very narrow". Back-up methods used in evaluating loading is the engine exhaust temperature pyrometers, although the final adjustment rests on fuel consumed relative to boat speed.

In adjusting the system, maximum engine loading is detected through the use of exhaust temperature pyrometers. Propeller r.p.m. and pitch is adjusted to minimize gallons per mile within the maximum allowable exhaust temperature envelope specified by the engine builder. To much pitch "shows up on the pyrometers" and "fuel consumed relative to boat speed goes up".

The fuel management system is used in setting propeller pitch and engine r.p.m., and the fuel management systems speed log is used primarily in adjusting sail. Although the adjustments on the sail and engine system are "highly weather variable", Dr. Scallenburger finds that he "must adjust the pitch and mostly r.p.m. frequently".

Dr. Schallenburger notes that the weather "makes an incredible difference" in vessel performance relative to fuel consumption primarily due to the additional parasitic drag of the sail rigging. Without sail assist in light air of 20 knots, Dr. Schallenburger records a 20 to 30% difference in fuel consumption upwind verse downwind (with 30% being common). In a 40 knot wind, this grows to a FACTOR of 2 difference. Because of the higher exponent logarithmic relationship of hull resistance relative to speed through the water as compared to the lower exponent logarithmic relationship of wind drag on the vessel rigging, these losses can be controlled through slight changes in vessel speed and/or course, e.g., borrow energy back from the hydraulic resistance side of his composite resistance curve to feed the energy losses due parasitic drag losses due to wind resistance in the rigging. "Slowing down enough can hold your fuel consumption" relative to the wind when not undersail.

Typically, when not using sails, the FERESA motors at 1,200 r.p.m. (4.0 g.p.h. average to 3.75 g.p.h. "nice day" at best pitch) to 1,400 r.p.m. (4.25 average to 4.0 g.p.h. "nice day").

The research vessel FERESA (after a type of small, and also rare, whale) is a SKOOKUM MOTORSAILER, manufactured by Skookum Marine (Skookum is local indian word for "good") of Port Townsend, Washington. Known for their fine motor sailing fishing vessels, their location at the head of Admiralty Inlet is on the last reaches of the Juan de Fuca Strait. Rapid changes in weather from the Northwest (known locally as "Norwesters") blow strait up its throat, building waves dozens of feet tall. With a funnel shaped channel tapering from several dozen miles across at the Pacific Ocean to several miles across (up to 600 feet deep) at the inlet, Juan de Fuca Strait is known as one of the more treacherous bodies of water in the world.

The FERESA is 60 ft. length overall, with 54 ft. on deck. She has a cutter rig of some 1,400 square ft. with mainsail and jib (she has a staysail, but is seldom used). Launched in January of 1981, she displaced 37 tons unloaded (40 gross tons, 30.25 net tons). Power is a single 4-71 Detroit of 115 hp. turning a 36" Hundested C.P. (VP-4) propeller through a Twin Disk 2.9:1 gear. For electricity, besides the main engine alternator, the vessel is equipped with a 2-71 Detroit diesel powered 40 Kw generator running at 1,500 r.p.m. and 50 cycles (instead of 1,800 r.p.m. and 60 cycles). Dr. Schallenburger suggests that the drop in cycles "really saves on noise" and fuel savings also results. His 60 cycle equipment at this time is tolerant of running off cycle, with motors operating slower.

Fuel storage is 1,400 gallons of number 2 diesel fuel. Using a 200 gallon brine tank for fuel, this gives a total capacity of 1,600 gallons useable. Using sail and motor power, and running the generator continuously for freezing fish, a typical trip can run 45 days. The vessel consumes on the main engine about 4.25 gallons per hour at 7.5 knots. Often he uses sail assist, which drops the fuel consumption to an average of about 2 gallons per hour on normal "trade wind" days found in the waters around the Hawaian Islands. Due to wave slamming and wind buffeting, consequential sinesoidal, pseudo-random and random effects cause instantaneous changes in vessel speed, engine rack hunting in response to governor setting (large changes in vessel fuel consumption with relatively small changes in r.p.m.) and operator manual control. In any vessel, a means of averaging the "hunting" rates of change of each inputted variables is necessary. Further, this averaging must be variable in character to allow the fastest possible read-out showing the impacts of the last equipment change to the operator. This averager must have a range suitable in sea states ranging from a dead calm to the force of a huricane.

Dr. Schallenburger regards the NAVSCANtm Variable Time Base Averager (or V.T.B.A.) feature as "essential" for his equipment application. For his long term data recording and use he uses VTBA 7, first clearing the computers internal registers on VTBA 0. On "normal" days he will use VTBA 5 to 8. His NAVSCANtm B-107 contains information regarding engine fuel flow, vessel speed and engine r.p.m., and is the only such instrumentation in the wheelhouse. He has a backup tachometer below decks in the engine room. (See figs. 13 thru 16)

In his use of fuel management equipment and in his limited manual data gathering methods, Dr. Schallenburger has clearly established a fuel saving relationship with sail assistance on the FERESA in the waters he has been sailing. Even though wind is highly variable, the additional safety factor of sail power "significantly increases range". His data thus far has indicated an approximate annual savings in fuel of about 30%. Dr. Shallenburger will be upgrading his system, in the near future, to A.D.R.E.S., thereby allowing a much greater control of experiment design, data gathering, reduction and interpretation without significantly altering his current time and financial commitments. Dr. Schallenburger can be reached at:

Dr. Edward Schallenburger
P.O. Box 516
Kailua, Hawaii 96734

The JAN PAMELA II, a 165 ft. private yacht of motor ship class (largest American flag private yacht in the world), installed an A-101 several years ago after fouled propellers caused an engine overload which precipitated an expensive engine room fire. Besides telling when to clean to propellers and service fuel injectors, the 'A-101' aids in extending the vessel's range. The vessel's meager fuel capacity (5,000 gallons) allows only short cruises with its twin 12V92TI Detroits and twin 4-71 generators. The fuel planning capability with the system has allowed Captain Norman Dahl to pilot the JAN PAMELA II around the world, and make regular transoceanic crossings with existing fuel stores (not practical without the system). (See figs. 24 and 25)

Some vessel burning large quantities of fuel also require "fuel loading" or "fuel transfer" sensors to indicate fuel movment onto and offloaded from the vessel. The system has fuel transfer functions on a number of units.

The Fuel Management system, when ordered with "Gallons Per mile land", the transportation efficiency function, is useful in seeing changes in vessel transportation costs due to shoals or isolated currents, and in planning river speed relative to river traffic and conditions at the objective offloading or barge fleeting site. The strategy would involve planning vessel course in repetitive runs (such as ferry service) to use either a course change, reduced speed or increased power (to "breakaway" region of the power to speed curve relative to vessel pressure wave intereference with river channel walls and/or bottom, e.g. break "suction". This, of course, assumes an intimate understanding of the vessel and its power characteristics.

In planning arrivals and departures relative to transportation efficiency, in river operations a fourty percent (40%) fuel savings is easily seen on down river operations, and five to fifteen percent (5-15%) savings up river, depending on previous vessel operation.

Frequently, significant changes in fuel consumption behavior can occur through reduction of throttle with negligible change in passage time either up or down river. In the case of the Agritrans vessel COOPERATIVE SPIRIT (3 ea. EMD 16-645 E7), it was found that frequently not enough water was under the vessel to allow water flow to sufficiently feed all three propellers. Pulling back the throttles from about 850 turns each ("design load" r.p.m.) to about 760 turns each, and design r.p.m. when water conditions would allow, caused a combined savings of over ten percent (10%) with undetectable change in LAND SPEED. Correction for traffic as mentioned above would yield even greater savings. Similar results have been observed in many other large work boats in the over 5,000 hp. class that have M.S.E. instrumentation with data processed by or reports given to M.S.E.

Recently, through advances in digital technolgy, M.S.E. has introduced a low cost digital torsion meter that is bolted either onto the engine shaft or the propeller shaft. Because of its simple mechanical structure, it is highly immune to the rigors of the commercial fishing and work boat environments and requires little in terms of maintenance and periodic recalibration. Because of its use of a long unit of shaft length to measurew twist (approx. 6 shaft diameters), stable readout on the order of the nearest horsepower and a few foot pounds of torque are easily accomplished. Its use on the workboat GREAT AMERICA has emerged this instrument as a viable reference in monitoring propeller loading and changes in propeller condition, as well as engine fuel to horsepower conversion ratios. (See figs. 26 thru 36)

CONCLUSION:

Fuel management computer based equipment is capable of bringing in a broad range of digital information into a single grouping of relatively low cost electronics and processing this information inexpensively on a per channel basis. It is much cheaper to buy a single integrated system then to purchase separate systems and integrate them. Also, single instrument design and utilization is limited, as the inquiry process usually broadens to the point where data must be gathered, stored, later summarized and interpreted by a person skilled in experiment design. Manual techniques are labor intensive and therefore expensive. An integrated computer based system, if designed as a fully integrated system, can meet these needs at a small increased incremental cost above simple instruments.

A single NAVSCANtm unit, as it is now built, is capable of monitoring, doing conversion ratio calculation, and register totalizing for up to eight engine fuel sensor systems as well as tachometer functions for up to three main engines and vessel speed. Specially sensored and equipped units can indicate kilowatt hours per barrel or gallon. Thrust, thrust conversion factors, and horsepower are available in separate units.

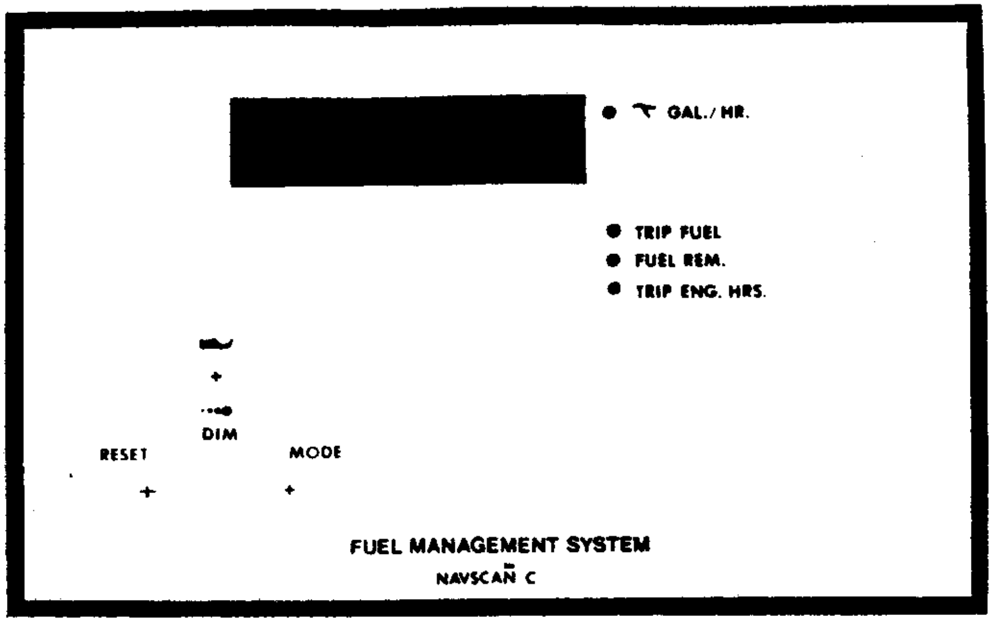
The NAVSCANtm unit is also capable of receiving other digital or frequency inputs for processing information on M.S.E. data storage equipment and recording on data tapes, and thereby has the flexibility for adaptation for a myriad of research applications. A.D.R.E.S.tm software can be easily tailored to specific researchers needs by consultants or themselves, then performs as a "robot" to run the designed experiment or management reporting requirement to finished report condition.

BACKGROUND OF THE AUTHOR:

Hendrick W. Haynes, a Seattle, Washington resident, is a member of the Society of Naval Architects and Marine Engineers, as well as other associations. He is currently active with M.S.E. Corp. in the development of marine instrumentation. This includes fundamental instrumentation design, design of data gathering systems and computer aided techniques for the reduction of mass data concerning propulsion dynamics into useful information fields. Mr. Haynes is involved in marketing functions associated with M.S.E. instrumentation as well.

Mr. Haynes is also an officer of Wolfpak Marine, a firm which specializes in submarine discharging jet drive systems for sailing craft applications (with particular emphasis on high speed multihull craft) and as side thrusters in moderate to high speed power vessels. His functions include marine jet propulsion system design, displacement vessel/jet system integration and the consequential evolution of this class of marine propulsion devices. These functions extend into applications engineering, marketing and management.

FIG. 1

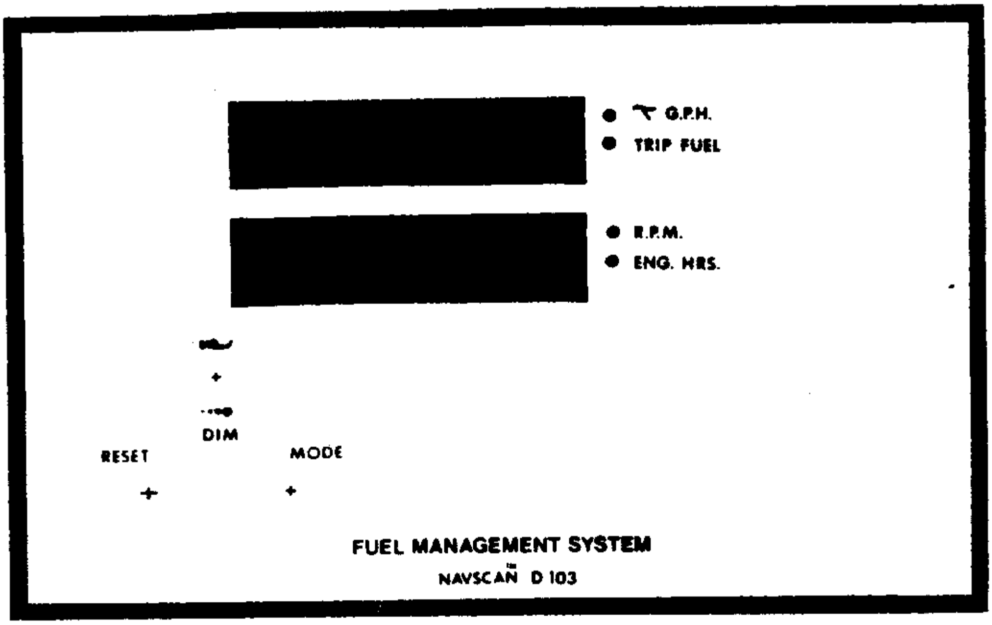


2

Singleton
Fleets
(Key West)

3

FIG. 4



5

Morgan Shrimp
(Key West)

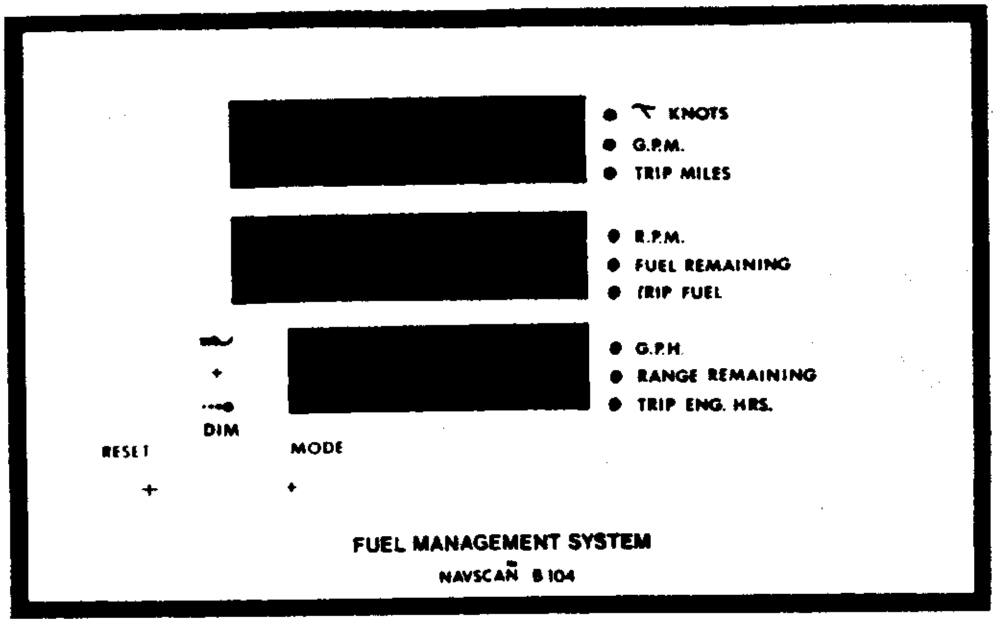
6

F/V Shaa
Isdan

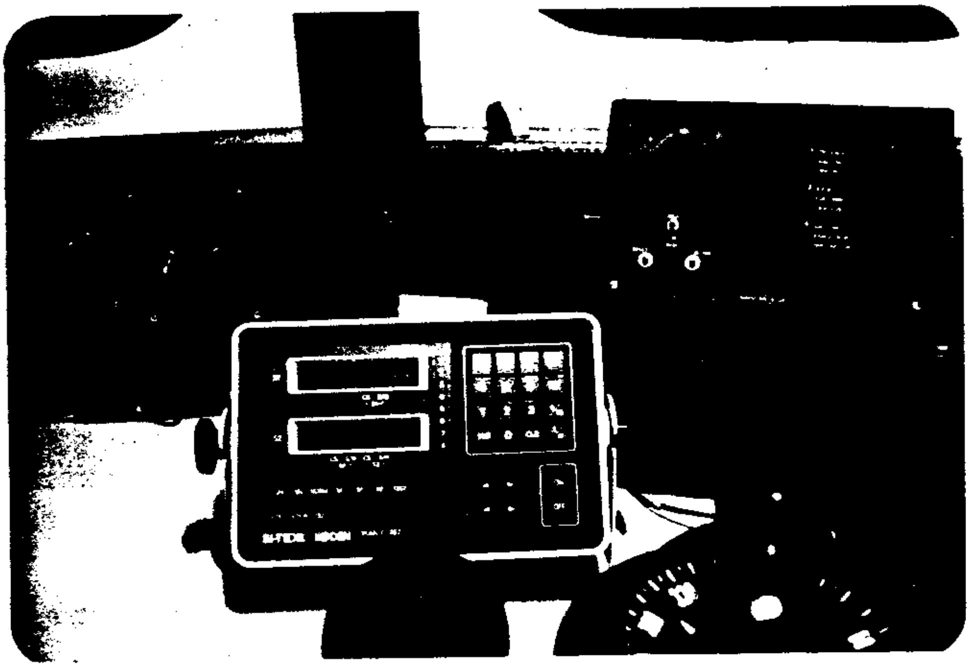
7

Fuel System
Shaa Isdan

FIG. 8

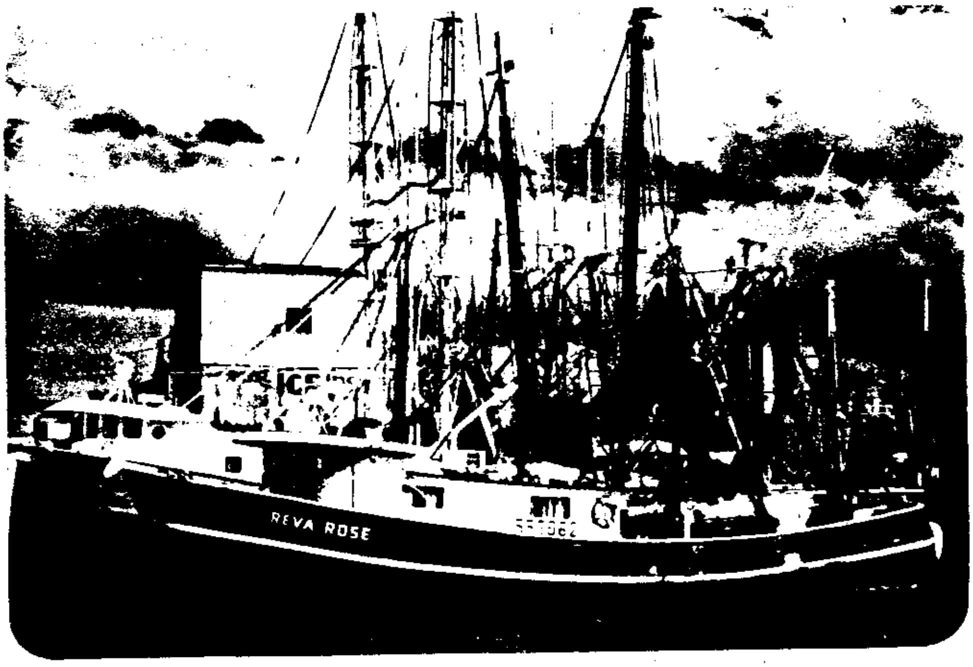


9



Navscan B-104
with Data Tagging
and Data Gathering
on board the
REVA ROSE

10



Reva Rose
(Buloxi)
at Del Cambre
La.

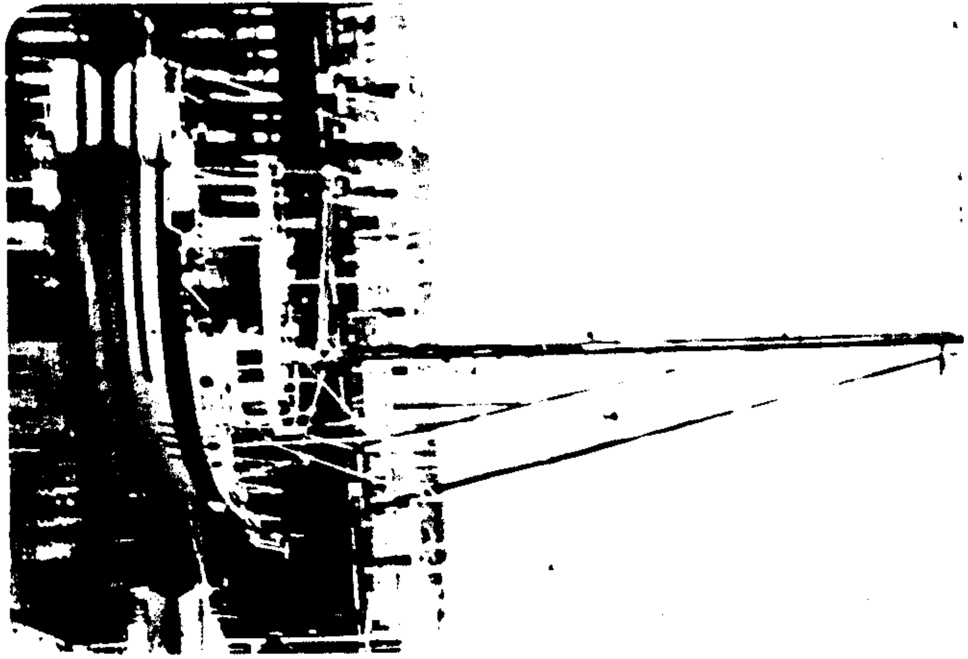
FIG. 11

Capt. Tommy Schultz
in the wheelhouse of
Reva Rose

12

Fuel System for
V-12 Cummins on
Reva Rose

FIG.13

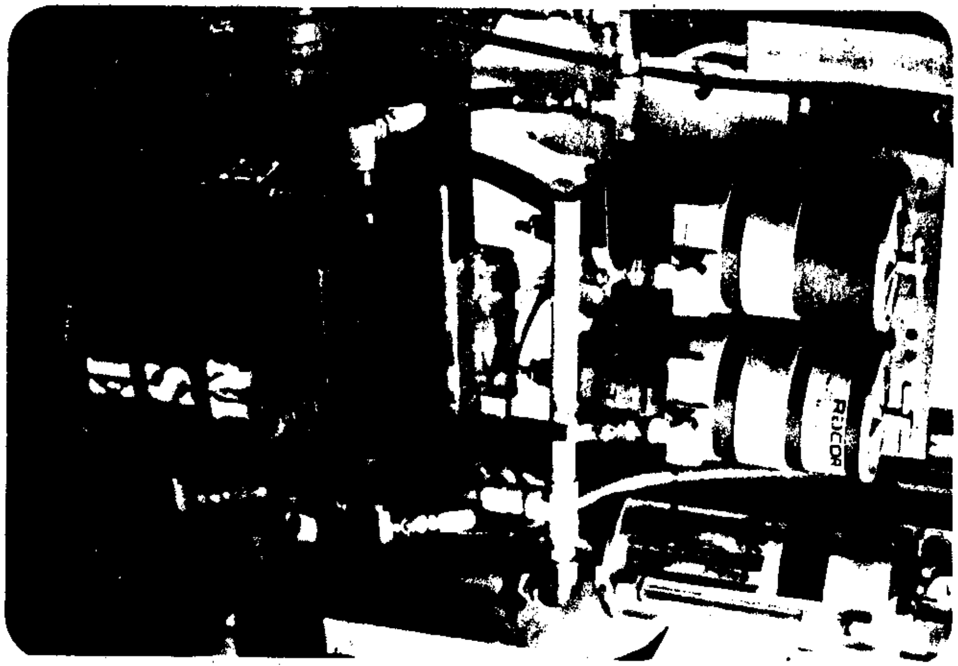


Research Vessel
(Motor Sailer)
FERESA
at Shilshole Marina,
Seattle (Wa.)

14

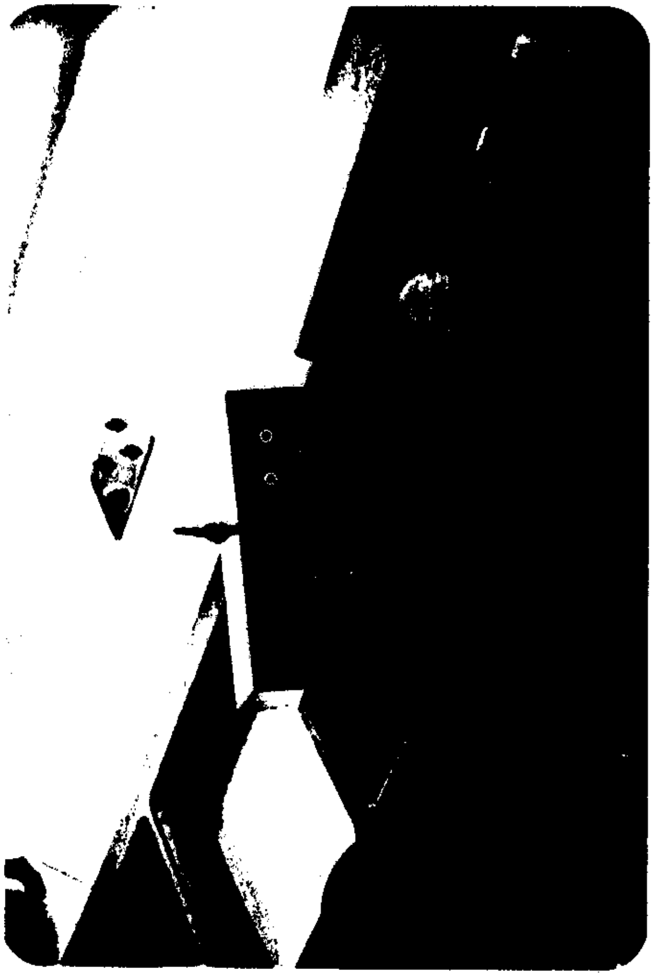
Dr. Edward
Schallenburger, Ph.D.
in wheelhouse of FERESA

FIG.15



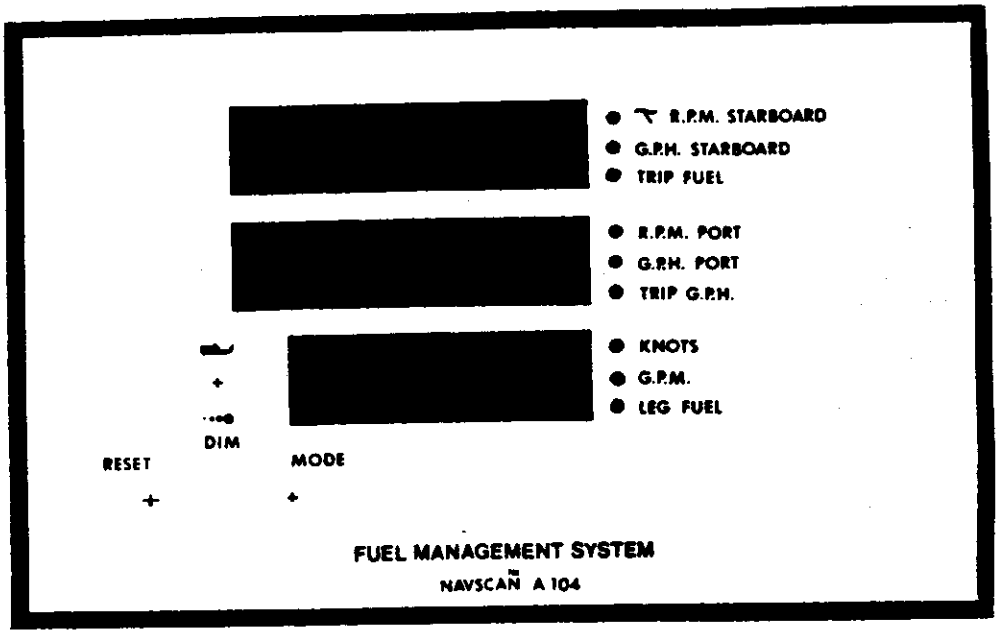
Fuel System on Detroit
4-71 (C.P. Propeller)
aboard Feresa

16



Navscan B-107 aboard
Feresa mounted above

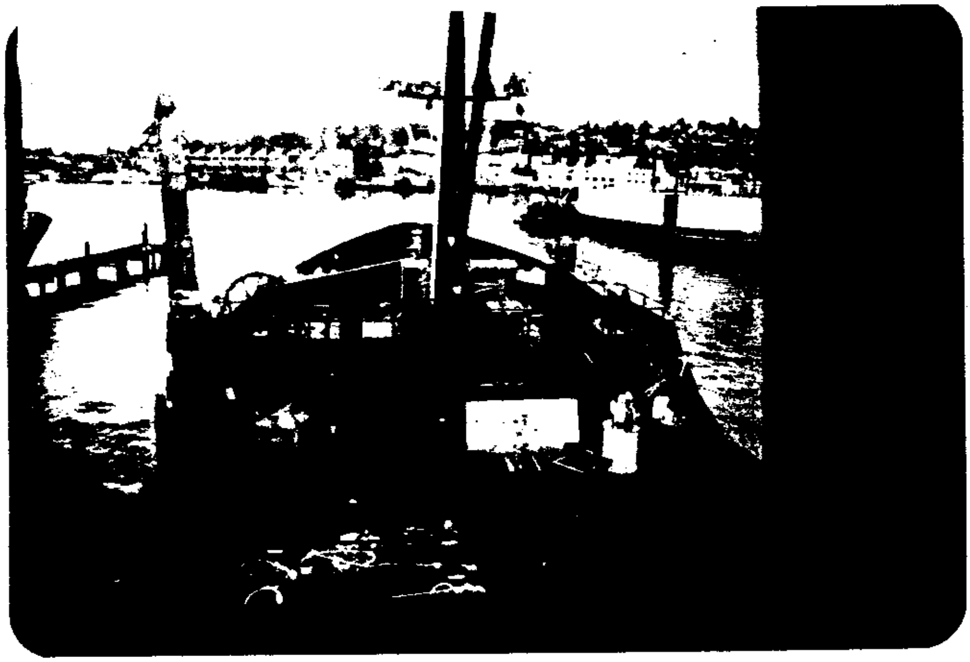
FIG 17



18

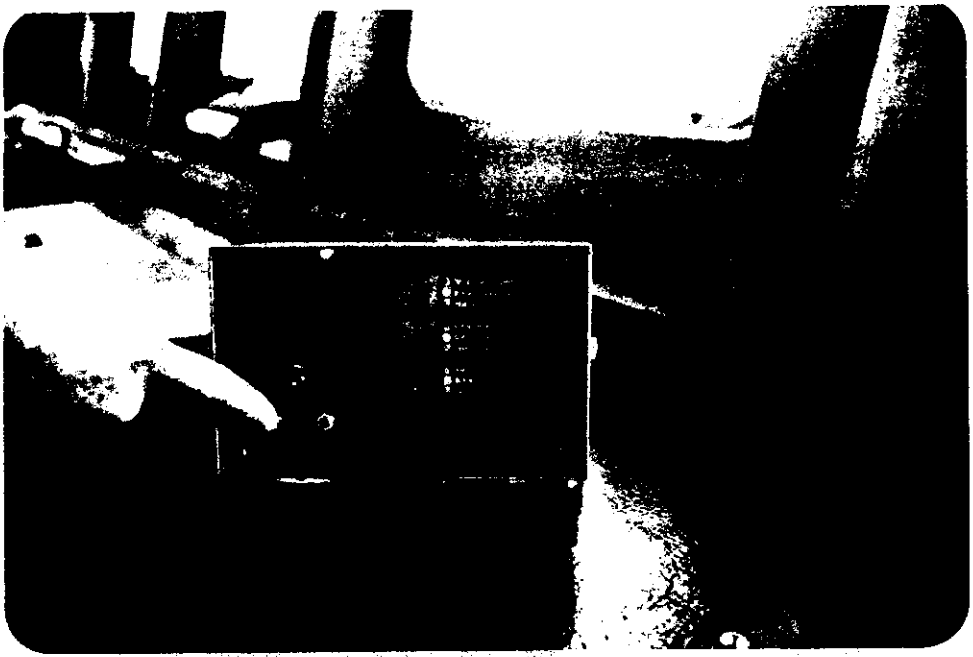
Navscan A-104
in wheelhouse
of Fish Processor/
Crabber Vessel
NORDIC MONARCH

19



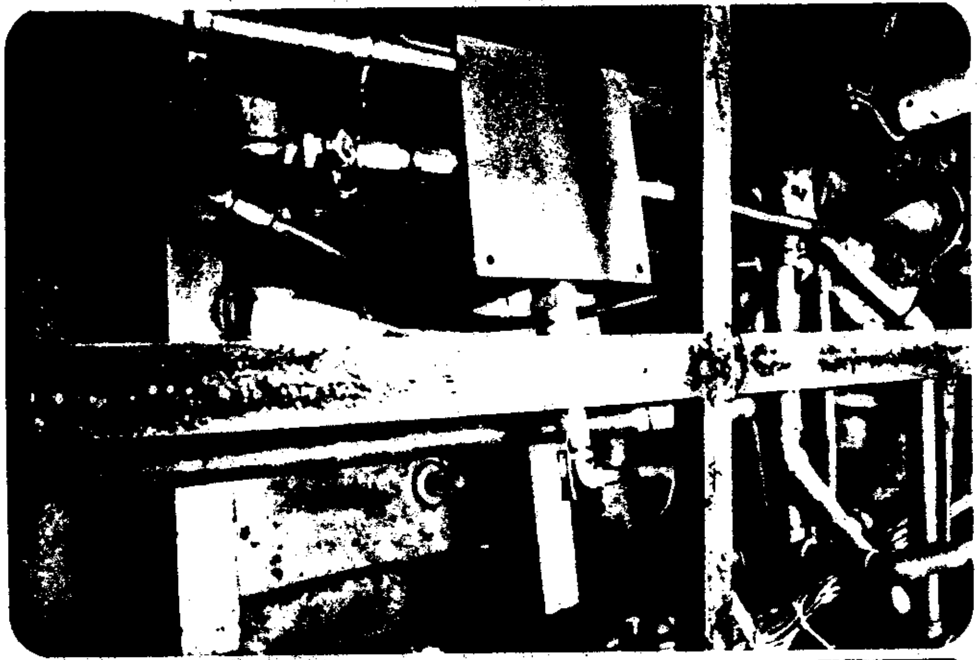
View from wheelhouse
of bow of Nordic
Monarch (Seattle)

FIG. 20



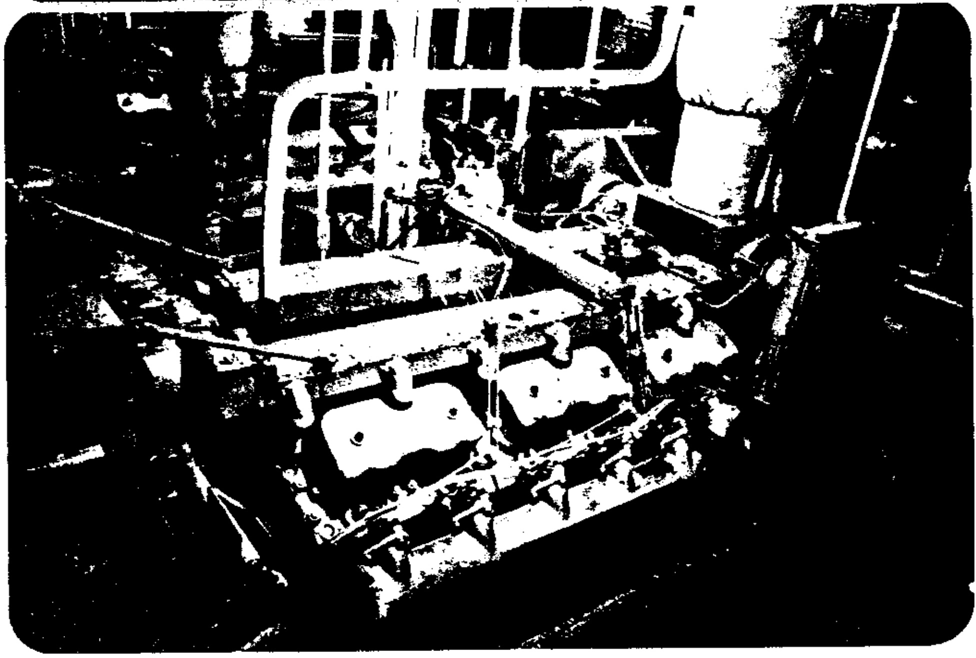
Navscan A-104
aboard Nordic Monarch

21



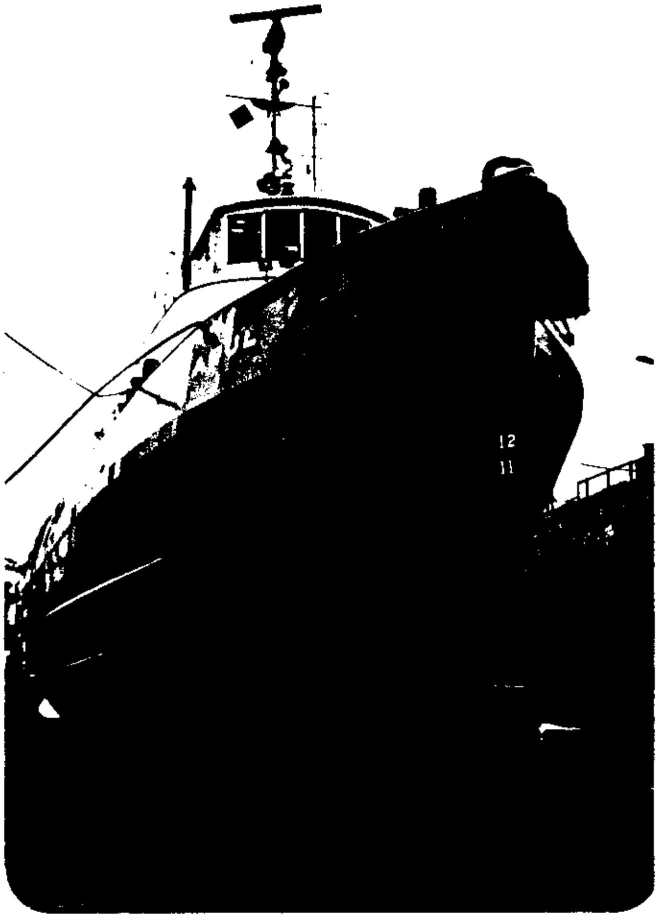
Fuel System
Nordic Monarch

22



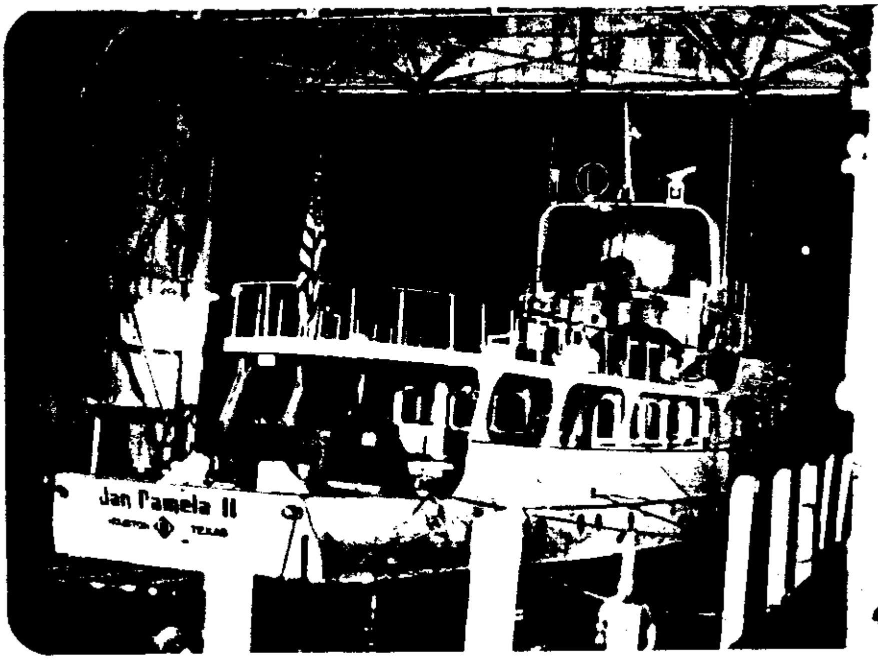
Engine Room
Nordic Monarch
with Cat. 398
engines and
Cat. Generators

FIG 23



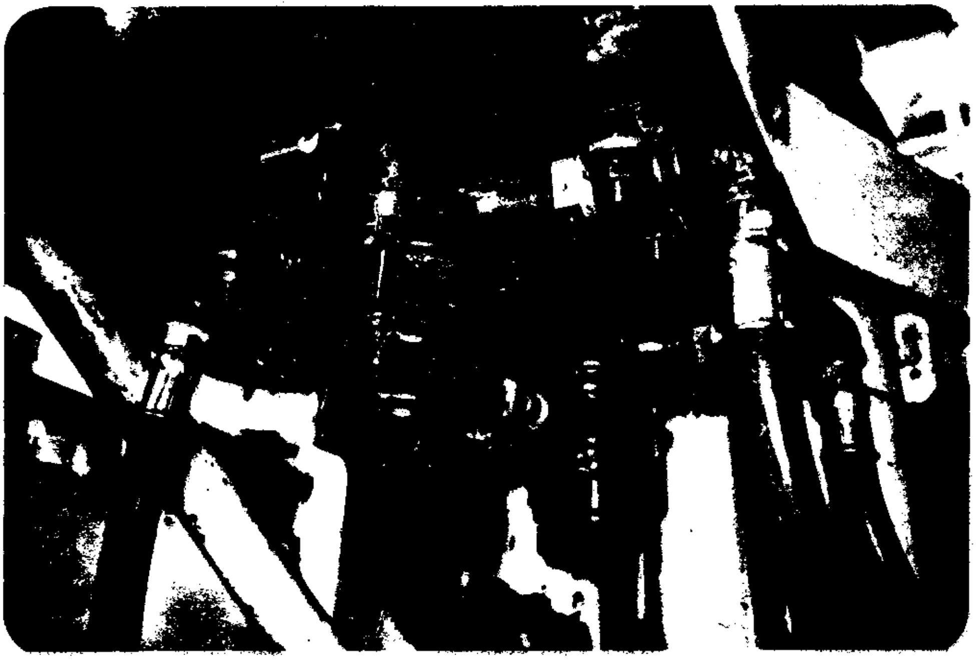
Tug ALAPUL
using B-104
Navscan on EMD
16-645 E-5

24



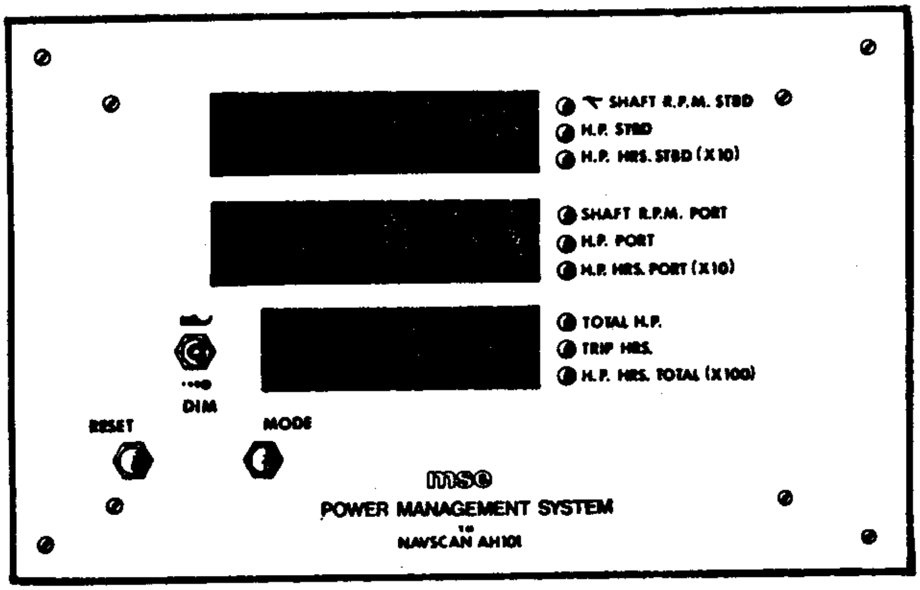
Motor Ship
JAN PAMELA II
using A-101
Navscan on
Detroit engines

