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.

d) 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 mechanically 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 availability 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.

REFERENCES


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 stationary 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.
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 are 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 individual 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 equipped 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'Études et de Résolvations 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 :             | 139 sq. meters |
| Genoa jib :             | 50 sq. meters |
| main sail :             | 47 sq. meters |
| mizzen :                |              |
| 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 practiced
- 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 1175 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 1500 to 2000 fishermen were involved, in one way or another.

It nevertheless appeared, once the campaign was over, that the two primary objectives: sensitibilization 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 "Cadoual". 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, respectively.

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):

\[ S + R + F_x + f_x = 0 \]

\[ S = \text{propeller thrust (s times power)} \]

\[ R = \text{resistance} \]

\[ F_x = \text{component of the lift due to sails along the longitudinal axis} \]

\[ f_x = \text{force due to relative wind on dead works} \]

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 1500 and 2500, 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

\[ S = s \cdot P \]

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:

\[
\begin{align*}
\text{number of blades: } & 2 \\
\text{diameter } D &= 1.32 \text{ m} \\
\text{pitch (constant) } H &= 0.90 \text{ m} \\
\text{surface ratio: } & 0.40 \frac{V}{N D}
\end{align*}
\]

and of each advance factor \( \frac{a}{n D} \), 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:

\[
f_x = K \frac{\rho}{2} a v^2
\]

\( \rho \) = 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:

\[
S + R + f_x = 0
\]

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

In the same way, under trials with both sails and engine, \( F_x \) is obtained from the equation:

\[
S + R + F_x + f_x = 0,
\]

\( S, R \) and \( f_x \) being calculated as functions of \( V, C \) and \( N \).

A dimensionless performance coefficient \( C_x \) for the sails is defined as the ratio between the useful longitudinal component and the resultant of the pressures applied on the sail:

\[
C_x = \frac{F_x}{\frac{\rho}{2} A v^2 \cos \theta}
\]
A = sail area  
\(v\) = apparent wind velocity  
\(\theta\) = 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 \(C_y\) relative to the transverse component of the wind force may be defined in a 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 \(f_x\) 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.

<table>
<thead>
<tr>
<th>trim</th>
<th>true wind speed (knots)</th>
<th>apparent wind (knots)</th>
<th>speed (knots)</th>
<th>list (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind astern</td>
<td>20</td>
<td>14</td>
<td>6.4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>15</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Broad reach</td>
<td>15</td>
<td>10</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>15</td>
<td>6.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>18</td>
<td>5.2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>12</td>
<td>4.1</td>
<td>0</td>
</tr>
<tr>
<td>Wind abeam</td>
<td>18</td>
<td>18</td>
<td>7.0</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>20</td>
<td>7.5</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>23</td>
<td>7.1</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>25</td>
<td>7.1</td>
<td>17</td>
</tr>
<tr>
<td>Full and by</td>
<td>18</td>
<td>20</td>
<td>6.6</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>20</td>
<td>6.7</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>20</td>
<td>5.2</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>19</td>
<td>4.4</td>
<td>8</td>
</tr>
<tr>
<td>Close hauled</td>
<td>18</td>
<td>20</td>
<td>5.3</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>26</td>
<td>6.6</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 1

Towing speeds are obtained for wind speeds exceeding 15 knots.

Values of the $C_x$ coefficient give a first indication of the efficiency of the sails.

$C_x$

- 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.

**Trim**
- ▲ CLOSE HAULED, 15 KNOTS
- ○ REACH, 15 KNOTS
- □ WIND ABEAM, 15 KNOTS
- ● WIND ABEAM, 20 KNOTS
- ★ BROAD REACH, 18 KNOTS

![Graph](image)

**Figure 5:** "Cadoulal" - 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 $F_x$ then deduced. The corresponding $C_x$ 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 repetitive 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:
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:

