

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 compatibility 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.

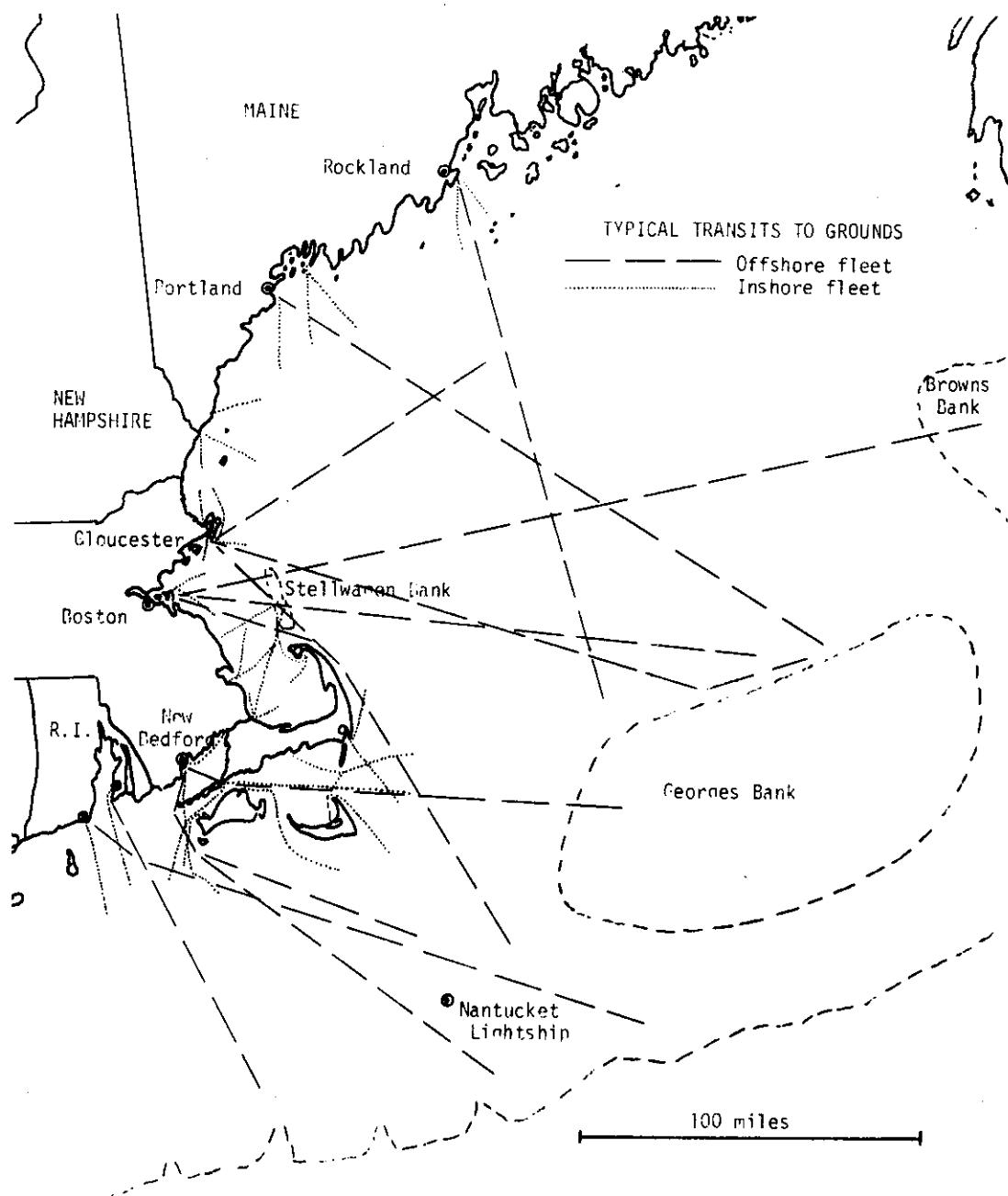


Figure 1. New England fishing grounds showing typical transits for the inshore and offshore fleets

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.	Nantucket	8.6	2.6	3	2.6	4.6	6	12.3	17
Feb.									
March	Gloucester	4	1	3	3.3	4	3.3	8.6	9.3
April	Nantucket	3.3	4.6	0	2.3	7.3	7.6	3.6	3.3
May									
June	Gloucester	0	0	0	3.6	4	4.3	2.6	10
July	Nantucket	2.3	1.6	2.3	1.6	5	3.6	0.6	2
Aug.									
Sept.	Gloucester	1.3	1	1	3	1.3	2	2.3	2.6
Oct.	Nantucket	6.3	3.3	5.3	3	2.6	5	9.6	11
Nov.									
Dec.	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.

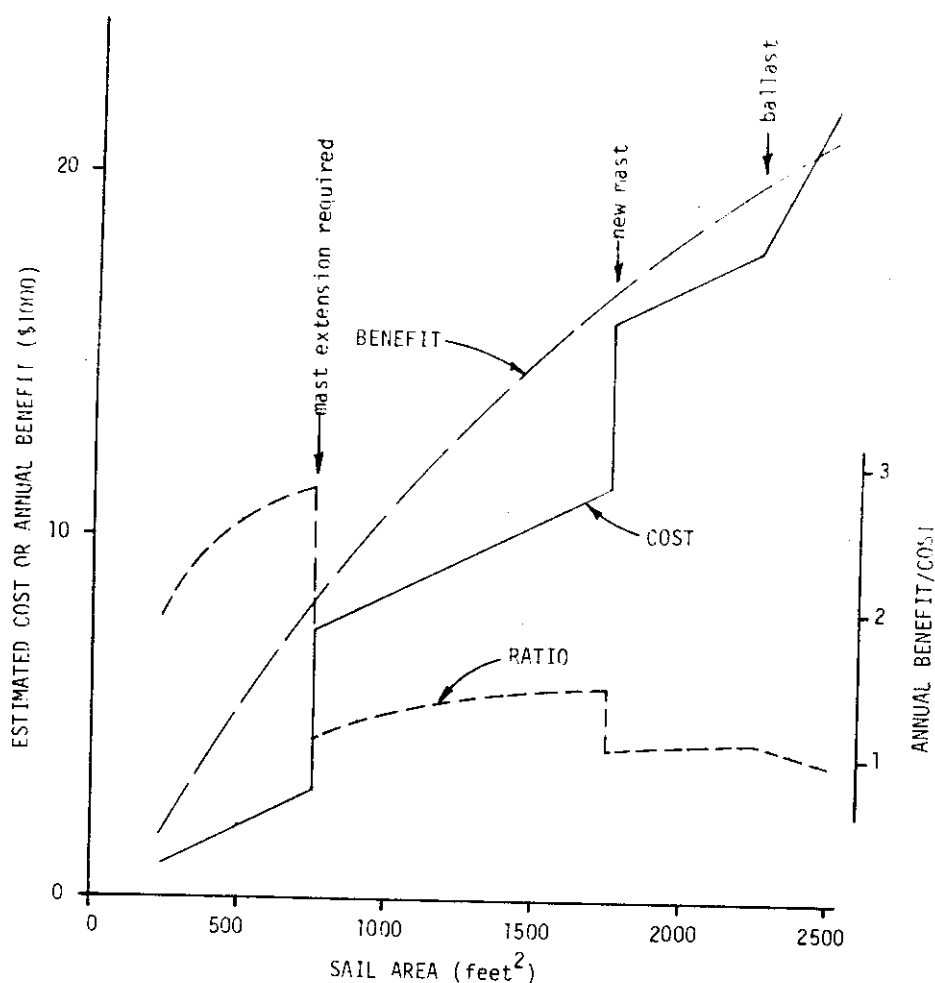


Figure 2. Costs and economic benefits versus sail area for a hypothetical retrofit sail-assist installation.

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.

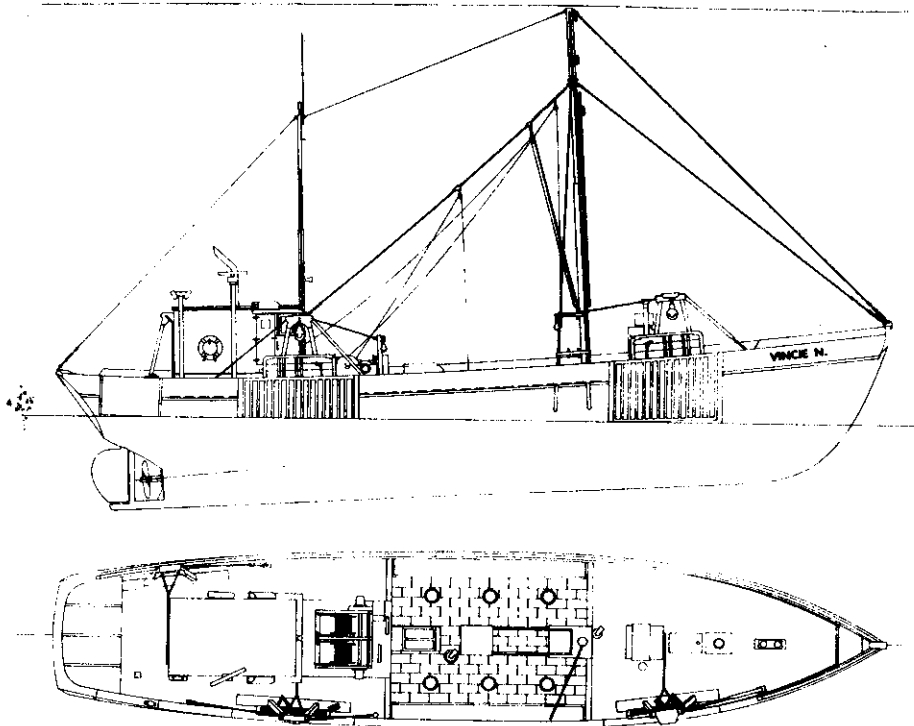


Figure 3. Outboard profile and deck plan of 86' side trawler Vincie N.

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.

VINCIE N.