FIG.25



Sensor In-
Sensor Out meter
pair as on ALAPUL
and JAN PAMELA II

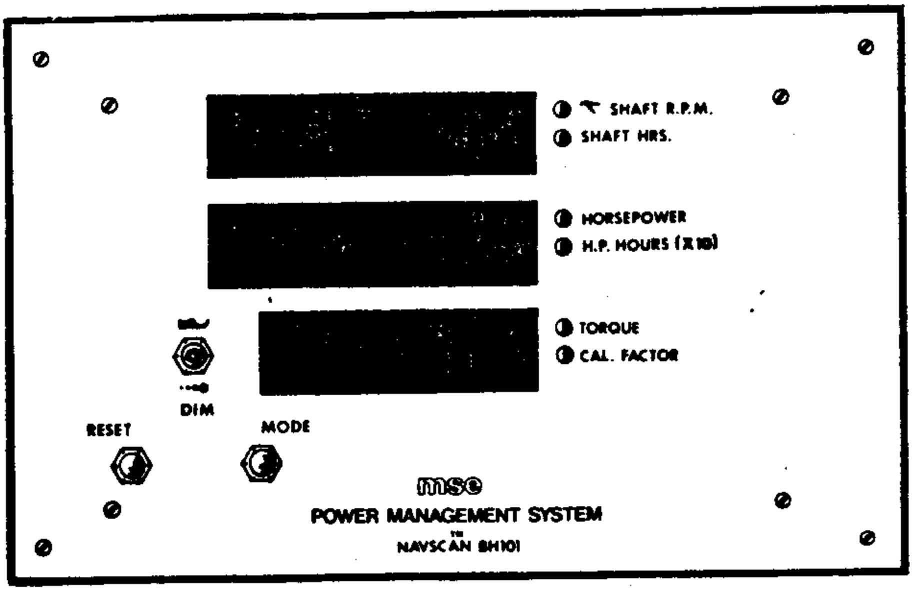
FIG. 26



DUAL ENGINE SYSTEM

POWER MANAGEMENT
SYSTEM read-outs
on m/v GREAT
AMERICA

27

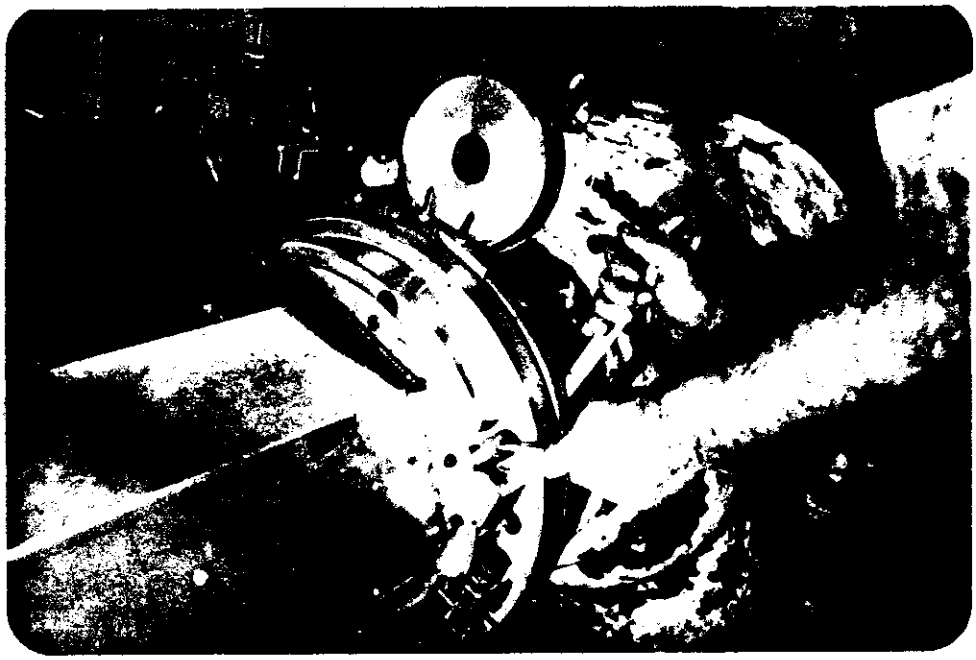


SINGLE SHAFT SYSTEM

FIG. 28

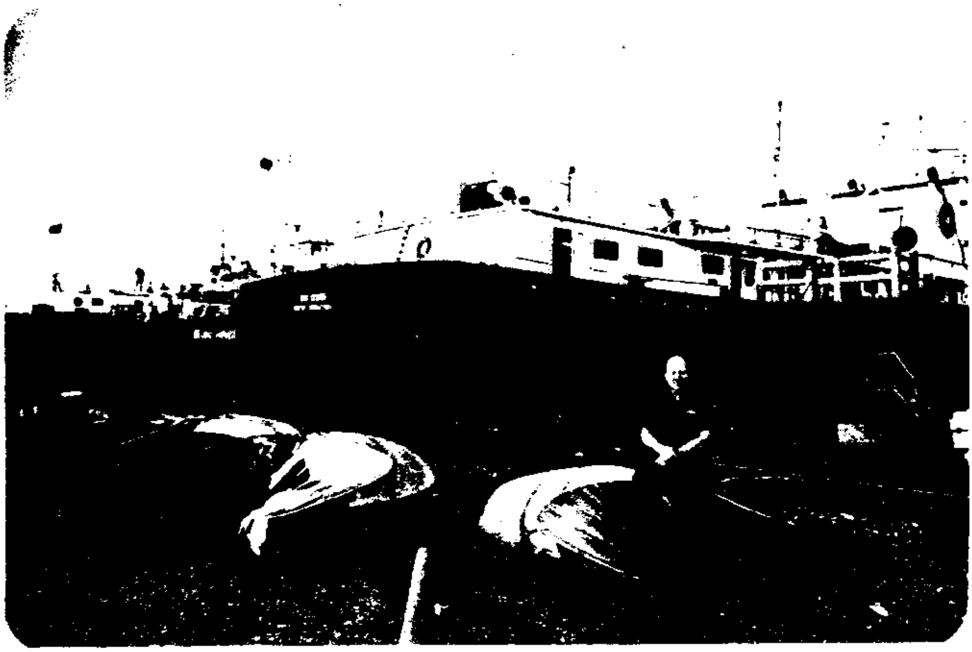
target pins passing through sensor pick-up on Great America

29



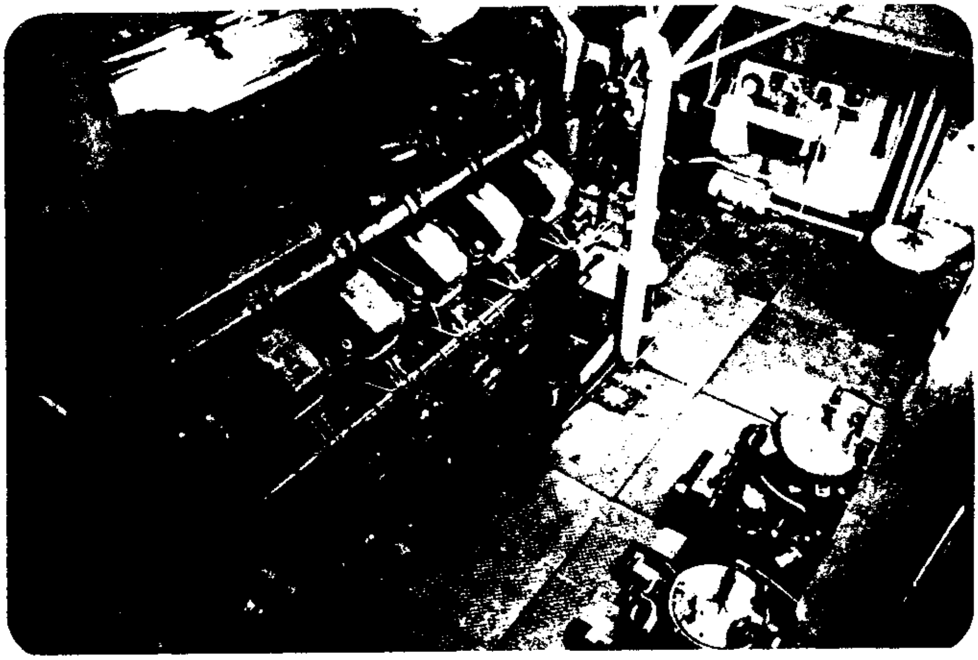
Adjusting shaft torsion meter

30



Bruce Ross sitting on hub of Great America propeller

FIG. 31



S.E.M.T. Pielstick
12 PA6 V280 heavy
fuel engines aboard
Great America

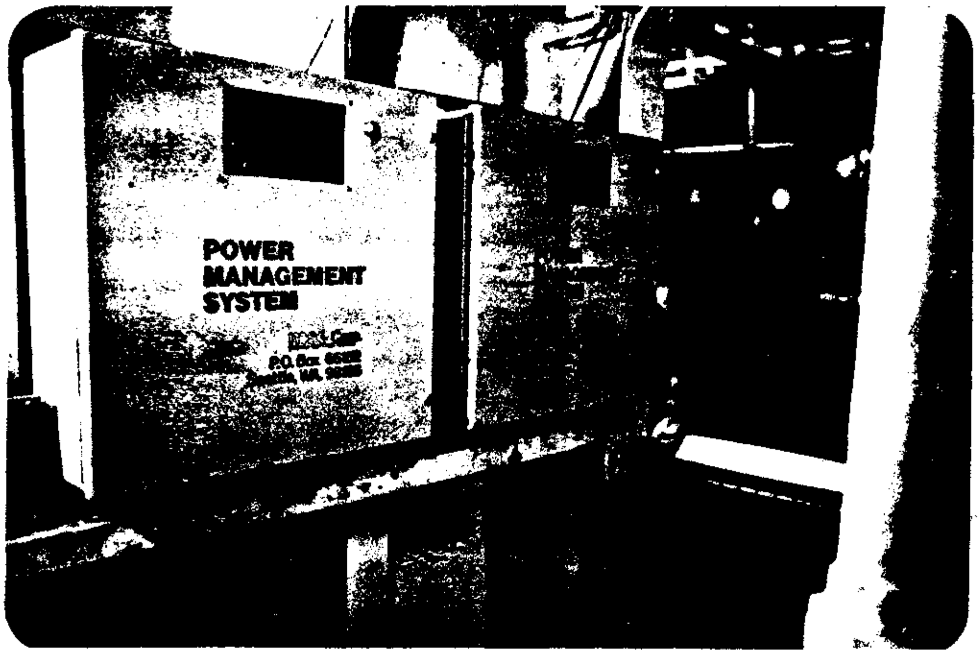
32

B. D. Ross in front
of Fuel System for
Great America

33

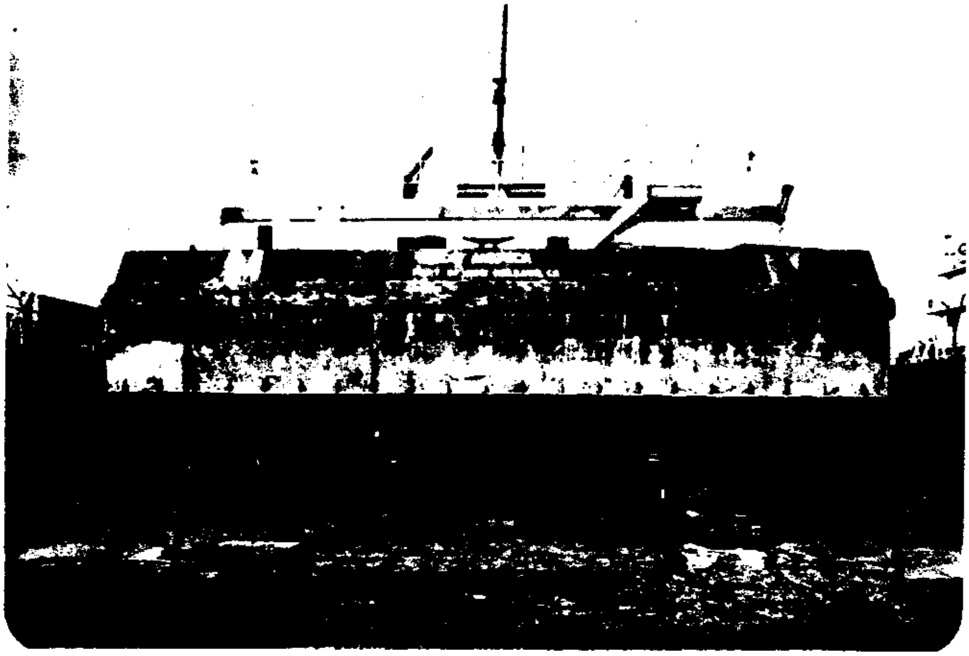
M.S.E. Torsion Meter
and Ross on Great
America (New Orleans)

FIG. 34



Shaft torsion meter read-outs

35.



Nozzles on M/V Great America

36

M/V GREAT AMERICA

FISHING VESSEL ACTIVITY SHEET

VESSEL	OBSERVER	START STATION	CRUISE
Reva Rose	G D D[illegible]		

MONTH	DAY	YEAR
11	19/20	80

STOP STATION

STATION SHEET NUMBER	START TIME*	STOP TIME*	ACT. TIME	RPM	FUEL FLOW (GAL/HR)	TOTAL FUEL USED	TOW SPD	TOW LINE OUT	RAIL PRESSURE
F 2/	1645	1934	2.49	1470	16	142/48		50 fathoms	
PT	1934	1948	~~:14~~ 0014	1474/714	16.1	148/1			
F 2	1748	0005	4.17	1466	16	218/70		50 fathoms	
PT	0005	0023	0018	1461/760	17/1	221/3			
FT	0023	0435	0412	1564	14	283/62			
F 2	04·46	0805	3:25	1495	15	337/54		60 fathoms	
PT	0805	0816	:11	1444/870	16/3	340/3			
F 2	0816	1235	4:22	1412	17	411/71		60 "	"
PT	12 38	1249	:11	1464/779	17/3	414/3			
F 2	1249	1654	4:05	1457	16	479/65		60 "	"
PT	1654	1714	:16	1453/769	14/2	479/0			

INSTRUCTIONS: Fill in one or more Activity Sheet(s) for each cruise. Fill in the vessel code, the observer code, the beginning and ending "Marine Turtle Conservation Shrimp Trawl Stations Sheet" numbers. Fill in the time that each separate activity starts and stops. If the activity requires filling out a "Marine Turtle Conservation Shrimp Trawl Stations Sheet", reference the station sheet number in the first column. Fill in the activity code from the code table below.

*Start and stop time must be entered in the standard 24 hour "Military Time" format.

ACTIVITY CODES:

F0 = Fishing With the Try Net Only
F1 = Fishing With 1 Trawl
F2 = Fishing With 2 Trawls
F3 = Twin Trawl, one side
F4 = Quad Trawl
WU = Warm-up Time at the Dock or After Being Anchored

FF = Running From 1 Fishing Area to Another
PF = Running From Port to First Fishing Area
FP = Running From the Last Fishing Area to Port
LT = Anchored or Laying-to
PT = Pick-up Time

TABLE 1

HAND RECORDED DATA, SAMPLE
Observer aboard "Reva Rose"

D. RAY MILLER

CLOCK	PORT RPM	PORT GPH	STB RPM	STB GPH	FUEL USED	MODE	AVG	DIM	FAULT CODE
.908533	350.14	4.98616	392.824	16.1164	21019	1	4	30	DOT
.910164	459.348	25.4271	497.375	29.0703	21024	1	4	30	DOT
.911795	904.477	147.345	905.433	146.326	21070	1	4	30	DOT
.913426	904.477	145.899	906.39	144.899	21117	1	4	30	DOT
.915057	904.477	144.747	906.39	145.014	21165	1	4	30	DOT
.916689	904.477	145.551	907.349	145.129	21212	1	4	30	DOT
.91832	904.477	145.397	907.03	144.519	21260	1	4	30	DOT
.919951	904.477	149.183	907.349	145.474	21307	1	4	30	DOT
.921582	904.477	145.091	906.71	145.628	21355	1	4	30	DOT
.923213	904.477	144.519	906.71	145.821	21402	1	4	30	DOT
.924844	904.477	145.091	907.349	145.205	21450	1	4	30	DOT
.926475	693.668	70.14	727.42	77.9533	21483	1	4	30	DOT
.928106	904.477	147.463	904.159	145.937	21518	1	4	30	DOT
.929737	904.795	146.248	907.03	145.244	21566	1	4	30	DOT
.931368	904.795	147.701	904.477	145.705	21613	1	4	30	DOT
.933	904.795	144.785	905.752	145.513	21661	1	4	30	DOT
.934631	904.795	144.671	907.03	145.513	21708	1	4	30	DOT
.936262	891.619	140.531	893.478	136.757	21748	1	4	30	DOT
.937893	904.795	147.108	905.114	145.937	21795	1	4	30	DOT
.939524	904.795	145.129	907.03	145.244	21843	1	4	30	DOT
.941155	815.809	108.553	771.043	87.4882	21889	1	4	30	DOT
.942786	754.527	91.2472	701.426	72.574	21916	1	4	30	DOT
.944417	469.753	25.5475	396.825	15.8915	21929	1	4	30	DOT
.946049	453.755	23.0392	553.352	39.8434	21943	1	4	30	DOT
.94768	596.204	45.6388	702.192	71.9663	21967	1	4	30	DOT
.949311	369.352	24.1839	384.025	6.67352	21977	1	4	30	DOT
.950942	366.3	12.232	346.181	5.41648	21982	1	4	30	DOT
.952573	362.53	5.34116	865.218	134.681	21992	1	4	30	DOT
.954204	904.477	145.783	907.03	143.388	22039	1	4	30	DOT
.955835	904.159	145.091	907.349	144.899	22086	1	2	15	DOT
.957466	904.477	146.404	907.349	143.463	22134	1	2	15	DOT
.959098	904.477	143.127	907.349	143.763	22181	1	2	15	DOT
.960729	904.795	146.054	907.03	146.131	22229	1	2	15	DOT
.96236	904.477	149.345	906.39	144.747	22276	1	2	15	DOT
.963991	904.795	146.599	907.67	142.534	22324	1	2	15	DOT
.965622	904.795	145.628	907.03	144.938	22371	1	2	15	DOT
.967253	904.795	145.551	907.67	144.747	22418	1	2	15	DOT
.968884	904.795	143.426	907.99	141.909	22466	1	2	15	DOT
.970516	904.795	146.404	905.752	147.187	22513	1	2	15	DOT
.972147	904.795	143.763	906.71	146.248	22560	1	2	15	DOT
.973778	904.795	146.99	906.39	145.937	22608	1	2	15	DOT
.975409	904.795	144.291	906.39	146.443	22655	1	2	15	DOT
.97704	904.795	145.551	907.67	144.405	22703	1	2	15	DOT
.978671	904.795	146.054	907.67	144.329	22750	1	2	15	DOT
.980302	904.477	146.404	907.349	145.474	22797	1	2	15	DOT
.981933	904.795	145.59	905.114	145.899	22845	1	2	15	DOT
.983564	904.795	146.015	903.841	145.937	22892	1	2	15	DOT
.985196	904.795	145.976	907.67	142.83	22940	1	2	15	DOT
.986827	904.795	145.899	907.99	143.763	22987	1	2	15	DOT
.988458	904.795	146.599	904.477	145.551	23034	1	2	15	DOT
.990089	904.795	147.741	907.349	145.282	23082	1	2	15	DOT
.99172	904.795	145.167	907.349	144.671	23129	1	2	15	DOT
.993351	876.126	143.053	874.041	136.825	23158	1	2	15	DOT

TABLE 2

DATA RECORDER LISTINGS
FROM MAGNETIC TAPE
Navscan^{tm} aboard D. Ray Miller

D. RAY MILLER

CLOCK	PORT RPM	PORT GPH	STB RPM	STB GPH	FUEL USED	MODE	AVG	DIM	FAULT CODE
.994982	904.795	147.148	907.03	145.937	23205	1	2	15	DOT
.996613	904.795	144.823	906.39	145.821	23253	1	2	15	DOT
.998244	349.807	6.34269	345.576	6.84962	23262	1	2	15	DOT
.999876	349.902	4.91654	361.511	5.64217	23265	1	2	15	DOT
1.00151	350.045	5.19669	345.39	4.76154	23266	1	2	15	DOT
1.00314	380.783	6.1369	360.801	16.0966	23269	1	2	15	DOT
1.00477	350.379	6.38295	353.412	7.96211	23272	1	2	15	DOT
1.0064	350.426	5.47313	345.483	5.6248	23273	1	2	15	DOT
1.00803	350.474	5.55617	345.251	5.91611	23275	1	2	15	DOT
1.00966	412.485	16.2043	393.245	14.2453	23279	1	2	15	DOT
1.01129	350.426	5.44792	345.762	5.94058	23282	1	2	15	DOT
1.01292	350.522	5.55987	345.251	6.19517	23284	1	2	15	DOT
1.01456	350.522	5.65423	345.622	6.36449	23286	1	2	15	DOT
1.01619	350.522	5.72432	345.529	6.55424	23288	1	2	15	DOT
1.01782	350.57	5.91643	345.529	6.60651	23290	1	2	15	DOT
1.01945	350.57	5.9443	345.622	6.65849	23292	1	2	15	DOT
1.02108	350.57	5.89335	345.39	6.72344	23294	1	2	15	DOT
1.02271	350.57	5.97043	345.715	6.80833	23296	1	2	15	DOT
1.02434	350.522	5.95486	345.436	6.87067	23298	1	2	15	DOT
1.02597	350.522	5.95511	345.576	6.88719	23300	1	2	15	DOT
1.0276	350.522	6.12242	345.669	6.94431	23302	1	2	15	DOT
1.02924	350.522	6.01904	345.576	6.97284	23304	1	2	15	DOT
1.03087	350.474	6.09447	345.436	6.95591	23306	1	2	15	DOT
1.0325	350.474	6.06477	345.483	6.98923	23309	1	2	15	DOT
1.03413	350.474	6.06517	345.669	6.98799	23311	1	2	15	DOT
1.03576	350.474	6.16905	345.715	7.03743	23313	1	2	15	DOT
1.03739	350.474	6.06684	345.762	7.02144	23315	1	2	15	DOT
1.03902	350.522	6.06638	345.436	6.9926	23317	1	2	15	DOT
1.04065	350.426	6.11684	345.948	7.0441	23319	1	2	15	DOT
1.04228	350.426	6.06704	345.576	7.05992	23321	1	2	15	DOT
1.04392	350.426	6.18785	345.297	7.00186	23324	1	2	15	DOT
1.04555	350.426	6.16697	345.808	7.03842	23326	1	2	15	DOT
1.04718	350.426	6.23513	345.669	7.03059	23328	1	2	15	DOT
1.04881	350.379	6.06337	345.576	7.01356	23330	1	2	15	DOT
1.05044	350.379	6.01766	345.855	6.96983	23332	1	2	15	DOT
1.05207	350.379	6.18347	345.669	6.97284	23334	1	2	15	DOT
1.0537	350.379	6.04371	345.483	6.96621	23336	1	2	15	DOT
1.05533	350.331	6.01411	345.948	6.92988	23339	1	2	15	DOT
2.09762	718.076	79.3477	658.328	60.0151	39876	1	3	13	DOT
2.10088	709.555	76.6604	653.476	57.8988	39921	1	3	13	DOT
2.10251	720.692	81.1146	650.83	58.6457	39943	1	3	13	DOT
2.10414	720.692	80.239	648.859	57.9109	39966	1	3	13	DOT
2.10577	719.482	79.5198	646.9	56.8104	39988	1	3	13	DOT
2.1074	719.281	79.3363	647.878	57.5233	40011	1	3	13	DOT
2.10904	700.28	72.6507	677.048	63.0272	40028	1	3	13	DOT
2.11067	731.975	82.0096	688.284	67.2418	40053	1	3	13	DOT
2.1123	732.184	82.3164	685.714	65.2245	40077	1	3	13	DOT
2.11393	731.767	83.0246	682.439	64.6723	40101	1	3	13	DOT
2.11556	731.559	82.8246	678.835	63.405	40125	1	3	13	DOT
2.11719	731.143	81.6565	677.226	63.2883	40149	1	3	13	DOT
2.11882	731.559	81.2224	675.625	62.8328	40173	1	3	13	DOT
2.12045	731.767	82.3904	676.158	63.3685	40196	1	3	13	DOT
2.12208	737.856	83.4529	698.189	69.423	40217	1	3	13	DOT

TABLE 2 (cont)

```
      D E S C R I P T I V E   S T A T I S T I C S
---------------------------------------------------------------


VARIABLE:  PORT TACH              SAMPLE SIZE N1= 463              SAMPLE SIZE N2= 463
           CTR TACH
                                  BOAT 1:KYLE                      BOAT 2:KYLE


  SAMPLE STATISTICS:

MEAN 1        =  569.761     MEAN 2        =  623.444    MEAN DIF.       =  53.6835     ( 9.42213 %)

VARIANCE 1    =  701.139     VARIANCE 2    =  727.071    VARIANCE DIF.   =  25.9321     ( 3.69856 %)

STD. DEV. 1   =  26.479      STD. DEV. 2   =  26.9643    STD. DEV. DIF.  =  .485226     ( 1.83249 %)

RANGE 1       =  760.103     RANGE 2       =  471.163    RANGE DIF.      = -288.94      (-38.0133 %)

MAXIMUM 1     =  760.103     MAXIMUM 2     =  820.494    MAXIMUM DIF.    =  60.3911     ( 7.94512 %)

MINIMUM 1     =  0           MINIMUM 2     =  349.331    MINIMUM DIF.    =  349.331     =  (1/0)%)


  UNBIASED ESTIMATES OF POPULATION PARAMETERS:

VARIANCE 1    =  702.656     VARIANCE 2    =  728.644    VARIANCE DIF.   =  25.9882     ( 3.69856 %)

STD. DEV. 1   =  26.5077     STD. DEV. 2   =  26.9934    STD. DEV. DIF.  =  .485758     ( 1.83252 %)


  DATA DISTRIBUTION COEFFICIENTS:

SKEWNESS 1    = -21.5174     SKEWNESS 2    = -20.2316    SKEWNESS DIF.   =  1.28578     (-5.97553 %)

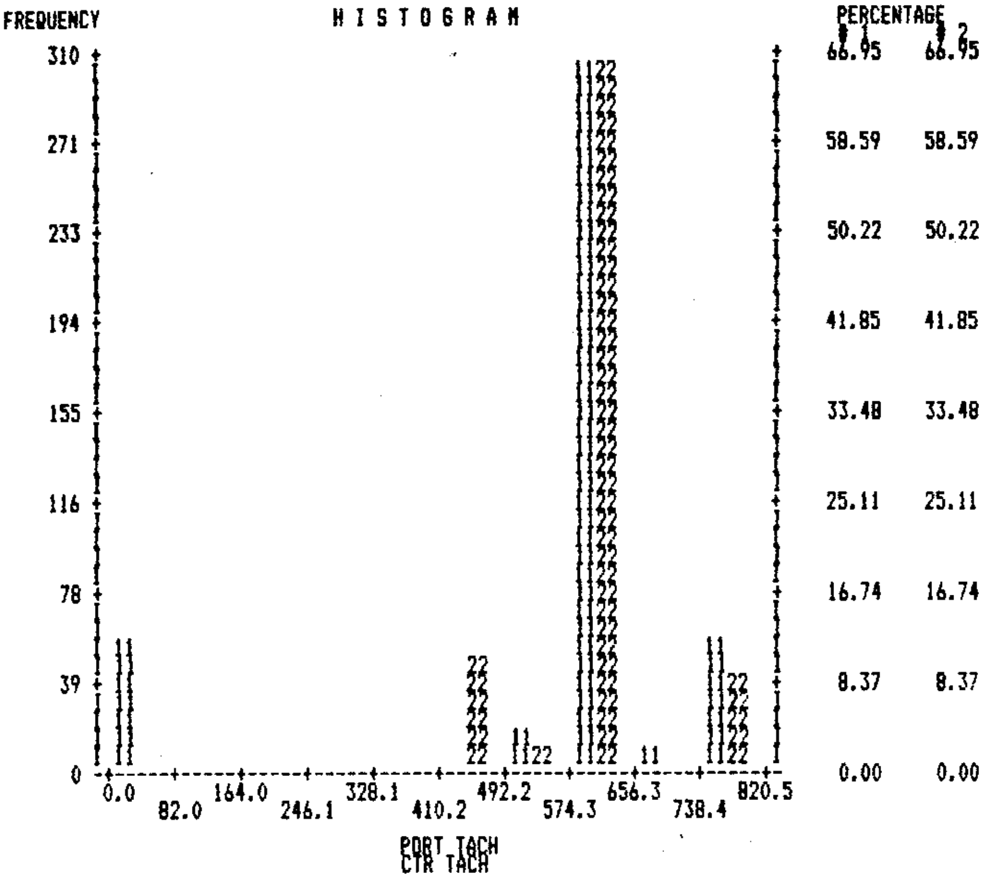
KURTOSIS 1    =  460         KURTOSIS 2    =  428.151    KURTOSIS DIF.   = -31.8491     (-6.92372 %)



------------------------------------------------------------
   DATA FILES USED FOR THIS ANALYSIS WERE 'KYLE' AND 'KYLE'
```

TABLE 3

ENGINE USE STATISTICS, m/v KYLE using A.D.R.E.S.$^{\text{tm}}$ (early engine "run-up" after heavy fuel conversion on EMD 16-645, not to full power of 900 r.p.m.)



DATA FILES USED WERE 'KYLE' AND 'KYLE'

```
SAMPLE SIZE N1 =  463                   SAMPLE SIZE N2 =  463
BOAT 1:KYLE                             BOAT 2:KYLE

INTERVAL                PERCENT 1  PERCENT 2  DELTA        FREQ. 1    FREQ. 2

   0.0  TO    0.0    12.743%     0.000%                        59          0
   0.0  TO   82.0     0.000%     0.000%                         0          0
  82.0  TO  164.0     0.000%     0.000%                         0          0
 164.0  TO  246.1     0.000%     0.000%                         0          0
 246.1  TO  328.1     0.648%     2.808%   333.333%              3         13
 328.1  TO  410.2     0.216%    12.527%  %5700.000%             1         58
 410.2  TO  492.2     3.888%     3.888%     0.000%             18         18
 492.2  TO  574.3    66.739%    66.955%     0.324%            309        310
 574.3  TO  656.3     3.024%     2.808%    -7.143%             14         13
 656.3  TO  738.4    12.743%    11.015%   -13.559%             59         51
```

TABLE 4

HISTOGRAMIC DATA COMPARISON

```
                     C O R R E L A T I O N   M A T R I X

 142.753. o                                                         X BY Y PLOT
        .                                                           -----------
        .
        .                                                           X-VARIABLE=
 115.173.                                                           CTR TACH
        .
        .                                                           Y-VARIABLE=
        .                                                           CTR FUEL
  87.594.
        .                                                           SLOPE=
        .                                                           .0928722
        .
  60.014.                                                           Y-INTERCEPT=
        .                                                        o -31.3217
        .                                                 oooo
        .                                            oo o.oo....   N PAIRS=
  32.435.                                        ......o...         463
        .                               .ooooo....
        .                      ....oooo..oo
        .      o     ....ooo.oo
   4.855.o   .o...o.ooo
        ..........................................................
      349.331    443.564    537.796    632.029    726.262    820.494

                       C O R R E L A T I O N   M A T R I X
-------------------------------------------------------------------------------
VAR. #        1       2


   1        463   0.795


   2        463  463
-------------------------------------------------------------------------------
Note: r's in upper triangle, N's in diagonal, contingent N's in lower triangle.


                     V A R I A B L E   S T A T I S T I C S
-------------------------------------------------------------------------------
VARIABLE #           VARIABLE NAME                    MEAN           S.D.
-------------------------------------------------------------------------------
     1                CTR TACH                   623.4440        98.5720

     2                CTR FUEL                    26.5791        11.5145
-------------------------------------------------------------------------------

DATA FILE USED: 'KYLE'
```