<table>
<thead>
<tr>
<th>Speed</th>
<th>Extra power, average</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.2 knots</td>
<td>56 h.p. (1.35 liters per mile)</td>
</tr>
<tr>
<td>8.7 knots</td>
<td>87 h.p. (1.96 liters per mile)</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th></th>
<th>speed (knots)</th>
<th>fuel consumption (liters per mile)</th>
<th>comparison index</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Cadoudal&quot;, engine alone</td>
<td>8.2</td>
<td>3.07</td>
<td>100</td>
</tr>
<tr>
<td>&quot;Cadoudal&quot;, sails and engine</td>
<td>8.2</td>
<td>2.61</td>
<td>85</td>
</tr>
<tr>
<td>&quot;Cadoudal&quot;, better adjustment</td>
<td>8.2</td>
<td>2.08</td>
<td>68</td>
</tr>
<tr>
<td>Improved ship</td>
<td>8.2</td>
<td>1.95</td>
<td>44</td>
</tr>
<tr>
<td>Improved ship</td>
<td>8.2</td>
<td>1.96</td>
<td>64</td>
</tr>
<tr>
<td>Trawler</td>
<td>8.7</td>
<td>4.56</td>
<td>149</td>
</tr>
</tbody>
</table>

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:

$$ R + f_x + F_x = 0 $$

The aerodynamic coefficient of the sails $C_x$ 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:
<table>
<thead>
<tr>
<th>trim</th>
<th>actual data</th>
<th>smoothed data</th>
<th>smoothed data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wind strength</td>
<td>speed (knots)</td>
<td>strength of true wind</td>
</tr>
<tr>
<td></td>
<td>(Beaufort)</td>
<td></td>
<td>(Beaufort)</td>
</tr>
<tr>
<td>Broad reach</td>
<td>3  4.7</td>
<td>4</td>
<td>4  13</td>
</tr>
<tr>
<td></td>
<td>4  4.0</td>
<td>5</td>
<td>5  15</td>
</tr>
<tr>
<td></td>
<td>5  6.0</td>
<td>5</td>
<td>5  19</td>
</tr>
<tr>
<td></td>
<td>6  7.0-7.1</td>
<td>6</td>
<td>5  20</td>
</tr>
<tr>
<td></td>
<td>7  9.0</td>
<td></td>
<td>6  19</td>
</tr>
<tr>
<td>Wind abeam</td>
<td>2  3</td>
<td>3</td>
<td>3  15</td>
</tr>
<tr>
<td></td>
<td>3  3.7</td>
<td>4</td>
<td>4  18</td>
</tr>
<tr>
<td></td>
<td>4  5.0-5.4</td>
<td>5</td>
<td>5  22</td>
</tr>
<tr>
<td></td>
<td>5  5.7-6.0-6.7</td>
<td>6</td>
<td>6  23</td>
</tr>
<tr>
<td></td>
<td>6  7.5-8.0</td>
<td>7</td>
<td>7  24</td>
</tr>
<tr>
<td>Full and by</td>
<td>2  4.1-4.0</td>
<td>4</td>
<td>5  25</td>
</tr>
<tr>
<td></td>
<td>3  4.5</td>
<td>5</td>
<td>5  26</td>
</tr>
<tr>
<td></td>
<td>4  5.5</td>
<td>5</td>
<td>5  27</td>
</tr>
<tr>
<td></td>
<td>5  5.5</td>
<td>6</td>
<td>6  28</td>
</tr>
<tr>
<td></td>
<td>6  5.5</td>
<td>6</td>
<td>6  29</td>
</tr>
</tbody>
</table>

Table 2

Cx

<table>
<thead>
<tr>
<th>trim</th>
<th>Cx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad reach</td>
<td>0.71 - 0.86</td>
</tr>
<tr>
<td>Wind abeam</td>
<td>0.56 - 0.77</td>
</tr>
<tr>
<td>Full and by</td>
<td>0.51 - 0.60</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Cx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind astern</td>
<td>0.45</td>
</tr>
<tr>
<td>Broad reach</td>
<td>0.75</td>
</tr>
<tr>
<td>Wind abeam</td>
<td>0.65</td>
</tr>
<tr>
<td>Full and by</td>
<td>0.58</td>
</tr>
</tbody>
</table>

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: manoeuvrability, 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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