PRINCIPAL	DIMENSIONS
LOA	84' 0"
LC	78' 0"
BEAM	18' 4"
DRAFT	9' 0"

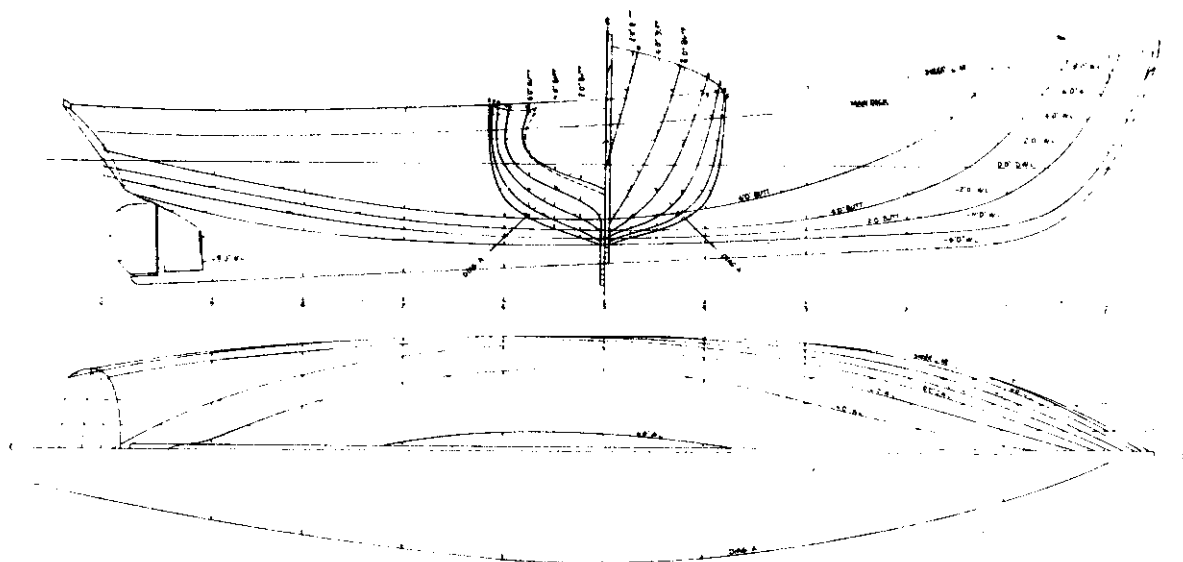


Figure 4. Lines drawing for Vincie N. reconstructed from hull measurements

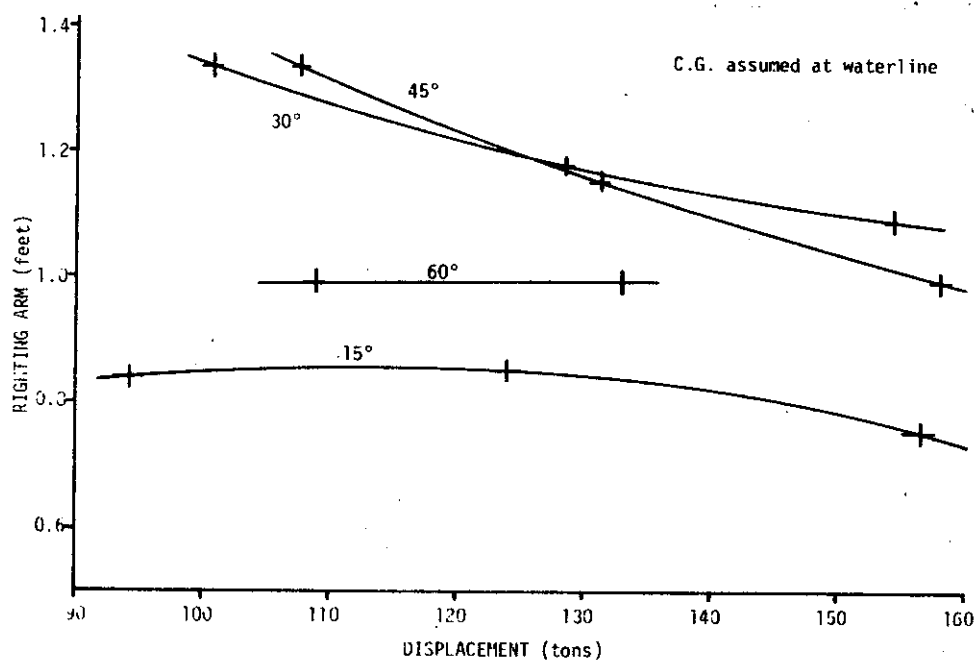


Figure 5. Cross curves of stability for Vincie N.

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.

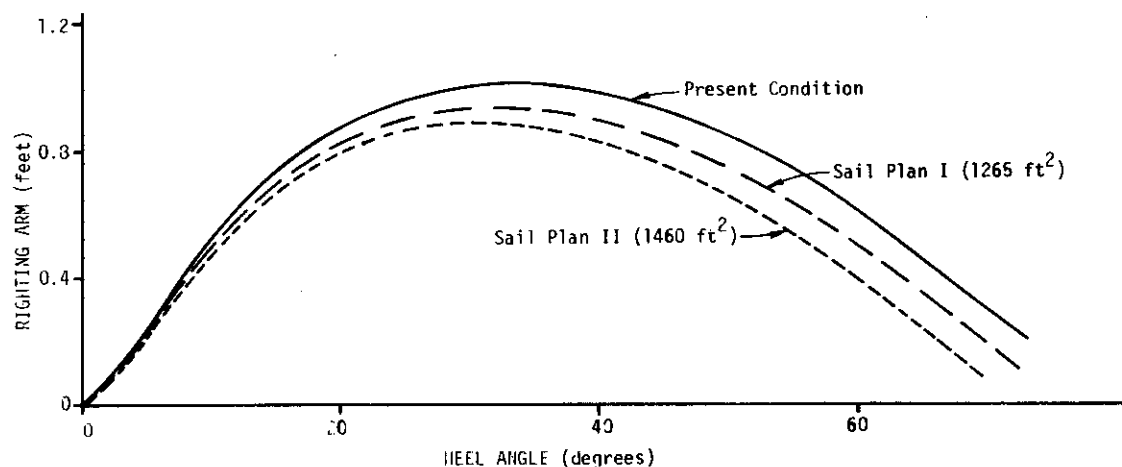


Figure 6. Righting arm for Vincie N. in present condition and with proposed sail-assist installations.

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.

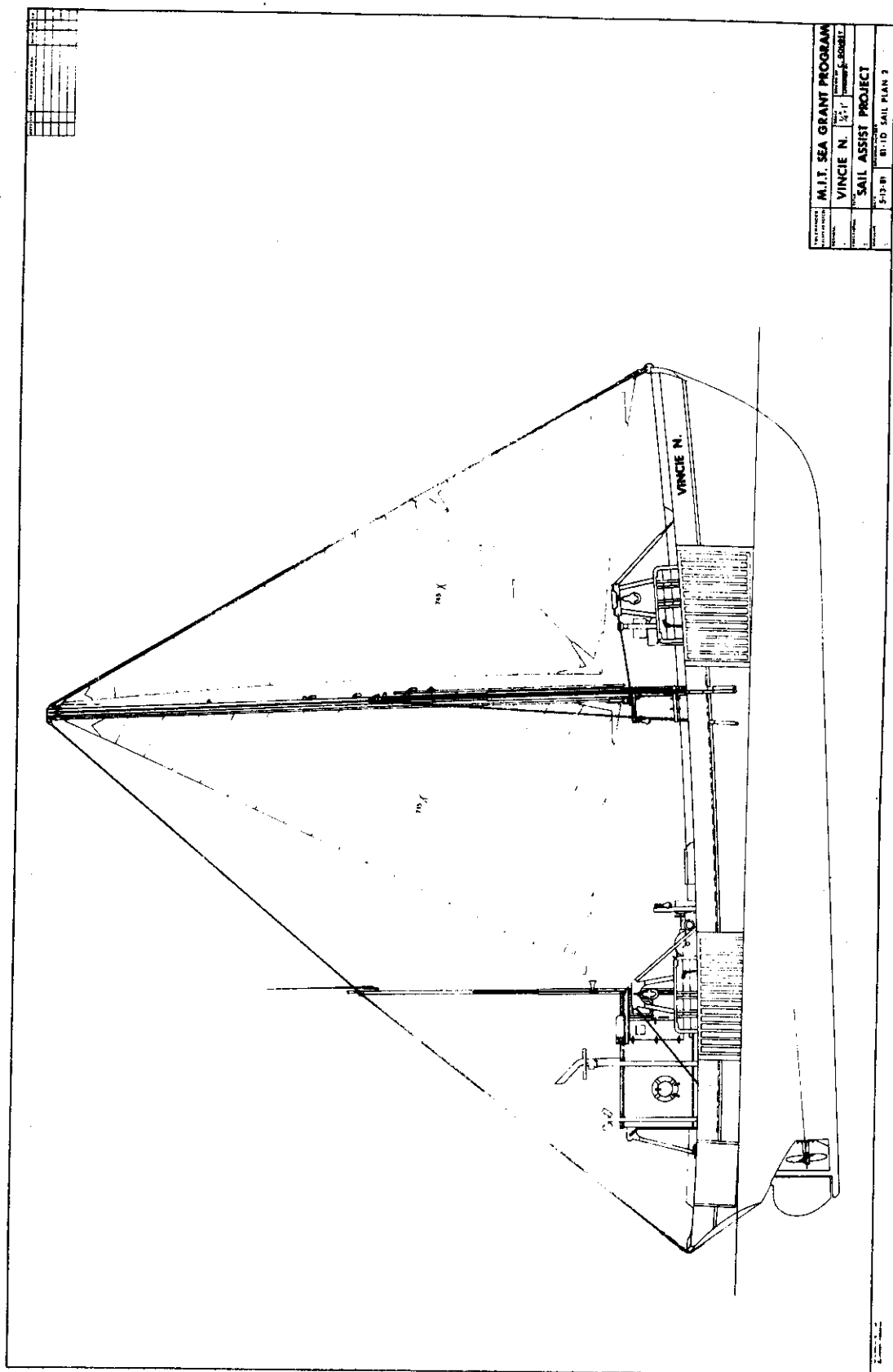


Figure 7. Proposed sail plan for the 86 foot side trawler Vincie N.

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.