TABLE 5

SIMPLE GRAPH REDUCTION

```
  MULTI SCATTER PLOT OF FILE 'KYLE'
             1 = 200  TO 900 CTR TACH

----------+....+....+....+....+....+....+....+....+....+....+....+....+.
CTR FUEL  .                                                            .
 49       .                                                  1         .
 48       .                                                 11         .
 47       .                                                  1         .
 46       .                                                            .
 45       .                                                1           .
 44       .                                                1           .
 43       .                                                1           .
 42       .                                              11            .
 41       .                                              1             .
 40       .                                                            .
 39       .                                            1               .
 38       .                                            11              .
 37       .                                                            .
 36       .                                                            .
 35       .                                                            .
 34       .                                                            .
 33       .                                                            .
 32       .                                                            .
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TABLE 5 (cont)

Advanced Wind Propulsion Devices-Current Status and Potential

Kenneth C. Morisseau
Naval Sea Systems Command (56W24)
Washington, D.C. 20362

ABSTRACT: Wind propulsion has evolved over thousands of years to the basic Marconi or Bermuda rig commonly seen on yachts and small workboats. In recent times some radical and not quite so radical concepts have been proposed and demonstrated for wind propulsion. Three of these relatively new ideas are explained and their potential compared to existing designs: Magnus effect devices or Flettner rotors, rigid airfoils and wind propellers. Each of the new concepts is discussed as to what has been done, is being done or is planned. The merits and problems with the concepts are reviewed and their potential for workboat and ship propulsion is evaluated. An appendix is included that reviews actual and potential marine applications of the Magnus effect other than for wind propulsion.

BACKGROUND

Surely sail propulsion dates back thousands of years to the time when an early sailor got tired of paddling and rigged a sail that was probably no more sophisticated than a bedsheet attached to some sort of pole (mast). Since those early times the sail has evolved into the relatively sophisticated form called either a Bermuda or Marconi Rig, currently in use on yachts. For more details on sail form evolution see Smith's fascinating book "The 40-Knot Sailboat." (1)

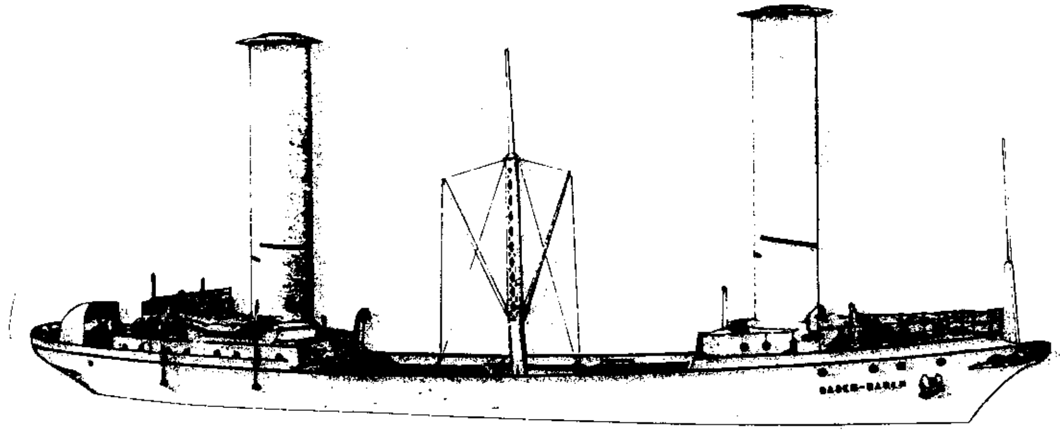


Figure 1: Flettner's first rotor ship - BADEN-BADEN

In 1924, a revolutionary sail form was introduced by Anton Flettner, a German entrepreneur. Flettner's device which he called the Flettner Rotor relies on a phenomenon discovered by Magnus before the turn of the century. Magnus' research was prompted by a desire on the part of the German military to find out why artillery projectiles would not stay on course. Magnus established that a spinning projectile in a cross wind would move at right angles to the wind. (This is also the phenomenon which causes baseballs to curve when spun by the pitcher.) Flettner's rotor was designed to take advantage of this characteristics called the Magnus effect. Flettner mounted two of his rotors on a small ship, the BADEN-BADEN shown in Figure 1, which successfully crossed the Atlantic and during the crossing passed through a hurricane. Flettner also fitted a larger vessel "BARBARA", with two rotors. (2) Although both these experimental ships were successful, the very low cost of fossil fuel caused the investigations to end in the late 1920's.

Since World War II, the small high performance sailboat community - most especially Class C catamaran proponents - developed small rigid airfoil sails. (Figure 2) The Cross Bow - a 70 foot catamaran with an airfoil rig - currently holds the sail speed record of 33.8 knots. (4) Rigid airfoil sails have the advantage of significantly higher lift coefficients than soft sails.

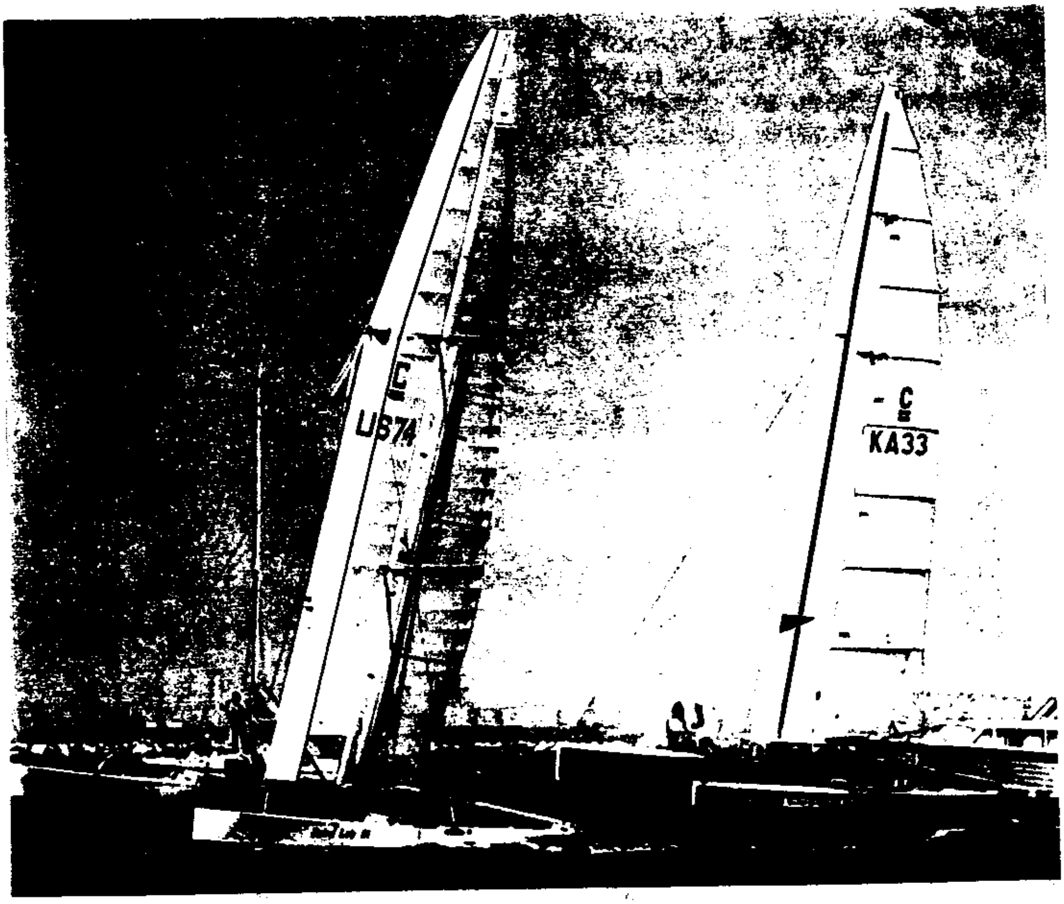


Figure 2: Class C catamarans with wing sails. Patient Lady on the left is a U.S. design and Nicholas II is an Australian design. (3)

Since 1956, the Shipbuilding Institute, in Hamburg, German, has been studying a modern square rig system with cloth sails and in-the-mast roller reefing and furling called Dynaship. (5) (Figure 3) Unfortunately the Dynaship system has not progressed past the model stage.

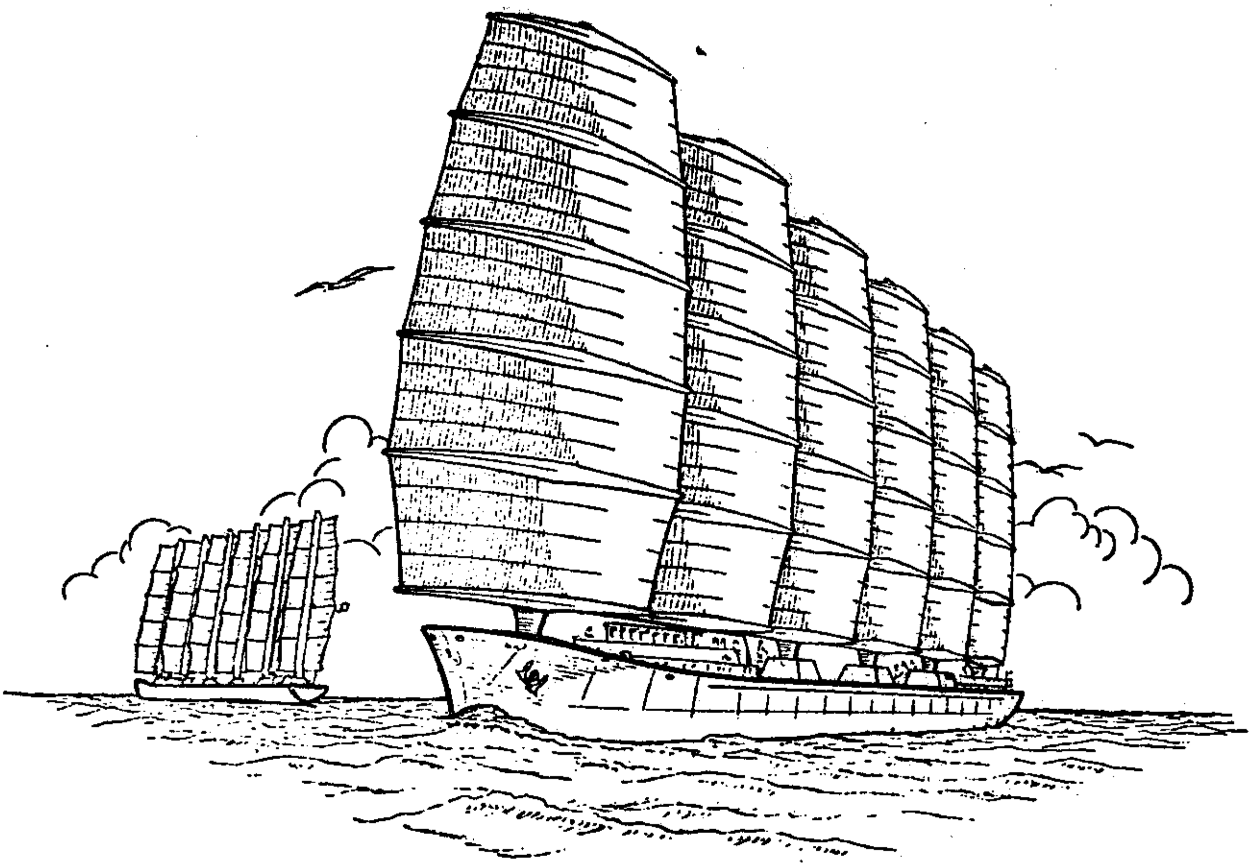


Figure 3: Hamburg University Institute for Shipbuilding's Dynaship. An automatated square rig design with in-the-mast roller furling. (5)

The Japanese have installed a unique rig on two ships, the SHIN AITUKO MARU and the AITUKO MURU. This rig is similar in form to Dynaship but uses rigid sails and is furled using a folding rather than a roller reef type system. (6) (Figure 4)

Wind Ship in Norwell, Mass., has installed a 3000 square foot (300 square meter) roller reefed cat rig on a small Greek flag tanker called MINI LACE. Fuel savings on this low speed coastal vessel have been on the order of 25 percent. (Figure 5)

Wind Ship has also built a 300 square foot (30 square meter) airfoil test rig which is currently undergoing limited testing. (9) (Figure 6) It is anticipated that the Government will underwrite extensive wind tunnel testing of this rig in the near future.

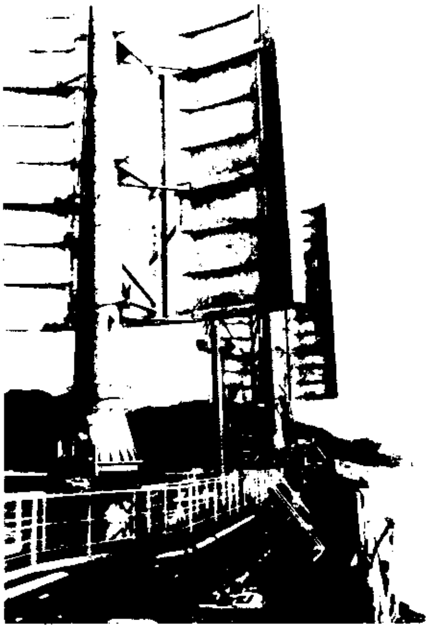


Figure 4: SHIN AITUKO MARU'S folding sails.(7)

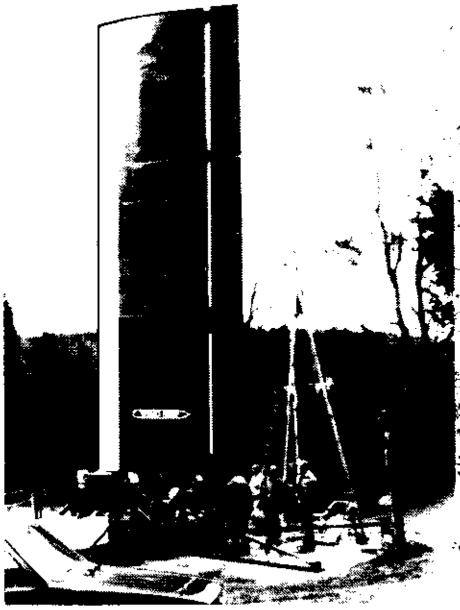


Figure 6: Wind Ship's 300 square foot (30 square meter) airfoil model.

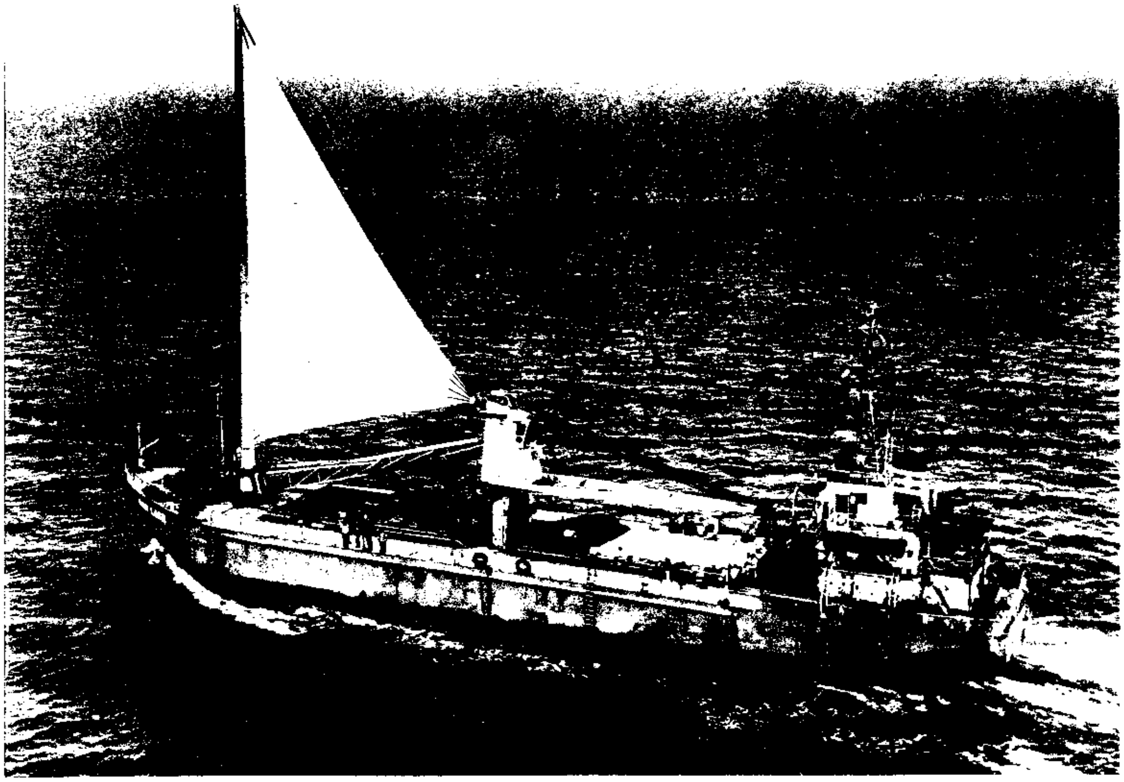


Figure 5: MINI-LACE - Small coastal tanker under Greek Flag with U.S. design roller furled cat rig.(6)

Dr. Blackford of Dalhousie University in Halifax, Nova Scotia, has built a windmill drive for a 12 foot (4 meter) catamaran which demonstrates the feasibility of windmill propulsion. (Figure 7)

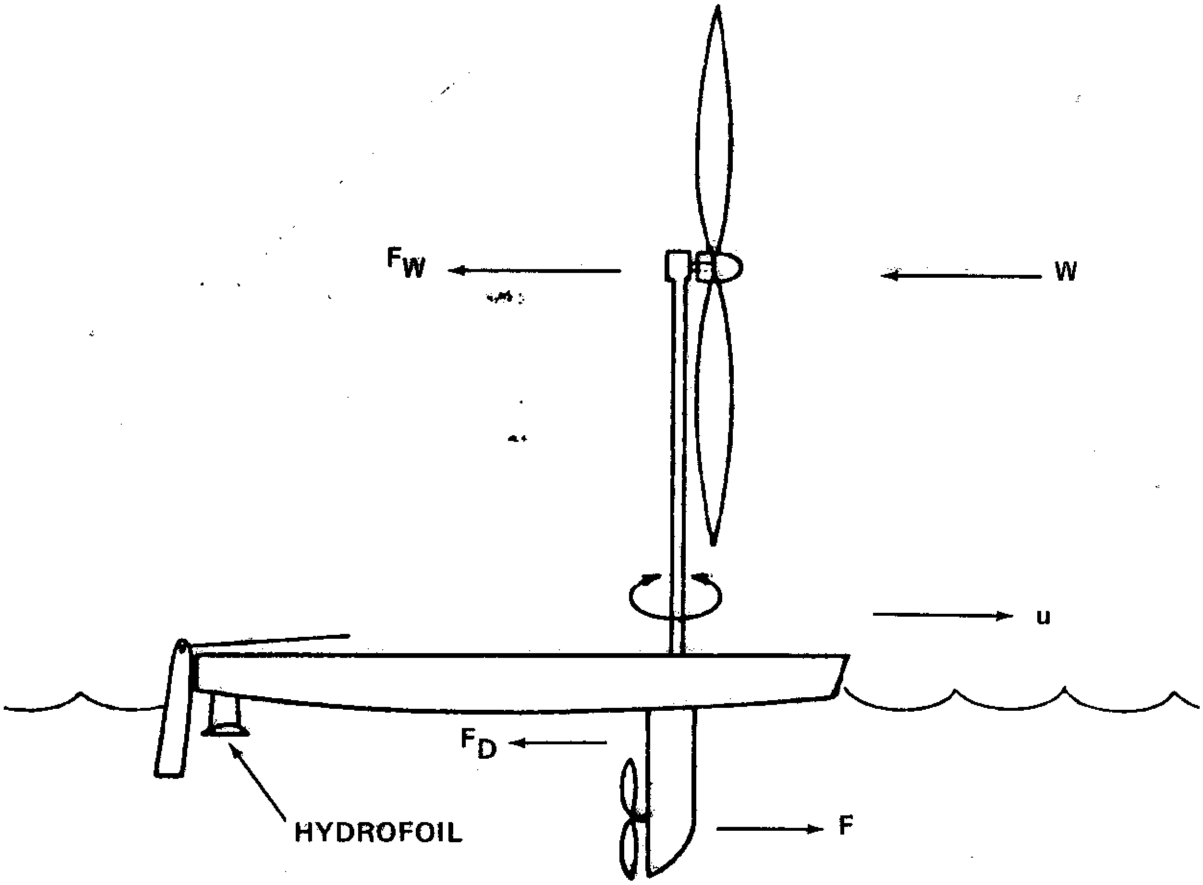


Figure 7: Dalhousie University windmill boat (catamaran) sailing straight upwind. The wind turbine can be rotated about the vertical mast so as to face the apparent wind, allowing the boat to be sailed in any direction without tacking. F_W *is the backward force on the wind turbine.* F *is the forward force produced by the underwater propeller and* F_D *is the drag force of the water on the boat. The net force* ($F-F_W$) *produces the forward speed,* u*, of the boat, at which* $F-F_WF_D = 0$*. The underwater hydrofoil at the rear of the boat counteracts the rearward pitching moment due to the forces* F_W*,* F *and* F_D*. (10).*

ONGOING EFFORTS

As previously noted, there are a number of ongoing efforts to develop advanced thrusters. The objective of most of these efforts is to establish feasibility and to find the best system from a life cycle cost basis for future sail assist applications.

Wind Ship is developing the technology needed to install large high lift airfoil sails for ships. Their designs are in the 3000 to 5000 square foot (300 to 500 square meter) range. (9) Studies indicate that of the forms investigated by Wind Ship for MARAD, the airfoil is the best. The French, having arrived at much the same conclusion as Wind Ship, are looking for even greater lift (11), the Japanese are sticking with their AITUKO MARU rig, however, they consider airfoils to be a close competitor, and the Germans continue to study the Dynaship form to the point that it seems that a rig could have been built and tested if much of the study cost had been put into hardware.

The Borg/Luther Group in Carpenteria, California, has been studying various configurations of Magnus effect devices for marine applications over the past four years. The potential applications include wind generators and thrusters, rudders, propellers, roll stabilizers, and tidal generators. Borg/Luther has applied for a number of patents and has done considerable small scale modeling.

Dr. Blackford of Dalhousie University is working on improving the efficiency of his propeller drive catamaran by evaluating such improvements as the use of variable pitch propellers.

OBJECTIVES OF ADVANCED WIND PROPULSION DEVICES

Table 1 was developed to compare wind thruster characteristics. The rigs listed include the now primitive square rig which made the so called "Yankee Clipper", which plied the oceans in the mid to late Nineteenth Century, the fastest sea transport of its time. The other end of the specturm includes advanced forms such as airfoils, windmills and rotors. Three comparative measures are used. Lift per dollar takes into account the initial cost and the life cycle maintenance cost. (Estimated cost/square foot to build, install and maintain multiplied by the lift coefficient (12)) The second factor is upwind performance which is meaningful when the vessel is attempting to follow an upwind course. The third factor is manning which is broken down into two parts - operational and shipboard maintenance. The maintenance manning category is further broken down into two parts - numbers of personnel and skill levels. There are at least four other categories that should be considered but are not particularly amenable to tabular presentation. These four categories are: Stability, Stowability, Backfit Potential and Mission Compatability.

The old square rig besides having the poorest cost factor is manning intensive, has poor upwind performance, requires more stability than most, is not particularly amenable to backfit, and tends to interfere with mission requirements. The stayed fore and aft rig represents the current state of the art and is being used for a number of sail assist applications. Hugh Lawrence's, PATRICIA A., is probably the most significant example. The drawbacks of the fore and aft rig are relatively high operator manning, stability and interference with mission requirements. Dynahsips major drawbacks are poor upwind performance, high maintenance manning because of the complexity of the furling mechanism, relatively high stability requirements and relative lack of mission compatability because of the yards. The SHIN AITUKO MARU rig and the unstayed cat rig's major drawback is the high maintenance skill levels required to maintain the actuators and controls.

Of the five state of the art rigs discussed above, the stayed fore and aft rig, the unstayed cat rig and the SHIN AITUKO MARU rig appear to be the best choices for current applications with selection depending on factors such as first cost, mission peculiar requirements, and backfit constraints.

RIG	LIFT/$*	MINIMUM ANGLE TO WIND	MANNING OPERATORS NO.	MANNING MAINTAINERS NO./SKILL
SQUARE	9.9	45°	VERY HIGH	HIGH/LOW
STAYED FORE & AFT	18.5	30°	HIGH	HIGH/LOW
UNSTATED CAT	13.2	30°	LOW	MOD/HIGH
DYNASHIP	21.1	40°	LOW	HIGH/HIGH
SHIN AITOKU MARU	22.5	20°	LOW	MOD/HIGH
AIRFOIL W/SIMPLE FLAP	34.5	15°	LOW	MOD/HIGH
SLOTTED AIRFOIL	41.7	15°	LOW	MOD/HIGH
WINDMILL	NA	0°	LOW	MOD/MOD
ROTOR	109.9	20°	LOW	MOD/HIGH

*$C_L/(\$1000/ft^2)$

Table 1: Rig Comparison Table. (2, 5, 6, 8, 9, 10, 11, 12, and 13)

The last four rigs in Table 1 are considered to be on the fringe of the current state of the art or beyond. Three out of four show a significant cost per unit of lift advantage. The fourth "rig" the windmill is not a lift device. The balance of this paper will focus on these high performance devices.

AIRFOILS

The airfoil is basically one half of an airplane wing. The physical laws that make it function are the same as those that apply to an airplane wing or a cloth fore and aft sail.

The main advantage of an airfoil over a cloth sail such as the unstayed cat rig is the higher lift coefficient that results from better control of the aerodynamic shape. The initial per square foot cost of an airfoil is greater than a cloth sail but life cycle cost is expected to be less. The major drawback of the airfoil is the low probability of making one that can be furled. To overcome this problem Wind Ship has designed an airfoil with a simple flap that can be set into the wind when not being used (feathered) without fluttering. With this design the airfoil sail does not need to be furled.

The tenth area model of an airfoil with a simple flap built by Wind Ship has demonstrated a lift coefficient of 2.0 in actual tests. (The best cloth sail rigs have lift coefficients of 1.5 to 1.6.) Although this 300 square foot model has the same area as the rigs being used on Class C catamarans, it is considerably heavier. The primary reason for the weight increase is that no relaxation of forces occurs when the wind hits an airfoil on a large stable ship whereas a small catamaran will heel, relieving the load on the rig.

Higher lift coefficients than 2.0 for an airfoil are considered feasible. Both references 11 and 14 indicate that a slotted entry design can result in lift coefficients in the range of 2.5 to 3.0.

References 9, 11 and 12 provide more detail on the merits and details of airfoil rigs.

WINDMILLS

In the Wind Ship report for the Maritime Administration (12), windmill propulsion was not seriously considered. Some of the reasons were: losses involved in converting windmill generated energy into propulsive energy, the large propeller size required to get enough power to drive a ship (200-300 foot diameters have been proposed), and the structural problems and bridge clearance problems with these large windmills. Table 1 does not include cost data on windmills in part because apparently no data on ship sized windmills has been generated.

However, even though windmills do not seem to show much promise at this time, there are factors that make them attractive and potential that has yet to be fully explored. As has been previously mentioned, Dr. Blackford of Dalhousie University, has developed a working small catamaran with a windmill/water propeller propulsion system. (10) With this small scale vehicle, he has achieved speeds on the order of 60 percent of wind speed regardless of wind direction. Although this does not compare favorably with conventional sail driven performance on most sailing points, with further improvements it has the potential for becoming more competitive, if not equal, to a conventionally rigged catamaran. The use of advanced windmill forms, such as the Magnus effect windmill discussed later, may help improve performance as well as minimizing many of the problems outlined in reference 12.

If windmill performance cannot be increased to the point where it is competitive with the performance of fore and aft rigs or airfoils then the only unique feature of windmills - the ability to sail directly into the wind - will not be enough to make windmills competitive. The inability of other sail forms to sail directly into the wind can be overcome by techniques which will be discussed later.

MAGNUS EFFECT ROTORS

Table 1 ranks the rotor as the most cost effective of the all known ship wind propulsion devices. However, before the merits of the Magnus rotor are discussed, an explanation of what it is and how it works is in order.

The Magnus effect or Flettner rotor is a cylinder with flat end plates which is spun at surface velocities greater than the velocity of the apparent wind. The force to spin the rotor is usually provided from an auxiliary power source. However, recent work by Aydlett (15) and Borg indicate that a Magnus effect rotor can be spun at reasonable speeds by the apparent wind. The Magnus effect causes a partial vacuum to develop on the side of a spinning cylinder where the velocity of the spin combines with the velocity of the apparent wind. The vacuum developed permits the higher pressure air on the opposite side to push the rotor at right angles to the wind. As the velocity of the surface of the rotor increases, the pressure on the high velocity side decreases, thereby increasing the lift. The revolving cylinder will perform in the same fashion in a stream of flowing air or water but the magnitude of the lifting force will be relative to the mass-density of the fluid used.

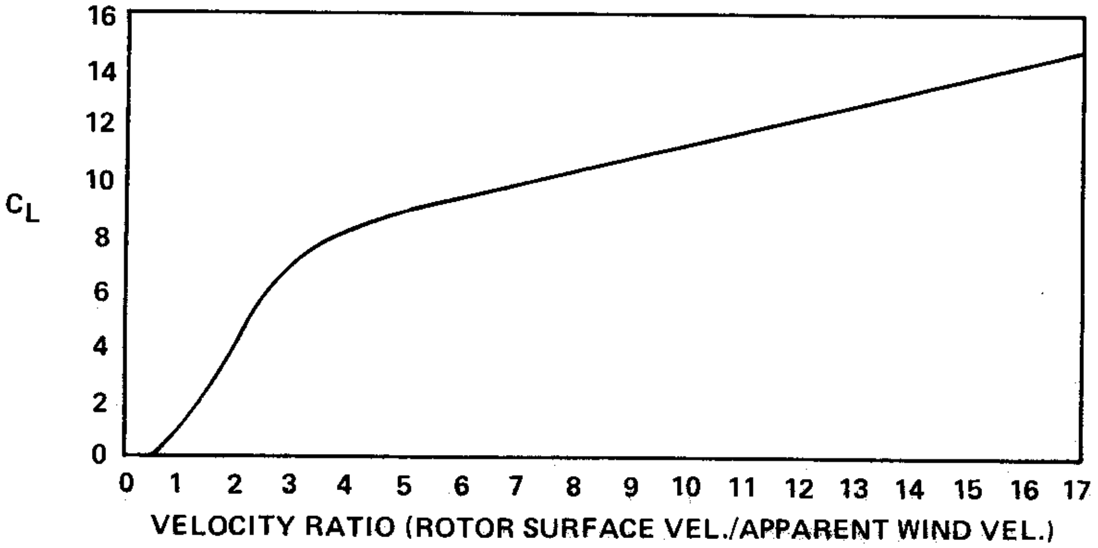


Figure 8: Magnus Rotor Lift vs Velocity Ratio (Experimental).(17)

According to Swanson (16) the lift coefficient for a long slender Magnus rotor follows the curve in Figure 8 as the spinning velocity is increased. However, Flettner's experiments with relatively fat cylinders indicated a lift coefficient maximum of 10 at a velocity ratio of 5:1. Our practical capability to design and build tall thin rotors may make Flettner's conclusions more significant than Swanson's.

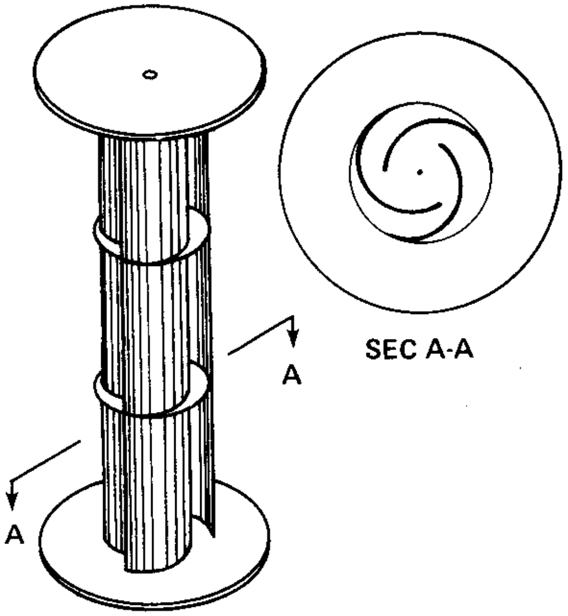


Figure 9: Self Starting, Auto-Rotating Magnus Effect Rotor (Borg/ Luther February 17, 1983).

As previously noted, Aydlett and Borg have been experimenting with wind spun rotors. Aydlett considers a lift coefficient of about 2.7 to be the maximum for a wind spun rotor. Borg considers a lift coefficient of about 5 to be possible. Regardless of who is right, a wind spun rotor is comparable to or perhaps better than an airfoil concerning lift. Figure 9 shows a typical wind spun rotor which uses a self spinning principle inspired by the Flettner rotor and postulated by Savonius in the mid 1920's. (15) A self spinning rotor could be used on a small vessel to avoid the need for an auxiliary drive.

The major advantages of the Magnus rotor are ease of control (speed and direction of the rotor is the total control requirement), high lift, the ability to reduce air draft by telescoping the rotors, and simple cylindrical construction. The major disadvantage of a single or a fore and aft pair of rotors, when used as a wind propulsion system is the lack of downwind performance. Figure 10 illustrates three possible arrangements of rotors. The first arrangement, which was the one Flettner used, performs reasonably well on a reach but as the wind comes around to the stern (downwind or running) the vessel will go sideways if both rotors are spun in the same direction or will turn in circles if the rotors are spun in opposite directions. By putting the two rotors side by side as shown in the second set of ships, Borg has postulated that some downwind capability will be obtained by the wind acting on the high pressure "wind wall" developed by the Magnus effect plus a pocket of low pressure expected to be between and extending somewhat forward of the rotors acting to let the force on the "wind wall" move the ship. The "four poster" arrangement is expected to perform in the same manner as the transverse arrangement but give more total thrust. The transverse dual rotor and "four poster" arrangements require considerable experimentation with diameters and spacing before Borg's theory can be proven. In all cases a broad reach is expected to generate a driving characteristics about the same as that for a close reach.

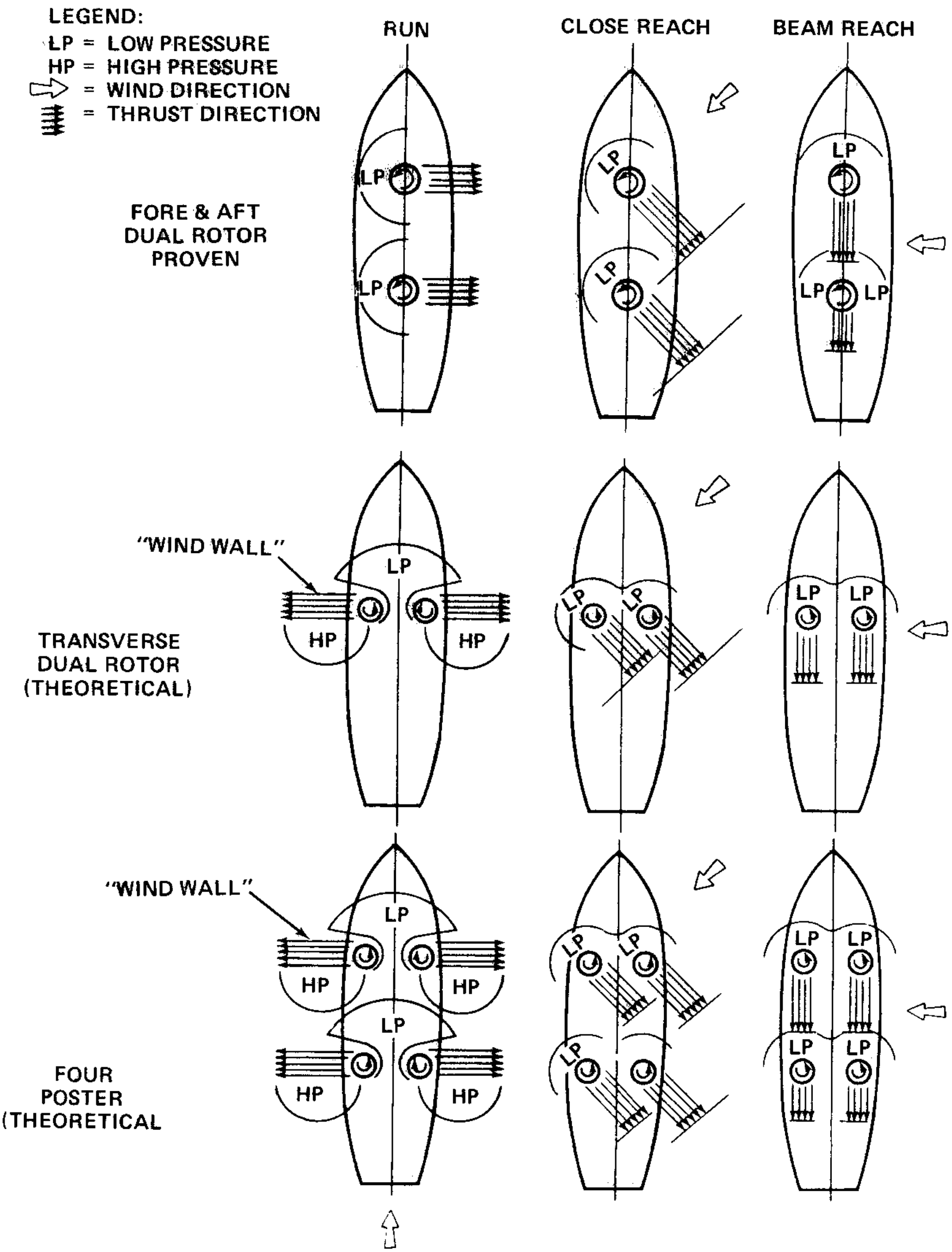


Figure 10: Magnus effect (Flettner) rotor arrangements. The fore and aft arrangement is the one used by Flettner on BADEN-BADEN and BARBARA (2). The transverse and "four poster" arrangements are theoretical (Borg/Luther February 17, 1983).

If Borg is wrong - and probably even if he is right - in his assumption, upwind performance can be improved by using the technique currently used by catamaran sailers to overcome cats notoriously dull downwind performance. Figure 11 illustrates the technique where the vessel is tacked downwind. In this case, where a very efficient hull form wind/speed diagram is used, the most effective course is 127 degrees and results in a speed made good downwind greater than wind speed. It should be noted that upwind performance with a high performance hull can be improved by coming off a point or close to the wind course, to a near reach. In the case shown in Figure 11, the optimum upwind course is 45 degrees which also produces an upwind speed greater than wind speed. Of course, tacking is not always possible in restricted waters, but large sail assist vessels would probably be under Diesel power when coming in or out of port. The technique of tacking up and downwind tends to reduce the significance of the windmill ships unique into the wind capability as well as diminishing the significance of the rotor's poor downwind performance.

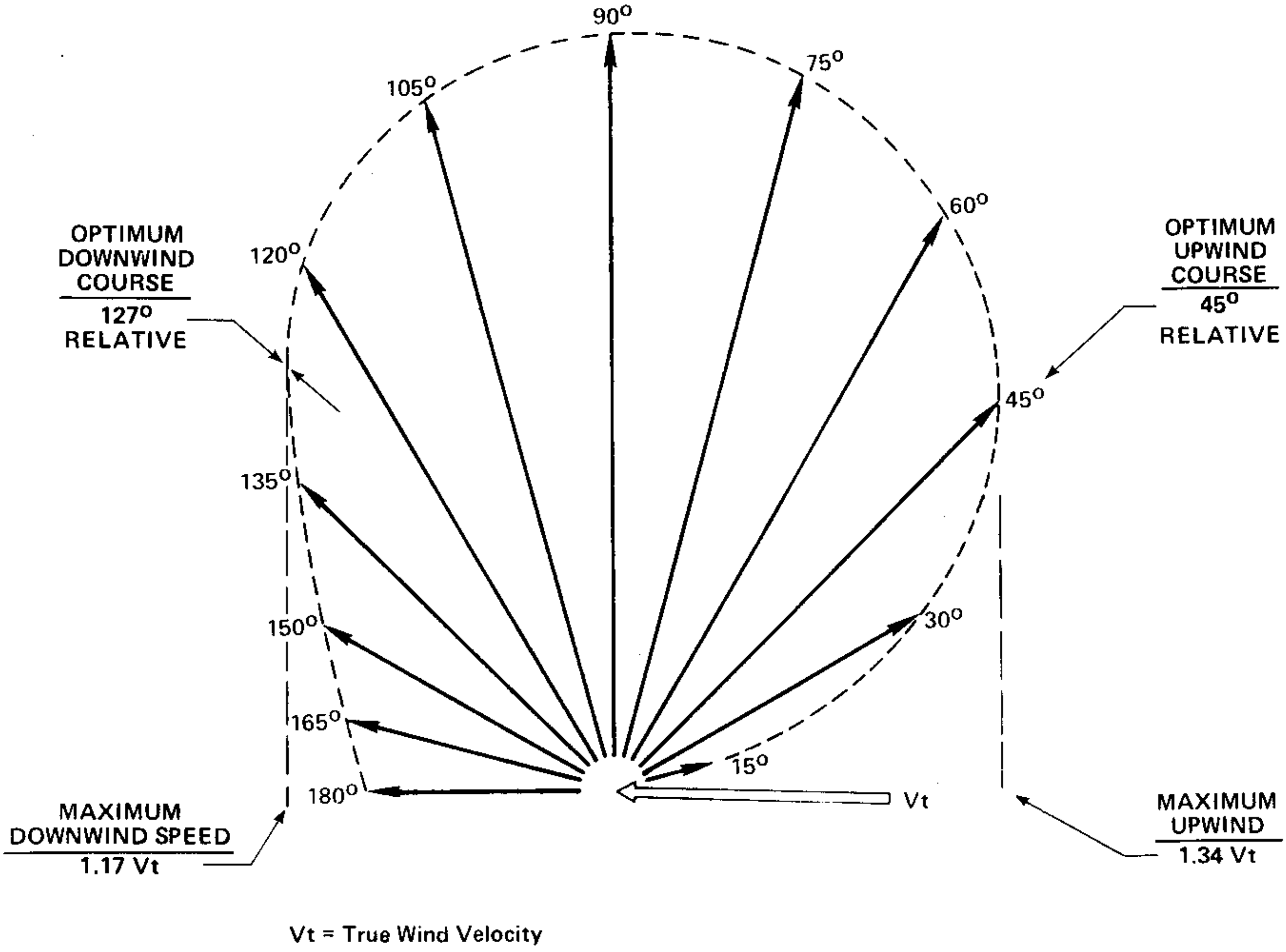


Figure 11: Downwind and Upwind routing of airfoil vessesls for best speed to destination. Wind boat speed diagram (1) is for an almost frictionless hull form.

In the interest of boat sized testing of the Magnus rotor, to prove to those that weren't around in the mid 1920's that the rotor works, and to re-evaluate the limits of lift increase with rotor velocity increase, the Author plans to build and test the rig shown in Figure 12. The rig is designed to provide the same lift as the Hobie 16's stock rig (fully battened Marconi sloop rig) at a velocity ratio of 4:1. The Hobie was selected because: it has low resistance as shown in Figure 13 as compared to a mono-hull, it is the largest class of catamarans in the world which should provide numerous opportunities for comparing performance with its conventional rig, and the author happens to own one.

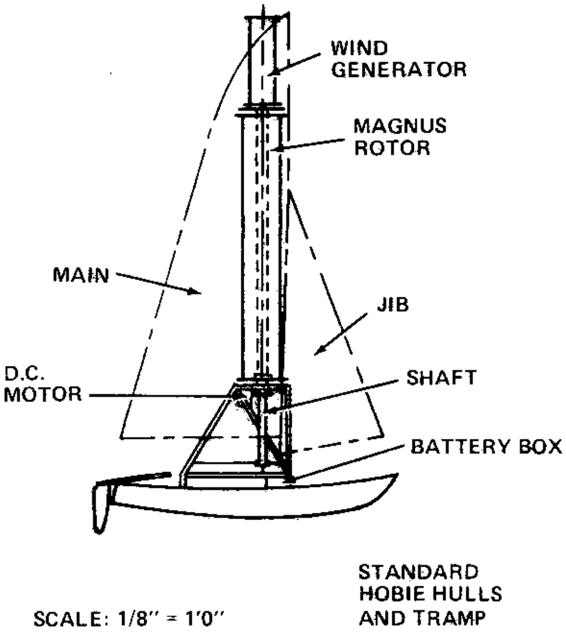


Figure 12: Hobie 16 foot catamaran with a powered Flettner Rotor and a wind generator. (Standard Hobie 16 sail shown in phantom.)

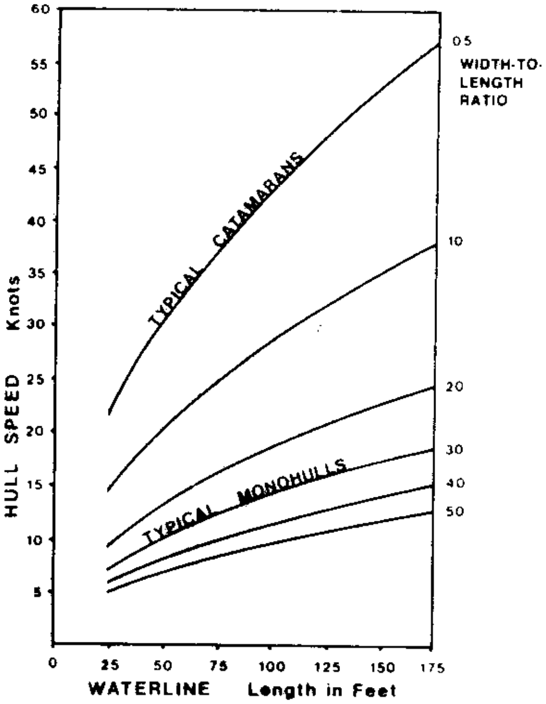


Figure 13: Hull Speed as a function of Width-to-Length. (17)

The Navy is currently negotiating with the Borg/Luther Group to study and develop a model test program to further evaluate applications of the Magnus effect to marine applications. The Flettner or Magnus rotor is the wind propulsion device under the proposed study which also includes rudders, propellers, wind generators and stabilizers which are discussed in the appendix to this paper. Lloyd Bergeson, president of Wind Ship also advises that Wind Ship is studying the Magnus effect.

CONCLUSION

The airfoil sail is almost ready for use for sail assist in large and small vessels. As previously noted, the Government is considering underwriting wind tunnel tests of Wind Ship's one tenth scale model which should provide adequate data to permit full scale use for sail assist at minimum risk.

The windmill system has a long way to go. However, Dr. Blackford should be encouraged to continue his research. In addition, the use of the Magnus effect windmills discussed in the Appendix should be evaluated for their potential to drive a propeller.

The Magnus effect rotor has the greatest potential. However, considerably more research, modeling and testing must be done before full scale development is indicated.

With these three high performance systems as candidates our ability to demonstrate high performance full size advanced thrusters in the next decade is only constrained by economics. The availability of development, fabrication and installation dollars and the cost of oil will control the continued development of these devices for wind propulsion.

Appendix

Actual and Potential Applications of the Magnus Effect Other Then For Wind Propulsion

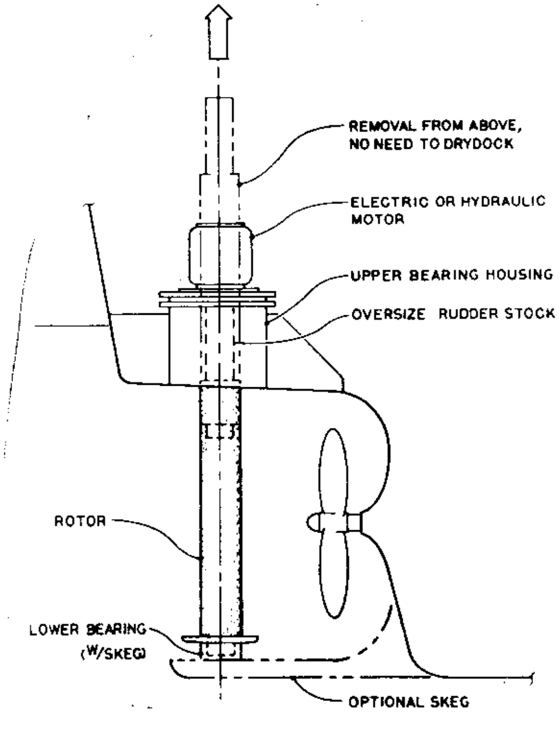


Figure A-1: Magnus Rudder. (19)

MAGNUS EFFECT RUDDERS

Cylindrical rudders designed by Borg/Luther have been used successfully on several vessels and are most advantageous for low speed, high thrust applications. (Figure A-1) The most obvious benefit is that no forward thrust is lost during a maneuver because the rotor does not act as a brake while a conventional rudder wastes large amounts of horsepower when hard over. (18)