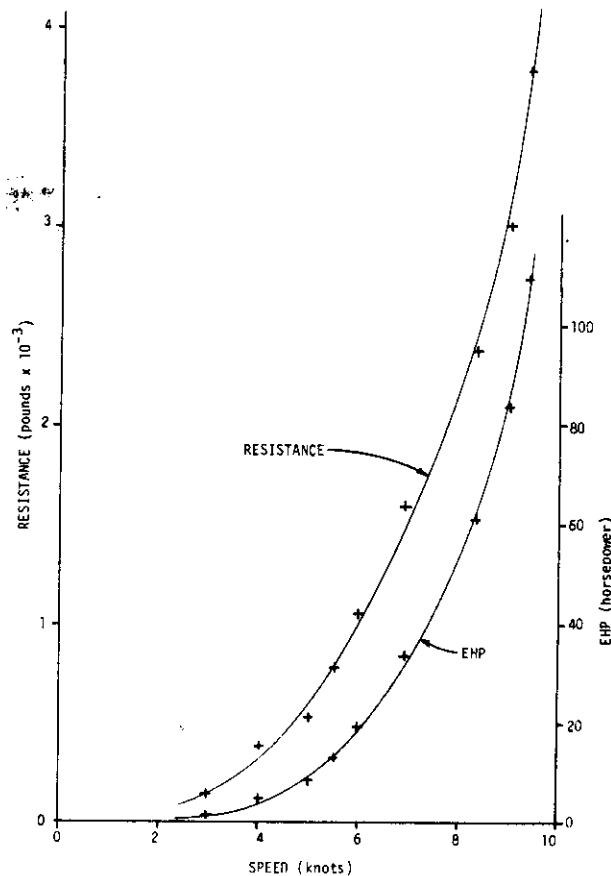


Figure 8. Resistance and EHP versus speed for 86 foot side trawler Vincie N. (from towing experiment)

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 commercial availability of such gear was not determined. The vessel was sold before further work could proceed.

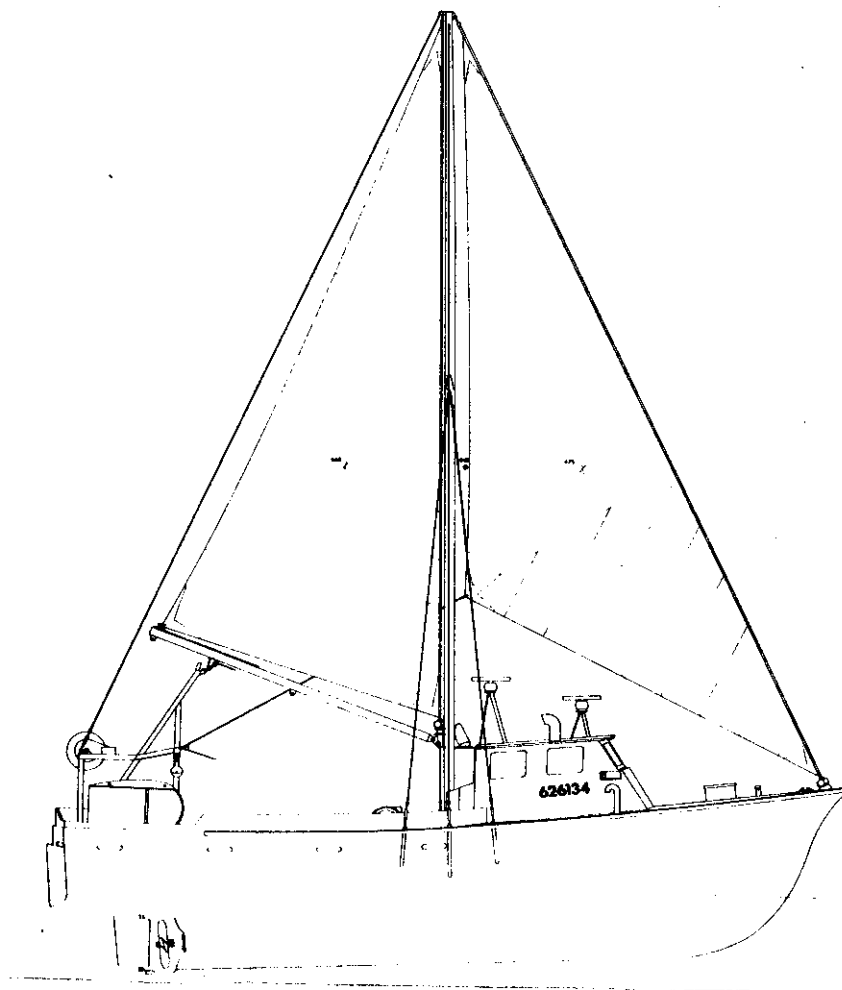


Figure 9. Proposed sail plan for 55 foot stern trawler Denyle.

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.

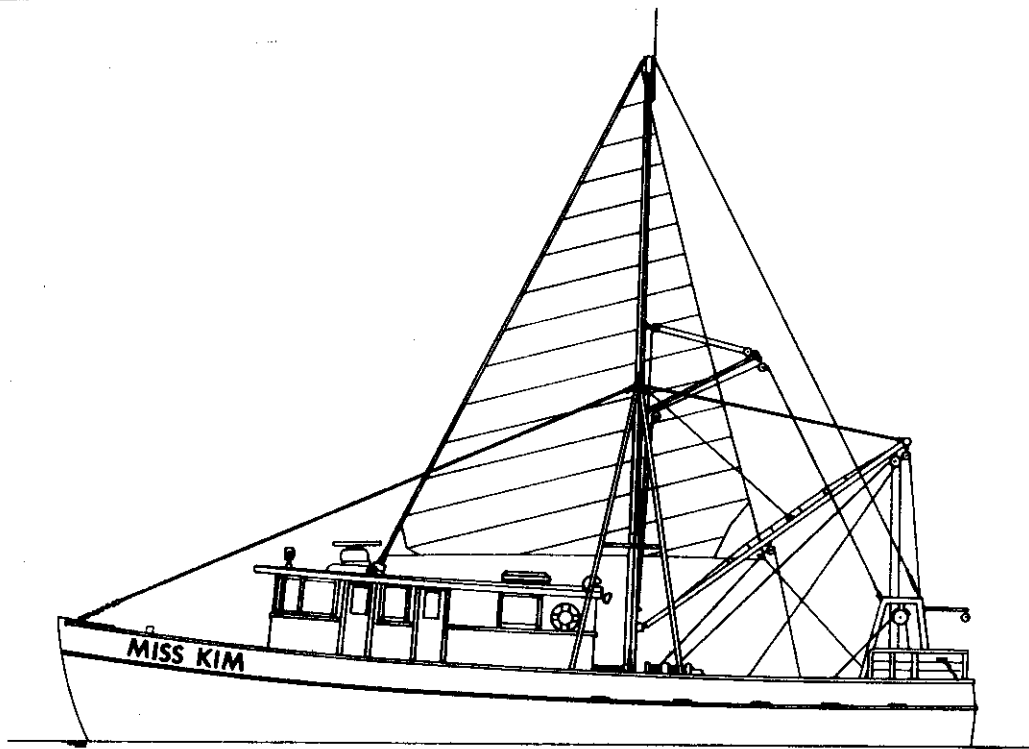


Figure 9. Proposed double headed sail plan for 58 foot stern trawler Miss Kim. Port jib is omitted for clarity.

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 cooperation 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

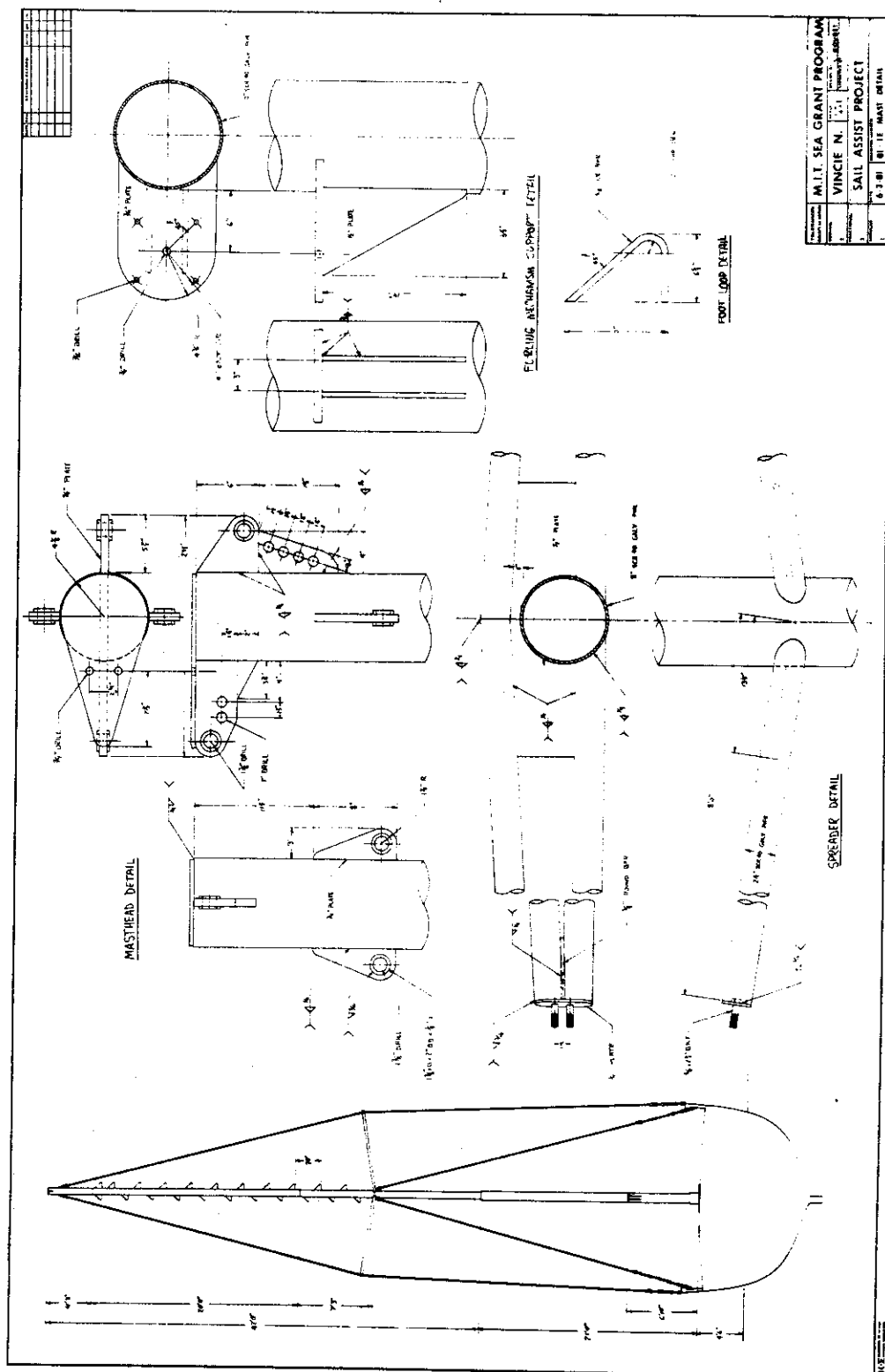


Figure 10. Detail of mast extension for 86 foot side trawler Vincie N.

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 contradiction 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 rhythmically 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.

(1) A proa is a slim hull to which is connected by beams athwartships a heavy float. This float is 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 Caribbean. 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 archipelagos. 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.

(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 enhanced 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 diesel 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 diesel 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 conform 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 archipelago. This includes sail-making, construction of spars, even some foundry work (marine blacksmithing) and welding. It includes splicing of metal cables, assembling 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 genealogies 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 forms 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 foolproof 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, perhaps 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, is 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 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

quarters, 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 sloop 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. They have 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 are stepped the same distance from the bows. And there are four, rather than two masts. There will 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 contemplated 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 shaft 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 grandchildren

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:

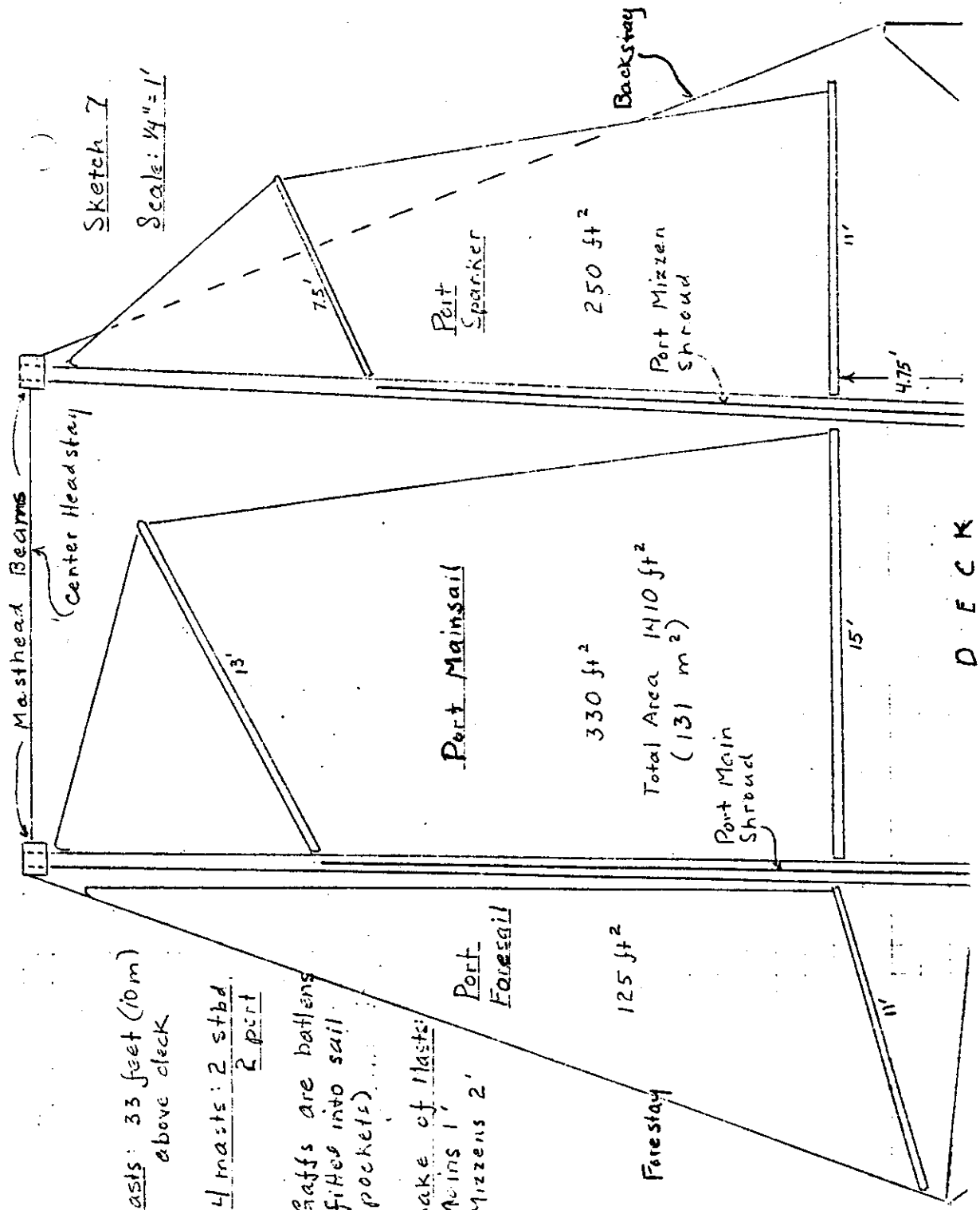
International contract; Real estate law;
Tax haven law; Civil trials

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 planta-
tions. 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.

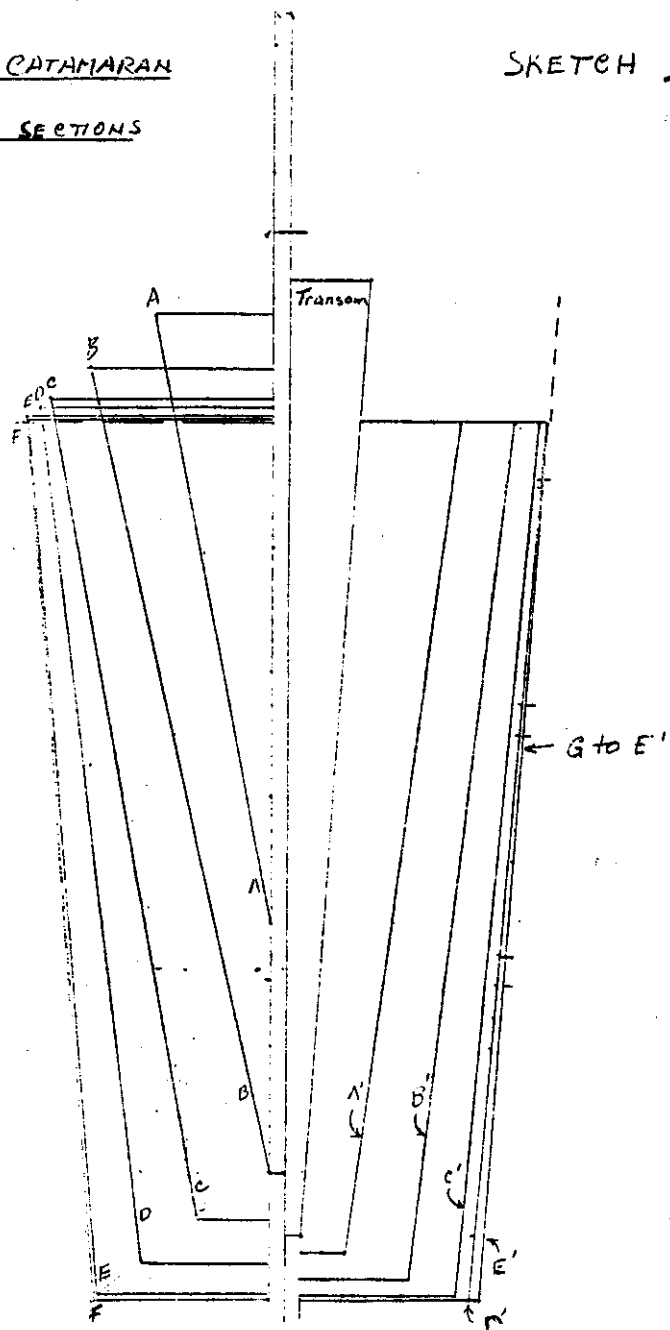
Avocations: Design of sailing vessels, light aircraft; design of
unconventional weapons systems; private pilot; sailing; military and
naval strategy and tactics; and history.