The Magnus Rudder requires more horsepower for the rudder system than a conventional rudder, however the reduction in drag at the equivalent of 10 or more degrees of rudder angle more than compensates by saving propulsion power. Although a higher power drive is required, the simplicity of the rotor as compared to a conventional rudder results in the rotor system cost being comparable to a conventional rudder system. The simplicity of the rotor rudder also makes it inherently strong and relatively impervious to ice and floating debris.

The above characteristics make the Magnus Effect rudder ideal for amphibious craft, tugs, towboats, craft operating in ice, and fishing vessels pulling nets underwater.

MAGNUS EFFECT PROPELLERS

Within the past few months a successful model Magnus effect propeller has been tested by Borg/Luther proving that the principle will work. Calculations based upon Magnus effect hydrodynamic theory indicate such a propulsion device could deliver twice the thrust per horsepower as a conventional propeller for low vessel speed applications. This could result in cutting an operators fuel bill in half. (20)

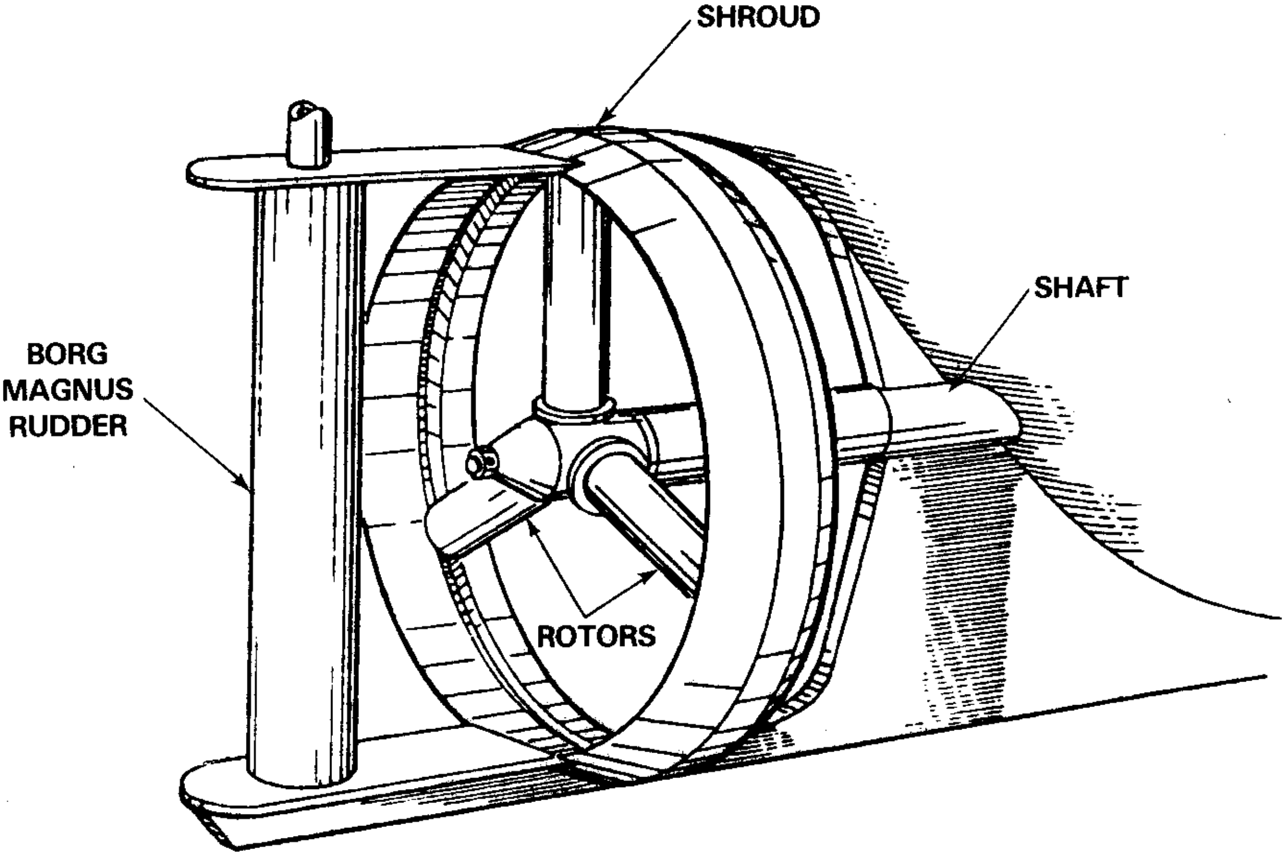


Figure A-2: Magnus Propeller (Borg drawing for pending patent).

The Magnus effect propeller rotors shown in Figure A-2 can be driven in one of two ways. Either the rotors could be spun by a gear or friction drive in the shroud or by a separate drive through a concentric shaft in the tail shaft. The shape of the rotors could be cylindrical or conical, whichever is most efficient.

The cost of a Magnus propeller will be higher than a conventional propeller. If concentric shaft rotor drive is used, the cost will approach controllable pitch propeller costs.

Figure A-3 provides a comparison of the Magnus effect or Borg propeller to conventional, nozzled and vertical axis (Voith-Schneider) propellers. Tankers, Navy oilers, and most smaller vessels will save fuel with Magnus effect propellers if the theoretical curve for the rotor propeller proves to be accurate.

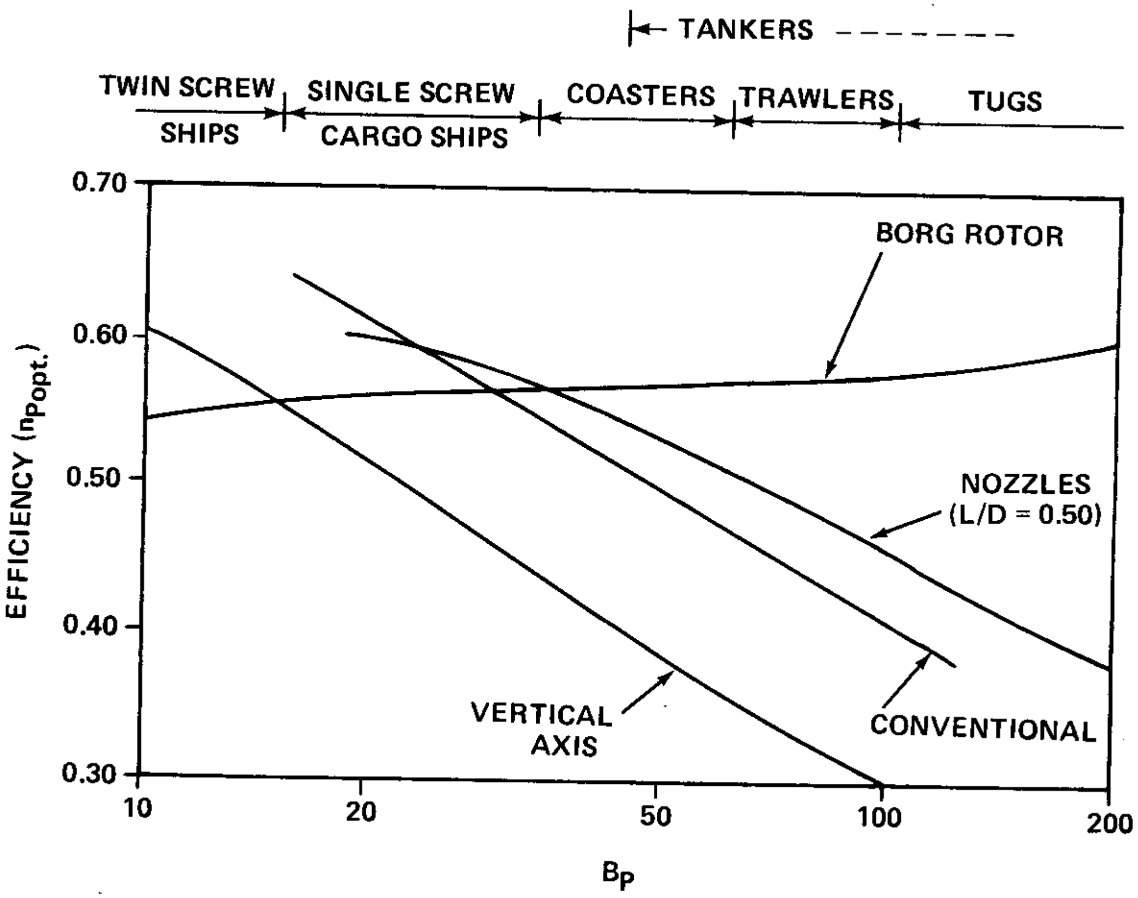
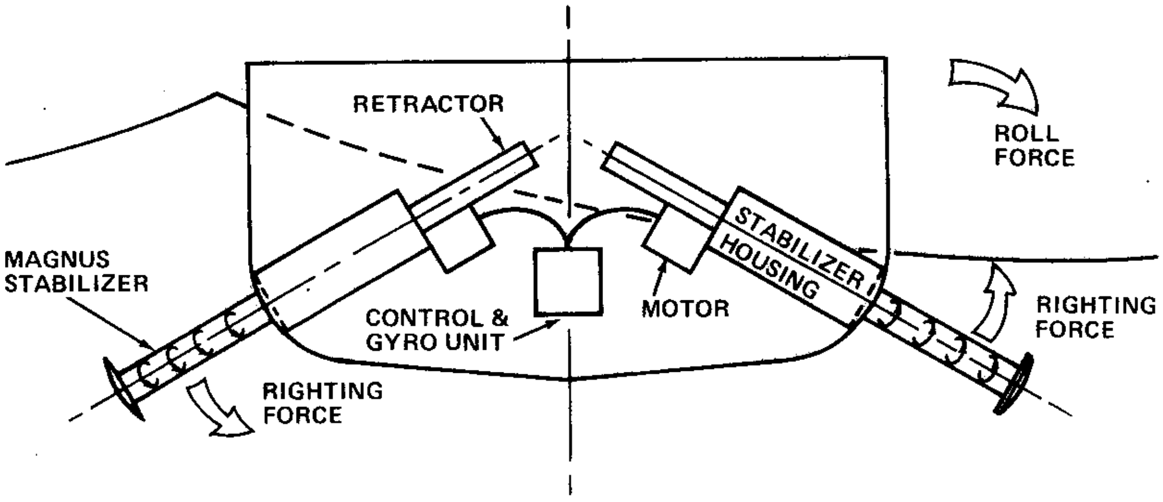


Figure A-3: Propeller Efficiency Curves comparing Borg Rotor propellers with conventional, nozzled and vertical axis propellers. The curve compares the optimum propeller coefficient (η_{Popt}) with Taylor's Power Coefficient ($B_p = NP^{0.5}/V_a^{2.5}$ were N = RPM; P = Horsepower; and V_a = Speed of Advance) (21 and Borg circa March 1983).

Further testing is required to establish optimum rotor shape and the method for rotor spinning.

MAGNUS EFFECT ROLL STABILIZERS

Cylindrical stabilizers are still in the conceptual stage and have not yet been installed on any vessels. They are simple in design and should cost a fraction of existing fin types. (Figure A-4) Considerable study and modeling will be required before the feasibility of using the Magnus effect for roll stabilization can be established. However, the potential of the device is too great to let it be overlooked.



MAGNUS EFFECT
STABILIZER SYSTEM

NOTE: STABILIZER SYSTEM SHOWN
OVERSIZE FOR CLARITY

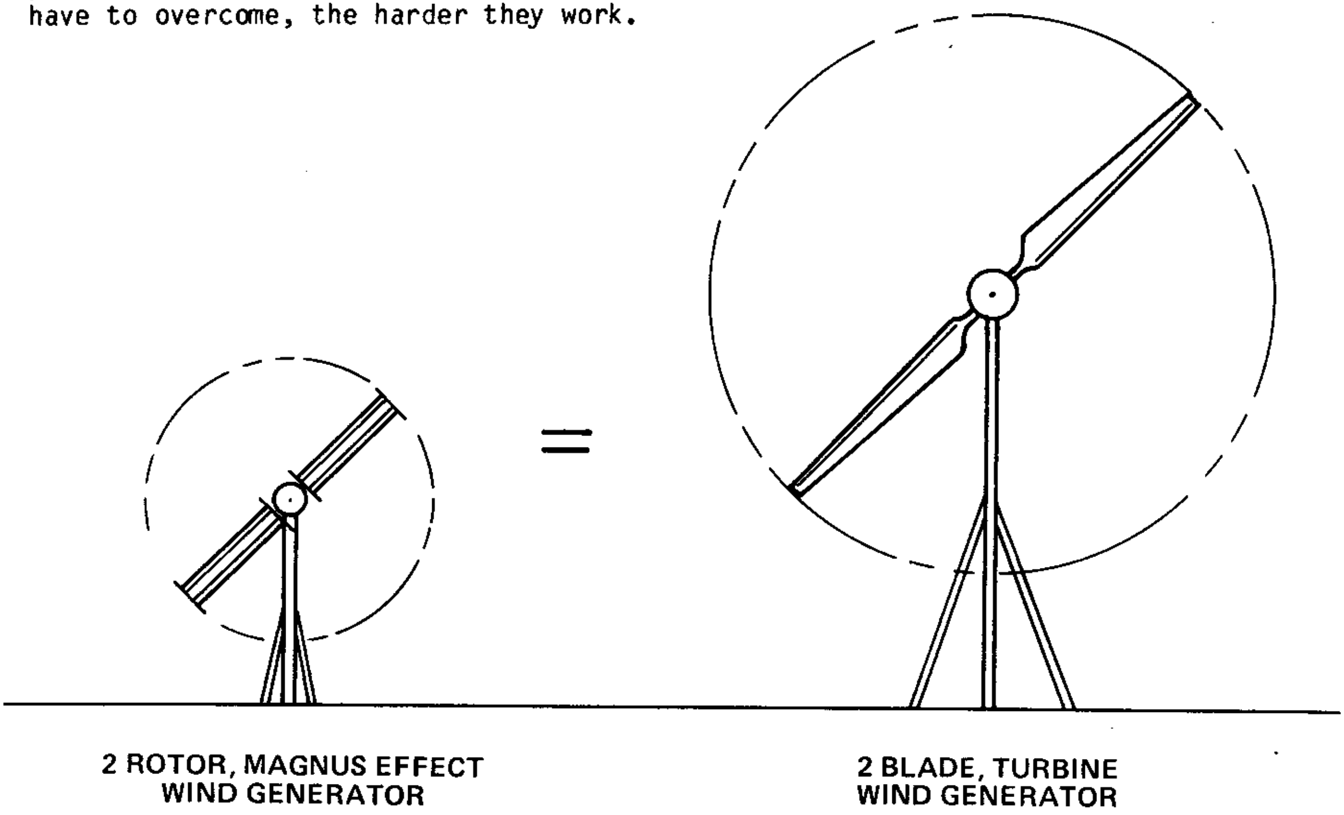
Figure A-4: Magnus effect stabilizer system. (Stabilizer system shown oversize for clarity.) (The author circa September 1982. Sketch by Borg/Luther February 17, 1983).

The factors that make further investigation worthwhile are:

- The high lift and low hydrodynamic resistance of rotors as compared to traditional foils.
- The simplicity of the structure of a rotor as compared to a foil.
- The ease with which a rotor can be retracted into a stowed position.
- The possibility of using electric rotor and retraction drives in lieu of complex hydraulics.

MAGNUS EFFECT WIND TURBINES

Although Flettner constructed Magnus Effect wind turbines in the mid-1920's, they seem not to have enjoyed much popularity. Perhaps the complexities of the rotor drives and relatively low RPM at which they turned contributed to their lack of acceptance. The powerful torque they produced is another story. Model tests indicate that the more load they have to overcome, the harder they work.



SIZE COMPARISON OF MAGNUS EFFECT AND TURBINE WIND GENERATORS OF EQUAL POWER

Figure A-5: Size comparison of horizontal axis Magnus effect and conventional wind generators of equal power. (Borg/Luther February 17, 1983).

Auto-rotating horizontal axis Magnus effect wind energy converters are about one fifth the size of comparable conventional blade types and power driven rotor units would be even smaller.

It is safe to say that a Magnus effect wind energy converter can presently be designed and constructed to serve any applications that are being considered for more conventional wind turbines, such as generator drives, pump drives, and as an alternate to the conventional propeller ship drive discussed earlier and in reference 10.

Figure A-5 shows Flettner's original (horizontal axis) form for a Magnus effect wind turbine and Figure A-6, shows Borg's recent vertical axis design. The vertical axis design although more complex than Flettner's design is expected to be more efficient for some applications.

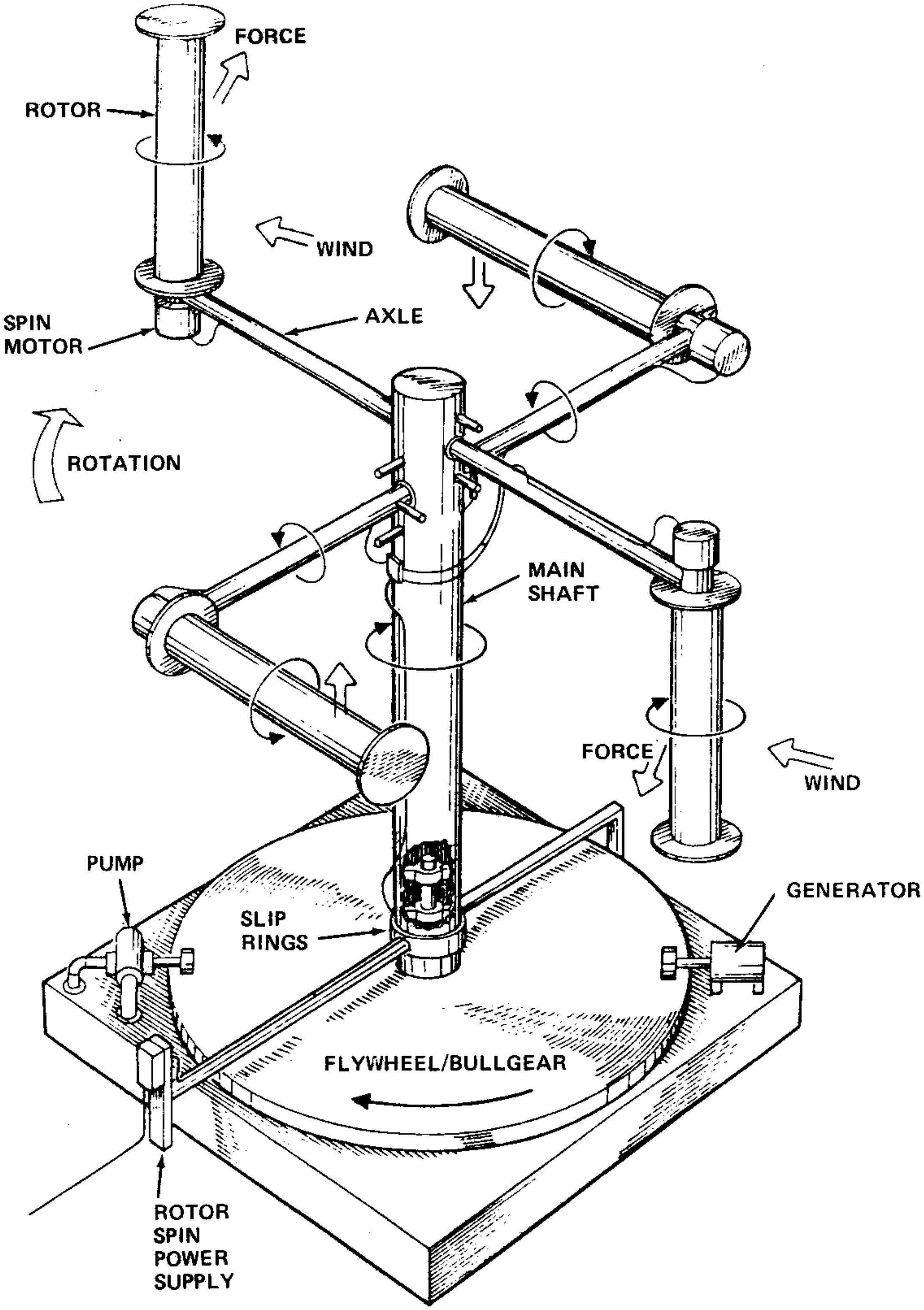


Figure A-6: Vertical Axis Magnus Effect Wind Generator. (Borg drawing for patent pending.)

Crimi, in reference 22, indicates that the size and simplicity of construction will make Flettner wind turbines competitive with more conventional wind turbine designs.

MAGNUS EFFECT TIDAL GENERATORS

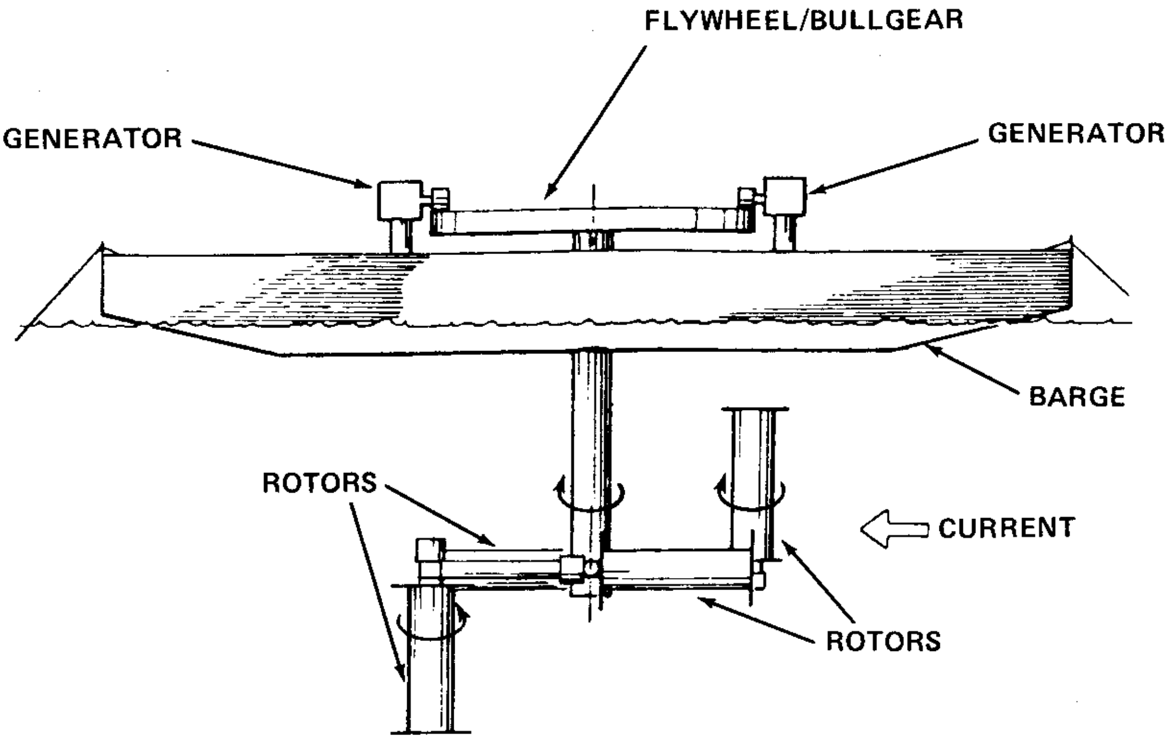


Figure A-7: Magnus Effect Tidal Generator - Uses vertical axis Magnus effect generator (Borg drawing for patent pending).

Figure A-7. is a patent drawing for the application of a vertical axis Magnus effect water turbine of essentially the same design as the vertical axis wind turbine shown in Figure A-6. The vertical axis configuration lends itself to this application because of its balanced design which does not generate large bending movements in the vertical shaft.

APPENDIX SUMMARY

With the exception of Borg's Magnus effect rudder, all the designs discussed in this appendix require further study, modeling, and small scale testing before their full potential can be established. Because this is so, the contract that the Navy is currently negotiating with the Borg/Luther Group includes work on these devices as well as the basic Magnus effect ship propulsion rotor.

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GLOSSARY:

Airfoil - A shape that takes advantage of the difference in wind velocity from one side to the other in order to create a pressure differential and therefore a lifting force.

Apparent Wind - The wind speed and direction as seen by a moving vessel.

Broad Reach - Sailing with the wind ranging from perpendicular to the ship to 45 degrees aft of perpendicular.

Catamaran - A vessel with two symetrical hulls.

Class C Catamaran - A catamaran with hulls not longer than 25 feet (7.6 meters), beam not in excess of 14 feet (4.2 meters) and 300 square feet (30 square meters) of sail area.

Downwind - Sailing with the wind behind the vessel.

Dynaship Rig - A sail form of the square-sail type that furls and unfurls the sails horizontally in and out of the mast while constrained by fixed spars.

Flettner Rotor - A vertical, cylindically-shaped sail used to drive a vessel. The Flettner rotor must be spun by auxiliary machinery to gain the lift required to provide a driving force.

Fore and Aft Sails - Sails fitted parallel to the ships centerline.

Furling - Stowing sails (unfurling is breaking out sails).

Lift Coefficient - The ratio of the lifting force per unit area (i.e. pounds per square foot or kilograms per square meter) to the pressure that results when the air is stopped by a flat surface perpendicular to the flow (12).

Magnus Effect - The phenomena where lift occurs on a spinning cylinder at right angles to fluid flow. the lift occurs in the direction of the side where the fluid flow and the cylinder are going in the same direction.

Magnus Rotor - A lift device using the Magnus effect. The Flettner rotor is a Magnus rotor.

Marconi Rig - A fore and aft sail plan which uses sails which are triangular in form, with the point at the top, and cut to provide an airfoil effect when the wind passes across it. Sometimes called a Bermuda sail.

Point - To go as close to into the wind as possible without losing the wind in the sails (luffing).

Reach - To sail with the wind off the beam or at right angles to the centerline of the craft or ship.

Reefing - To shorten sail. This is accomplished in a variety of ways such as using reef points (lines attached to the sail) to put part of the sail around the boom or spar, or by rolling part of the sail up on the boom. This is done to limit heel by reducing sail area in high winds.

Run - To sail downwind (with the wind astern or behind the vessel).

Savonius Rotor - A Magnus effect device conceived by the Finnish inventor Sigurd Savonius in the early 1920's. (Figure 9)

Sloop - A single-masted craft with a small triangular sail called a jib forward of the mast and a larger sail, called the mainsail, aft of the mast.

Square Rig - A rig with sails at right angles to the centerline of the vessel. The sails were traditionally hung from spars and furled by manually gathering the sails up to the spars. The full-rigged ship typified by the Clippers of the early nineteenth century, were rigged with square sails on three masts.

Spars - Horizontal beams, hung on a mast at right angles to the vessel's centerline, used to support square rigged sails.

Tack - A technique used by sailing vessel operators to get to a location which is upwind of the vessel's position. The vessel is sailed as close to the wind as possible with the wind coming from the right (starboard) and alternately shifted so that the wind is coming in from the left (port). By tacking to port and starboard the vessel can (slowly) arrive at a destination directly upwind of the starting point.

True Wind - The speed and direction of wind seen by a stationary object.

Upwind - Sailing into the wind.

Wing Sails - Airfoils used as sails.

THE AUTHOR

Graduated from the New York State Maritime College in 1956, receiving his degree in Marine Engineering. While attending the Maritime College he was active in intercollegiate sailing. He then reported to the Navy's Bureau of Ships where he was assigned to the Hull Mechanical Section in the Hull Design Branch. During this period he was involved in the contract design of various materials handling features of naval ships including vehicle and cargo handling for amphibious ships, electronic equipment handling, and underway replenishment, and, in addition, managed the Design Division's computer installation. In 1964, he was the Hull Project Coordinator for the AOR 1 Class, AO(J) 51 Class, and the AOE 3 Class ships. From 1965 until 1974 he was the Program Manager for the FAST System and the Missile/Cargo STREAM System in the Underway Replenishment Project Office. In April 1974 he became Head of the Underway Replenishment Improvement Branch in the Amphibious and Combat Support Ship Logistics Division. In July 1979, he was transferred, along with the management of the Underway Replenishment Improvement Program, to the Deck and Replenishment Systems Division as Head of the Underway Replenishment Systems Branch, the position he now holds in the Naval Sea Systems Command. In addition to his duties concerning underway replenishment, he has been active in sailing ship research and the promotion of sail assist for Navy ships. He has presented two papers on sail assist to Navy oriented technical societies. The author is an active member of the Society of Naval Architects and Marine Engineers and the Association of Scientists and Engineers.

ACKNOWLEDGMENTS

The Author would like to thank John Borg, William Luther, B.L. Blackford, Lloyd Bergeson, and Larry Cautilli for their knowledgeable assistance in the development of the technical aspects of this paper. In addition, the assistance of Anne Morisseau and John Shortall in searching the literature, Anne and Dolores Morisseau in editing the paper, Anne Craig, Darlene Soltis and Karen Browning for the typing (and retyping), and Pat Wilson and John Monell for the graphics and assembly of the paper is sincerely appreciated.

THE TUNNY RIG - A VARIABLE CAMBER FLEXIBLE WING SAIL

By E W H Gifford
Gifford Technology, Southampton

SUMMARY

A prime need for the rig for a sailing fishing boat is that it should not obstruct the handling of the fishing gear. It should also be efficient, robust, and easy to handle. If damage occurs, it should be simply repaired. It is well known that traditional and conventional modern rigs fail to meet one or more of the above requirements.

The Tunny rig, invented by the Combewrights, and being further developed by the author's company, meets them all. It is a wing sail with a double surface of sailcloth shaped by fish-shaped battens (the "tunnies") which are warped to the required asymmetrical shape by an internal system of lines. Wide chord shapes are used giving space for a cantilever mast and a safe crew access throughout the inside of the sail. Multiple sheets are used, as in the junk rig, so that sail and rigging loads are small but the asymmetric aerofoil ensures that the lift is high.

The prototype rig has recently reached the United States from England on a double-hulled boat crewed by the two inventors, who have their six month old child with them.

A second prototype rig, shaped to the NASA GA(W)1 profile, is now being fitted to a Sandskipper double-hulled beach fishing boat. This is described in the paper but trial results will be reported at the Conference.

The paper also describes a proposed gill-netter for Western Scotland carrying a single Tunny sail.

INTRODUCTION

This paper is an account of another person's invention and successful first voyage and the author's plans for future development, the first results of which have been presented verbally at the Conference.

The Combewrights, Wayland and Aruna, wished to visit the West coast of America and to stay there for some time. They decided that the cheapest way to do this was to design and build a boat, which they did for $3,000! They crossed the Atlantic during last November, averaging 4 knots, with just the two of them as crew and yet with a 6 month baby, thus demonstrating the capabilities of their invention in terms of weatherliness and ease of handling.

They chose to build a double-hulled boat, in Irish curragh style of multi-layered tarred canvas on cleft ash framing but that will be described by them elsewhere.

For the rig they considered the Chinese lug but felt that its handiness was offset by its poor windward performance so, having little previous knowledge of sailing, they talked to many experts, aerodynamicists among them, and read a great deal, and produced a scheme for a fully battened, double-skinned sail. They did not like the idea of symmetrical fixed camber (they knew nothing of Jack Manners-Spence's work at this time) so they decided on an ingenious method of warping the sail, which Orville Wright would surely have approved, so that it presents an asymmetric aerofoil of appropriate shape on either tack (Fig 1 and 2).

They built a one-fifth scale model which performed so well that they built the full size boat, 40ft by 20ft (12m x 6m) straight off this and it too works well.

The hull forms are not ideal, they are too blunt at entry and too tucked up in the stern, so the maximum speed attained of 6½ knots is all that can be expected but a remarkable quality of the rig is that it continues to draw up to within 30° of the apparent wind and has satisfactory lift characteristics, and it is really docile and easy to handle. Reefing is simple and on the whole voyage across there was no chafe.

The author learned of the venture when it was nearly complete and so had no influence on anything but was so attracted by the idea that the Combewrights agreed that whilst they were sailing to America etc., the author could develop the idea scientifically.

It so happened that Gifford Technology are working on timber windmill blades which are of the NASA GA(W)1 section.

A little simple geometry showed that a close approximation to the required asymmetric form could be achieved by simply warping a symmetrical shape. This particular aerofoil is designed to be relatively insensitive to surface roughness and it is hoped that it will be equally tolerant of slight deviations from its proper form.

In addition to the close windedness of the rig, equivalent to a first class Bermudan rig but without all the high rigging loads and complication, wind tunnel tests on the wing section have given a lift coefficient of 1.60 which, if realised with the sail, should give excellent speed to windward.

The rig is also very seamanlike for, in addition to its low chafe, it is fully accessible from the inside at any time as a seaman can climb aloft in good shelter and comfort whilst the sail is fully set and drawing.

DEVELOPMENT OF THE RIG

A sail of simple rectangular profile using battens to give the required shape (Fig 3) is being fitted to a standard Sandskipper 24ft (7.3m) hull. This particular layout is intended for use in artisanal fisheries but the data obtained will be directly transferable to more elaborate applications. The mast is a simple cantilever ply-wood box, the lower part of which is fitted with straingauges to enable the direction of thrust of the rig to be calculated. The actual thrust on the longitudinal axis of the boat will be determined by measuring boat speed, the speed/drag characteristic of the boat being known. Thus the main characteristic of the rig dynamics can be obtained.

The boat speed and course made good will be measured from shore stations and wind speeds will be electronically averaged.

To increase drag, when sailing down wind a "flap" rather like a triangular bonnet will be hoisted at the trailing edge of the sail. This has not yet been tried but, if successful, will reduce the need for special running sails which, for simple fishing use, are an unwelcome complication. The rig is virtually complete at the time of writing this paper and so it is hoped to present first trial results at the Conference.

FUTURE DEVELOPMENT

Gifford Technology have been invited by Mr Ian Nicholson, a senior partner of Alfred Mylne & Company, the famous Scottish naval architects, to join with them in the design of a motor sailing gillnetter to operate out of Mallaigh in Western Scotland where conditions of wind and sea are very severe. The client is a successful working fisherman with a scientific education.

The rig shown in Figure 4 is a straight development of that of the experimental Sandskipper rig but of substantially larger area and with an increased aspect ratio. The mast will be a cantilevered hollow round section and it should be noted that the rig does not obstruct the deck as gear can be handled at any point over the rail; even the sheets lead to the top of the wheelhouse and leave the stern free for lines or net shooting. Such freedom could not be obtained with any conventional rig requiring stayed masts.

As the sail can be readily lowered and stowed in a neat package above the head level on deck, it is considered that this would be the best approach when proceeding to windward under power in heavy weather. The alternative advocated for rigid wing sails, namely feathering the full sail aloft, seems likely to produce problems of oscillation unless the roll periods of the vessel can be kept well out of match with the "flutter" of the rig and this might sometimes be difficult.

Applications for an energy saving grant in addition to the standard UK fishing grants are at present being considered and if sufficient money is available then the project will go ahead as soon as sufficient rig data has been obtained from the Sandskipper experiment.

CONCLUSION

This brief paper outlines a new rig which appears to offer very real possibilities of considerable aerodynamic improvement combined with good seamanship.

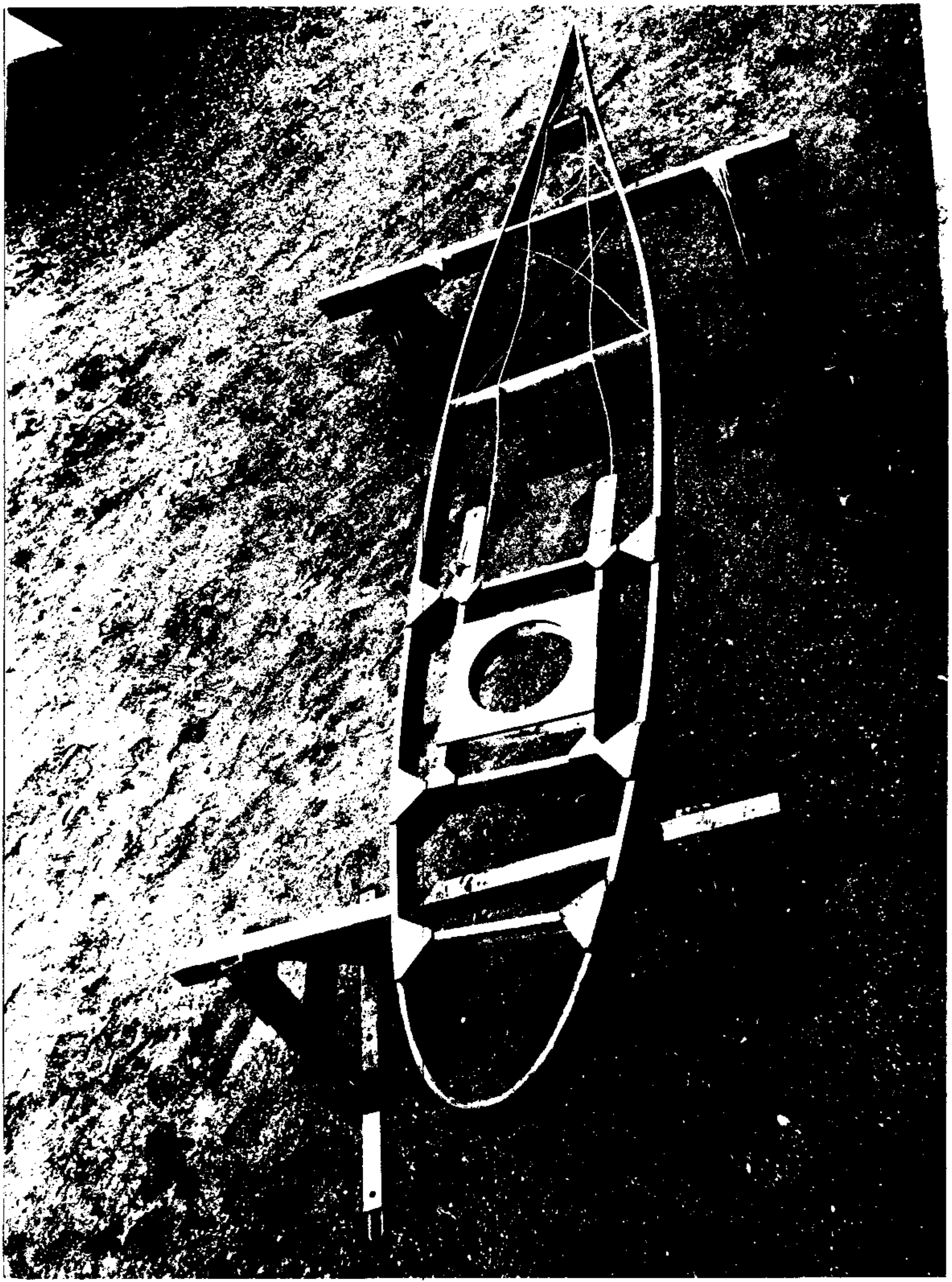

Fig. 1 BATTEN OF TUNNY SAIL IN SYMMETRICAL POSITION

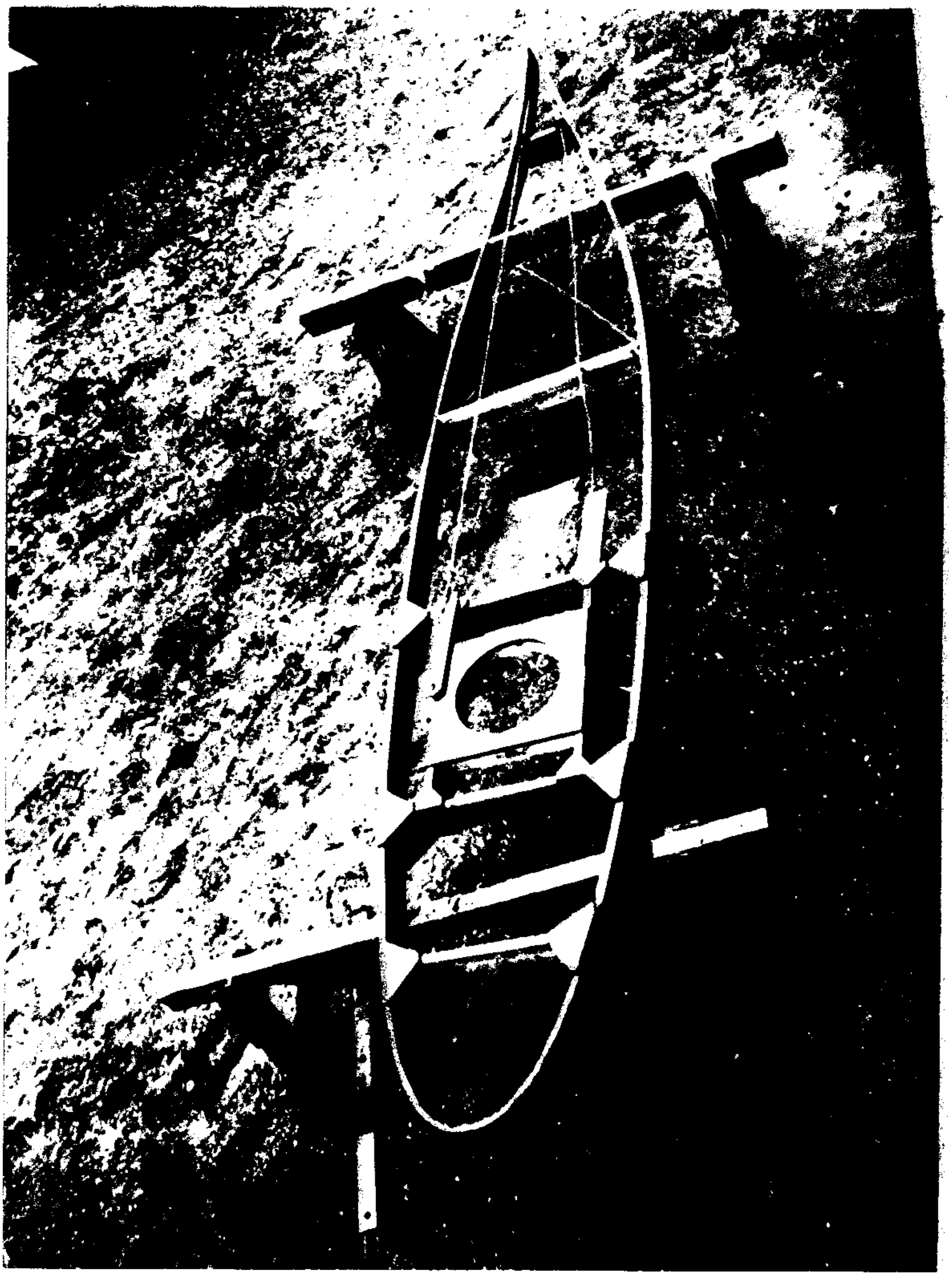

Fig. 2 BATTEN WARPED TO NASA GA(W) 1 PROFILE

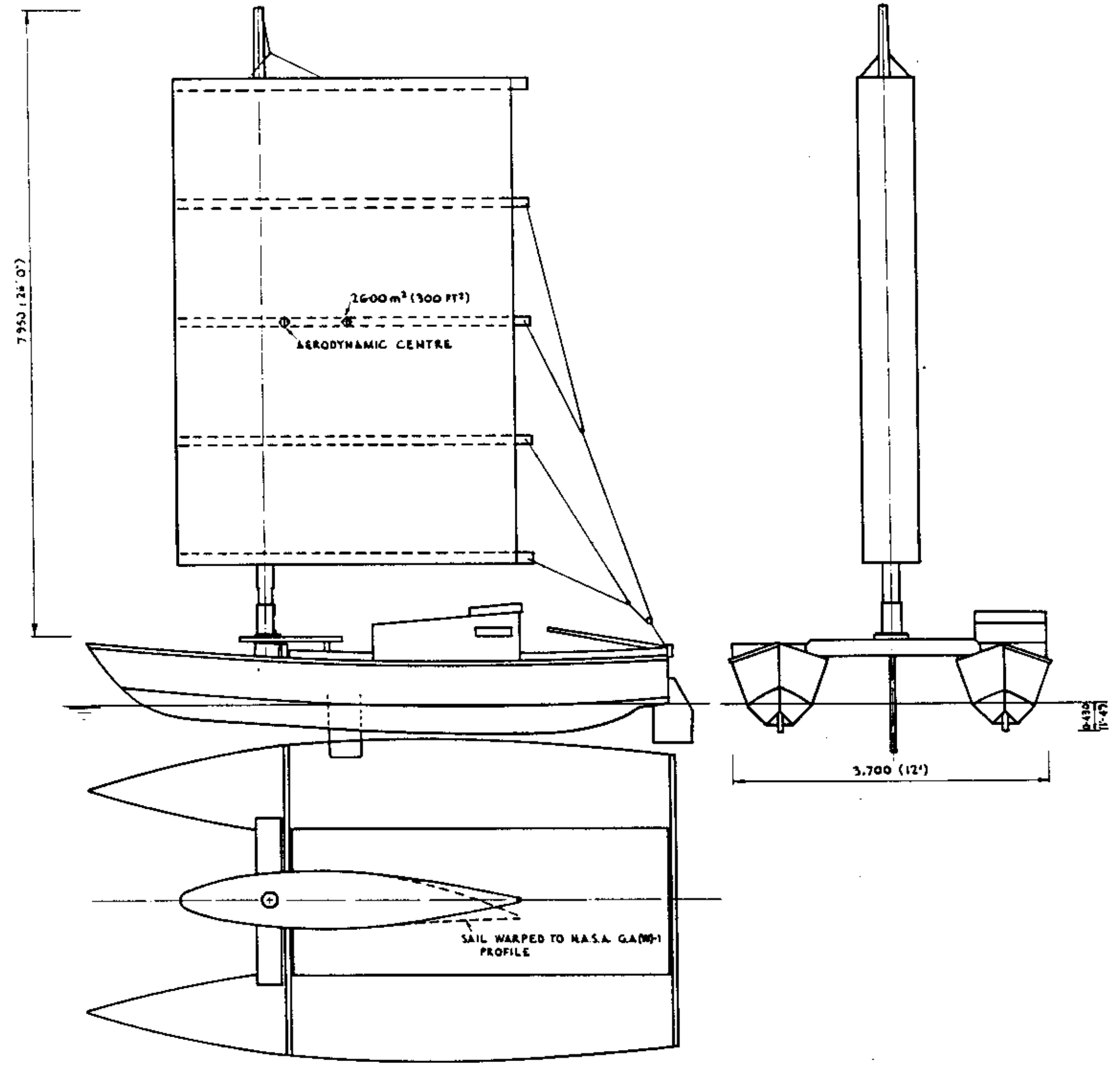

FIG. 3 EXPERIMENTAL TUNNY RIG ON SANDSKIPPER

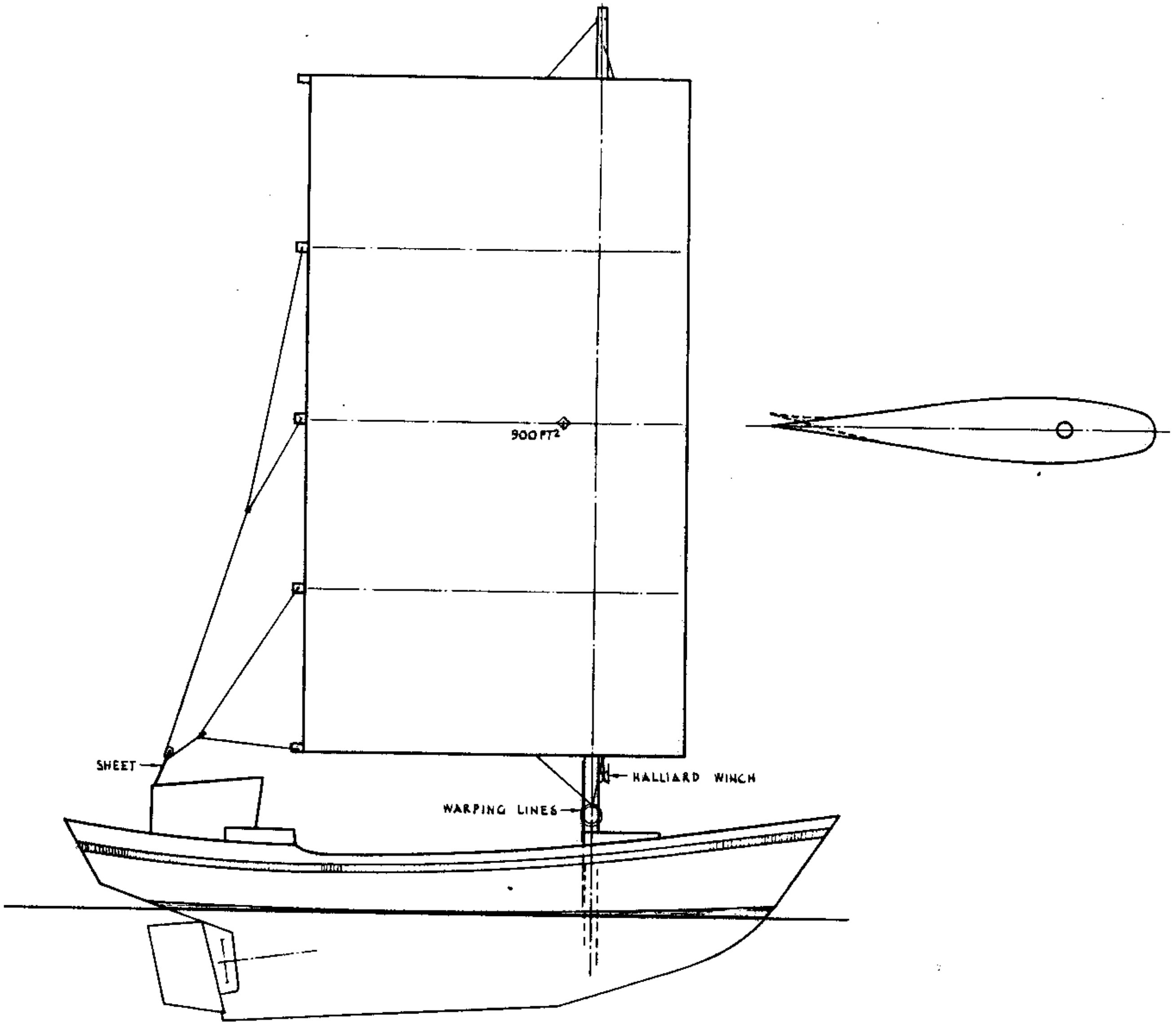

FIG.4 PROPOSED TUNNY RIG FOR 40FT. SCOTTISH GILL-NETTER

WINDMILL THRUSTERS FOR COMMERCIAL FISHING CRAFT

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ABSTRACT

This paper discusses the theoretical design of windmill thrusters for assisting the conventional propulsion system on commercial fishing craft. The windmill thruster consists of a windmill mechanically coupled to an underwater propeller. Kinetic energy extracted from the wind by the windmill is used by the underwater propeller to produce a net forward thrust. This can be achieved in all relative wind directions, even when the boat is proceeding directly against the wind. Using the theory of these devices, quantitative estimates are given of the expected thrust under a variety of operating conditions. Some consideration is also given to the best type of hull configuration for this application. A comparison between a windmill thruster and an aerofoil sail is given in the appendix.

INTRODUCTION

A windmill boat is a wind-driven boat in which a windmill type air turbine is mechanically coupled to an underwater propeller. Kinetic energy extracted from the wind by the windmill blades is used by the underwater propeller to push the boat directly against the wind, Fig. 1. The boat moves forward because the momentum added to the water can be greater than that removed from the air, despite unavoidable energy losses in the system. In a similar manner, a wheeled vehicle can move against the wind by coupling the windmill blades to a driving wheel. In addition to the capability of sailing directly upwind, windmill boats and vehicles can also sail at any other direction relative to the wind, by orienting the windmill blade to face the apparent wind, Fig. 1.

Historically, the concept of windmill boats and vehicles can be traced back to the early 1900's, by numerous patents and published articles in Europe and America.(1) More recently, interest in wind propulsion was revived by the "oil crisis" and the subsequent search for alternative energy sources(2),(3),(4). During the past several years we have worked on the theory of windmill boats and vehicles and have carried out numerous experiments(5)-(9). Our objecive was to develop a fundamental understanding of these devices and, thereby, to identify the parameters which are important for their efficient, fast operation.

In the present paper, the theory is used to design windmill thrusters for possible use on commercial fishing craft. Quantitative thrust predictions are given for a variety of windspeeds, boat speeds, apparent wind directions and underwater propeller efficiencies. The theory shows that the efficiency of the underwater propeller is of the utmost importance, especially when proceeding against the wind where it is desirable that it be greater than 80%. To achieve such high propeller efficiencies requires a considerably larger diameter propeller than would normally be used on conventional fishing boats. This is an intrinsic problem that could be overcome by designing deeper draft boats or by using an independent, retractable propeller for the windmill thruster.

BACKGROUND THEORY

The theory of windmill boats and vehicles has been presented previously(5)-(9), including a comprehensive account of blade design, for sailing at arbitrary directions with respect to the wind(9). For the present purpose the power output, P, from the windmill and, more importantly, the forces F_W, F and F_{NET} are of interest. Here F_W is the longitudinal component of the downwind force on the wind turbine and F is forward force produced by the underwater propeller, as shown in Fig. 1. $F_{NET} \equiv F-F_W$ is the net forward force effective at propelling the boat.

Expressions for the above quantities can be written as follows(9),

$$\frac{P}{4\pi\rho R^2 W^3} = \frac{(U/W)^3}{S^2} \int_0^S (1-a)\ a'\ s^3 ds \qquad (1)$$