FISHING CATAMARAN

SKETCH 6

HULL SECTIONS



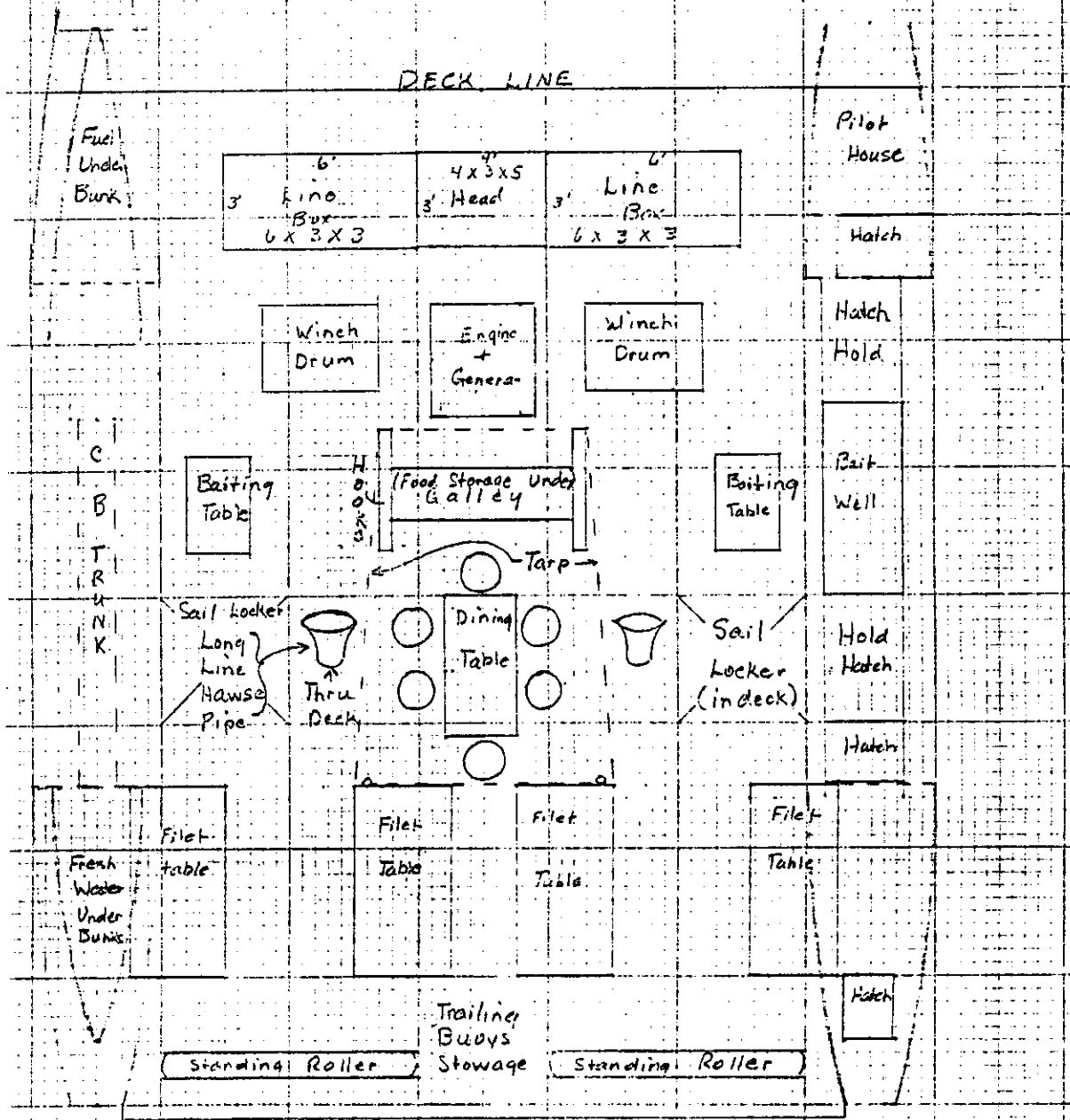
Deck Arrangement

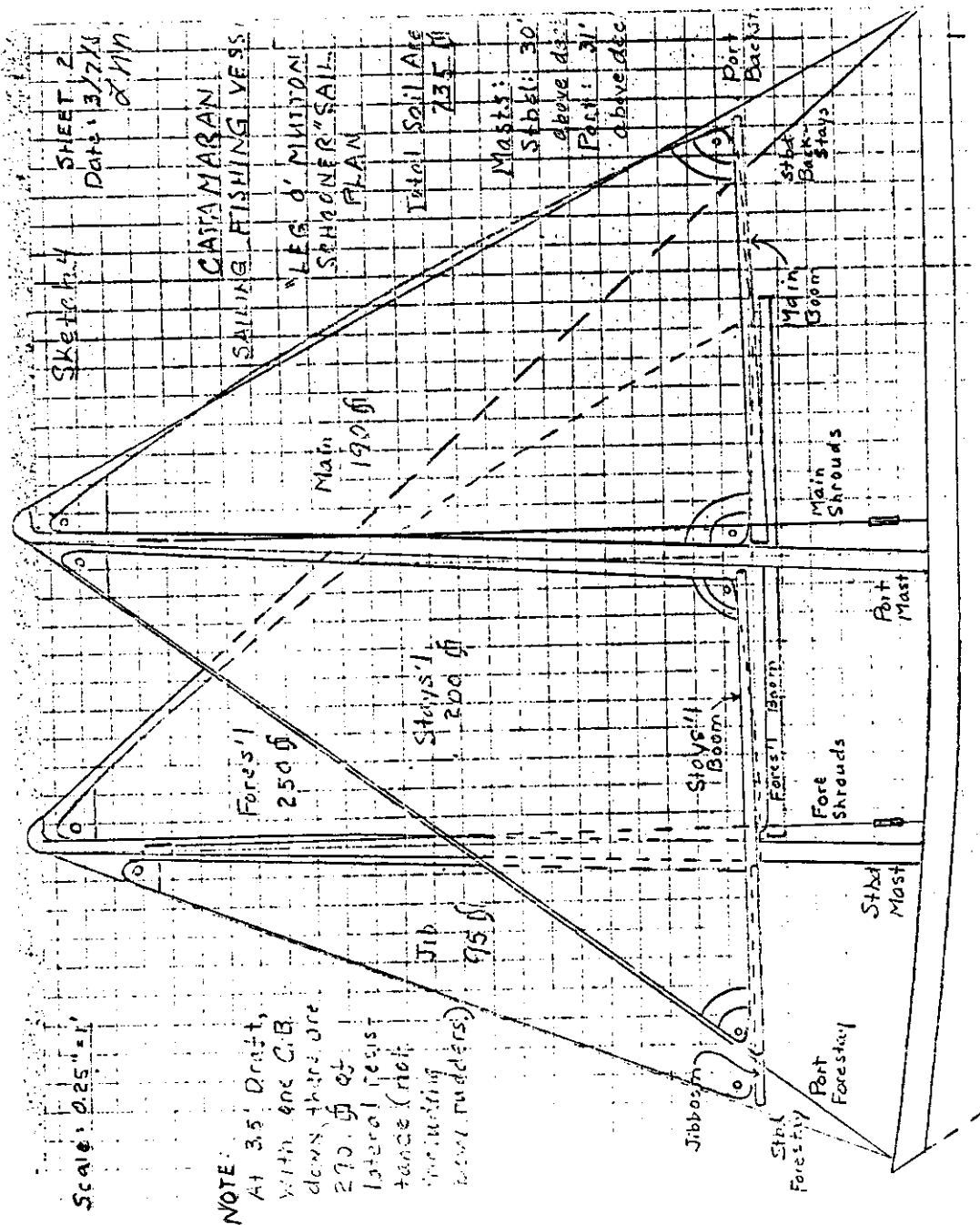
41' CAT
Sailing Fisherman
(for long line use)

April 17 82

LMH

Sketch 5





Sketch: 3

CATAMARAN SAILING FISHING VESSEL

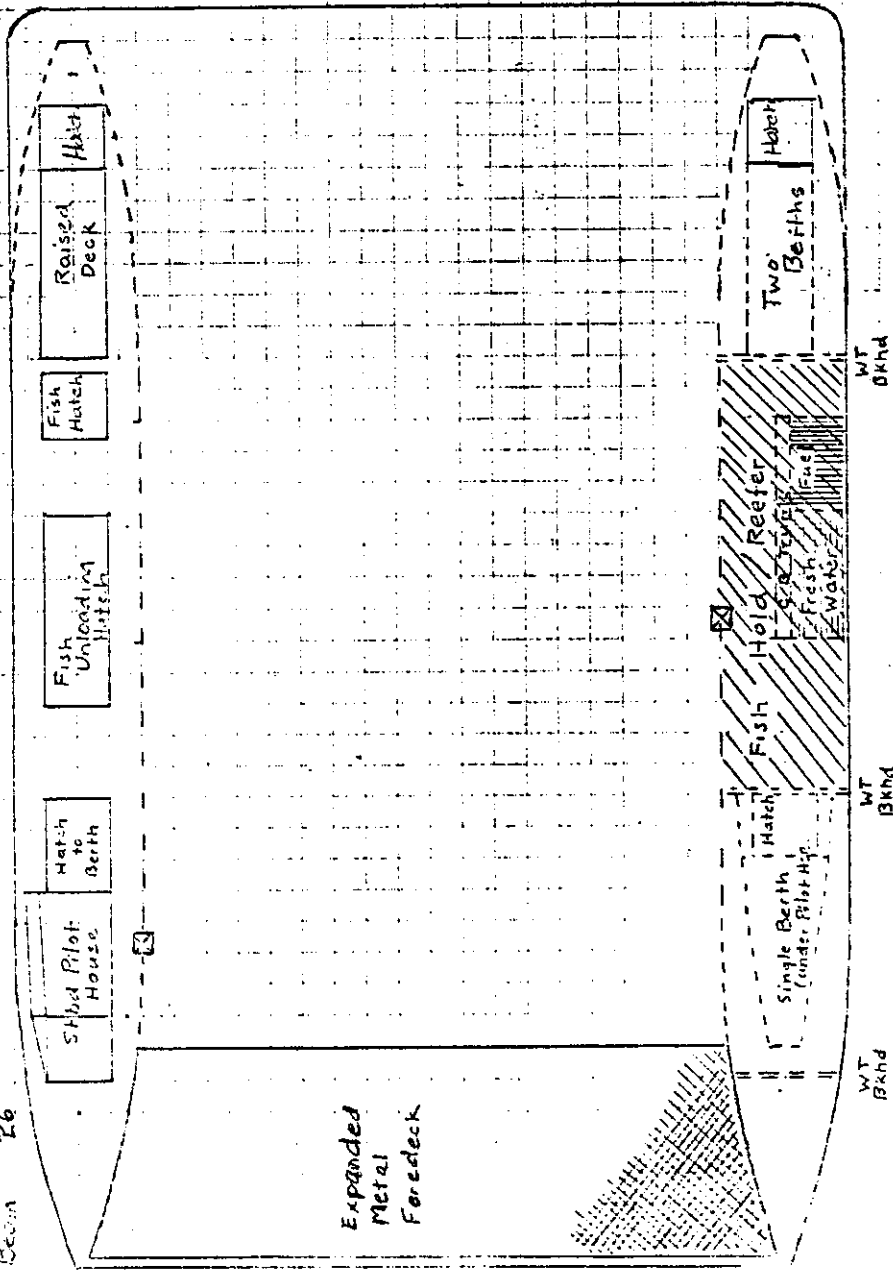
SHEET

Date: 3/7/82

Configuration:

SCALE: 0.25" = 1'

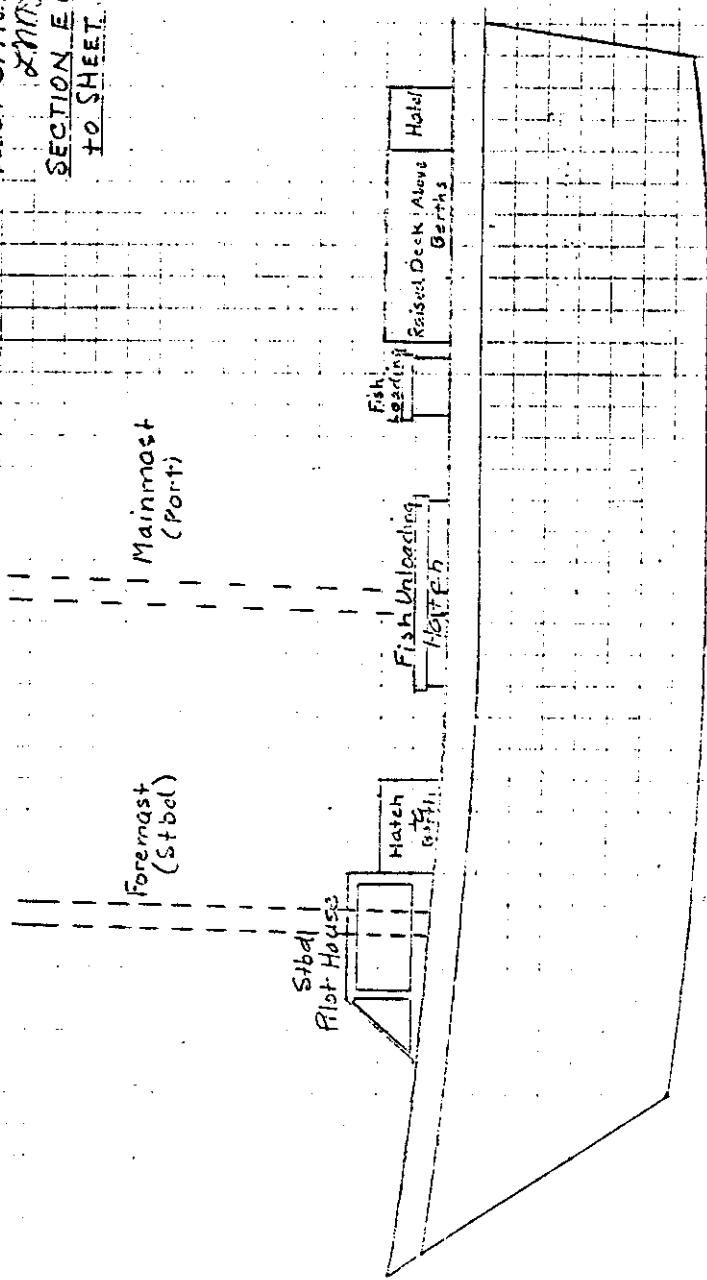
Length: 41'
Beam: 26'



Scale: 1/25" = 1'

Sketch 2
CATAMARAN SAILING FISHING VESSEL

SHEET
Date: 3/7/8
XMT
SECTION E
TO SHEET

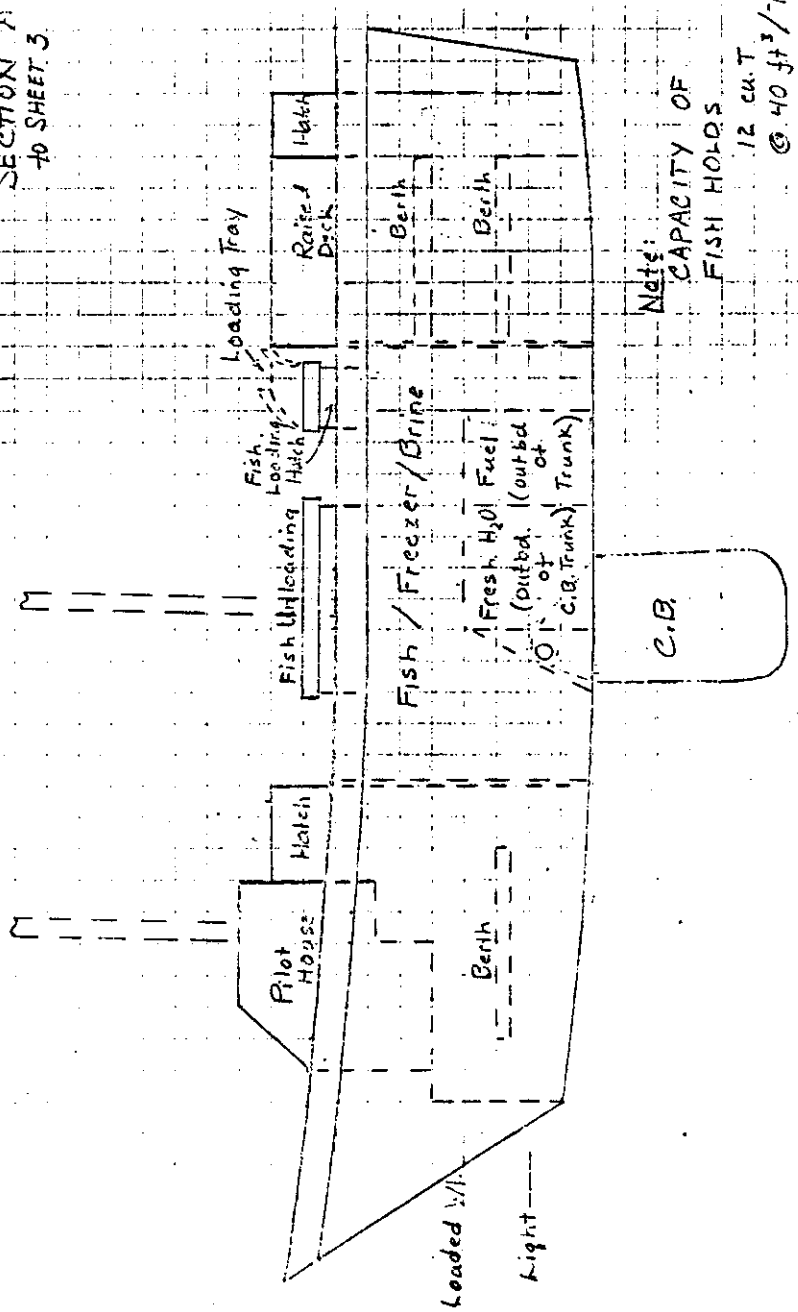


Scale: 1/25" = 1'

Sketch 1
CATAMARAN SAILING FISHING VESSEL

SHEET
Date: 3/7/82

SECTION 1
TO SHEET 3



SAIL-ASSISTED FISHING VESSELS FOR GULF OF MEXICO,
CARIBBEAN AND NEAR-ATLANTIC WATERS

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University of South Florida
College of Engineering
Tampa, Florida 33620
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 necessarily 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
SPEED	55.95	0.02	-4.54

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.