$$\frac{F_W}{4\pi\rho R^2 W^2} = \frac{(U/W)^2 \cos\theta'}{S^2} \int_0^S a(1-a)s\ ds \qquad (2)$$

and

$$\frac{F_{NET}}{4\pi\rho R^2 W^2} = \frac{(U/W)^2}{S^2} \int_0^S \left(\frac{U\zeta}{u} a's^2 - a\cos\theta'\right)(1-a)s\ ds \qquad (3)$$

where $$\frac{U}{W} = (1+f^2+2f\cos\theta)^{1/2} \qquad (4)$$

as shown in Fig (2), and
$$\cos\theta' = \pm\left(1 - \left(\frac{W\sin\theta}{U}\right)^2\right)^{1/2} \qquad (5)$$

In Eqn. (5) the +th sign is to be used for $0<\theta'<\pi/2$ and the -th sign for $\pi/2<\theta'<\pi$. The various parameters appearing in Eqns. (1)-(5) are defined as follows:

a = windspeed reduction factor at the blade element.
a' = wind rotation factor at the blade element.
f = u/W = boat speed/wind speed.
r = radius of blade element measured from rotation axis.
R = radius of blade tip
s = $\Omega r/U$ = dimensionless speed ratio.
S = $\Omega R/U$ = tip speed ratio

(continued)

u = boat speed with respect to the water, Fig. (2).
U = apparent windspeed with respect to the boat, Fig. (2).
W = true windspeed with respect to the water, Fig. (2)
ε = drag/lift ratio of the wind turbine blades.
ρ = air density
θ = angle between true wind and boat course, Fig. (2)
θ' = angle between apparent wind and boat course, Fig. (2)
Ω = wind turbine rotation rate, (rad/sec)
ζ = efficiency factor of drive train, including water propeller

The factors a and a' both depend upon radius, and therefore on s, and are functionally related to each other by

$$a'(s) = -\frac{1}{2}(1+\varepsilon/s) + \frac{1}{2}\sqrt{(1+\varepsilon/s)^2 + 4a[(1-a)/s^2-\varepsilon/s]} \tag{6}$$

It is assumed, with considerable justification$^{(8),(9)}$, that a(s) is of the form

$$a(s) = a_o(1-\exp(-2s)) \tag{7}$$

where a_o is a constant to be chosen so as to maximize the net thrust.

A correction factor for a finite number of blades$^{(9,10)}$ can be introduced by replacing a with a.G in all of the preceding equations, where G(s) is given by

$$G = 2/\pi \text{ arc cos } (\exp(-g)) \tag{8}$$

and

$$g = \frac{N}{2}(1-s/S)\sqrt{1+S^2} \tag{9}$$

The efficiency factor of the underwater propeller, which is the major part of ζ, is a very important factor in determining the net thrust, as can be seen from Eqn. (3). To calculate this efficiency, the computational procedure worked out by Larrabee$^{(10)}$ can be used. The necessary input parameters are shaft power, shaft rotational speed, boat speed, propeller radius and the drag/lift ratio of the blades used. Once ζ is known, the various thrusts can be calculated using Eqns. (1)-(9).

DESIGN DESCRIPTIONS

Three different hull types are considered: (a) a medium displacement, shallow draft monohull capable of semi-planing operation; (b) a heavy displacement, deep draft monohull operating at hull speed and; (c) a shallow draft catamaran hull operating at hull speed. All three are currently used by the fishing industry, but the catamaran is not very common. Sketches of the three different types are shown in Fig. 3 (a,b,c), respectively.

Referring to Fig. 3, the horizontal axis wind turbine is mounted on top of a vertical mast and drives, through a 90° gear box, a vertical concentric shaft inside the mast. The mast can be rotated through 360° about the vertical so as to position the wind turbine to face the apparent wind. For the monohulls, Fig. 3(a,b), the power from the wind turbine is coupled to the drive shaft of the existing underwater propeller, through a gearbox and clutch mechanism. For the catamaran hull, Fig. 3(c), the wind turbine drives an independent water propeller which can be pivoted up out of the water between the two hulls when not in use. The latter ability would be useful for operating in shallow water and for reducing the water drag during operation in calm weather.

The blades of the wind turbine must be mounted on a controllable pitch hub. This is necessary for two reasons: (a) to achieve the optimal blade pitch, and thereby maximum thrust(9), in all wind directions, and (b) to feather the blade for safety purposes when winds become too strong.

Streamlining of the pilot house and forward section of the boat would be desirable for delivering a clear air flow to the wind turbine.

THRUST PREDICTIONS

To work with a specific example, an overall boat length of 15 m (~50 ft) was used for each of the hull configurations in Fig. (3). In each case the diameter of the wind turbine was assumed to be 11 m (36 ft) which is about 75% of the boat length. Thrust predictions were calculated for wind speeds of 7 m/s (14 knots) and 10 m/s (20 knots). The results for each type of hull configuration are as follows:

(a) Shallow Draft Monohull.

For this semi-planing hull the cruising speed is assumed to be 6 m/s (12 knots), which is somewhat greater than hull speed. This is achieved normally by a 190 KW (250 HP) engine, driving a 0.75 m (30") diameter 4-bladed propeller at 105 rad/sec (1000 rpm). Using the procedure of Larrabee(10) the propeller efficiency is found to be 57% and the thrust of the propeller is 18,000 Newtons (4000 lbf). Thus a net forward thrust of 4000 lbf is needed to propel the boat at 12 knots. Now the wind turbine is added to the boat and the power from it is coupled to the same underwater propeller, as shown in Fig (3a). The wind turbine is assumed to operate at a tip speed ratio of S=4 when going upwind, S=5 when going at θ=90° to the true wind and S=6 when going downwind at θ=180°, respectively(9). The results are summarized in Table 1.

Examination of Table 1 shows that when the boat speed is u = 6 m/s(12 knots) the presence of the wind turbine would be detrimental, except when proceeding down wind in a wind of 10 m/s (20 knots) where the engine power could be reduced from 190 to 180 KW. The situation is worst when proceeding upwind in a wind of 10 m/s, where the engine power would have to be increased from 190 to 240 KW because of the wind turbine.

Note that the wave and wind drag forces on the hull and superstructure of the boat were ignored in this study in order to show the effect of the wind turbine. Power train losses, typically a few percent, were also ignored.

For u = 2 m/s the situation is somewhat better. For $\theta = 90°$ and 180° the thrust derived from the wind turbine is more than adequate and no power is required from the engine. However, for $\theta = 0°$, the windturbine is a detriment.

(b) Deep Draft Monohull

For this case, heavy displacement hull, the cruising speed is assumed to be 5 m/s (10 knots), which is the hull speed. This is achieved normally by a 230 KW (300 HP) engine driving a 1.52 m (60") diameter 4-bladed propeller at 52 rad/sec (500 rpm). Using the procedure of Larrabee(10) the propeller efficiency is found to be 69% and the thrust of the propeller is 31,800 Newtons (7200 lbf). Now add the wind turbine and couple the power from it to the same underwater propeller, as shown in Fig. (3b). The results are summarized in Table 2.

Examination of Table 2 shows that the situation is somewhat better than for Table 1. This is mainly due to the increased efficiency derived from the larger diameter underwater propeller. For u = 5 m/s, the wind turbine leads to a slight reduction of engine power, except when proceeding upwind in a wind of W = 7 m/s where the required engine power is increased from 230 to 234 KW. For u = 2 m/s, the wind turbine leads to a substantial reduction in engine power for W = 7 m/s and produces more than enough thrust when W = 10 m/s.

(c) Shallow Draft Catamaran.

For this case the cruising speed is again assumed to be 5 m/s (10 knots), which is the hull speed. However, the drag force is less than for the heavy displacement hull (b) and consequently the cruising speed can be achieved with 2 - 76 KW (100 HP) engines, each driving a 0.65 m (26") diameter propeller at a shaft speed of 104 rad/sec (1000 rpm). The propeller efficiency in this case 57% and the thrust of each propeller is 8700 Newtons (1950 lbf). Thus a total thrust of 17,400 Newtons (3,900 lb) is required to move the boat at u = 5 m/s.

The wind turbine in this case is coupled to its own underwater propeller, 3-bladed and having a large diameter of 2.5 m (98"), as shown in Fig. (3c). The underwater propeller rotates 2.0 times faster than the wind turbine. The results for this case are summarized in Table 3.

Examination of Table 3 shows that the situation is <u>much</u> better than for Tables 1 and 2. For u = 5 m/s the required engine power is reduced in all cases and substantially so (nearly 50%) when proceeding upwind in a wind of W = 10 m/s. For u = 2 m/s the windmill thruster produces more than enough thrust for all cases considered. This is particularly true for W = 10 m/s, for which the thrust is ~3 times the minimum amount required to move the catamaran at u = 2 m/s.

CONCLUSIONS

The conclusions to be drawn from this study are:

(a) The use of a wind turbine on a commercial fishing boat in which the power output from the wind turbine is coupled to the existing underwater propeller is not recommended. The size of the propeller used on a conventional fishing boat is too small to realize the high propeller efficiences which are needed to make the wind thruster of practical value. The situation would be improved considerably by using a much larger propeller in cases where there is no need to operate in shallow water.

b) An alternative, recommended procedure is to couple the wind turbine to an independent propeller of sufficiently large diameter, i.e. about 20-25% of the diameter of the wind turbine. The predicted results for this case are encouraging, and suggest that the system would be of practical value. The large propeller would be retracted when not in use or when operating in shallow water. This system could be installed on a monohull, but the catamaran would be more ideally suited. In the latter case the large propeller could be pivoted out of the water and stored between the two hulls. The catamaran has the additional advantage of a very large initial stability which would minimize the heeling caused by the wind turbine.

TABLE 1

WIND					PROPELLER		
Speed W(m/s)	Direction θ(deg)	Power P (KW)	Force F_W(10^3 N)		Thrust (10^3N)	Engine Power(KW)	Efficiency
Boat speed u = 6 m/s							
0	-	-	-		18.0	190	.57
7	0	39	3.9		21.9	220	.51
7	90	17	1.7		19.7	200	.54
7	180	.02	- .05		18.0	190	.57
10	0	86	7.5		25.5	240	.47
10	90	37	2.4		20.4	193	.53
10	180	1.5	-0.8		17.2	180	.57
Boat speed u = 2 m/s							
0	-	-	-		2.0	7	.57
7	0	18	3.1		5.1	10	.37
7	90	10	0.6		3.2	-	.49
7	180	3.0	-1.3		1.1	-	.74
10	0	44	5.7		7.7	14	.26
10	90	27	0.9		5.0	-	.37
10	180	12	-3.3		3.0	-	.50

Table 1. Thrust and power predictions for a wind turbine mounted on a shallow draft monohull and coupled to the existing engine propeller, as shown in Fig. (3a). θ = 0° corresponds to going upwind and +th F_W is against the boat motion. The required net thrust is 18,000 Newtons (4,000 lbf) at u = 6 m/s and 2,000 Newtons (450 lbf) at u = 2 m/s. See text for further discussion.

TABLE 2

WIND					PROPELLER		
Speed W(m/s)	Direction θ(deg)	Power P (KW)	Force F_W(10^3 N)		Thrust (10^3N)	Engine Power(KW)	Efficiency
Boat speed u = 5 m/s							
0	-	-	-		31.8	230	.69
7	0	34	3.8		35.6	234	.67
7	90	14	1.3		33.1	229	.68
7	180	0.2	-0.2		31.6	228	.69
10	0	75	7.1		38.9	230	.64
10	90	33	2.0		33.8	216	.68
10	180	3.0	-1.3		30.5	215	.70
Boat speed u = 2 m/s							
0	-	-	-		5.3	15	0.70
7	0	18	3.1		8.4	11	.59
7	90	10	0.6		5.9	8.0	.67
7	180	3.0	-1.3		4.0	6.5	.76
10	0	44	5.7		11.3	-	.52
10	90	27	0.9		8.1	-	.60
10	180	12	-3.3		4.4	-	.74

Table 2. Thrust and power predictions for a wind turbine mounted on a deep draft monohull and coupled to the existing engine propeller, as shown in Fig. (3b). The required net thrust is 31,800 Newtons (7,150 lbf) at u = 5 m/s and 5,300 Newtons (1,200 lbf) at u = 2 m/s. See text for further discussion.

TABLE 3

WIND THRUSTER						ENGINES		
Speed W(m/s)	Direction θ(deg)	Power P(KW)	Net Force F_{net} (10^3N)	Prop. Efficiency		Thrust (10^3N)	Power (KW)	Propeller Efficiency
Boat speed u = 5 m/s								
0	-	-	-	-		17.4	2x76	.58
7	0	34	2.6	.94		14.8	2x59	.62
7	90	14	1.3	.96		16.1	2x66	.60
7	180	0.2	0.2	.92		17.2	2x75	.58
10	0	75	6.5	.91		10.9	2x39	.70
10	90	33	4.3	.95		13.1	2x50	.65
10	180	3.0	1.9	.96		15.5	2x62	.61
Boat speed u = 2 m/s								
0	-	-	-	-		2.8	2x4.8	.61
7	0	18	4.1	.81		-	-	-
7	90	10	3.6	.87		-	-	-
7	180	3.0	2.8	.94		-	-	-
10	0	44	9.3	.68		-	-	-
10	90	27	9.4	.76		-	-	-
10	180	12	8.5	.86		-	-	-

Table 3. Thrust and power predictions for a wind turbine mounted on a shallow draft catamaran and coupled to a large (2.5 m) diameter propeller which is independent of the engine propeller. The required net thrust is 17,400 Newtons (3,910 lbf) at u = 5 m/s and 2,800 Newtons (630 lbf) at u = 2 m/s. See text for further discussion.

BIOGRAPHY

Brad Blackford is a native of Nova Scotia. He graduated from Acadia University in 1961 with B.S honours degree in physics. In 1963 he received an M.S degree in physics from the Massachusetts Institute of Technology and in 1969 a Ph.D in physics from Dalhousie University. Research topics have ranged from fluid dynamics to high temperature thermionic emission, to low temperature superconductivity phenomena. He is an active sailor and finds the application of physics to windmill boats and vehicles an interesting topic. He is associate professor of Physics at Dalhousie University, and is currently on sabatical leave at the Institute of Ocean Sciences in Sidney, British Columbia.

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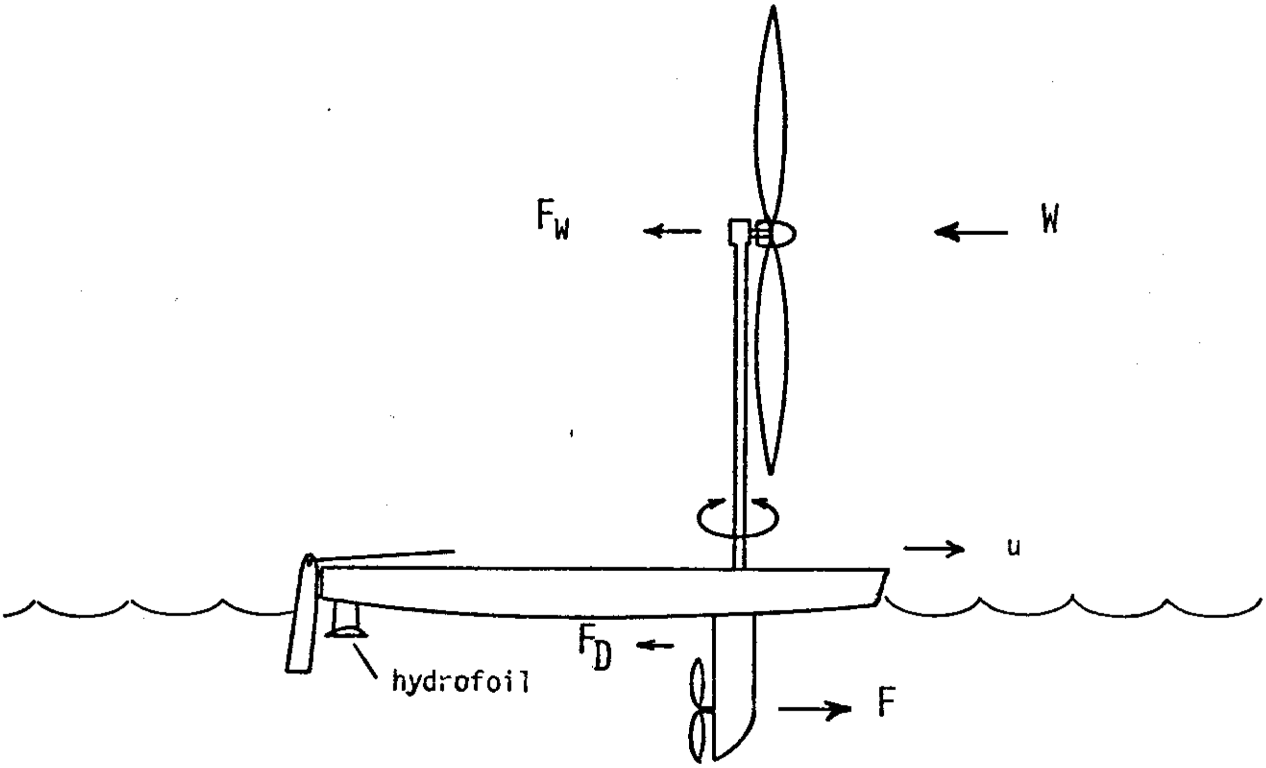

Fig. 1. Sketch of a windmill boat (catamaran) sailing straight upwind. The wind turbine can be rotated about the vertical mast so as to face the apparent wind, allowing the boat to be sailed in any direction without tacking. F_W is the backward force on the wind turbine, F is the forward force produced by the underwater propeller and F_D is the drag force of the water on the boat. The net force $(F-F_W)$ produces the forward speed, u, of the boat, at which $F-F_W-F_D = 0$. The under-water hydrofoil at the rear of the boat produces a lifting force which counteracts the rearward pitching moment due to the forces F_W, F and F_D.

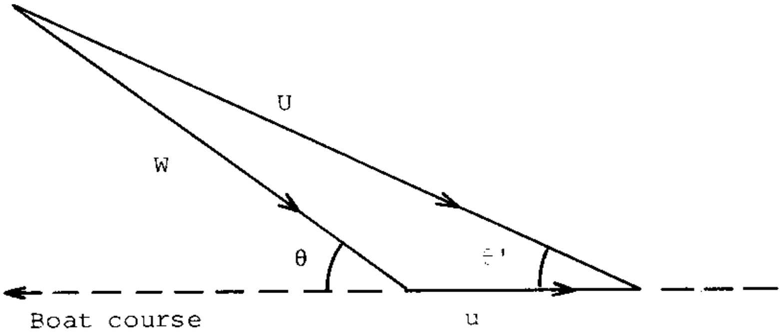

Fig. 2. Sketch of a windmill boat sailing at an angle θ with respect to the true wind. U is the apparent windspeed, which makes an angle θ' with respect to the boat's course.

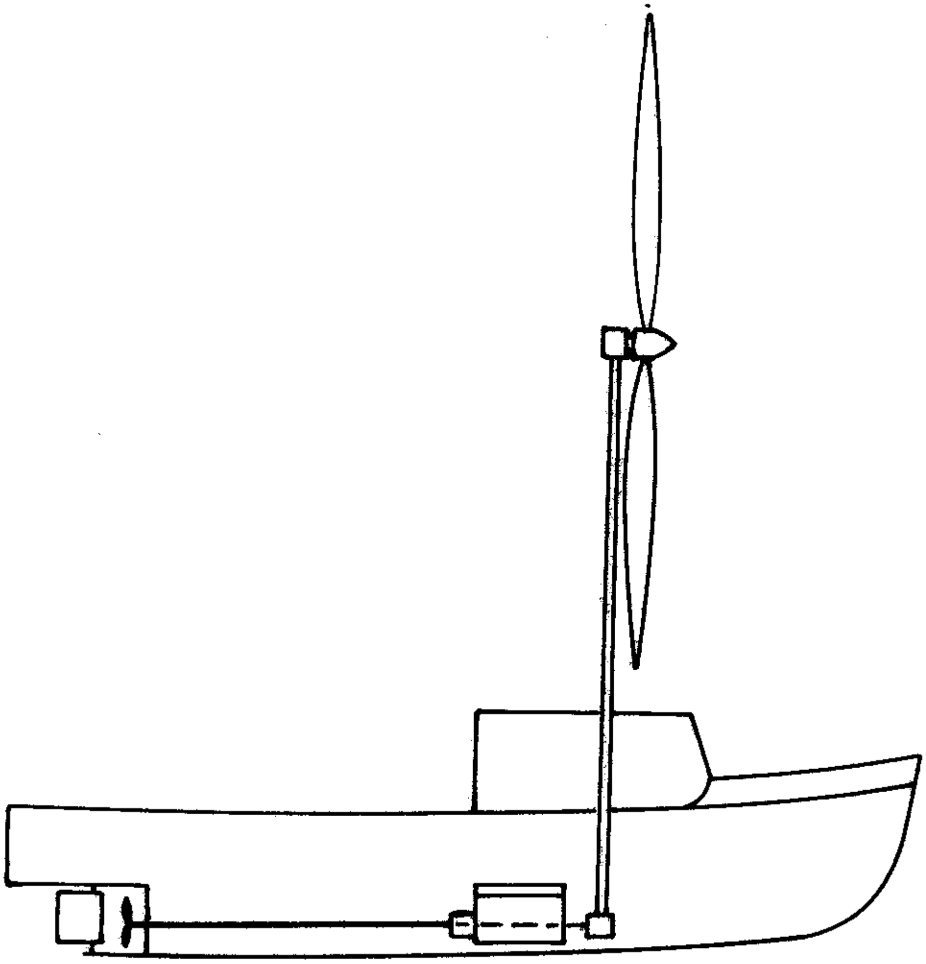

Fig. 3(a). Wind turbine mounted on a medium displacement, shallow draft boat. The power output from the wind turbine is coupled to the same propeller used by the engine.

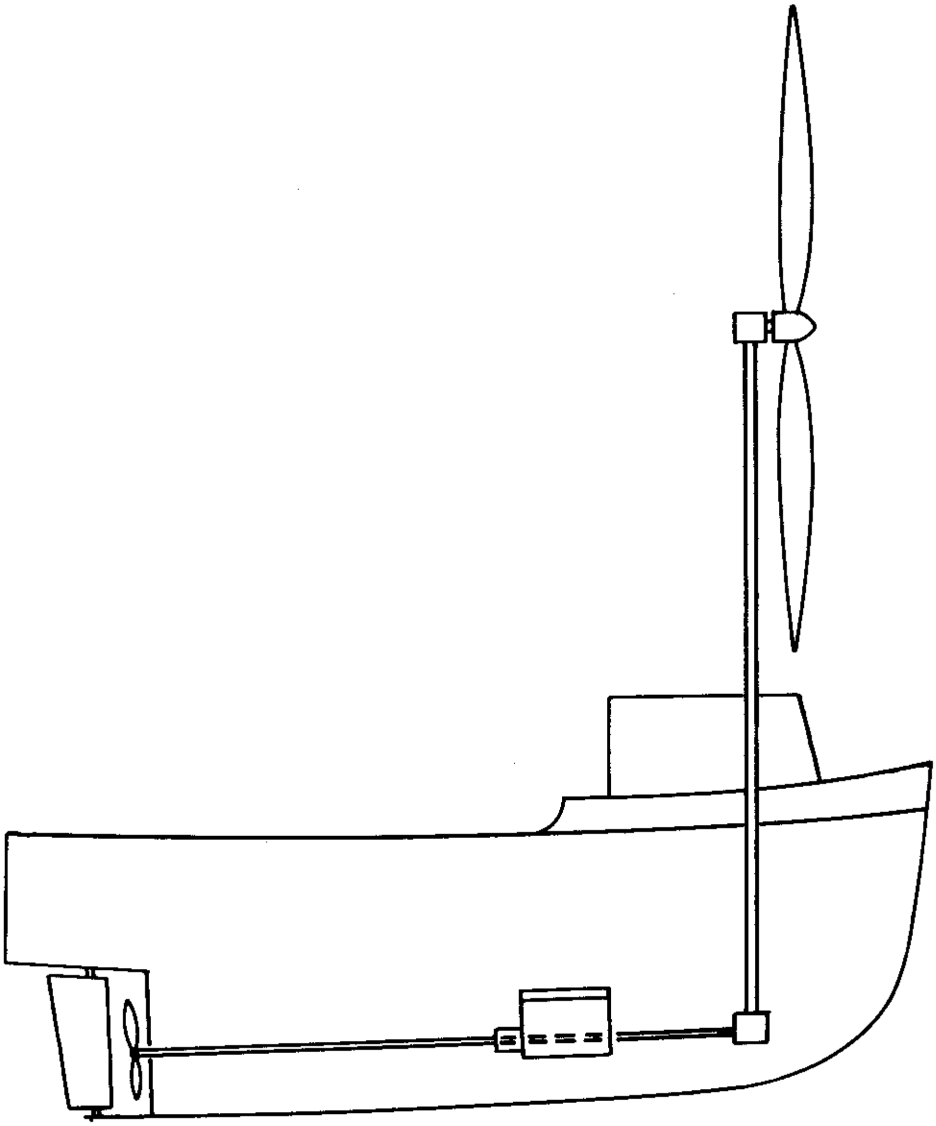

Fig. 3(b). Wind turbine mounted on a heavy displacement, deep draft boat. The power from the wind turbine is coupled to the same propeller as that used by the boat's engine.

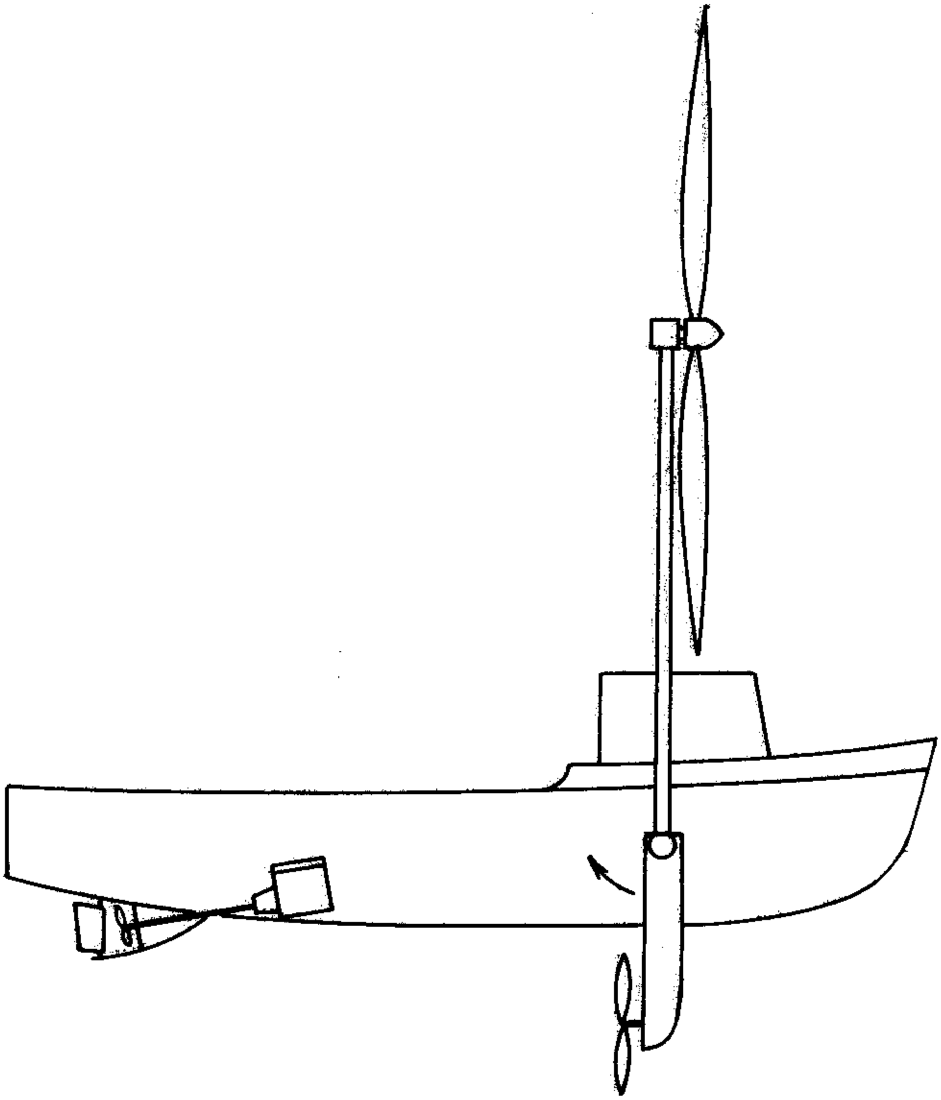

Fig. 3(c). Wind turbine mounted on a catamaran hull and coupled to an independent propeller which can be pivoted out of the water between the hulls when not in use.

APPENDIX

Comparison of a Windmill Thruster and an Aerofoil Sail

The net forward thrusts produced by a windmill thruster and by an aerofoil sail, respectively, will be compared for all sailing directions, θ. Consider an aerofoil sail mounted on a boat which is proceeding at a speed u and whose course makes an angle θ with respect to the true wind, Fig. (2). The lift force, F_L, produced by the sail is perpendicular to the apparent wind, $\vec{U}$, and is given by

$$F_L = \frac{1}{2} \rho C_L A U^2 \tag{10}$$

where C_L is the lift coefficient of the sail, A the sail area, and U is obtained from Eqn. (4). Similarly, the drag force, F_D, which is parallel to $\vec{U}$, is given by

$$F_D = \frac{1}{2} \rho C_D A U^2 \tag{11}$$

The net force propelling the boat forward is given by

$$F_L \sin\theta' - F_D \cos\theta' \tag{12}$$

where θ' is given by Eqn. (5). For comparison purposes, the normalized forward force will be of interest,

$$F_{\text{forward}} / \rho A W^2 = \frac{1}{2} \left[\frac{U}{W} \right)^2 \left[C_L \sin\theta' - C_D \cos\theta' \right] \tag{13}$$

In a realistic situation C_L and C_D will depend on the apparent wind angle θ' and the following forms were used here:

$$\begin{aligned} \text{For} \quad & 0 < \theta' < 90^\circ, \; C_L = 1.5 \text{ and } C_D = 0.3 \\ & 90^\circ < \theta' < 180^\circ, \; C_L = 1.5(1+\cos\theta') \text{ and } C_D = 0.3 - \cos\theta' \end{aligned} \tag{14}$$

The lift coefficient maintains a high constant value, 1.5, up to $\theta' = 90^\circ$ and thereafter decreases to zero at $\theta' = 180^\circ$. The drag coefficient maintains a constant value of 0.3 up to $\theta' = 90^\circ$ and then increases to 1.3 at $\theta' = 180^\circ$. Note that these values of C_L and C_D are about the best that one could hope for.

The normalized net forward force produced by the aerofoil sail is plotted as curve (a) in Fig. (4), for a boat traveling at a speed $u = W/2$. The thrust is negative for small values of θ and increases to its maximum value for $\theta \simeq 90^\circ$.

Now consider the case of the windmill thruster, for which the net forward force is given by Eqn. (3). The effective area of the windmill is taken to be πR^2, the swept-out area. The appropriate normalized force is then $F_{net}/\rho\pi R^2W^2$, so that the factor of 4 in Eqn. (3) must be taken to the right hand side.

To obtain optimal net thrust from the windmill, the wind speed reduction factor a_0, Eqn. (7), and the tip speed ratio S must be allowed to vary with θ, as discussed in references $^{(8,9)}$. To take this effect into account, the following approximate forms were used for $a_0(\theta)$ and $S(\theta)$,

$$a_0(\theta) \simeq 0.21 + 0.24\ (\theta/180)^2 \tag{15}$$

when u/W = 0.5, and

$$S(\theta) \simeq 4 + \theta/90 \tag{16}$$

The efficiency factor, ζ, of the underwater propeller, and the drag/lift ratio, ε, of the windmill blades were chosen to be $\zeta = 0.95$ and $\varepsilon = 0.01$, which again are about the best values that one could hope to achieve.

The normalized net thrust produced by the windmill thruster is plotted as curve (b) in Fig. (4). In contrast to the sail, the thrust is maximum for $\theta = 0°$ and remains high in the interval $0 < \theta \lesssim 45°$, which is normally forbidden to a conventional sailboat. On the other hand, for $45° \lesssim \theta \lesssim 135°$ the windmill produces less thrust than the sail, as much as 35% less. For $135° \lesssim \theta \lesssim 180°$ the windmill produces somewhat more thrust.

The comparison depends strongly on the boat speed ratio u/W as can be seen from Fig. (5), where the narmalized thrusts are given for u/W = 0.75. In this case, the aerofoil sail is much better than the windmill thruster for $45° < \theta < 135°$. For larger values of u/W the windmill thruster becomes progressively worse. On the other hand, for $u/W < 0.33$, the windmill thruster is better than the sail for all θ.

The general conclusion here is that; the windmill thruster would likely be a superior propulsion system to the aerofoil sail for $u/W \lesssim 0.5$, whereas the opposite is true for $u/W \gtrsim 0.5$.

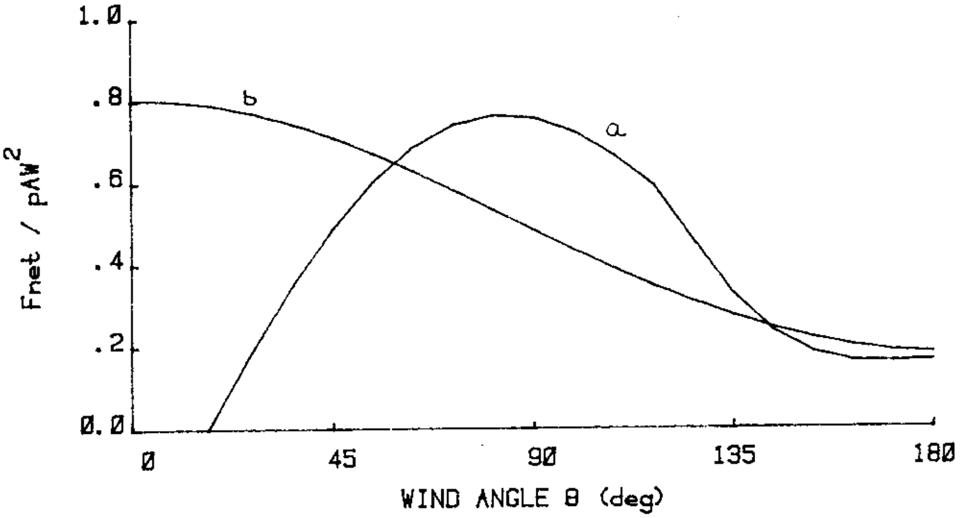

Fig. (4). Normalized net forward force versus wind angle θ for an aerofoil sail (a) and a windmill thruster (b). The boat is travelling at u = 0.5W.

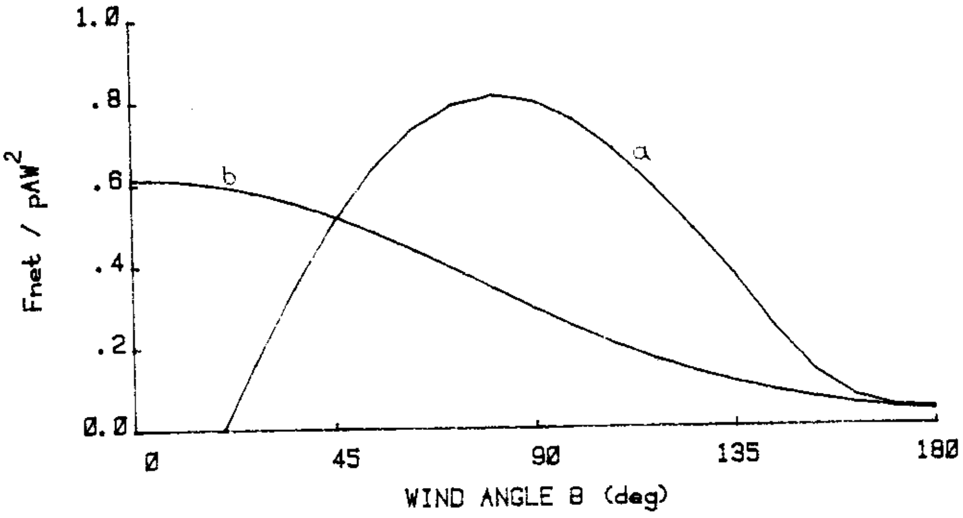

Fig.(5). Same as Fig. (4), but with u = 0.75W.

FISHING VESSELS WITH THE AEROSYSTEMS WINGSAIL

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ABSTRACT:

This brief paper points out the problems with hull design in new construction or in adding sail to an existing fishing boat. Ballasted and non-ballasted hulls are discussed as well as the need for individual stability calculations in order to determine allowable sail area.

The primary importance of the fishing gear is stressed, with the sailing rig designed for least interference. Two sketches of proposed sail-assisted fishing vessels are introduced, which use the patented AEROSYSTEMS WINGSAIL invented by Jack Manners-Spencer. This system is discussed at length, emphasizing the ease of handling by one person, without the need for jibs, large winches, or sail lockers.

The efficiency of the symmetrical, airfoil-shaped wingsail is discussed along with the presentation of some wind tunnel test data. Further, the development problems and construction details of the wingsail are mentioned, along with the procedure used to calculate the free standing glass fiber masts.

Probably the most important task that we have is to convince the fishing vessel owners that the installation of a sailing rig is worthwhile and will be accepted by the crew. A few suggestions are offered in this direction.

OBJECTIVE:

To investigate the use of a patented wingsail rig on commercial fishing vessels, both on existing hulls and on new designs. This involves the non-ballasted powerboat hull form with a shallow draft and the deep, ballasted, keel on a conventional sailboat hull form. The two types must be clearly defined when installing a sailing rig, and their handling characteristics considered separately, even though they must perform the same working functions. There seems to be general reluctance on the part of fishermen to accept a sailing rig, especially in the United States, although they do realize the necessity for saving fuel costs. We must develop convincing thoughts so that sail-assisted commercial fishing vessels will have a favorable public relations image.

DEFINITION OF THE PROBLEMS:

We are trying to bring together the efficient powering advantages of a sailboat with the wide working platform, heavy winches, and heavy booms that are traditionally placed on a powerboat hull form. In order to do this we will probably have to limit our investigation to boats of a speed-length ratio of less than 1.3, and possibly with a prismatic coefficient between 0.54 and 0.64. In other words, we are dealing with displacement speed hull forms, just as with any sailing vessel. Boats that insist on moving faster than this will have the apparent wind dead ahead, and the sailing rig will probably not be able to be used very often. Those small boats that travel at high speeds in order to reach a warm water canyon 60 miles offshore will probably not be able to use sail power, but they wish they might have the sail steadying effect when they are trolling at slow speeds.

It would seem obvious that any commercial boat has to show a profit, and thus our first priority would be the fishing gear that makes the craft function efficiently. Just because we are putting sails on a fishing boat, we cannot change the gear that the crew has found to be necessary. The net roller, winches, power blocks on booms, long-line reel, down-rigger, or pot hauler all have to be installed in their correct location around the fish hold. After this, the sail plan can be designed to work around the booms and gantry, leaving space for a workable deckhouse.

HULL SHAPE:

In order for the crew to work properly, the deck shape cannot be changed greatly, but it may be possible to narrow the stern sections slightly, from the traditional fishing powerboat hull lines. This would produce a lower prismatic coefficient and thus decrease the low speed resistance when under sail-assisted power in the motorsailing mode. In some boats, depending on the owner's preference, the working deck aft may be shortened slightly in order to provide more room forward for a larger sail plan. This is illustrated in drawings B and C, where two wingsails are used instead of one and the sail area is increased by 50%, while the aft deck length is reduced from 37 feet to 27 feet. It is suggested that this still leaves sufficient deck area so that fishing operations are not impaired. In both sketches, the topside hull shape is the same, they are both 75 foot combination fishing vessels, and they both have the same deck equipment, according to the owner's needs.

The underwater hull shape can be that of a traditional powerboat, without ballast, or a deep draft fin keel with ballast can be designed, without changing the remainder of the underbody in sketches A, B, and C. The difference, of course, is that the ballasted hull can carry the total sail area in stronger winds as long as the maximum angle of heel, previously calculated, will not be exceeded.