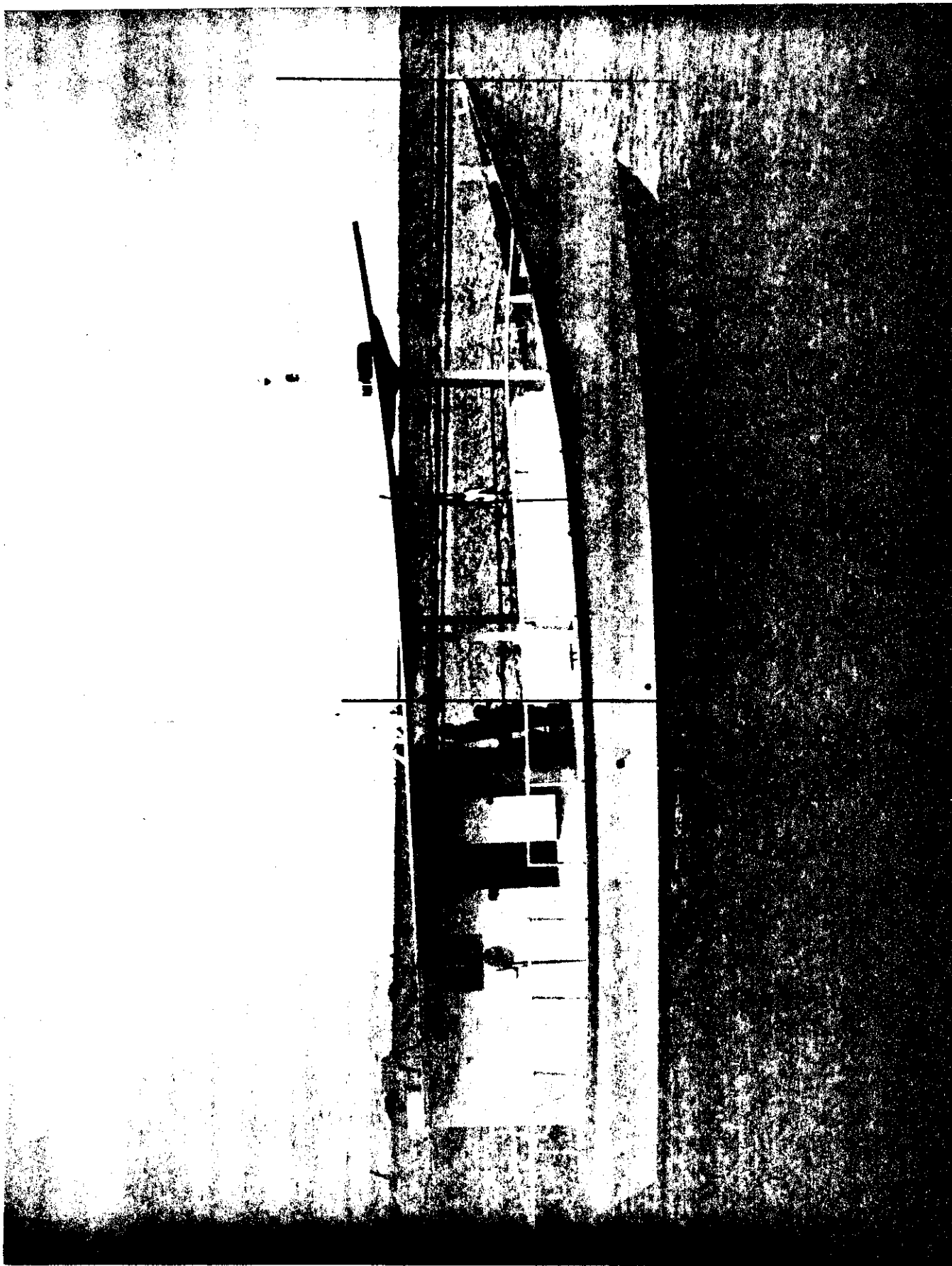


Figure 1

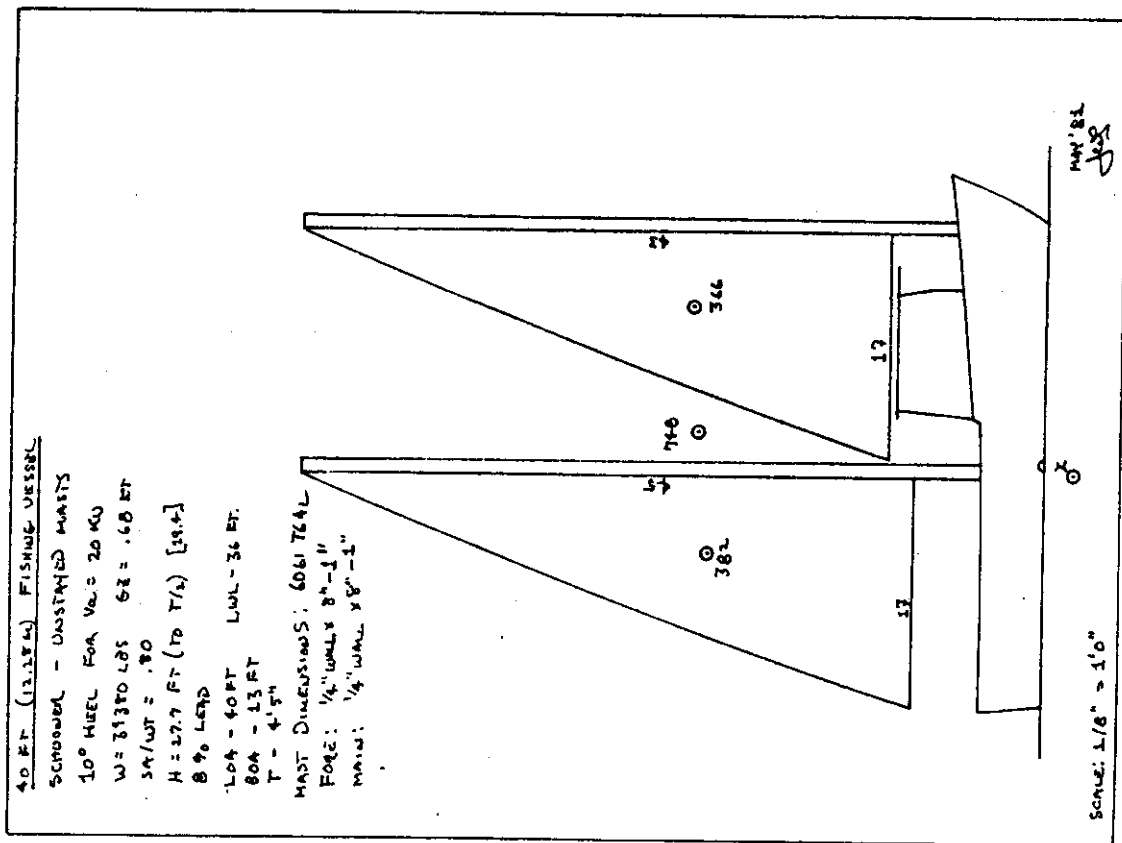


Fig 3

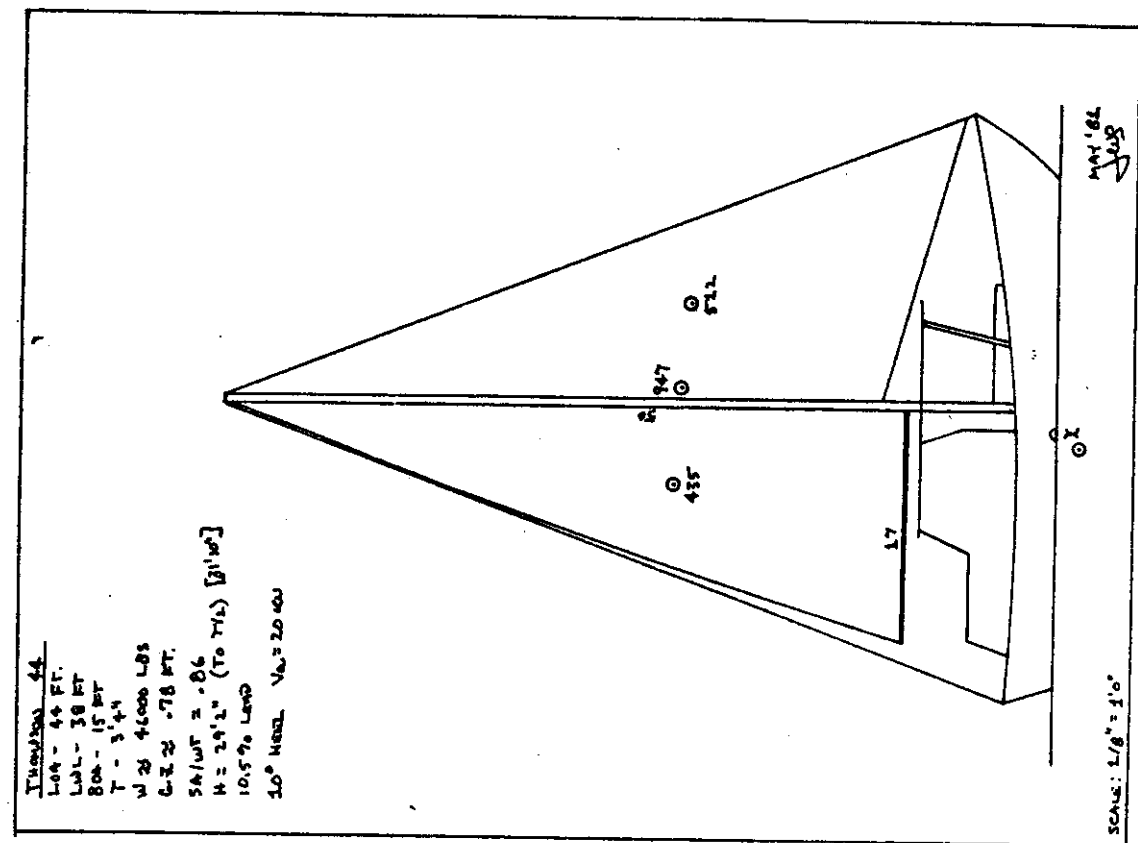


Fig 2

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

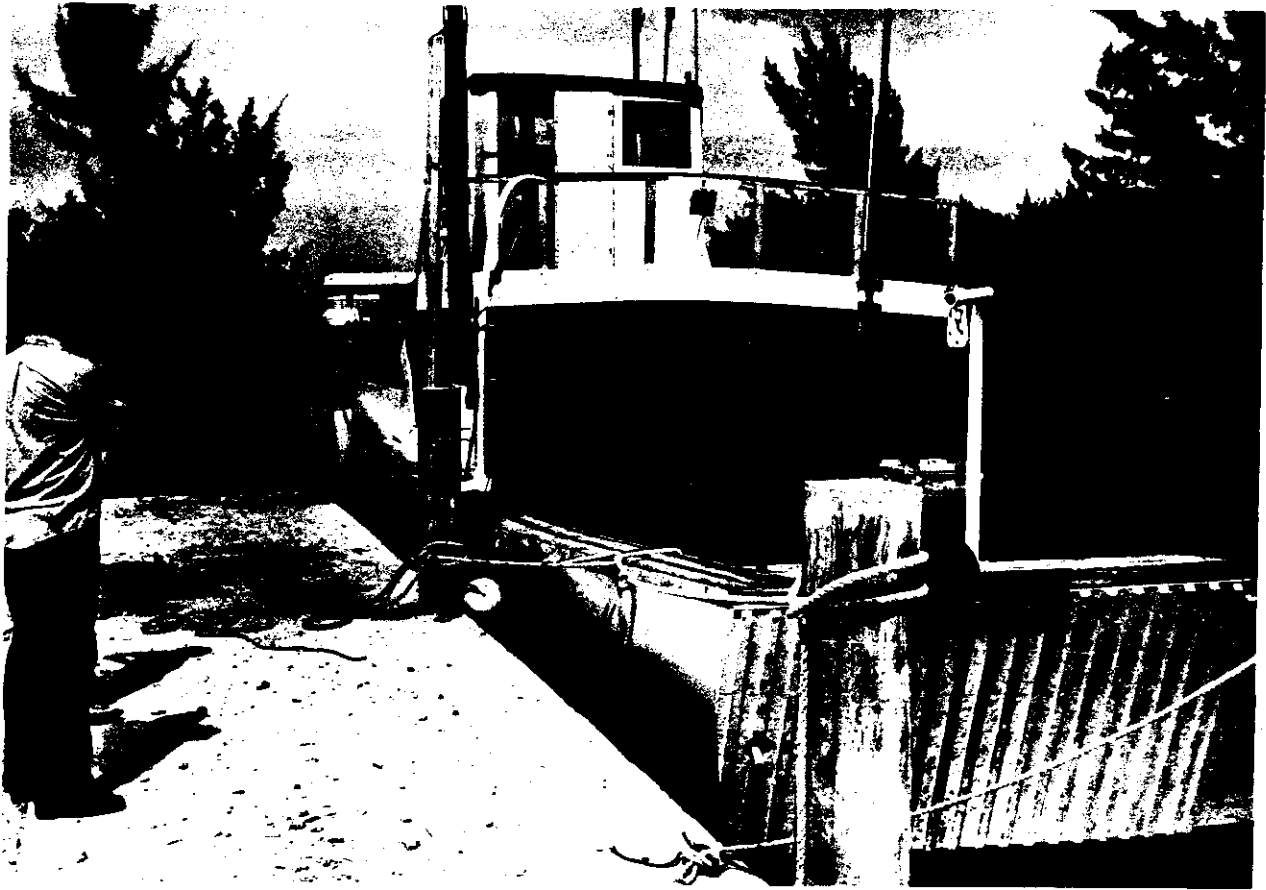
In the Florida Keys, southeast winds prevail with a year-round average of approximately 11 knots. This is sufficient to provide a meaningful measure of wind-assisted propulsion. Superstructures are relatively clean. However, range to the fishing ground is so short that major fuel savings are unlikely. 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