Why can't we add a ballast fin keel to a traditional fishing boat hull? Why don't we see deep draft, deep keel commercial hulls? The answers are increased building costs initially, increased resistance in a hull that is driven faster than displacement speeds, and that the boats are used in shallow water where minimum draft is a necessity. But when we use deep, ballasted keels in combination with sails to reduce fuel costs, and we move the hull at low speeds, we are then only limited to any shallow draft requirements. If we do install a deep ballast keel on a commercial fishing boat hull, we would probably be in the five-foot draft range for a boat under forty feet and in the six-foot draft range for a boat between forty and sixty feet in length.

On the hull shown in illustration A, we have an average 38 foot fishing boat with 18 feet of aft deck working space. Here, the 400 sq. ft. AEROSYSTEMS wingsail does not interfere with any of the fishing gear. If the wind were abeam, the sail area shown could probably be used in winds up to 18 knots before the area would have to be reduced by reefing the sail, assuming a boat without ballast. Coincidentally, this is approximately the wind speed that most all sailboats start reefing, if they want to sail comfortably and safely. If this same hull had a ballasted keel, the center of gravity would be lowered, the maximum righting moment increased, and the total sail area would probably be able to be carried in winds up to 22 knots before reefing, with the wind abeam. The selection of a ballasted keel and deeper draft is again a personal preference of the owner and is largely dictated by the area and type of fishing operation.

SAIL AREA:

Wind pressure on the sails causes the hull to heel over to a point where there is a balance of heeling forces and righting force. This wind pressure acts through a heeling arm which is the distance from the center of the sail plan to the vertical position of the center of buoyancy of the hull. This resultant heeling moment is counteracted by the ability of the hull to right itself from an angle of heel. This ability can only be determined from a stability calculation of each particular hull in the loaded condition in which it will be operating. The total center of gravity of all the items in the boat is first calculated, and then the righting arm (GZ) is determined. Illustration D is a table of righting arms of various hulls, which is presented only as an example of how widely the GZ can vary with different hull shapes. We cannot over emphasize how important it is to calculate the stability on each hull, rather than simply copy the results from what appears to be a similar boat.

After the righting moment of the hull has been determined, (RM = GZ x Displacement) it can be divided by the heeling arm and then divided again by the selected wind pressure desired for reefing, in order to obtain the maximum amount of sail area that we can safely use. The wind pressure is about 2.1 lb./sq.ft. at 20 knots; 3.25 lb./sq.ft. at 25 kts; and about 4.8 lb./sq.ft. at 30 knots. Certainly, we should reef the sail soon enough so that the heeling moment does not exceed the maximum righting moment of the hull, as we would then risk a capsize. Practically speaking, most hulls of normal shape have a maximum righting moment that occurs at a large angle of heel, so that if we reef the sail to limit the heel angle to about 15 degrees, we should remain within safe limits.

The calculation of righting moment is the only method of determining sail area for commercial boats with little or no ballast, as the traditional methods for well-ballasted sailboats has proven ineffective. This usual technique involves the ratio of sail area divided by the two-thirds power of displacement (cu. ft.). This normally results in a number between 15 and 19. If used for non-ballasted fishing boats, this ratio will result in excessive areas.

Most of the previous discussion of hull shape and sail area determination has been directed towards using a standard fishing boat hull and converting it to a sail-assisted, more economical type of operation. To take another approach, we could think more about a true sailing hull, and how we can best locate all of the fishing equipment for efficient operation. It would seem that we are now looking at the motorsailer type of hull with a fairly broad beam both amidships and at the transom, with full bilges and sufficient displacement to allow a profitable fish hold. The term 'motorsailor' is open to many definitions, such as a boat that is faster under power than under sail, or a boat that has the transom partially in the water rather than entirely out of the water. Let's just say that we want a broad-beamed, husky, sailboat hull for a commercial fishing boat, with a open deck area aft.

WHY THE WINGSAIL?

For many years, innovative sailors have attempted to improve on the conventional sailing gear, realizing the turbulence produced by the wind shadow of the exposed mast, the stretching of the sailcloth, and the variation in sail camber from top to bottom and from edge to edge. The racing catamaran sailors improved their speed with the building of partially rigid wingsails that formed an airfoil-shaped mast, but they could not be reefed and were thus not suitable for offshore vessels. Those wingsails had to be removed from the boat each day and were strictly racing oriented. But the efficiency of the wingsail was proven, and especially the concept of concealing the mast inside the wing structure, insuring a smooth, non-turbulent flow over the surface of the sail.

Jack Manners-Spencer, of Hampshire, England, had been working on this concept, also, and he has invented and patented the AEROSYSTEMS wingsail. His primary objectives were to have a sail that is easy to handle in all conditions, that is easy to reef by one person, and which is aerodynamically efficient. Further, the rig had to be priced in competition with conventional rigs, and it had to be able to be used as a replacement rig in existing hulls as well as in new construction. All of these requirements have been met in his invention. In addition, there is no wire rigging required for the free-standing mast, large winches are not needed, there are no jibs to set or change, and sail lockers are not needed. One large expense in a new installation is the location of eight chainplates (for a sloop rig) with a conventional sail plan, together with the eight turnbuckles and clevises. This expense can be saved with the AEROSYSTEMS wingsail, keeping the costs within reasonable limits.

This sail innovation can easily be handled by one person, and is ideal for single-handing. There is only the halyard and sheet to use in the conventional manner, just as one would handle a mainsail on any boat. Since there is some sail area projecting forward of the mast (pivoting point), there is wind pressure tending to rotate the sail in both directions, and there is a reduced load on the sheet as a result.

DEVELOPMENT OF THE WINGSAIL:

Jack Manners-Spencer has devoted thousands of hours to bring his wingsail invention to its present state, and most of the time was actual sailing hours in open sea conditions. After perfecting this system, Jack has cruised over 8000 miles in his 40 foot sailboat with many crossings of the rough English Channel and trips to the Bay of Biscay and Northern Spain. Other boats with his wingsail have logged over 18,000 sea miles, both in Europe and Australia.

In 1981, Arthur Edmunds designed a 44 foot steel cruising sailboat for an owner who wanted to live aboard and sail the Caribbean, mostly single-handed. The owner had sailed with Jack Manners-Spencer in England and was convinced of the efficiency and practicality of the wingsail. This boat is now pleasantly cruising and the owner is very well satisfied with the performance after 4000 miles.

The sheet and the halyard can be led to the cockpit or deck working area so that reefing or furling is very quickly accomplished. It was found that this sail can be set closer to the apparent wind without any flapping or banging around, because of the constraint provided by the airfoil-shaped symmetrical battens. Thus, this rig is better suited to motorsailing, as would commonly be used on commercial vessels. With a normal sailboat hull form, one can tack through 90 degrees on the compass.

The NACA 0015 sectional shape was selected as optimum and the elliptical planform proved to be the most practical as a greater amount of sail area can be used with the same mast height when compared with the conventional triangular shape.

Wind tunnel tests were conducted at Southampton University in England, on a twenty square foot model, and the results are shown on illustration F. The maximum coefficient of lift was 1.15 at a 22 degree angle of incidence and the lift coefficient has been projected to 1.75 with a full size 600 sq.ft. sail at 17 knots windspeed. The best lift/drag ratio was 9.25:1 at an angle of incidence of 5 degrees with the Reynold's Number equal to 500,000.

The mechanics of the system were based on the premise that an un-complicated structure results in less problems of a maintenance nature. As the sail is reefed (lowered), the weight is lowered also, and it is easy to control in heavy weather due to the full length battens restricting the sail's movement. These battens also hold the sail clear of the mast so that chafe is greatly reduced. Also, there are no stays or spreaders for the sail to rub against. As the battens reduce the flapping and flogging, the life of the sails is greatly extended.

When sailors first look at the wingsail, they are incredulous, in that the simplicity of the structure is overwhelming. It really is a true wing of symmetrical shape. The sail operates at an angle of attack to the relative wind and thus produces lift, similar to the function of a properly shaped symmetrical keel in providing lift to reduce leeway.

After many miles of sailing, the basic structure of the AEROSYSTEMS wimgsail has proven very effective and the concept has been refined only in small detail, but without any real change. Recently, extruded aluminum battens have been used to replace ordinary aluminum tubing. These new extrusions have bolt rope grooves top and bottom that allow the sail to be made in separate panels rather than in one piece. This means that the sails can be conveniently fabricated and that a torn section can quickly be replaced. The wingsail continues to be ocean tested on various types of hulls, both for pleasure and commercial applications.

CONSTRUCTION OF THE WINGSAIL:

The sectional shape of the boom and all of the battens is that of a symmetrical airfoil and can be seen in the photos of illustration E. Small diameter rope is used for internal bracing lines that connect each batten and the boom so that they all stay parallel and so that there is minimum twist from headboard to boom. The new, extruded aluminum battens are stiffened with cross-bracing of aluminum angle. At the mast, this bracing is covered with nylon strips so that there is little friction as the entire assembly rotates around the mast. These strips are the only material that contacts the mast, which is circular with a constant outside diameter.

Wide headboards of light weight aluminum are located at each side of the mast and they assist in holding the elliptical shape at the head of the sail. The halyard is secured to the headboard and runs through a masthead block, as normal, and the halyard then runs down inside the battens, further reducing any windage. The boom is an aluminum extrusion which is bent to the foil shape and it is supported by both a collar around the mast and by lazyjacks.

The sails are flat panels of ordinary sailcloth, and are supplied with the mast, boom, and batten assembly when ordering from AEROSYSTEMS in England. The wingsail construction is rugged simplicity shaped to a functional form that is ready to go to sea.

THE CANTILEVERED MAST:

The free-standing mast is considered to be a cantilevered beam with a uniformly distributed load, and with the maximum bending moment at the deck, or deckhouse roof. This load at the deck must be carefully considered and extra framing and stiffeners must be installed.

The maximum bending moment of the beam is W x L /2, where 'L' is the total length of the mast from masthead to deck. The total load 'W' is simply the sail area multiplied by the wind pressure that is to be expected before reefing, including a large safety factor. Here at AEROSYSTEMS we use 18 lb. per sq. ft. which occurs at a wind speed of 58 knots, well in excess of the speed in which full sail would be set. Following conventional procedure, the maximum bending moment is then divided by the flexural strength of the mast material in order to arrive at a required section modulus. It is important to keep in mind that the entire load on the cantilevered beam mast is in bending, rather than compression as with a conventional sailing rig.

Any mast material could possibly be used with the wingsail rig, using the correct flexural strength in the section modulus calculation. Aluminum tubing is used in boats under 25 feet in order to reduce costs, but AEROSYSTEMS has found that the most cost effective material for larger boats is a fiber glass laminate of unidirectional woven roving with each fifth layer of ordinary woven roving. The mast fabricator has found that this laminate produces a flexural strength of 66,000 psi. In comparison, the average hull laminate of 35 % glass content has a flexural strength of approximately 30,000 psi. These glass fiber masts are made with a tapered wall thickness and a constant outside diameter, but the maximum thickness is used from the bottom up to the boom.

Since the mast is cantilevered, it is essential that the bottom is absolutely rigid in the mast step, which is always on the keel. A lightning ground wire, wiring for electronics, and electrical wiring for a masthead light may all be run inside the mast, as normal, and the mast step should have four drain holes.

CAN WE CONVINCE THE FISHERMEN?

There is no doubt that most fishing people would like to reduce their fuel costs and sail-assisted vessels would seem to be an important solution. But at the same time, there is a natural resistance to change, and most fishermen with many years of experience as good seamen, are reluctant to learn all those lines, blocks and sails that are usually required. The thought of tacking a jib, or changing to a smaller jib in rough weather, only seems to complicate their schedule of hard work with the fishing gear. But the Aerosystems wingsail eliminates these problems by designing the rig so that it is clear of the fishing equipment, so that there is only one line (the mainsheet) to handle, so that the wingsail is self-tacking, and so that there are no jibs to change or stow in wet sail lockers.

It is the job of designers to develop a fishing boat with customary equipment and a hold that can produce a profit, and then contact the fishing industry to learn of their specific requirements. After the fishing gear has been decided, a sailing rig can be adapted to the hull so that it will not interefere with normal operations. The boat owners must be informed that their crews will not have to learn new procedures or perform a great deal of additional work, as it should only require one or two people to take care of the sails at any time. If the crew is paid on a share basis, they should be informed that the sailing rig will reduce the operating costs of the vessel and thus their individual shares will be larger.

Under normal operations, the engine will be in use all of the time, and the boat will be 'motorsailing' with the sail set as often as the wind is not dead ahead. Some propulsion thrust is provided by the sail and the engine revolutions can be reduced in order to conserve fuel. The amount of this reduction will be determined by the wind force and reduction, and by the boat's fishing requirements. The amount of fuel saved by reducing engine revolutions varies with that engine's characteristics, but it can be impressed on the crew that each gallon per hour saved is another dollar saved each hour. The concept of sail-assisted powering will be successful in most, but not all, cases. But the use of sail must be tried and developed if we are going to make progress in fuel conservation.

BIOGRAPHY:

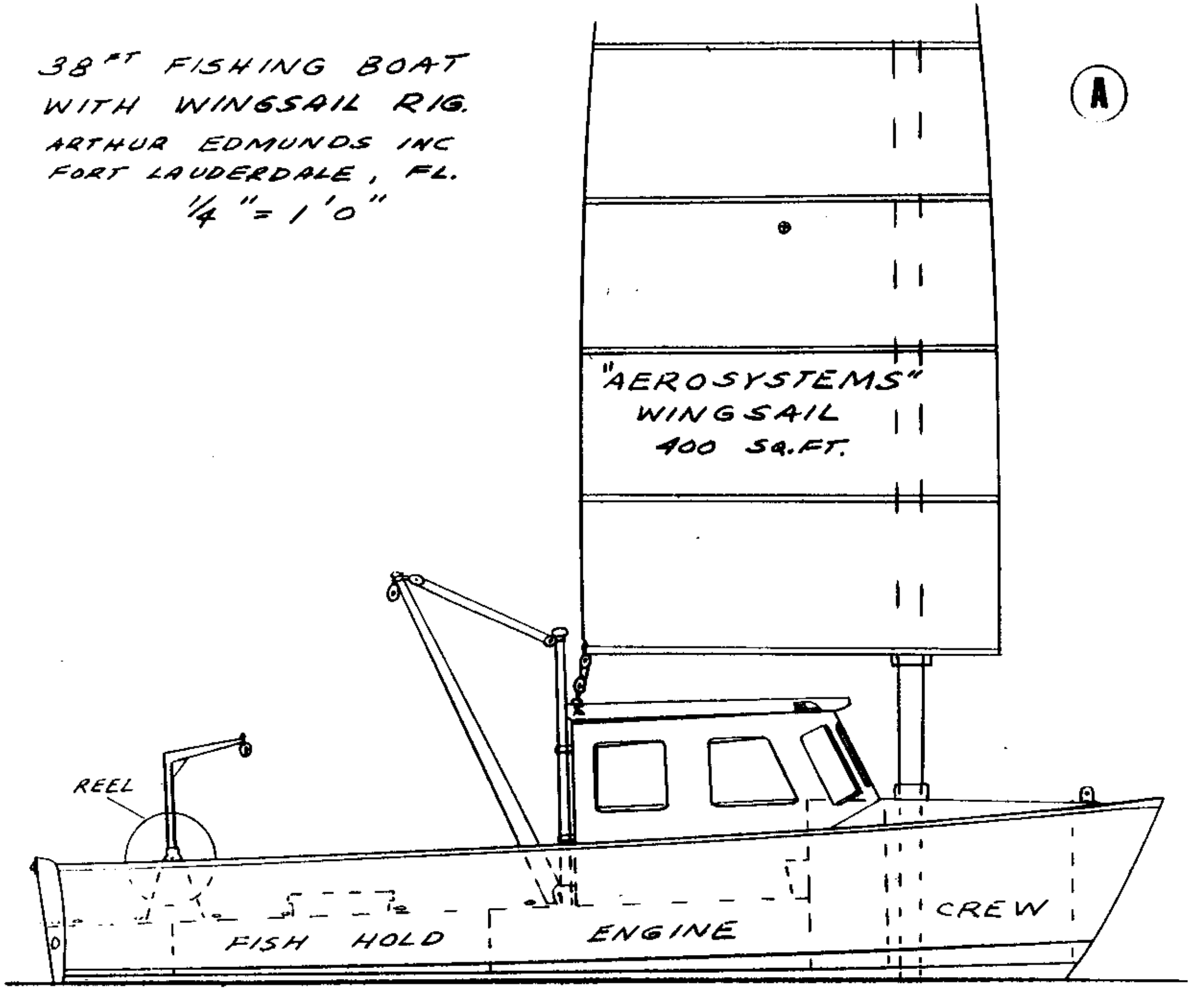
Jack Manners-Spencer has degrees in Civil Engineering and Transportation Planning and lives near Southampton, England. After a career in the Royal Air Force as a pilot on the delta-wing 'Vulcan' bomber, he started sailing offshore and developed, invented, and patented his ideas for new cruising rigs. It was at Southampton University that he made some in-depth studies of sail and wing aerodynamics, working closely with the Wolfson Marine Craft Research Unit. One of his early experiments was the 'Pyramid' rig on a 34 ft. cruising catamaran, where two jib-shaped sails were rotated about a free-standing mast.

Further work with fully-battened mainsails led to the present AEROSYSTEMS wingsail, but only after 6 years and 10,000 hard sea miles of rigorous testing. Mr. Manners-Spencer believes in exposing his ideas to all types of weather on long passages, and he combines good seamanship with sound engineering practice in the sensible application of aerodynamics.

Arthur Edmunds graduated from the U.S. Coast Guard Academy in 1954 and served four years, which included duty aboard an Ocean Station Vessel in the Pacific and at a LORAN transmitting station.

Following four years as a field engineer with Combustion Engineering Inc., he was a design engineer with Chris Craft Corp. Since 1967, Arthur Edmunds has had his design office in Fort Lauderdale, working with both individuals and production manufacturers in the design of both sailboats and powerboats.

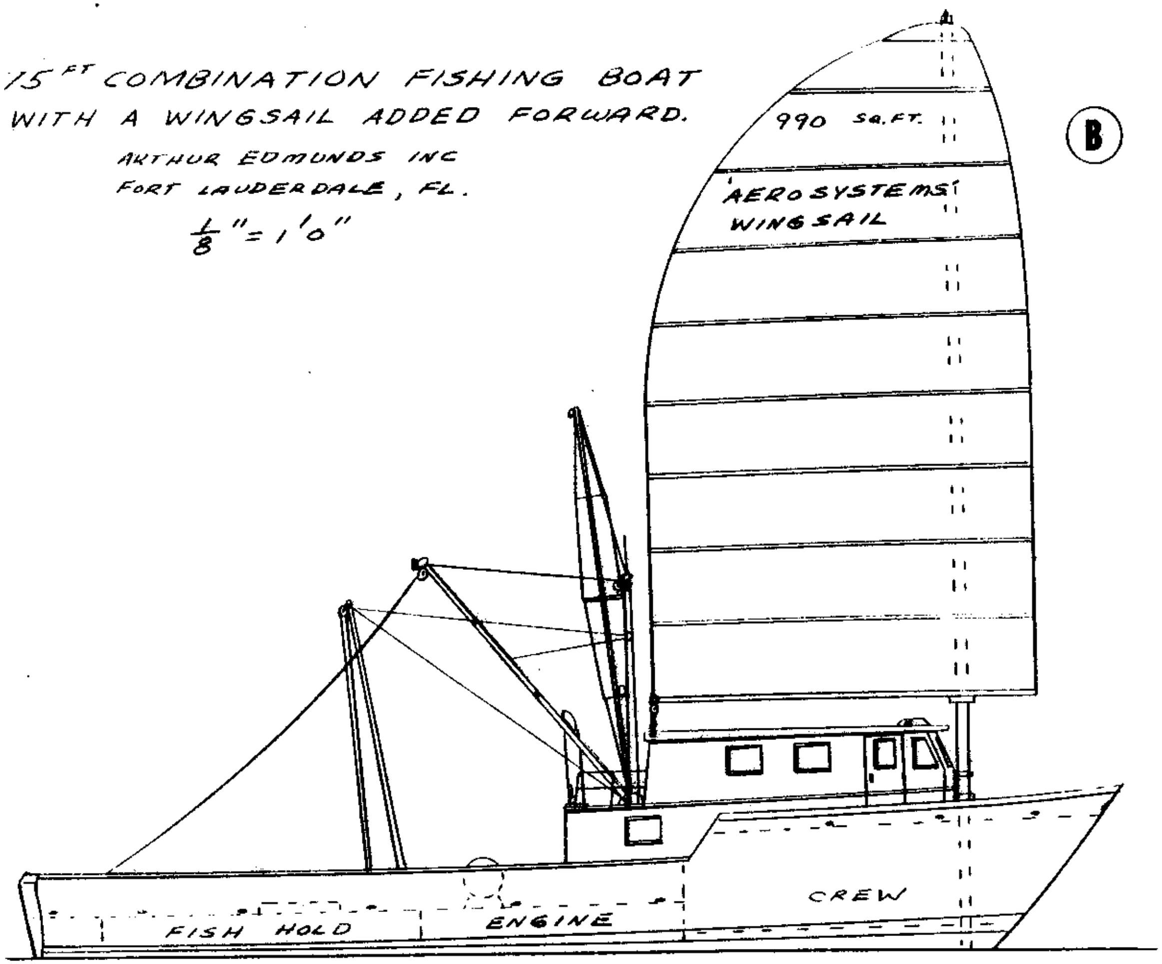
He has written many articles for the boating magazines and has authored, 'Fiberglass Boat Survey Manual' (John De Graff Inc., Clinton Corners, N.Y., 1979). Recently, he has been assisting Jack Manners-Spencer in representing the AEROSYSTEMS wingsail in the U.S.A.



38FT FISHING BOAT
WITH WINGSAIL RIG.
ARTHUR EDMUNDS INC
FORT LAUDERDALE, FL.
1/4" = 1'0"

75 FT COMBINATION FISHING BOAT
WITH A WINGSAIL ADDED FORWARD.

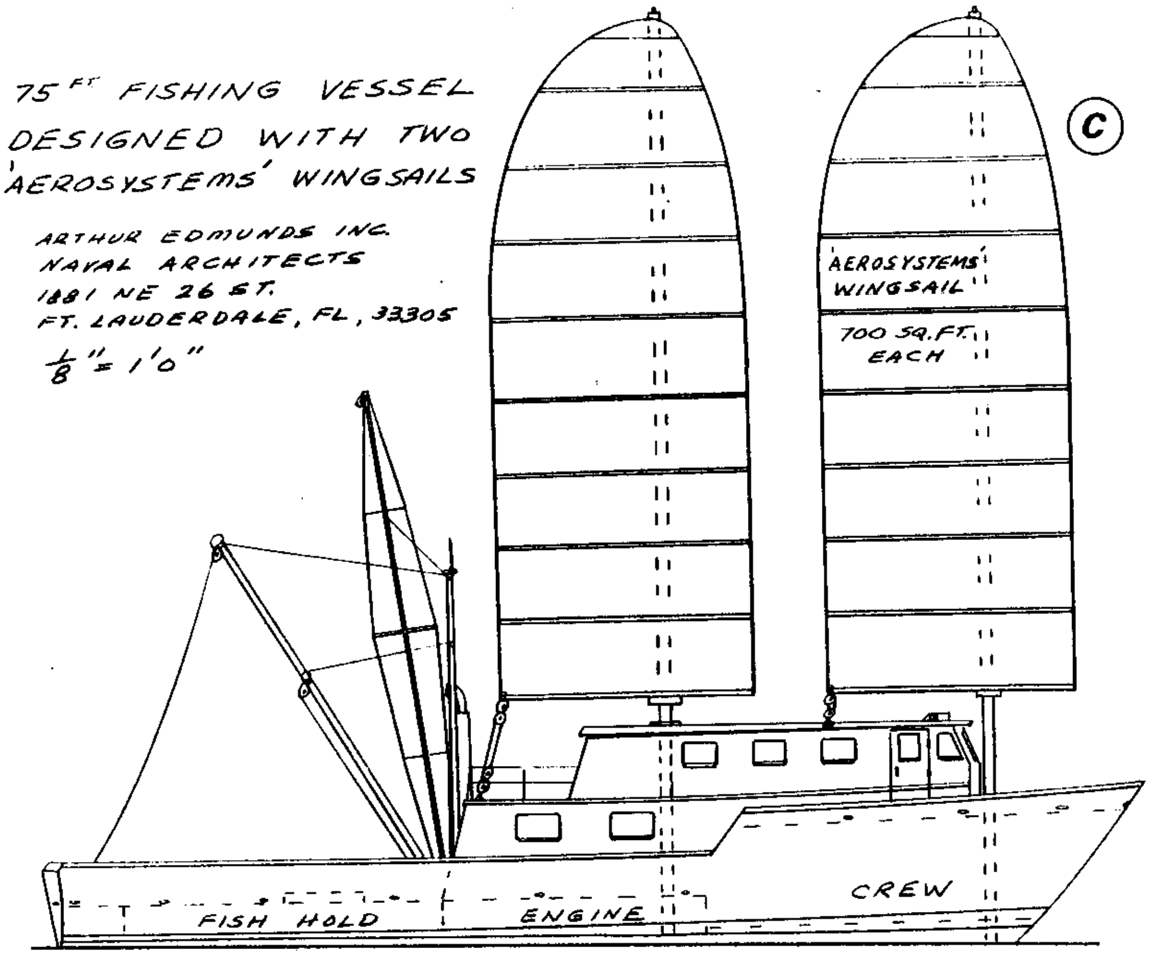
ARTHUR EDMUNDS INC
FORT LAUDERDALE, FL.
$\frac{1}{8}'' = 1'0''$



Ⓒ

75 FT FISHING VESSEL
DESIGNED WITH TWO
'AEROSYSTEMS' WINGSAILS

ARTHUR EDMUNDS INC.
NAVAL ARCHITECTS
1881 NE 26 ST.
FT. LAUDERDALE, FL, 33305
$\frac{1}{8}'' = 1'0''$



THE AEROSYSTEMS WINGSAIL FOR FISHING VESSELS

MAXIMUM RIGHTING ARMS FOR VARIOUS NON - BALLASTED POWERBOATS

Ⓓ

CAUTION: The data presented vary widely with hull form and installed equipment and is only representative of a few types of hulls. The righting arms should be calculated for each hull designed.

Water-line length ft.	Type of Hull	Displacement. pounds	Maximum Righting Arm (GZ) ft	Maximum Righting Moment.	Vertical height of C.G. above designed waterline	ANGLE OF HEEL AT MAXIMUM RIGHTING MOMENT
20.0	Round bilge troller	6100	0.8	4880	(empty tanks) 1.5 ft	55 degrees
32.5	planing sport fish	16,500	1.67	27,580	1.95 ft.	40
44.2	Aluminum trawler	62,300	2.1	131,000	1.75 ft	52
55.5	narrow houseboat	47,600	0.7	33,300	3.3 ft	15
56.7	Trawler	110,000	1.235	136,000	1.2 ft	55
65.0	Passenger Vessel	110,000	2.9	319,000	3.7 ft	30
67.5	Barge Hull	172,500	2.7	465,500	4.3 ft	15
75.0	St. Marks shrimper	298,000	4.2	1,250,000	2.0 ft.	40
80.0	Trawler	215,000	3.2	688,000	3.0 ft.	40

ARTHUR EDMUNDS INC.

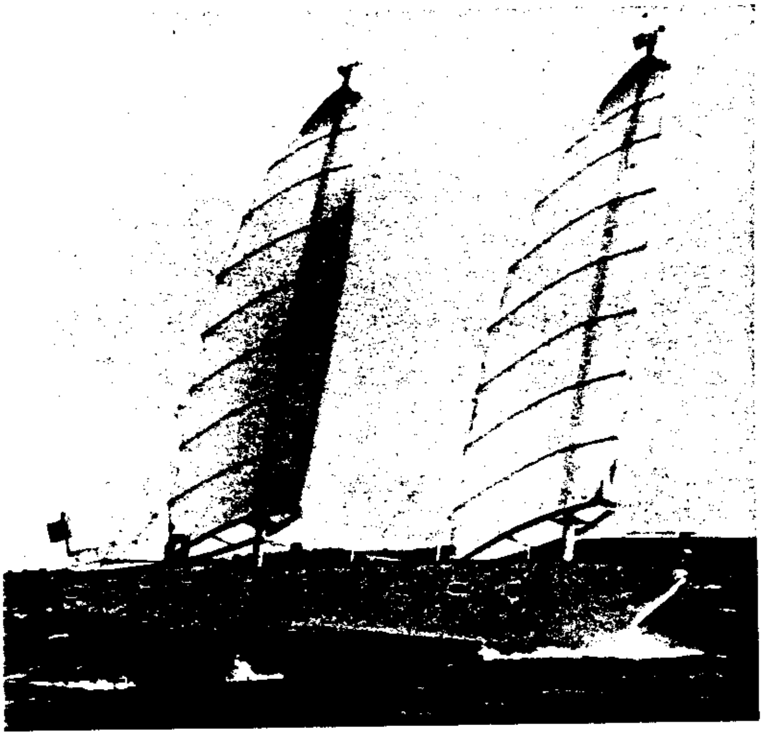
1881 N.E. 26 Street - Office 242
Ft. Lauderdale, FL, 33305

AEROSYSTEMS

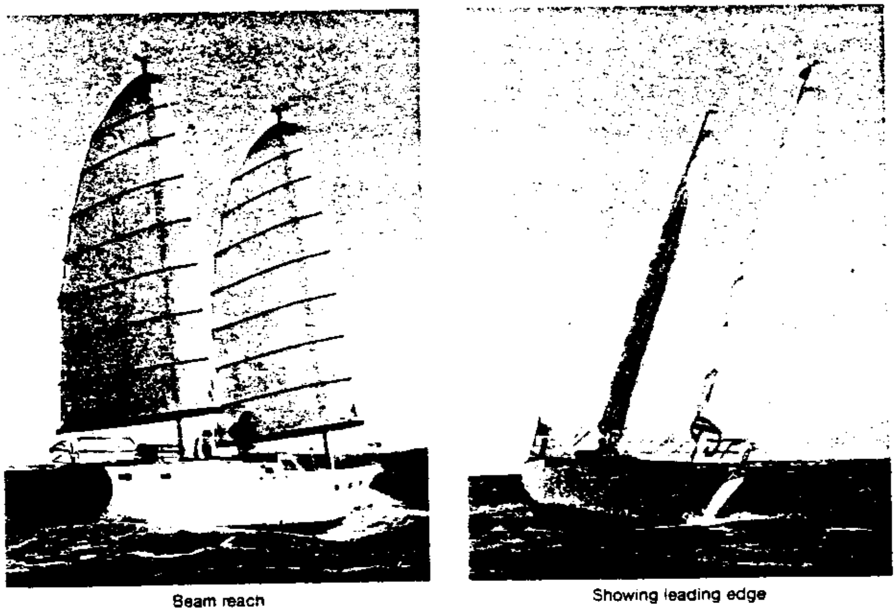
GALLANT RIG

Arthur Edmunds, Inc.
NAVAL ARCHITECTS

1881 N.E. 26 STREET, SUITE 242
FORT LAUDERDALE, FLORIDA 33305



Beating into a Force 7



Beam reach

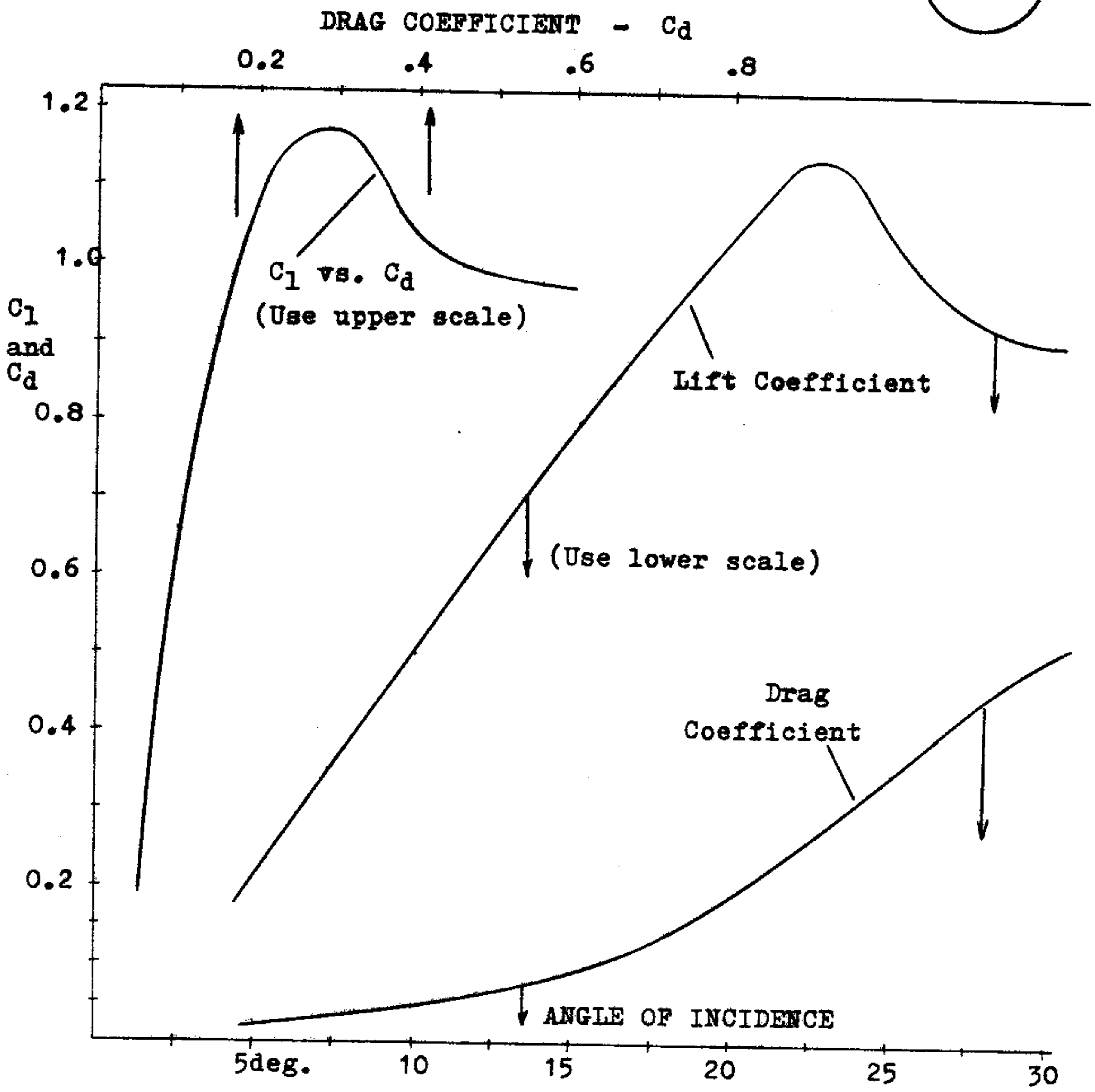
Showing leading edge

WIND TUNNEL TEST ON 20 SQ.FT. MODEL OF GALLANT RIG
AT SOUTHAMPTON UNIVERSITY, U.K.: 'AEROSYSTEMS',
KELHAM, DOCK LANE, BEAULIEU, HAMPSHIRE, SO4 7YH
ENGLAND. TEL: 0590 - 612220

Wind Speed: 17 kt. **Chord length:** 2.6 ft.

Reynolds Number: 500,000

F



INVESTIGATIONS INTO 2D MAST/SAIL INTERACTION

Stuart Wilkinson

Ship Science Dept. University of Southampton, England

A variable camber aerofoil and a miniature boundary layer traverse unit have been designed and built to investigate the nature of flows around 2-dimensional, highly cambered, sail-like aerofoil sections with circular masts. Data has been obtained in the form of static pressure distributions and boundary layer velocity profiles over representative ranges of Reynolds number, camber ratio, incidence angle, mast diameter/chord ratio and mast angle for both NACA a=0.8 and NACA 63 mean-line camber distributions. All flow regimes present have been identified and related to the salient model and flow parameters.

INTRODUCTION

Whenever conventional cloth sails are used to propel a vessel they inevitably have to be held in place by some form of support. A mast provides this support in the case of a mainsail whilst a forestay and luff groove system is more usual for foresails. Whatever the form of this support it will undoubtedly act as a leading edge obstruction to the airflow, and a related interference effect can therefore be expected.

Some work on the interaction between masts and sails has been carried out by Milgram (1), however he presents his results purely in terms of overall lift and drag coefficients, with no attempt made to investigate the fundamental flow regimes involved. Milgram was also only able to test one sail shape (NACA a=0.8) and at just two settings of camber ratio (CR=12% & 15%).

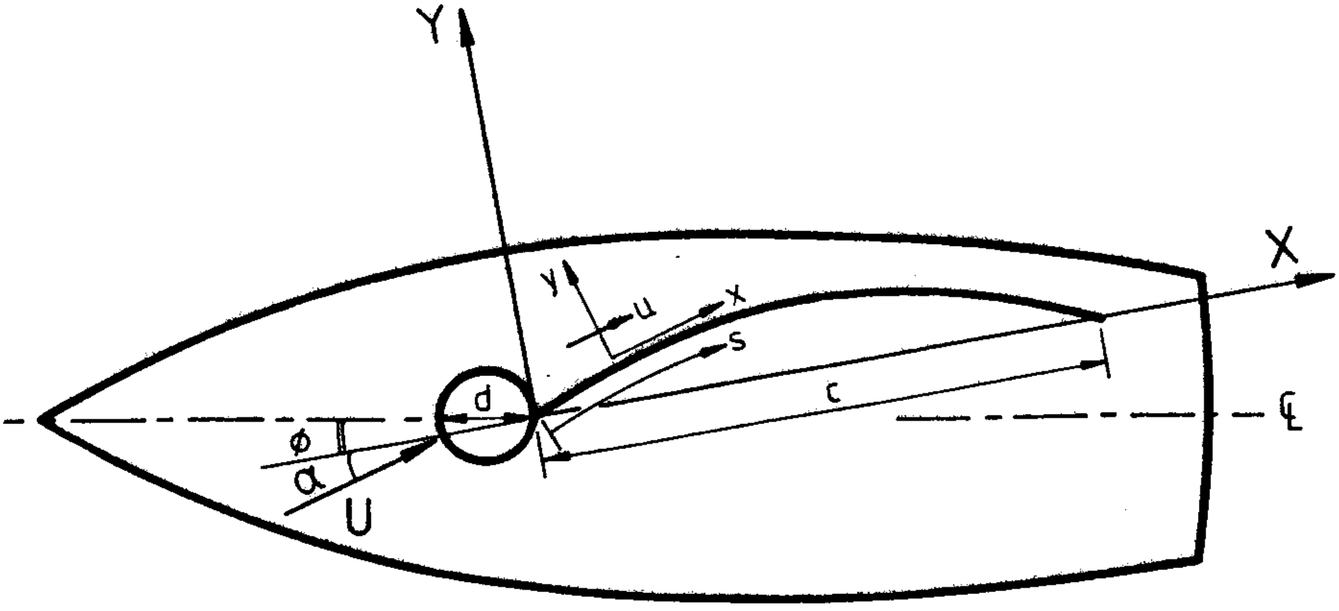
The study outlined in this paper was intended to provide a much more comprehensive body of data relating to the aerodynamics of masts and sails. In view of the lack of fundamental research in this area, the present work was restricted to two-dimensional sail forms only, and with masts of circular cross section.

Data was obtained in the form of static pressure distributions around each mast and over the upper and lower surfaces of the sail model. In addition, further fundamental information about the flows was acquired by performing a number of boundary layer traverses at various chordwise stations.

Using the knowledge gained from these experiments a partially separated flow theory was developed for predicting the pressure distributions around 2D sails and masts. The details of this theory will be published in a later paper.

NOMENCLATURE

α	aerodynamic incidence angle
CR	camber ratio
ϕ	mast angle (angle between mast ℄ and sail chord line)
C	sail chord length
Re	Reynolds number (based on local spanwise chord length)
d	mast diameter
X	chordwise coordinate (origin at sail leading edge)
Y	coordinate normal to chord line
x	curvilinear coordinate parallel to local sail surface
y	curvilinear coordinate normal to local sail surface
U	apparent wind velocity (tunnel free stream velocity)
u	local velocity
ρ	air density
p	local surface static pressure
p'	tunnel static pressure
Cp	pressure coefficient $(p-p')/(\frac{1}{2}\rho U^2)$



TEST FACILITY AND APPARATUS

Sail Model and Support System

The test facility available was the 7' x 5' high speed section of the Southampton University wind tunnel. To achieve 2D flow conditions, with this tunnel over a suitable Reynolds number range (up to Re=1600 000) a sail model of 2.11m(6.9')span and 0.7m (2.3') chord was required.

It was intended to test at least two sail forms each at approximately five settings of camber ratio. Normally this would have involved building ten different 2D sail models, each requiring the installation of a suitable number of pressure tappings, but instead a single variable camber aerofoil concept was adopted.

This variable camber aerofoil model was constructed in the form of a three part laminate. To maintain spanwise dimensional stability a number of extruded stiffening elements were employed which were each bonded to a sail-cloth lower skin, and a 0.25mm ($^{10}/1000$") thick neoprene/latex rubber upper skin as shown in fig. (1). Using the hollow cross section of the stiffening elements, three rows of pressure tappings were installed on both upper and lower surfaces at various spanwise locations, with each row containing 40 tappings.

The final aerofoil form was only 5mm(0.2") thick yet could be set to any required sail shape with a camber ratio range 0 to 20% without any skin wrinkling or significant spanwise deflection.

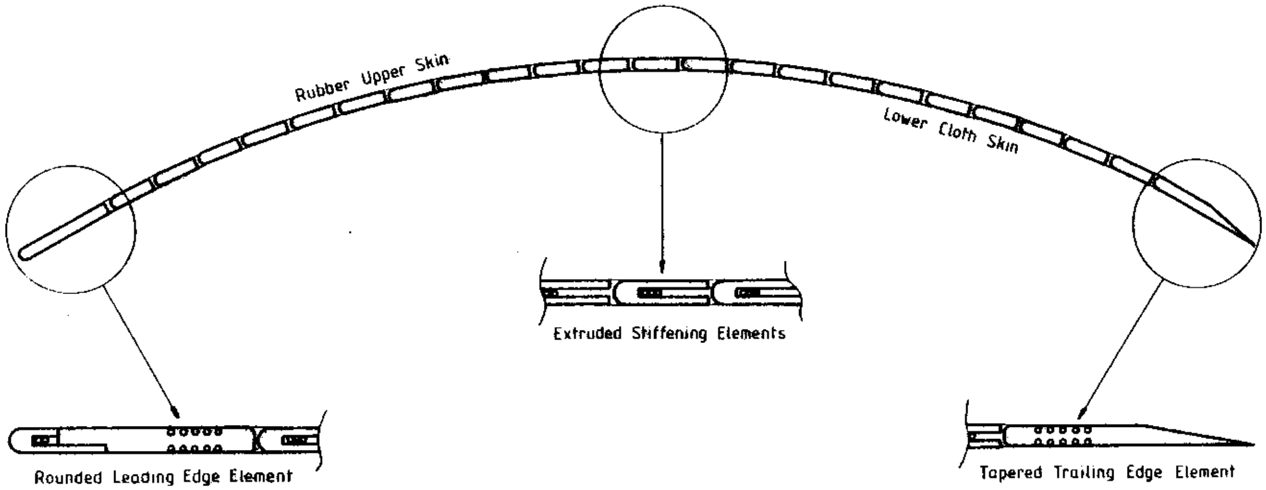
The variable camber aerofoil was held in the tunnel working section by four slender support frames which were rigidly fixed to the tunnel floor. These support frames enabled the sail model to be tilted to any required incidence angle within the range -5 to +25 degrees.

Any camber distribution of the sail model could be achieved by using four trays of preset screw jacks, one of these could be pushed from below into each of the support frames. With two complete sets of these trays it was possible to change the sail shape in a matter of minutes.

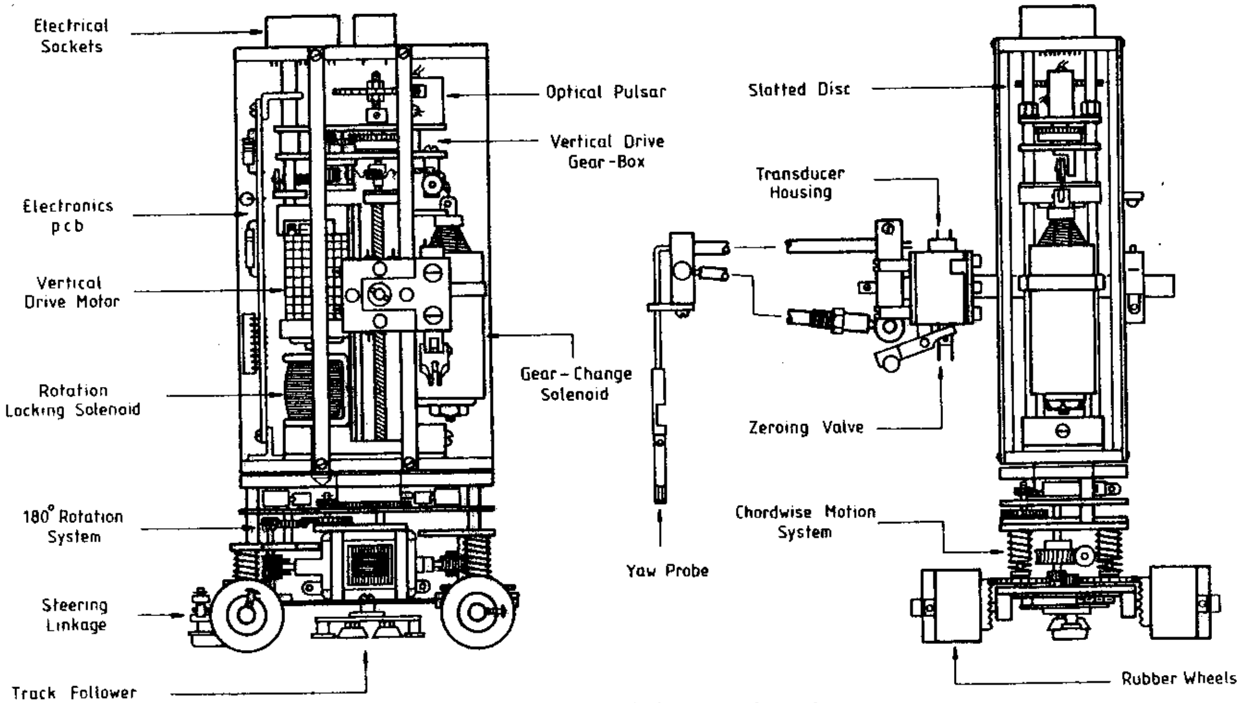
All the circular mast sections were fitted with ten equally spaced pressure tappings around the circumference at the mid span position. Fittings at the tunnel walls enabled these masts to be set to any required mast angle (ϕ) relative to the sail model chord line.

Boundary Layer Traverse Unit

No overhead precision boundary layer traversing system was available above the Southampton University tunnel, so in order to obtain the required boundary layer velocity profiles, a small, self-contained, remotely-controlled traversing unit was specially designed and built to run over the upper and lower aerofoil surfaces on a segmented tack.



Fig(1) Variable Camber Aerofoil



Fig(2) 'Mouse' Systems Layout

This traversing unit, referred to as the 'mouse', was enclosed in a 2:1 Rankine oval streamlined casing which measured only 150 mm tall x 35 mm wide x 70 mm long. Contained within this casing were several systems these included:

a) A chordwise motion system to drive the 'mouse' across the aerofoil upper and lower surfaces.
b) A 180 degree rotation system to change the measuring probe orientation for use in reverse flow regions.
c) A vertical motion system for moving the probe normal to the surface to an accuracy of ± 0.011mm (0.0004").
d) A remote gear change system for switching to rapid normal motion of the probe.
e) A system for accurately measuring the height of the measuring probe above the local aerofoil surface.
f) A system for automatically zeroing the height measuring system when the probe touches the aerofoil surface.
g) A track follower system to hold the 'mouse' to the aerofoil surface whilst allowing low friction running.

To construct all these individual systems required the installation within the limited volume of the 'mouse' of three 12v d.c. permanent magnet motors, three miniature gear boxes, two solenoids, a leadscrew and carriage assembly, an optical pulsing unit, a pcb containing integrated circuitry, magnetic screening material to reduce electrical interference, four micro switches, 26 sub-miniature ball race bearings plus various lengths of connecting wiring and structural members.

The whole 'mouse' unit could be remotely controlled in all its functions from outside the tunnel using a special electronic control box upon which was constantly displayed the real time position of the probe above the local aerofoil surface.

Measuring Probe.

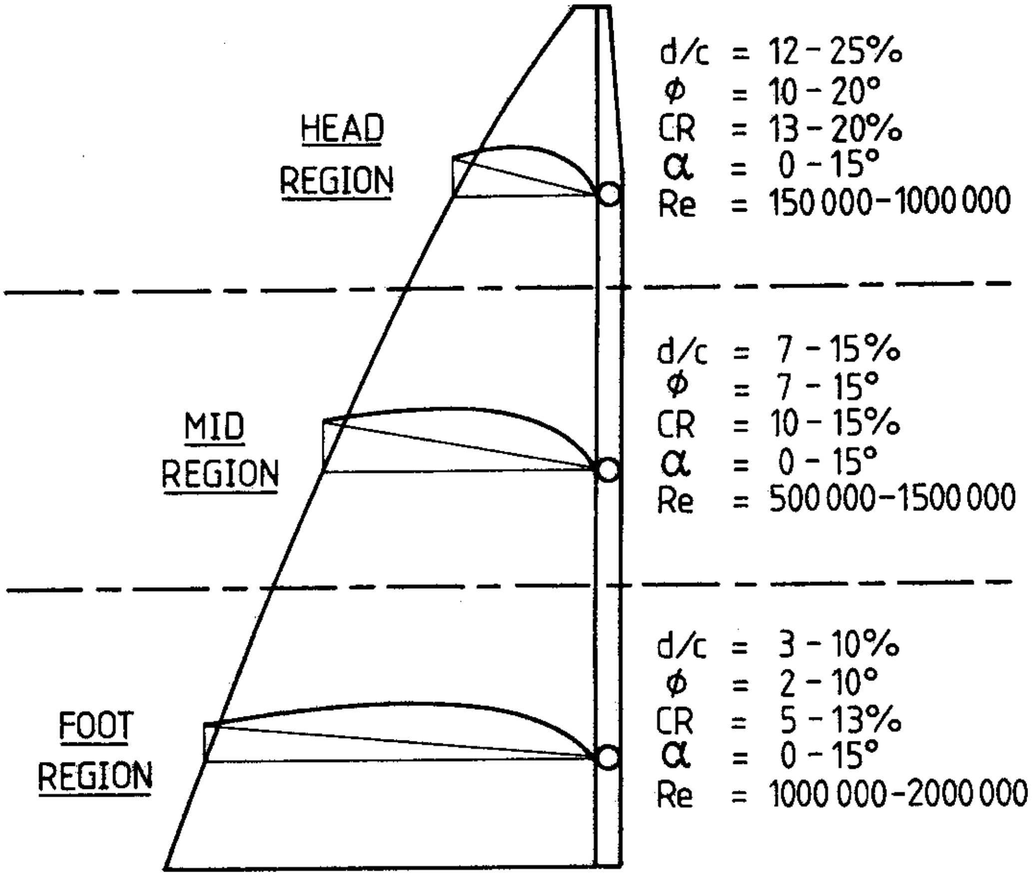
The measuring probe chosen was a three tube yaw probe with a 90 degree head angle, constructed from 0.8mm (0.03")stainless steel hypodermic tubing. This was calibrated using the method described by Rajaratnam (2) up to a yaw angle of 40 degrees, and was also found to be insensitive to pitch over a ± 12 degree range.

This probe was placed on the end of a rigid arm projecting from the side of the 'mouse'. The arm length was calculated to reduce any interference from the 'mouse' body to within ± 1% in measured velocity at the probe nose.

TEST PROGRAMME

The salient model and flow parameters involved in the 2D mast/sail experiments were: sail camber distribution (shape), camber ratio (CR), Reynolds number (Re), aerodynamic incidence angle (α), mast diameter/chord ratio (d/c) and mast angle (ϕ).

With such a large number of variables involved it would have been impossible to test every possible combination, some of these combinations would in any case have been irrelevant to actual full



Fig(3) Typical Parameter Ranges Across a Mainsail

<table>
<tr><th></th><th colspan="12">HEAD REGION</th><th colspan="12">MID REGION</th><th colspan="12">FOOT REGION</th></tr>
<tr><td>d/c (%)</td><td colspan="12">17</td><td colspan="12">10</td><td colspan="12">4</td></tr>
<tr><td>φ (°)</td><td colspan="12">15</td><td colspan="12">10</td><td colspan="12">5</td></tr>
<tr><td>CR (%)</td><td colspan="4">12·5</td><td colspan="4">15·0</td><td colspan="4">17·5</td><td colspan="4">10·0</td><td colspan="4">12·5</td><td colspan="4">15·0</td><td colspan="4">7·5</td><td colspan="4">10·0</td><td colspan="4">12·5</td></tr>
<tr><td>Re x 10⁵</td><td colspan="4">3·5</td><td colspan="4">6</td><td colspan="4">10</td><td colspan="4">6</td><td colspan="4">10</td><td colspan="4">14</td><td colspan="4">10</td><td colspan="4">14</td><td colspan="4">16</td></tr>
<tr><td>α (°)</td><td colspan="3">2·5</td><td colspan="3">5</td><td colspan="3">7·5</td><td colspan="3">10</td><td colspan="3">2·5</td><td colspan="3">5</td><td colspan="3">7·5</td><td colspan="3">10</td><td colspan="3">2·5</td><td colspan="3">5</td><td colspan="3">7·5</td><td colspan="3">10</td></tr>
</table>

Table(1) Parameter Values Tested

size sails. In order to test only those parameter combinations that were realistic, a typical main sail was divided into three regions as shown in fig. (3). Within each region typical parameter ranges were identified, and from these a number of representative values were selected for testing, these are given in Table (1). For each of the three regions, there were chosen one value of mast diameter/chord ratio, one value of mast angle, three values of camber ratio, three values of Reynolds number and four values of incidence angle. The total number of tests performed to cover all the combinations within each region was 36. For all three sail regions the number of tests required was therefore 108.

All these test runs had to be repeated for each sail shape required, two of these were selected namely the NACA a=0.8 and the NACA 63 mean lines (see Abbott(3)), making a total number of tests in the programme of 216.

The NACA a = 0.8 mean line shape was chosen since it was similar to modern sails and so that the results could be compared with the work of Milgram. The NACA 63 mean line shape was selected to note the effect of moving the point of maximum camber forward towards the mast.

The 'mouse' traverse unit was used to obtain velocity profiles above the sail surface at positions of interest as indicated by the pressure distributions obtained.

TEST PROCEDURES AND DATA ACQUISITION

For each of the 216 tests performed the corresponding model parameters were firstly mechanically set using the adjustment facilities on the apparatus. With this completed the tunnel was switched on and run up to a free stream velocity corresponding to the required Reynolds number. The design of the variable camber aerofoil meant that the model chord length was not constant but was dependant on both shape and camber ratio, the true chord length was therefore taken into account each time that a particular setting of Reynolds number was required. All the static pressure tappings around the mast and aerofoil mid-span surfaces were connected to a scani-valve system. Time was allowed during each test run for pressure equalisation in all tubes before the scani-valve system was activated.

When performing boundary layer traverses, wool tufts were initially applied to the sail model surface to identify regions of separated and attached flow. With the tunnel running, the 'mouse' traverse unit was moved remotely to the required chordwise location, and then the probe was similarly driven down to the model surface. At this point the height measuring system was automatically zeroed and further vertical motion stopped. The yaw probe was then driven away from the surface at low speed and stopped at various distances above the aerofoil as indicated by the real-time height display on the control box. Pressure differences were then measured between the three tubes of the yaw probe at each height. When collecting data within regions of separated flow, as indicated by the wool tufts, the probe was remotely rotated through 180 degrees to record any reverse flow velocities.

DATA ANALYSIS

On activation of the scani-valve system for each test the static pressure information from the mast and sail model was automatically data logged. Once a sufficient amount of data had been amassed in this way, it was run through a series of machine steps that firstly converted it to pressure coefficient (Cp) form (using the definition given in the nomenclature) and then related each of these pressures to a corresponding tapping location projected onto the sail model chord line (X/C). These locations had to be specially calculated for each test since they were not constant but were dependant on shape camber ratio, mast size and mast angle.

Having reduced the data to the form of pressure coefficients at corresponding chordwise locations, the automated data analysis system finally presented the information in graphical form.

The pressure differences obtained between the tubes of the yaw probe at various heights in the boundary layers were converted into local velocity values using the calibration graphs. The corresponding heights above the sail model surface were obtained using the 'mouse' probe height measuring system with corrections made for the effect of shear and the wall proximity using the method developed by MacMillan(4).

With the yaw probe resting on the sail model surface at various chordwise locations the local wall shear stress was determined using the method devised by Preston(5) and calibration data presented by Patel(6). Detailed analysis of the velocity profiles including values of friction velocity, local skin friction coefficient, displacement thickness, momentum thickness and shape factor will be presented in a future paper.

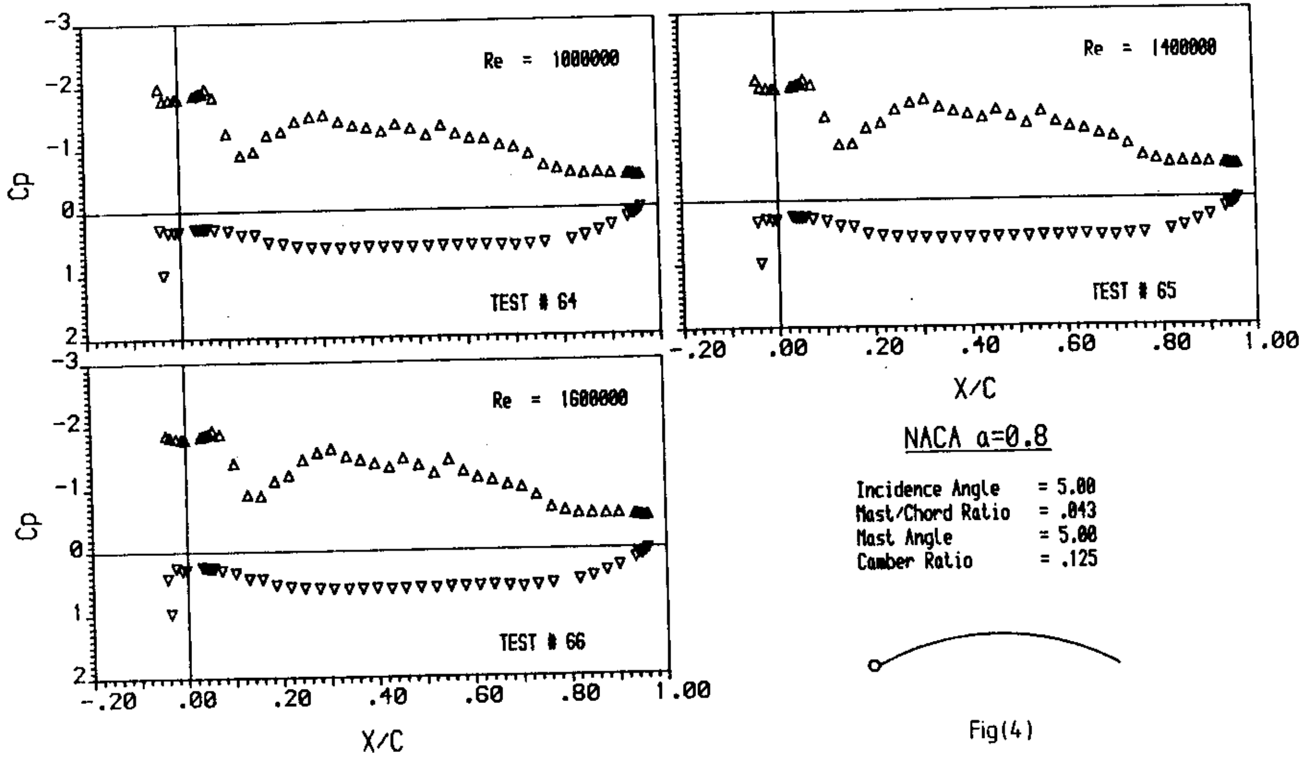
DISCUSSION OF RESULTS

Three examples from the 216 pressure distributions obtained are shown in fig.(4) to indicate the extent to which the number of pressure tappings used was able to define the details of the static pressure variations.

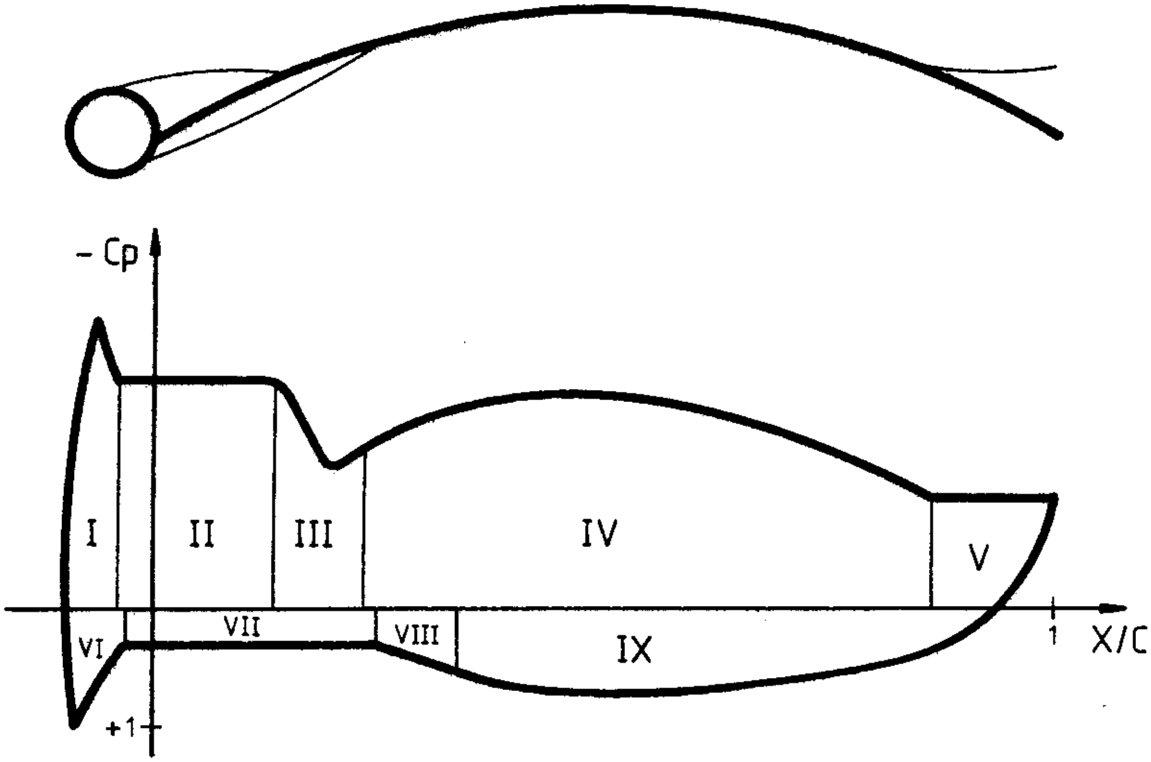
After studying the entire set of 216 test results it was concluded that all the pressure distributions obtained could be accurately described by reference to just one universal form of pressure distribution as shown in fig.(5). This could be subdivided into nine regions, where each indicated the presence of a particular flow regime. In this way it was found that all of the apparently different pressure distribution shapes observed during testing were in fact just forms of this universal distribution, where the model and flow parameters present had merely modified the relative length and magnitudes of each region.

The nine regions can be briefly described as follows:

Region I - As the flow was initially deflected around the mast upper surface, it underwent an acceleration followed by a decceleration as the surface of the mast curved away. This is shown on the pressure distributions as a small suction peak characteristic


Re = 1000000
TEST # 64
Re = 1400000
TEST # 65
Re = 1600000
TEST # 66
Cp
X/C
-3
-2
-1
0
1
2
-.20
.00
.20
.40
.60
.80
1.00
NACA a=0.8
Incidence Angle = 5.00
Mast/Chord Ratio = .043
Mast Angle = 5.00
Camber Ratio = .125

Fig(4)



REGION	DESCRIPTION
I	Upper Mast Attached Flow Region
II	Upper Separation Bubble
III	Upper Reattachment Region
IV	Upper Aerofoil Attached Flow Region
V	Trailing Edge Separation Region
VI	Lower Mast Attached Flow Region
VII	Lower Separation Bubble
VIII	Lower Reattachment Region
IX	Lower Aerofoil Attached Flow Region

Fig(5) Universal Pressure Distribution of attached cylinder flows.

Region II - As the flow advanced around the contour of the mast, the boundary layer that had been building up from the forward stagnation point was forced to separate due to the large adverse pressure gradient towards the rear of the mast. This separated boundary layer, then in the form of a free shear layer, was swept away from the mast in a down-stream direction by the main body of the flow. This situation continued until, due to a combination of model geometry and local flow parameters, conditions again became conducive to attached flow, this was called the 'reattachment point'.

A line of zero velocity or 'separation stream-line' could be regarded as running along the lower extremity of the free shear layer between the mast separation point and the aerofoil reattachment point. This separation stream-line defined the boundary of an upper surface separation bubble, all flow within this bubble was slow moving and very disturbed. The mast and aerofoil surface pressure tappings within this bubble all recorded the same 'base pressure', the extent of the upper surface bubble was thus represented as a horizontal straight line in Region II of fig. (5). The base-pressure observed was always equal to the static pressure on the mast at the point of separation.

Region III - At the reattachment point rapid changes of pressure were observed in a number of the tests, this was essentially as a consequence of two different pressures existing at adjacent surface locations. Just prior to reattachment the surface pressure was equal to the base-pressure of the bubble, whilst immediately following reattachment the pressure was governed by the local tangential flow velocity. The magnitude of the pressure change ranged from virtually nothing to very large depending on the amount of decceleration suffered by the flow at reattachment, which was in turn related to the model and flow parameters.

Region IV - Following reattachment the flow accelerated around the upper aerofoil surface, this is shown in Region IV of fig.(5) as a characteristic 'domed' shape representing the lift producing suction side of the sail.

Region V - As is typical of flows around highly cambered aerofoils, the attached upper surface flow became increasingly under the influence of an adverse pressure gradient as the trailing edge was approached. Eventually the flow was forced to separate, resulting in another base-pressure region as shown in fig. (5) as Region V.

Region VI - Some of the flow approaching the mast was initially deflected around its lower surface. This gave rise to a flow decceleration which is shown in fig. (5) as a +ve pressure peak. The maximum pressure coefficient obtained each time was unity, which identified the location of the forward stagnation point.

Region VII - In exactly the same way as described for Region II, there existed a constant base-pressure region behind the mast on the lower aerofoil surface. This confirmed the presence of a lower surface separation bubble.

Region VIII -Again in a similar way to that on the upper aerofoil surface the flow underwent a decceleration at reattachment on the sail underside. This decceleration was not as severe as that in Region III because of the local geometry of the convex lower surface.

Region IX - Following reattachment the flow remained attached over the whole of the remaining lower surface of the aerofoil. There was no trailing edge separation present since the pressure gradient in that area was always favourable. There was a rapid acceleration of the lower surface flow as the rear of the sail was approached, such that at the point of the trailing edge both upper and lower surface pressures were equal to the base pressure in Region V.

Having identified each of the fundamental regions that comprised all the pressure distributions, it was then possible to look at the way in which these regions were influenced by the various model and flow parameters.

Effect of Reynolds Number - Generally the shapes of the pressure distributions were independent of Reynolds number over the ranges tested.

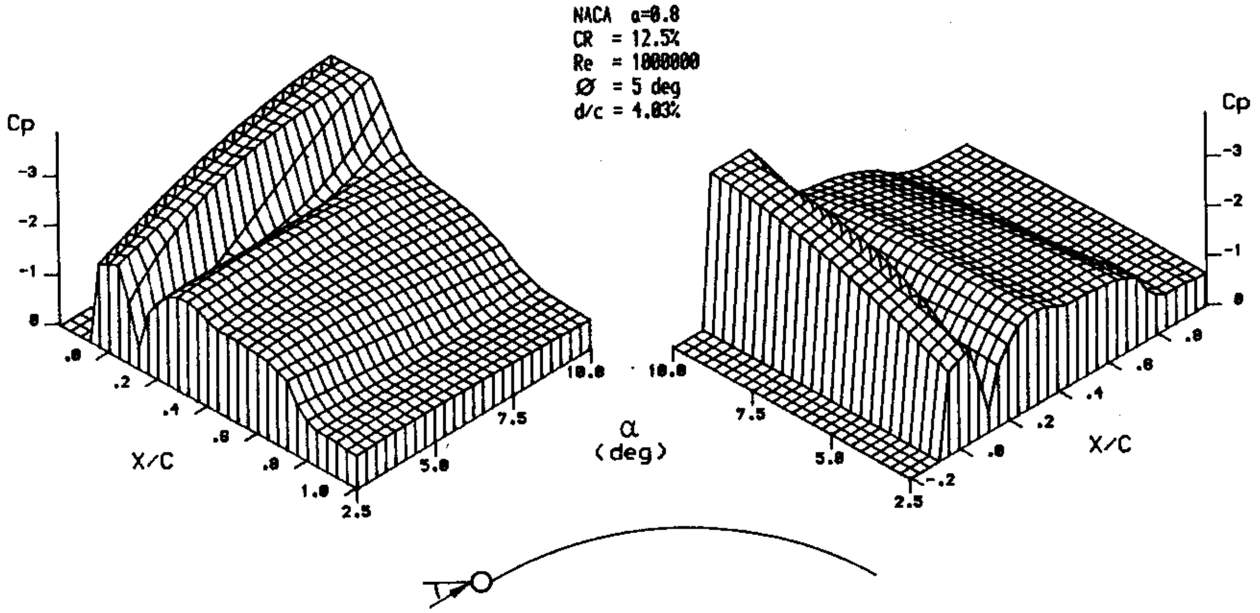
Effect of Incidence Angle - A number of upper surface pressure distribution results have been correlated together into the form of 3-dimensional surface plots. The effect of incidence angle is therefore clearly described in figs (6), (7) and (8), one plot being presented for each of the three mast sizes tested.

It was found that changes in incidence angle effected all of the pressure distribution regions to some extent. Whatever the mast size, as the incidence angle was increased so the base pressure of the upper surface bubble (Region II) decreased, and the severity of the pressure rise at reattachment (Region III) was reduced. Also as the incidence angle was increased so the characteristic suction 'dome' of the attached flow region (Region IV) was flattened, and the trailing edge separation region (Region V) increased in length. For the medium and large mast cases the base-pressure in this trailing edge separation region fell with increasing incidence angle.

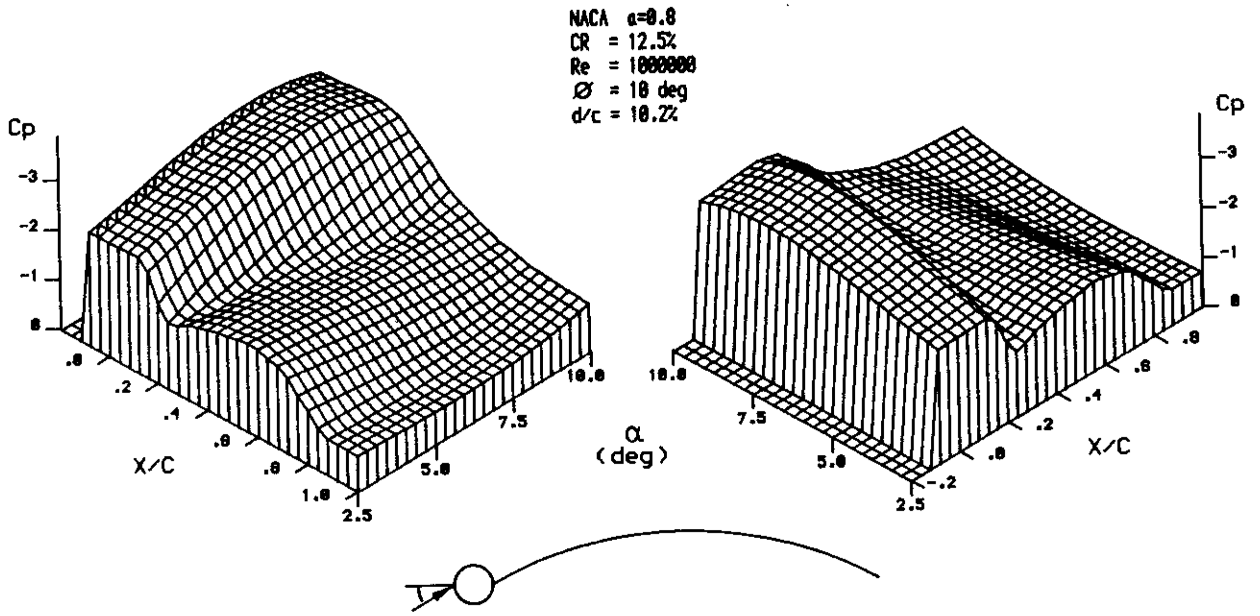
Although not shown on the surface plots, it was also found that the lower surface bubble was reduced in length with increasing incidence angle.

Effect of Mast Size - By considering the same plane of constant incidence angle in each of the figs (6),(7) and (8) the effect of mast size can be seen.

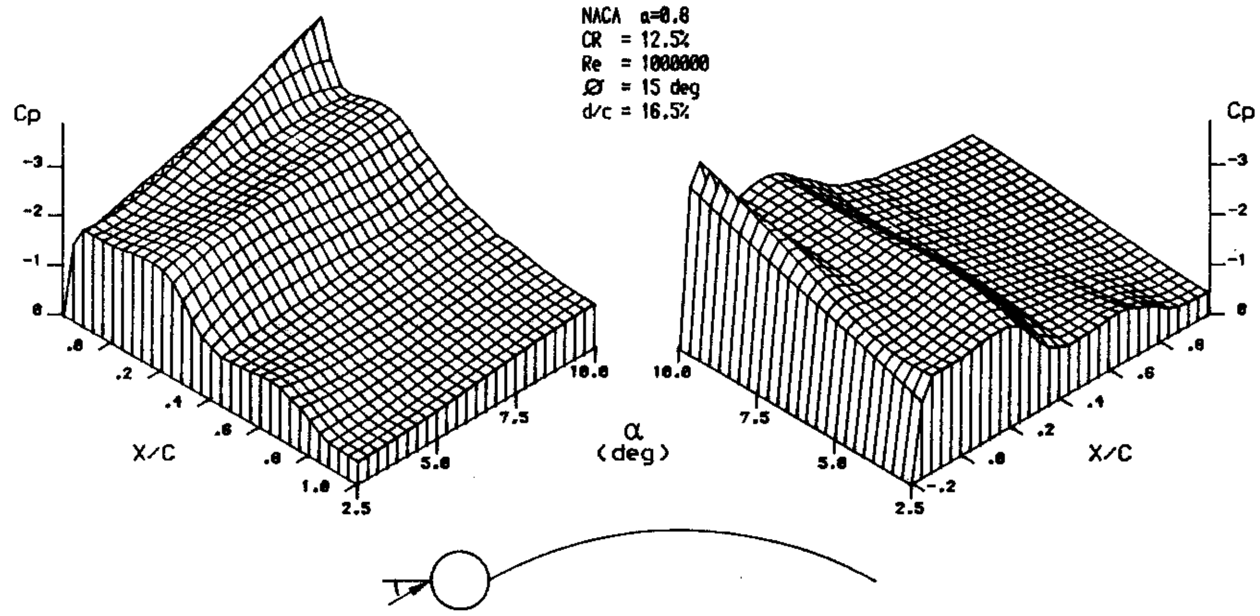
The changes shown are of course not just as a consequence of



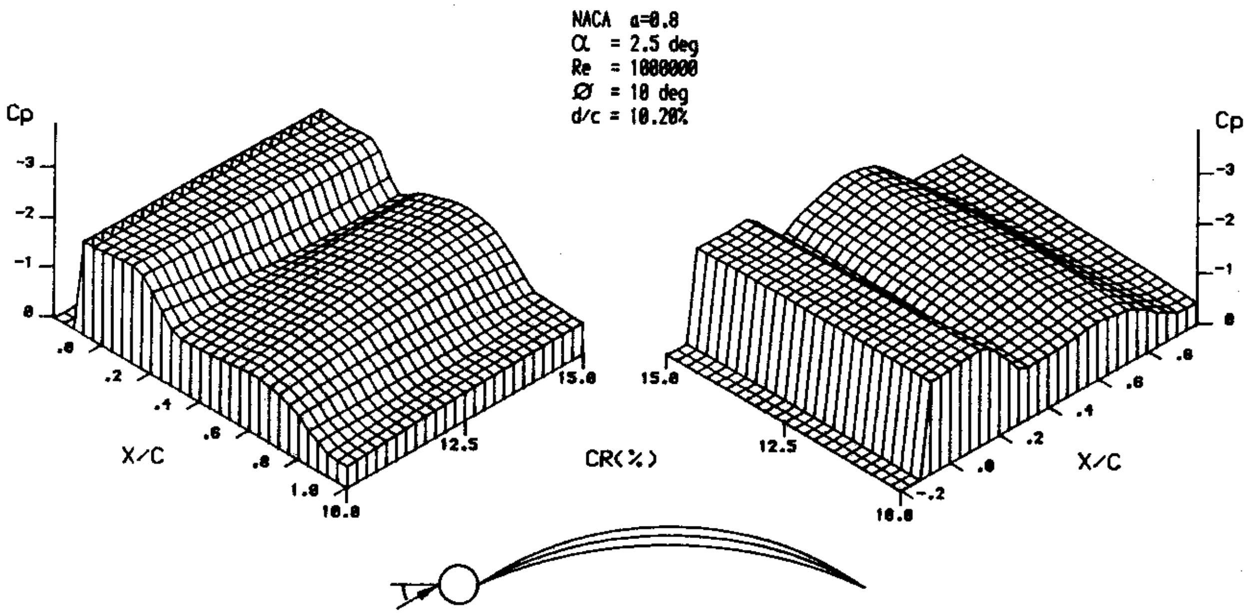
Fig(6) Evolution of Static Pressure Distribution with Changing Incidence Angle



Fig(7) Evolution of Static Pressure Distribution with Changing Incidence Angle



Fig(8) Evolution of Static Pressure Distribution with Changing Incidence Angle



Fig(9) Evolution of Static Pressure Distribution with Changing Camber Ratio mast size but also of mast angle, since this was reset with each mast. These mast size and angle combinations are however representative of real sails, it would be unusual in practice to have an increasing mast diameter/chord ratio up a mainsail without an associated increase in mast angle due to sail twist.

Increasing the mast size and angle increased the length of the upper surface bubble (Region II) not only over the now larger chordwise expanse of the mast but also over the forward portion of the sail. The severity of the pressure rise at reattachment (Region III) was reduced with increasing mast size and the attached flow suction 'dome' (Region IV) was suppressed. Finally the length of the trailing edge separation region (Region V) was shortened with increasing mast size.

Effect of Camber Ratio - Again some of the pressure distribution results have been presented together in the form of surface plots, but this time with camber ratio as the varying parameter, these are shown in figs (9) and (10).

Camber ratio has virtually no effect on either length or base pressure of the upper surface bubble (Region II), however the reattachment pressure rise (Region III) was more severe and the attached flow suction 'dome' (Region IV) became much fuller with increasing camber ratio. Finally, the extent of the trailing edge separation region (Region V) grew with increasing camber ratio, whilst the base-pressure was reduced.

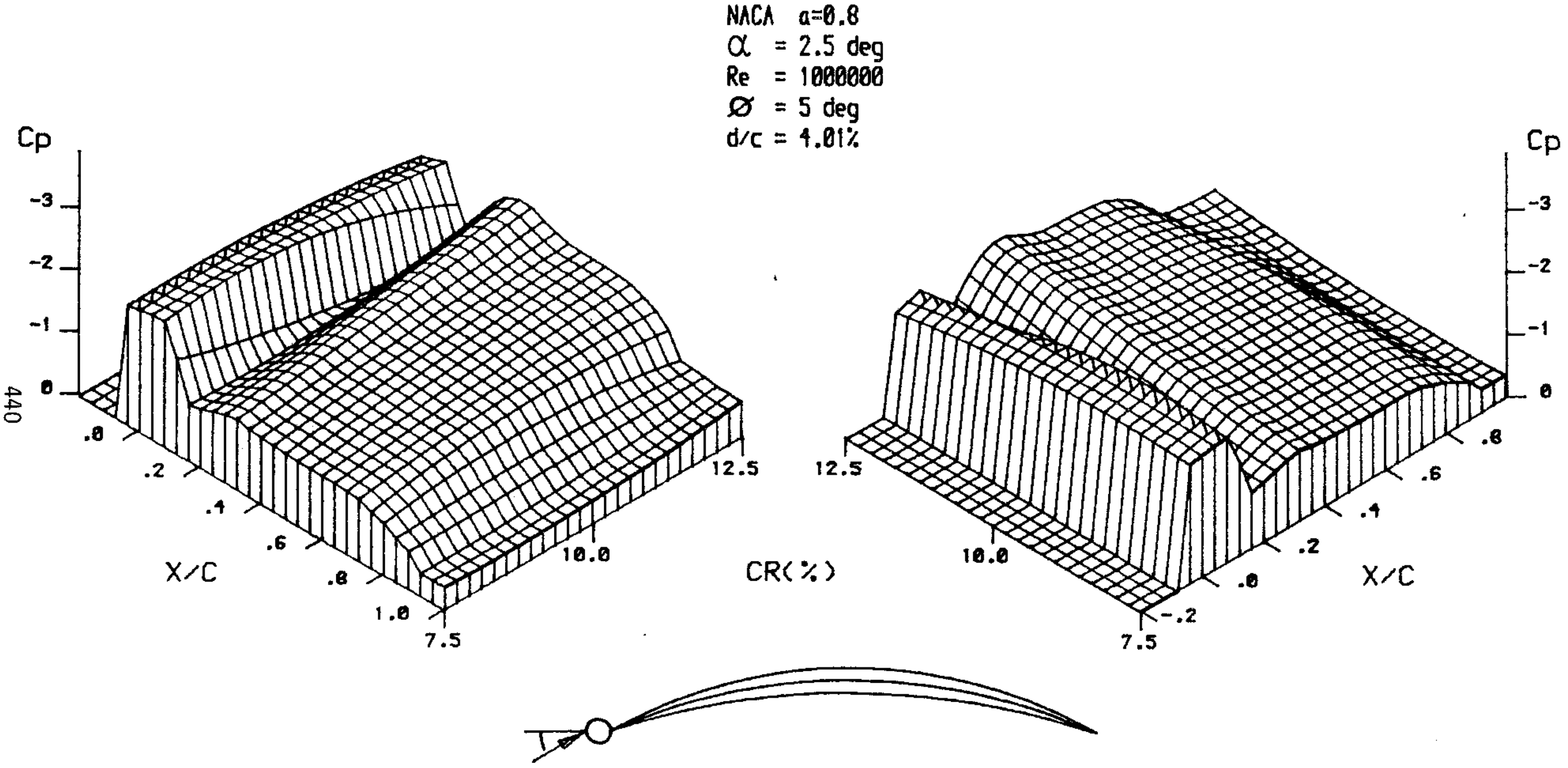
Effect of Sail Shape - Generally the NACA a = 0.8 and NACA 63 aerofoil shapes responded in a similar way to changes in the various model and flow parameters. However the severity of the pressure peak at reattachment (Region III) was always greater with the NACA 63 and the point of minimum pressure within the upper attached flow 'dome' occurred further forward. Finally the lower surface attached flow region (Region IX) was much fuller with the NACA 63.

Boundary Layer Velocity Profiles

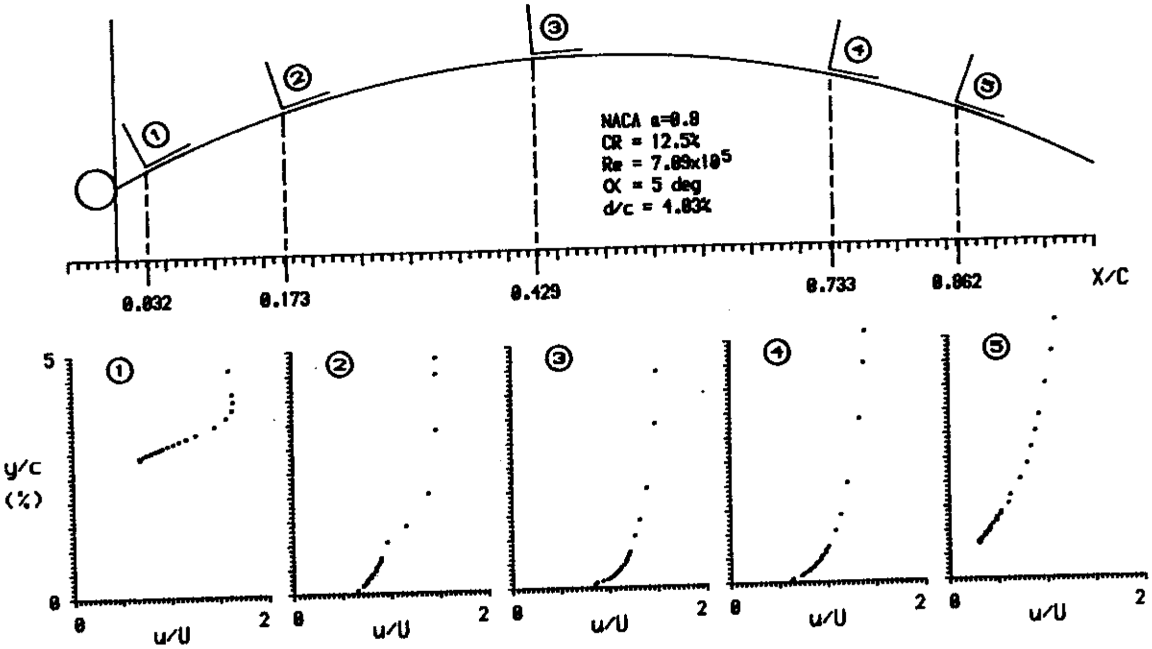
Fig.(11) shows a set of five velocity profiles obtained at various chordwise locations along the upper surface of a sail model. The corresponding static pressure distribution for this case is shown in fig.(12).

Traverse Location ① - The first of these traverses was performed close behind the mast at a location within the upper bubble region as indicated by the wool tufts at the time of testing. It can be seen from fig. (12) that this traverse passed through the constant base-pressure of Region II on the corresponding pressure distribution.

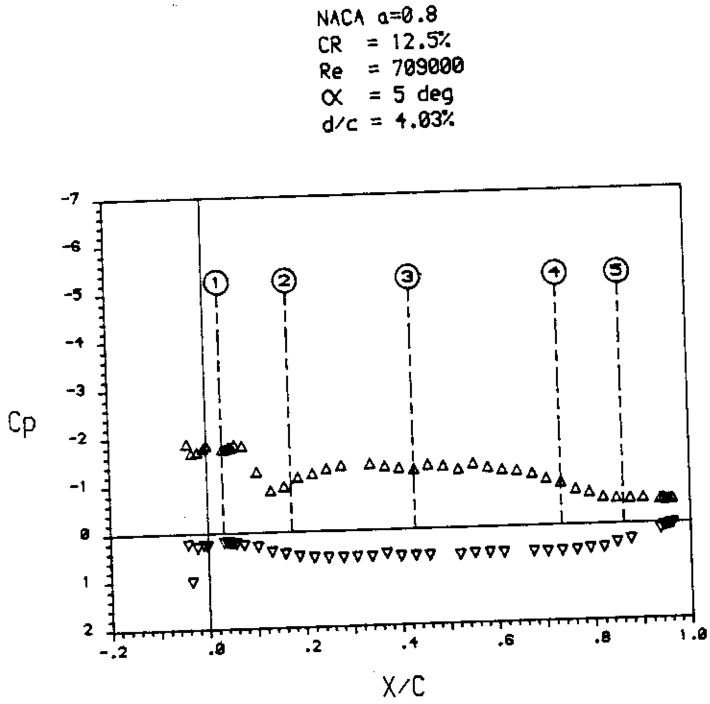
Although the wool tufts clearly indicated reverse flow, no velocity readings could be detected by the yaw probe at any orientation. This was similar to the result obtained by Seetharam (7) when investigating aerofoil separated flow regions. It was concluded that reverse flow velocities were probably present but too small to measure.



Fig(10) Evolution of Static Pressure Distribution with Changing Camber Ratio



Fig(11) Boundary Layer Velocity Profiles



Fig(12) Boundary Layer Traverse Positions Relative to the Corresponding Pressure Distribution

In contrast, above the bubble boundary the free shear layer or separated mast boundary layer was easily detected as shown in fig.(11).

Traverse Location ② - Using the wool tufts as a guide, a traverse was performed close to the reattachment point of the upper surface bubble. It can be seen from fig.(12) that this traverse took place just ahead of the maximum pressure peak at Region III. The flow at this point was fully attached but exhibited a curious double curvature profile, this was thought to be as a result of the superposition of the reattaching shear layer velocity profile onto the normal profile associated with turbulent boundary layer growth on a solid surface.

Traverse Location ③ - This velocity profile, which was obtained in the centre of the attached flow region (Region IV) was typical of a fully developed turbulent boundary layer.

Traverse Location ④ - This traverse location was placed just prior to the trailing edge separation point. It can be seen that the profile has become less full as a result of the decceleration suffered by the flow in overcoming the adverse pressure gradient.

Traverse Location ⑤ - This final traverse was carried out well into the trailing edge separation region as shown both by the wool tufts and the corresponding pressure distribution in fig. (12). No velocities could be detected low in the separation region due to the sluggish nature of the reverse flow, but above the separation stream line the profile of the free shear layer was quite clear. This shear layer was very thick, so much so that the 'mouses' total traverse range of 40mm(1.6") was unable to detect its upper limit.

CONCLUSIONS

The large number of parameter combinations tested in the complete experimental programme effectively covered most of the mast and sail conditions likely to be met in practice. The entire body of data obtained is to be published shortly, but this paper has briefly presented some of the broad observations that have been made from this data.

Although the physics of the air flows around mast and sail combinations is highly complex, the resulting form of the static pressure distributions was found to be remarkably ordered. The pressure distributions were in each case built up from nine fundamental regions which were readily identifiable as being representative of particular flow regimes.

The boundary layer velocity profiles obtained helped to confirm the nature of the flows within each region, but these can also be used to predict separation locations as well as effective surface displacements. The detailed analysis of the boundary layer profiles will be published in a later paper, together with a new partially separated flow theory.

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PERSONAL BIOGRAPHY

Stuart Wilkinson graduated with honours in Mechanical Engineering in 1977 prior to taking up a research post with British Aerospace at Bristol, England. Whilst in this post he was actively involved in mechanical and aerodynamic design aspects of guided weapons systems, and is the holder of a British Design Council national design competition prize.

For the last $3\frac{1}{2}$ years since 1979 he has been engaged in research work within the Ship Science Dept. of Southampton University. During this time he has been undertaking the development of precision measuring equipment for use in wind tunnels, and has been applying this work to aspects of air flows over masts and sails.

Recently he has commenced work on the feasibility of various forms of emergency wind propulsion systems for ships.

WINGSAIL

AUXILIARY SHIP

PROPULSION SYSTEMS

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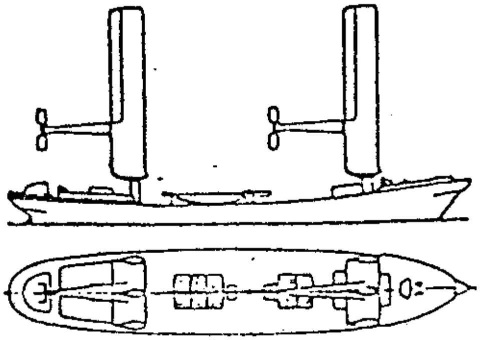
1. WINGSAIL HISTORY

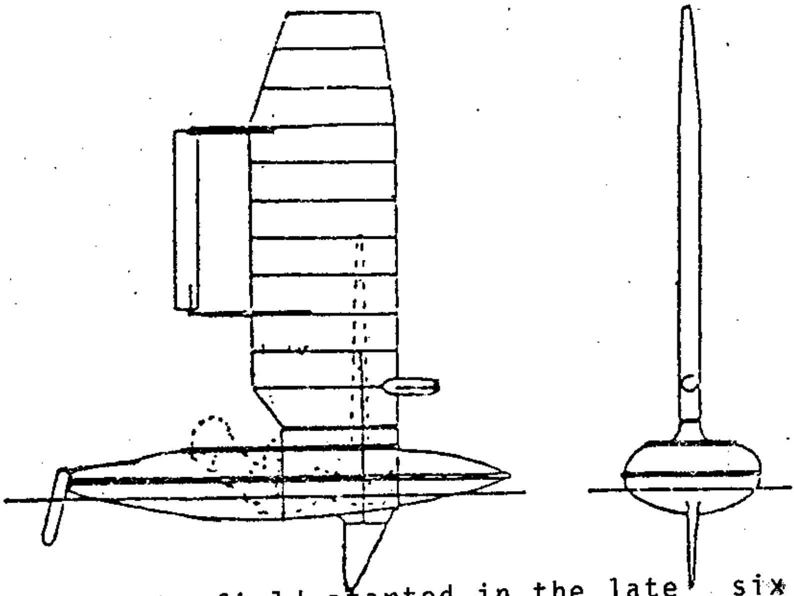
It must have occurred to many experimenters in the early years of this century to try fitting the new fangled aeroplane wings to ships. After all there had already been a remarkable plan in 1712 to propel a vessel with a wind turbine. So far as we know, the first engineer to propose a workable system was the German Anton Flettner, who in the early twenties suggested self-trimming metal wings to propel the "Buckau, a 150 tonne barquentine (Fig. 1).



He obtained the backing of Krupps at Hamburg, and designs were well advanced when Flettner became obsessed with his famous rotor concept. By an amazing feat of persuasion, he caused the Krupp board to transfer their allegiance. "Buckau" got her rotors, and the "Barbara" and the "Baden Baden" were also fitted in due course. The project then fizzled out, Flettner not surfacing again until he reappeared as a leading figure in the German helicopter programme during World War II.

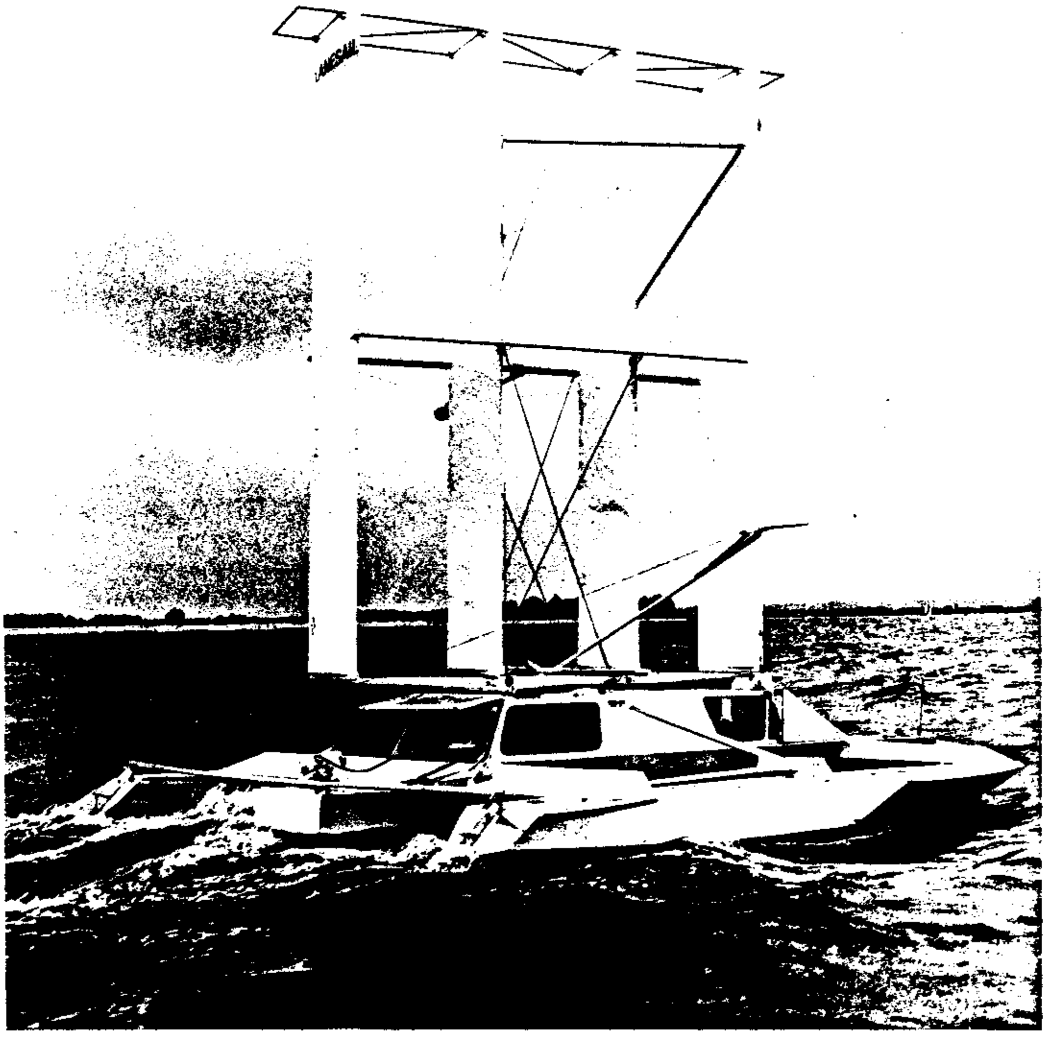
We believe, of course, that a major error of judgement was made. The Magnus effect rotor suffers from the very serious disadvantage, for ship propulsion work, of a fundamentally poor lift/drag ratio. Thus offwind force is available aplenty, but windward efficiency tends to be lacking.

The next experimenter to make a significant contribution was Fin Utne, who was working in Norway in the years immediately before the Second World War. His excellent little boat "Flaunder" (Fig. 2) was the first fully worked out self trimming vessel known to us. She was, most sadly, destroyed by the German occupying forces as "a potential weapon of war."

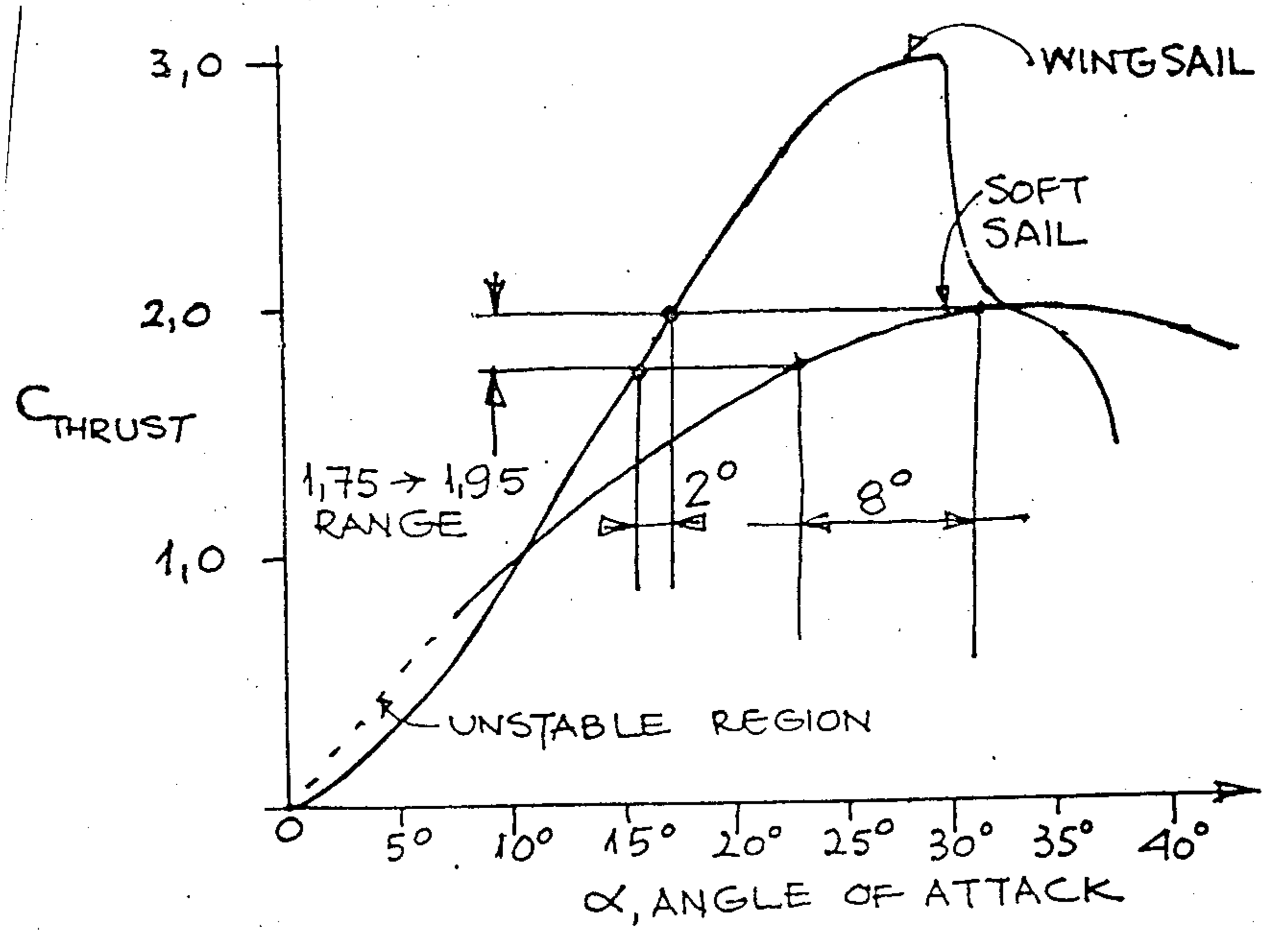


Our work in the field started in the late sixties, with Planesail (Fig. 3), a 10m long wingsail propelled cruiser. She shared a simple symmetrical type of aerofoil section with "Flaunder" but had four main sail panels instead of one, to provide extra thrust, and she worked extremely well.

In parallel with these ventures in the field of self trimming wingsails, all of which had failed. This is because of the far higher demands made upon the trimming system by an efficient high aspect ratio wing. A cloth sail (or a low efficiency, low aspect ratio wingsail) is much "easier on the sheets." This is graphically illustrated in Fig. 4, which shows curves of crosswind force against angle of incidence for a typical efficient wingsail and a low efficiency cloth (or rigid) device. The wide tolerance shown by the low efficiency device means that it can be controlled by slow, even manual means. The search for high efficiency leads one inexorably towards systems needing very rapid angle trimming rates, and thus logically to the self trimming wingsail.



LANESAIL



2. SYSTEM DEFINITION

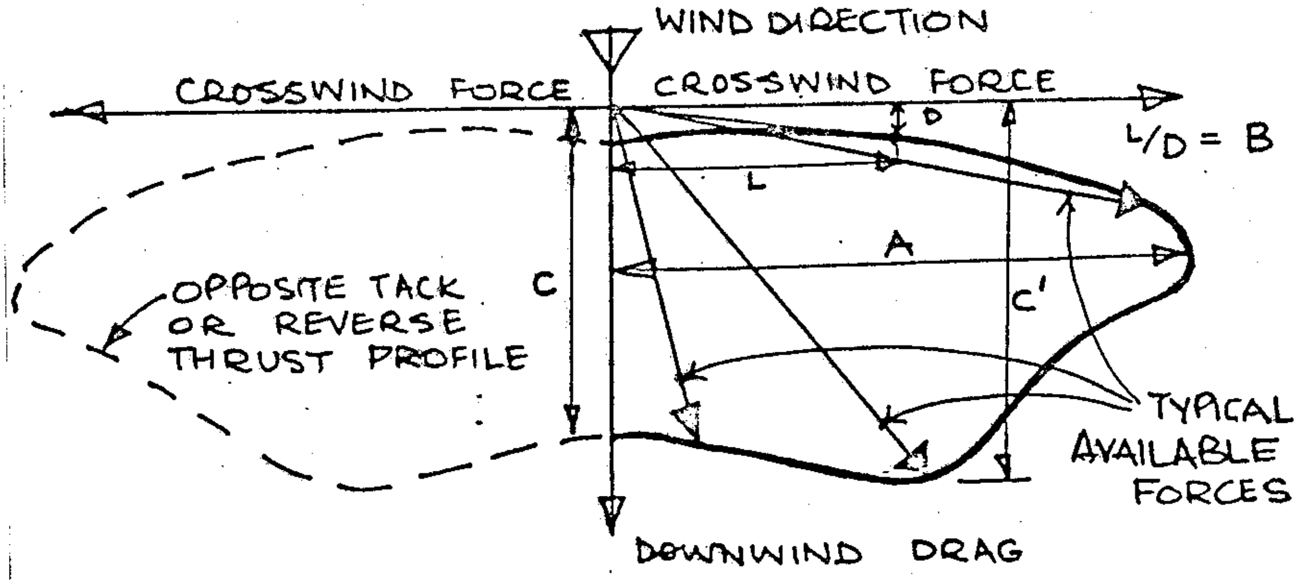
Modern motor ships have bunker fuel costs which amount to some 40-60% of total running costs, and the present thrust towards wingsail assistance arises because of the bunker cost reductions offered at quite low capital cost by such systems. To enable a given system to make a worthwhile contribution in the field, it should perform well against the following criteria:

1. High maximum thrust levels in a given wind per unit size.
2. High course efficiency. This we define as the percentage of the 360 degree total course circle over which forward thrust can be applied in the vessel at a nominal 10 knot forward speed. Thus 100% would only be available from a wind turbine system capable of giving thrust directly towards the wind; 80% would be a very good figure for a wingsail system; while figures below 60% suggest rather poor overall system effectiveness.
3. Safety, in structural, operation and failsafe modes
4. Low or neglible crew demands
5. Rapid pay-back period. This factor is the result of an efficient system, thrusting strongly over a wide range of course angles, saving considerable amounts of fuel, reliable and cheap to maintain, with low first cost. We aim for a maximum of 3 years and 1.5 to 2.5 years seems likely to be attainable.

3. THEORY AND PRACTICE

All the aerodynamic devices proposed to extract solar energy from the wind for ship propulsion work on exactly the same principle, of deflecting the air flow and using the resultant reaction force in some way. Turbines have symmetrically opposed reactions, and so the output is a torque calling for some form of transmission system. Auto-rotation systems (sutogyros) react direct force on to the vessel, so do all Magnus effect rotors, circulation control columns, wings and cloth sails.

The best way to visualise this deflection is perhaps the envelope curve, plotting crosswind force coefficient against downwind drag force coefficient, giving a characteristic symmetrical butterfly shape (Fig. 5).



The three main parameters measured by this graph are:

maximum crosswind force coefficient (A)

optimum crosswind force/drag ratio (B)

maximum downwind force (fully stalled) (C and C')

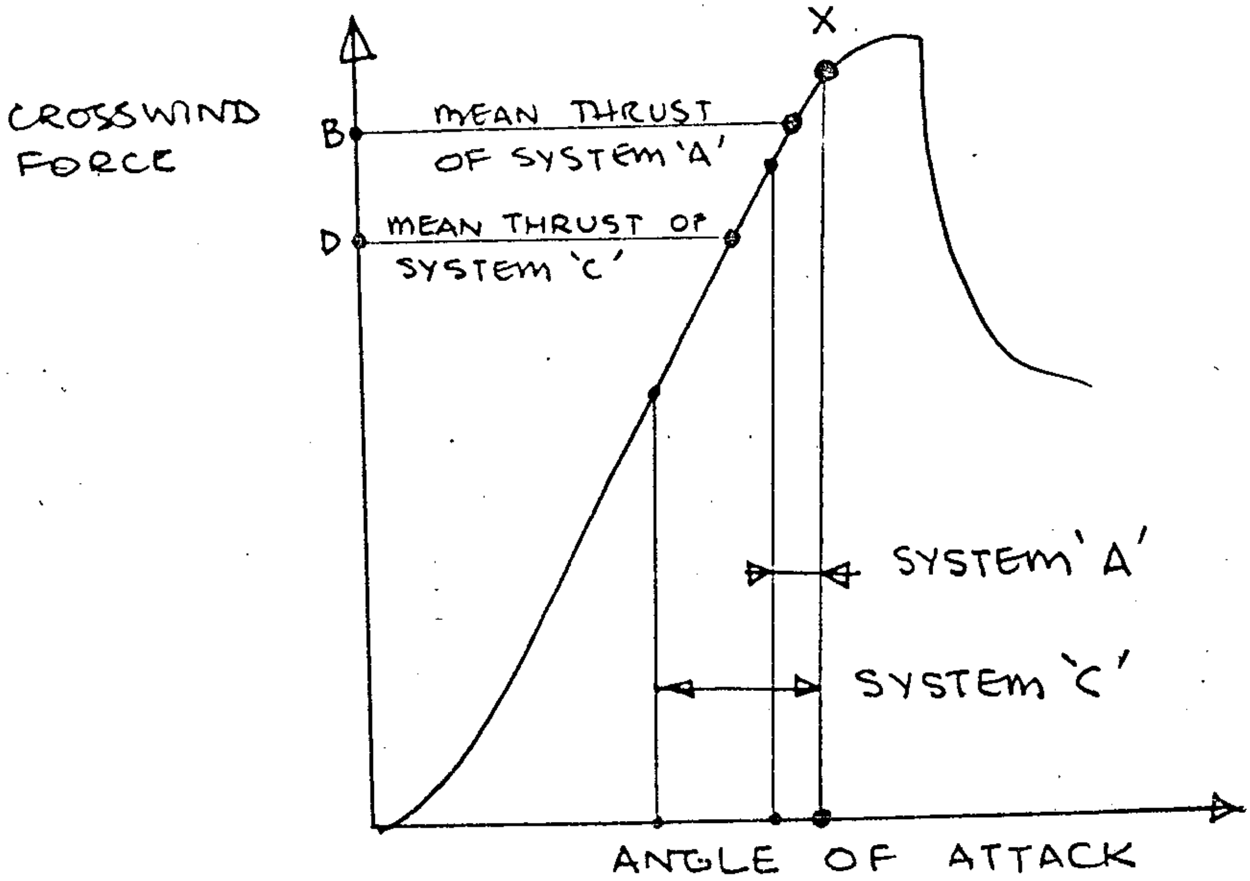
All vessels apart from specialised one-track only record breakers need to be able to perform just as well on the port tack as on starboard. This requires symmmetrically invertable configurations, which can fall into one of two possible types:

Symmetry across the wind line. This group includes all square rigged ships, and the Nippon Kokan system for example.

Symmetry along the wind line. This group includes all fore and aft rigged yachts, all self trimming wingsails such as our own, and the Windship proposed design for example.

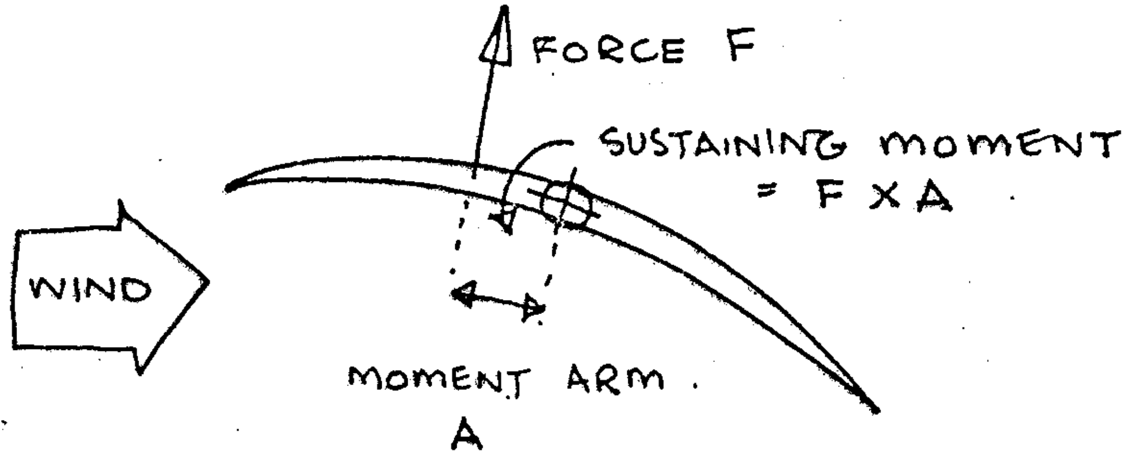
The choice is important, especially for highly efficient computer controlled systems suitable for fitment to modern minimally manned commercial vessels.

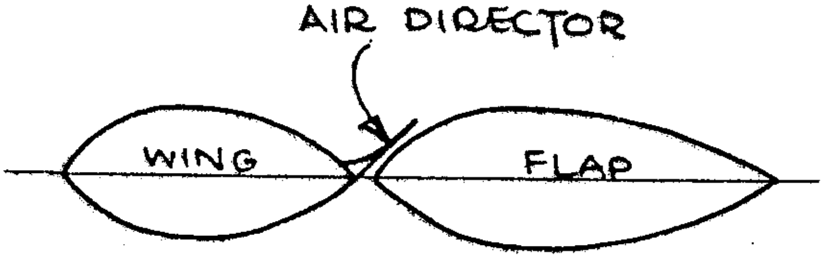
In Fig.6 a crosswind force/angle of attack curve is drawn for a hypothetical wingsail device. It can easily be seen that if X is a "maximum permitted" angle chosen to prevent unwanted stalling, (undesirable because of sharply reduced crosswind force, increased drag and the large "hysteresis loop" needed to re-establish a smooth flow) - then a trimming system, A, with small angular excursions from the set level, will produce a higher mean thrust B than a less efficient trimming system, C, permitting wider angular excursions from the set level and giving a mean thrust level D.



The efficiency of a trimming system is a function of the energy levels required to rotate the wingsail against inertia and air loads. The "crosswind symmetry" style of wingsail system suffers in this respect because the pivot axis must be at the 50% point in the chord width, while the total output force from a cambered surface usually acts at approximately 33% of the chord back from the leading edge (or "luff").

Thus, there will always be a moment of some 0.17 x chord x force, amounting in ship propulsion sized systems to many tonnes metres, to be reacted by the trimming system in addition to the effects of inertia, when the system tries to turn the wingsail so as to avoid the highly undesirable stall (Fig. 7).



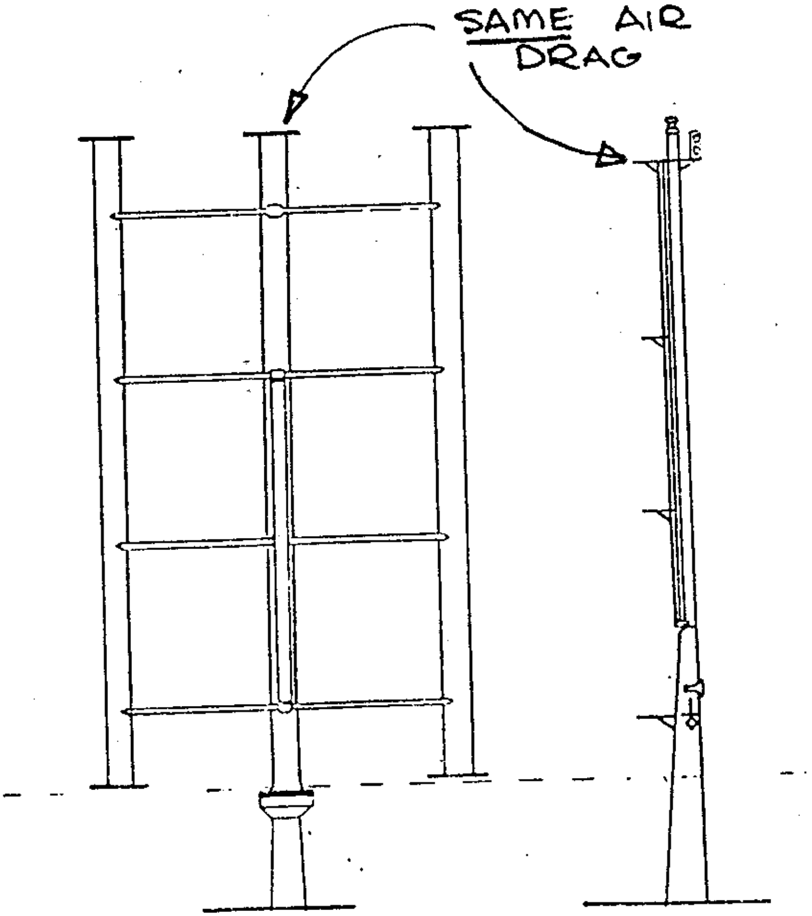


"Wind-line symmetry" systems avoid this disadvantage, and the pivot axis can be palced by the designers to minimise air load torque demands on the trimming sytem. Thus, efficient, fast, reliable tail vane trimmed designs capable of automatic governing and fail-safe operation can be produced.

The aerofoil section to be used is of course most important, and we have spent six years and five separate series of wind tunnel tests on this vital subject. Our present JW05-3 section has been independently tested at coefficients of crosswind thrust of more than 3.0, with very low downwind drag when configured for upwind work, and very high downwind drag when configured for downwind running. Its thick rounded section elements are specifically adapted to allow a light and stiff internal strucutural design, avoidind the need for external masts or bracing wires; and its centre of pressure zone behaves exactly as a wingsail centre of pressure zone should. This allows free, safe, power-off weathercocking with minimal air resistance, combined with extremely low air-load torques when thrusting. Thus a simple and reliable control system may easily hold it close to point 'X' on the output curve (Fig. 6), giving real world effectiveness very close to theoretical predictions.

The section consists of three main elements, a short chord leading section, with an air director and a longer chord flap both coupled to it by simple and robust hinges. There are two primary modes of operation. flat (or symmetrical) and cambered (to port or, in mirror image, to starboard).

The flat mode, (Fig. 8), gives a low-drag, low maximum thrust performance envelope, useful for power-off alongside situations and low speed close quarters manoeuvring.

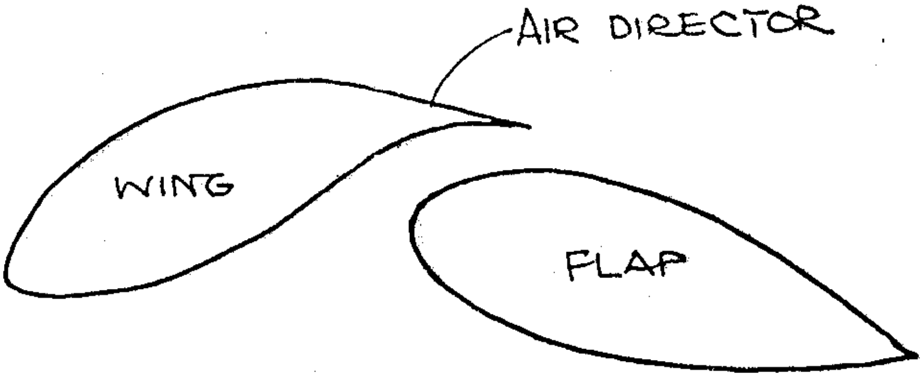


Maximum cross wind thrust is approximately one third of that in the cambered mode, while downwind drag is less than that of an equivalent mast or derrick (Fig. 9).

In the cambered mode the flap and air director move to positions giving a carefully profiled single slotted flap configuration. (Fig. 10). This allows considerable increases in incidence before stall. For example, the plain symmetrical wingsails of Flaunder and Planesail stall at 12 to 15 degrees with crosswind force coefficients of 1.0;

Maximum cross wind thrust is approximately one third of that in the cambered mode, while downwind drag is less than that of an

In the cambered mode the flap and air director move to positions giving a carefully profiled single slotted flap configuration. (Fig. 10). This allows considerable increases in incidence before stall. For example, the plain symmetrical wingsails of Flaunder and Planesail stall at 12 to 15 degrees with crosswind force coefficients of 1.0; highly cambered unslotted shapes rotate to some 20 degrees before stall, giving coefficients rather less than 2.0; JW05-3 turns up to 35 to 40 degrees before stall, with a maximum crosswind force coefficient of 3.0.



So far as maximum downwind drag is concerned, for sailing away from the wind, very few devices can achieve much more than a coefficient of about 1,2, even, for example, specially designed parachutes and spinnakers. Our section design work has moved on from the early symmetrical days, with downwind drag coefficients of only about 0,5, and we now achieve just over 1,3, quite close to the maximum theoretically obtainable.

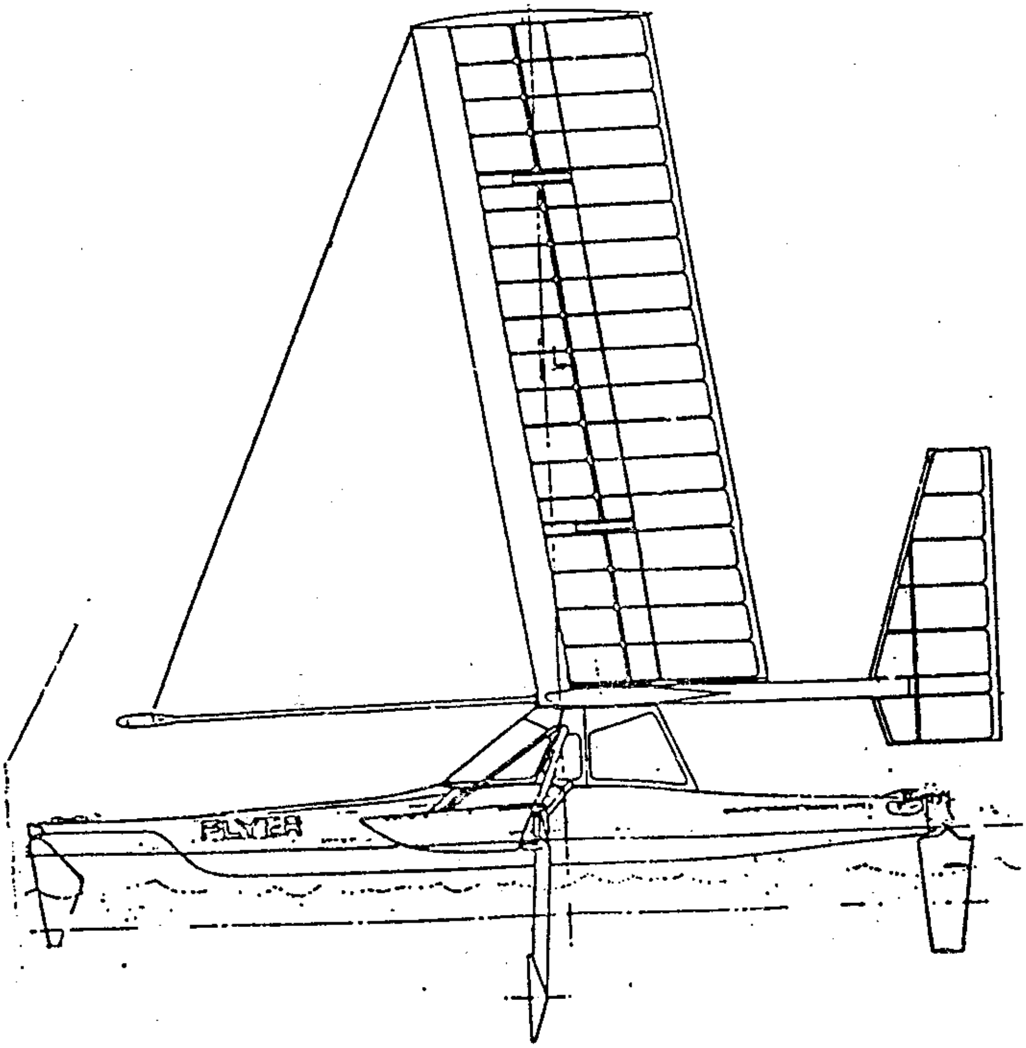
All of our wind tunnel work has been performed with models of approximately one metre span and 0,3m; chord, fitted with end plates and tested at 25 m/s. The section displays extremely tolerant Reynolds Number characteristics, and the graphs for 10 m/s and 75 m/s are virtually identical. Since we are very interested in triplane configurations, we also have a triplane wind tunnel model, with which such variables as spacing and stagger have been exhaustively analysed.

Current work in the wind tunnel explores various end plate configurations, for optimum effective aspect ratio, while further work on upwash, downwash and detailed pressure distribution is due to start almost immediately.

While our early wind tunnel was carried out at Southhampton University, all the more recent work has been done at Cambridge University engineering department, where the enthusiastic support and encouragement of Professor Austyn Mair has been a very great help to us.

4. FULL SIZE PROTOTYPE TESTING - THE FLYER PROGRAMME

In 1976 we iniated a programme aimed at the construction of a full size prototype and demonstration craft called Flyer. She utilizes the JW05 section in its Dash 2 form (capable of a maximum crosswind force coefficient of some 2.7, as against 2.9 to 3.0 for the present Dash 3).



Flyer (Fig. 11) is 10m long, with a 7.2m x 2.5m single wingsail mounted on a free rotation slewing ring type bearing. It is trimmed by a quite low aspect ratio tail vane mounted on a single lower boom. Flap and vane actuation are by hydraulic means, for hydraulic pathways connecting the sailset to the hull passing through a low friction four-way rotary union specially designed by Filton Ltd. The other hydraulics, including a DC electrohydraulic power pack are partly by UCC Ltd. and partly Spencer Franklin, and the whole system has worked with great reliability and sensitivity.

On the water, Flyer has been a source of great satisfaction, giving silent and controllable thrust exactly as planned. The fingertip lever control valves, soon to be solenoid operated by Sinclair Spectrum based microprocessor as part of the major control system work, give progressive thrust availability from zero to maximum in either crosswind direction with very low drag. In force 5, the highest wind yet experienced, Flyer will lie quite stationary when so desired, accelerating away and leaving our 70hp chaseboat standing at the touch of the vane control. Tests continue, of course, but we have already seen sailing within 25 degrees of the apparent wind when "closehauled", and most abundant and exhilarating silent thrust off the wind. Fully stalled, she runs away from the wind quietly and effectively, showing far greater performance than Planesail, not only on this point of sailing, but on all others as well.

The sailset, which we can Module 1, has shown itself to be reliable, strong and controllable, and gives us every hope that the virtually identical technology in Module 2 will provide a most acceptable product for ship propulsion by early 1984.

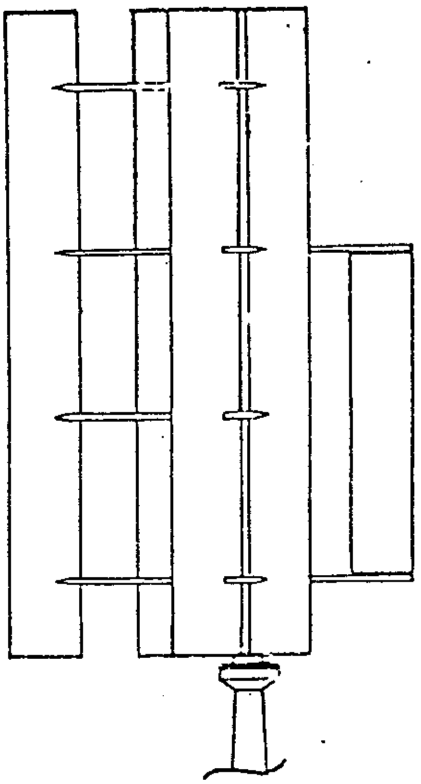
5. TOWARDS THE MODULE 2 SYSTEM DESIGN

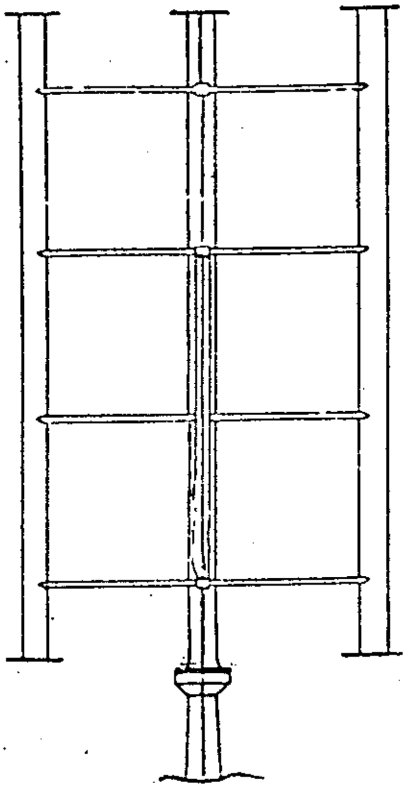
Wind tunnel tests and theory are all very well, but a viable product needs verry much more, if it is to be valuable and sought after in the market place.

The application of the JW05-3 section to the propulsion of ships according to the system defintion criteria set out in Section 2, called for very careful evaluation of our Flyer testing work. A natural corollary of the decision to go for self trimming, using a tail vane, is that the vane on its boom or booms tends to trace out a comparatively large circle in plan view. So that the vessel may go alongside quays and other vessels, it is naturally desirable that this "trimming circle" is well within the beam. We therefore, to get the maximum possible propulsive thrusting area into this circle, investigated the triplane configuration. Here a central main sail panel is flanked by two lighter ones, all three being controlled by a single tail vane assembly. There is of course multiplane loss in using such a layout. Nevertheless we can get 2.5 times the thrust loss provides quite high effective aspect ratios for good course efficiency.

Module 2 has therefore three main panels, almost identical in chord width and rib and hinge details to Module 1, but each panel is 11.8m high instead of 7.2m. The resulting sailset (Fig. 12) has a nominal thrust area of 100 sqm, and is rated at 2 tonnes of static thrust in a 25kt beam wind. The output force will be electronically governed to a constant level after reaching 8 tonnes in 50 kts of wind.

The sailsets are of mainly reinforced plastics design, calling upon the latest aerospace materials such as Kevlar and Nomex in epoxide resin systems. All panels have identical external section profiles, to reduce tooling costs, but the central panel has a very robust main spar carrying all the bending loads, tapering in section from a 30mm wall thickness at the bottom, where it is flange mounted to a proprietary low friciton slewing ring main bearing, to less than 2mm, honeycomb stabilised, at the top. Filton will again provide the high pressure low friction rotary union, this time carrying, in addition to the hydraulic ports, electrical sliprings and an infra-red axial data link.





Both vane and flap will have fully closed loop servo control systems, so that the computer will be able to tell where the various moving elements are at any time, while various transducers, stall warning devices etc. will also be mounted in the rig, using the data link to transmit their information.

The computer itself, in a twin sailset installation, will have two channels, and will accept information not only from its own family of transducers, giving wind speed, wind direction, flow state etc., but autopilot data such as speed required (as decided on the bridge).

In operation, the computer system (to be tried out first in prototype form, of course, aboard Flyer) will notice the call for speed on a given course from the autopilot, and each channel will at once angle its own sailset to give the optimum thrust available. This will include deciding on which tack to angle the wing sails, and whether close hauled, reaching or running settings are called for. As soon as the vessel's speed exceeds the set level, the main engine will be automatically throttled back. If the wind strength rises, or the course angle or wind direction become more favourable, then the computer will throttle back the main engine or engines further, thus saving progressively more fuel.

If the chosen course lies in the ±25 degree zone dead to windward, the computer will feather the sialsets, giving no crosswind thrust and minimal drag.

A full diagnostic programme, checking elctronics, hydraulics and mechanics will be run by the computer at approximately one second intervals, and a range of phased close-down procedures will be available. For example one computer channel failure will result in both sailsets being controlled by the remaining channel, at a small loss in efficiency. If the computer discovers a fault for which there is no redundancy available, the system will cut its power, putting up pne or more red lights on the bridge, and that sailset will automatically go to symmetrical settings, weathercocking safely until the fault can be attended to.

6. NAVAL ARCHITECTURAL CONSIDERATIONS

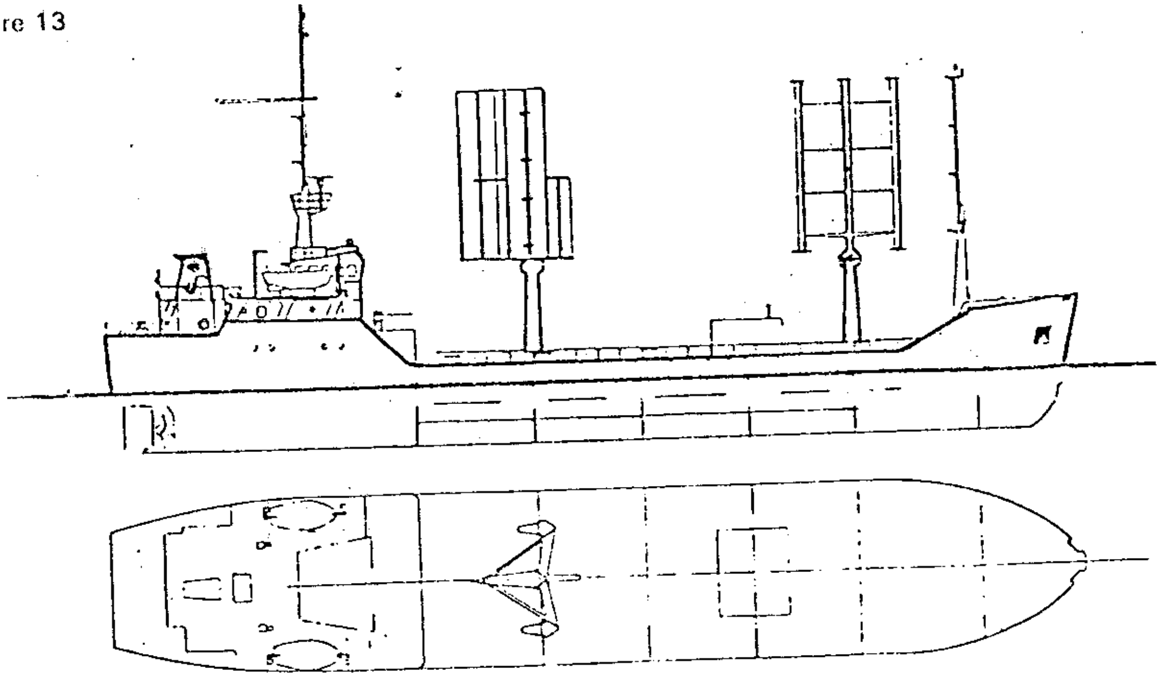
We consider it imperative that the Master has as full a field of view as possible, and therefore to mount our sailsets on short cantilever steel columns, so that the lower edges of the sailsets are above the upper edges of the bridge windows(Fig. 13).

It will be noticed that only very moderate height sailsets are specified - in most cases panel heights will approximate to the beam of the ship. This modest overall height will for example permit the 1600 dwt "Oilman" to negotiate the Manchester Ship Canal bridge in ballast at an air draught of 21.34m (70ft.).

There are further benefits resulting from these modest first generation sailset specifications:

-- small heel angles, averaging 2 to 3 degrees, with only 5 to 8 degree maxima, even in the worst conditions.

Figure 13



-- low column loads, of the same order of magnitude for example as the average deck crane installation, calling only for simple deck doubling plates etc. Full engineering design work on "Oilman's" structure is already under way, and seems unlikely to present major problems.

-- reduction of rhythmic rolling in beam sea, amplitudes being cut by 30 to 50%, with later generations affording active aerodynamic roll reduction. This effect reduces both hull resistance and seasickness, increasing morale and crew effectiveness.

The simple constant vessel speed control system described above, whereby the computer cuts engine power in stronger winds winds and vice versam is of course only the first level of sophistication possible. Later generations can allow the vessel to speed up in favourable wind energy conditions, memorising distance/time data so as to permit lower speed running in light winds later, for the same scheduled arrival time. Satellite based weather information systems can also be used, the bridge monitor showing course planning recommendations for a range of speed/economy/time options.

While most early installations will be retrofits onto existing vessels, in due course there will emerge ship designs specifically adapted for wingsail auxiliary propulsion.

Main engine specifications will tend to move further in the direction of flexible operation over a wide range of power output levels, with controllable pitch propeller and perhaps multiple engine installations being specified. In such a design with twin engines for example, both engines would run at say 90% of MCR for service speed in low wind conditions, being progressively throttled back, as winds improve, until both are at say 60% of MCR. The next stage would be to cut out one engine completely, raising the output of the remaining engine at the same time to MCR before again progressively throttling back to the minimum level of 50 to 60% MCR, i.e. 25% to 30% of total installed rating. Eventually, with a high enough installed wingsail area and a strong wind, all main propulsion could be temporarily shut down.

There is no reason why modern c.p. propellers should not blend very well with this unusual pattern of operation, being used as at present to optimise rpm against load for each different rating. In the fullness of time we shall be able to make use of a fully feathering propeller design with main engines stopped. Such fully feathering designs, with pitch ranges of approximately 115 degrees, already exist at Stone Vickers, for example, and are not predicted to add appreciably to installed costs.

Cargo handling is of course of vital importance in considering the fitment of wingsails to vessels, and it is no coincidence that we have chosen an oil tanker as our first installation. "Oilman", owned by Rowbotham Tankships Ltd., presents no cargo handling problems - the wingsails must simply be kept clear of the hose handling crane.

Low level horizontal cranes mounted on the wingsail support columns seem likely to solve most reefer, container and general cargo problems, although smaller vessels alongside high walls at low tide may present difficulties - we are confident that the innovation skills of the cargo handling specialists will solve most of the snags likely to arise.

Car carriers and Ro-ro vessels, provided that stability is adequate, seem well adapted to benefit from wingsail auxiliary propulsion, while passenger vessels are also favoured, the reduced noise and vibration levels seeming likely to prove especially valuable in the cruise market.

7. SUMMARY

We are confident that not major technical or operating problems lie in the path of this new industry's progress towards saving the shipping industry consdierable quantities of bunker fuel each year. We therefore look forward to wingsail installations becoming an increasingly normal sight on the oceans of the world.

BIOGRAPHY

John Walker is 45, and was originally trained as an aircraft engineer, working on the very early stages of the Concorde Project. However, since 1965, he has been concentrating virtually exclusively on wingsails, developing aerofoil sections, self trimming systems and their associated computer control to their present high level of sophistication.