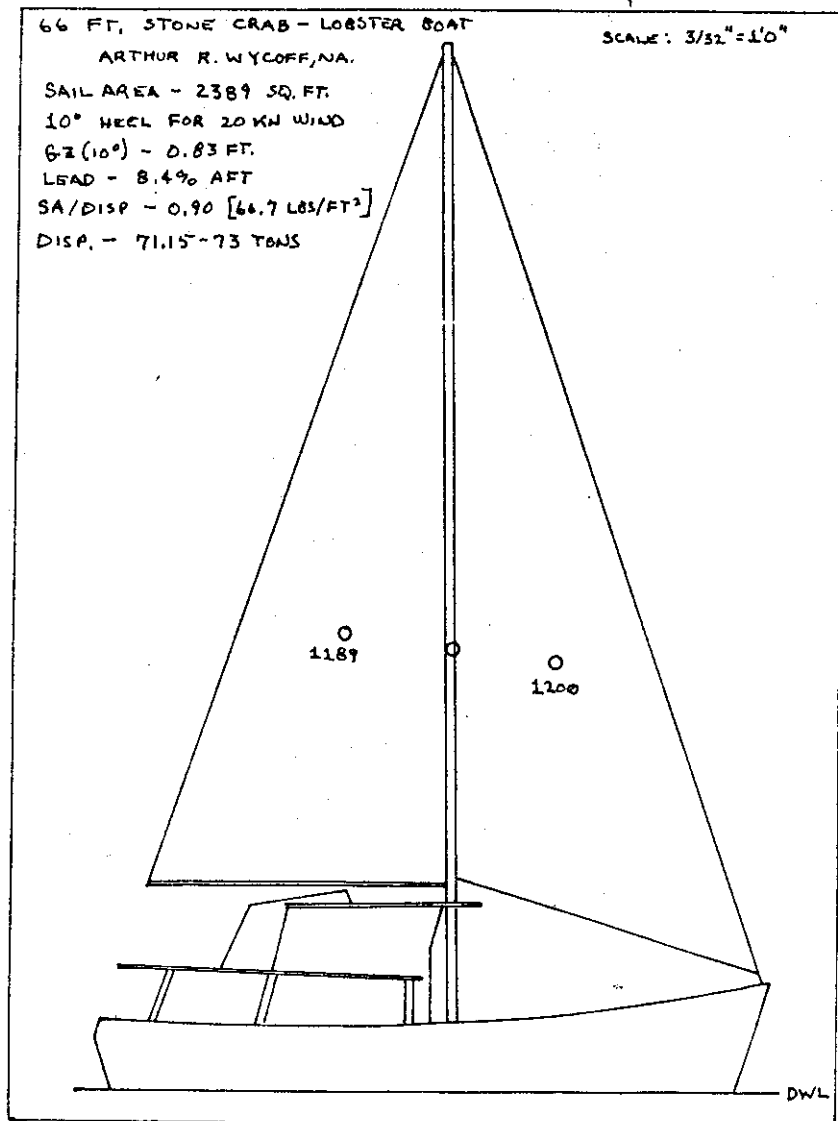


Fig. 6

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 usage 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 extraordinarily 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 Mississippi 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 Gulf of 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, roughly 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 advisable 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.

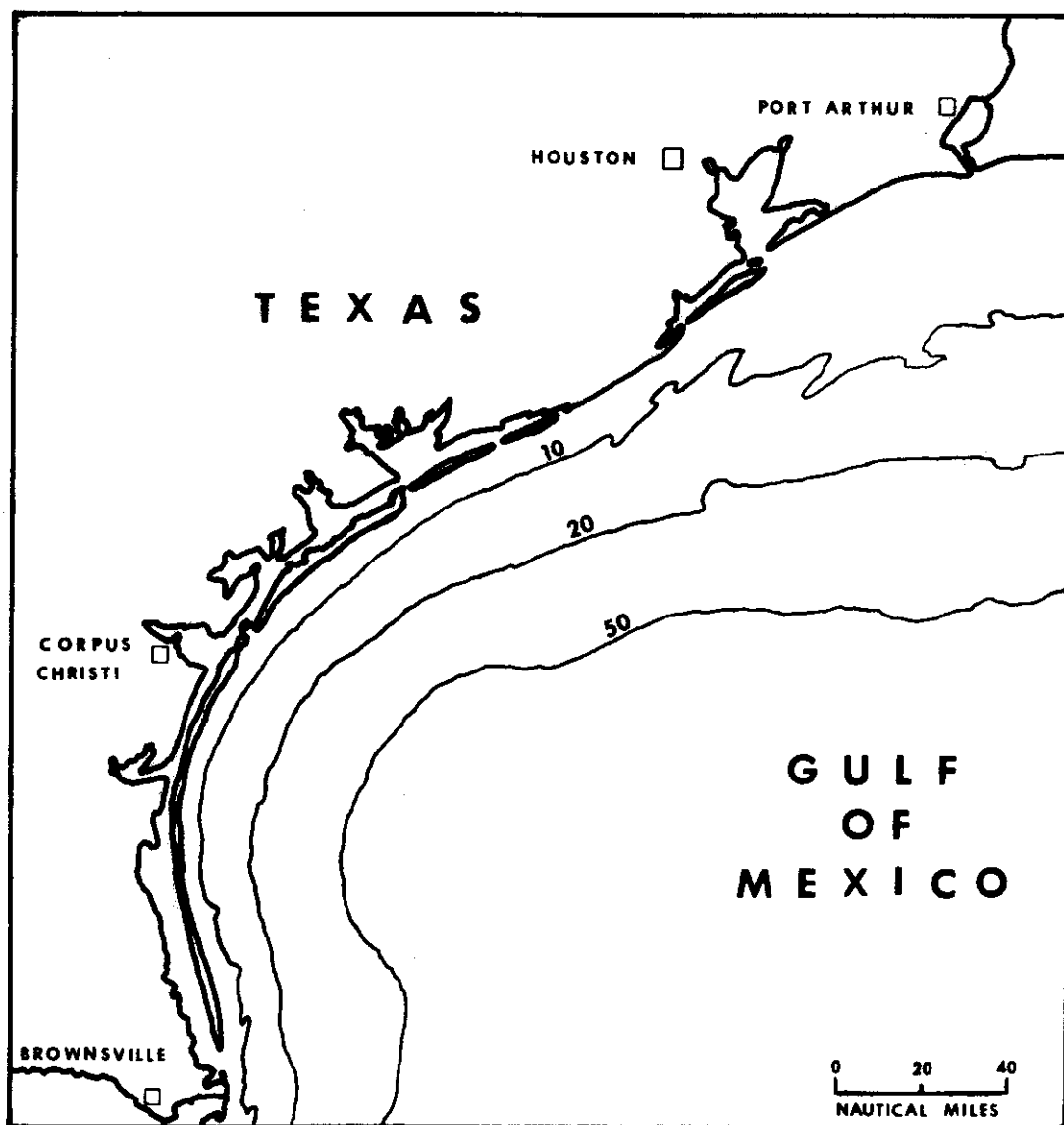


Figure 7 Isobath Map. Depths in fathoms.

Taken from Reference 4

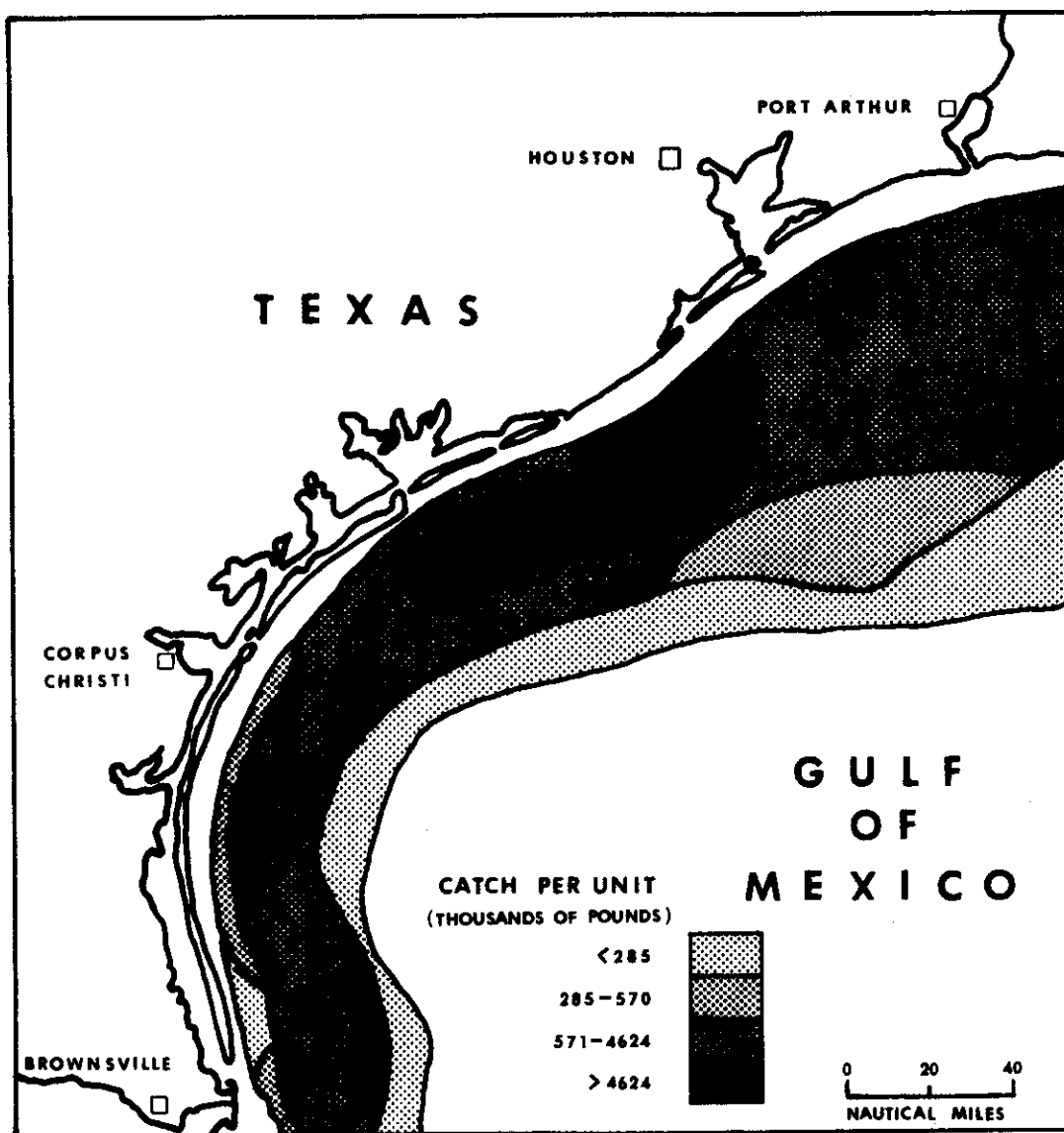
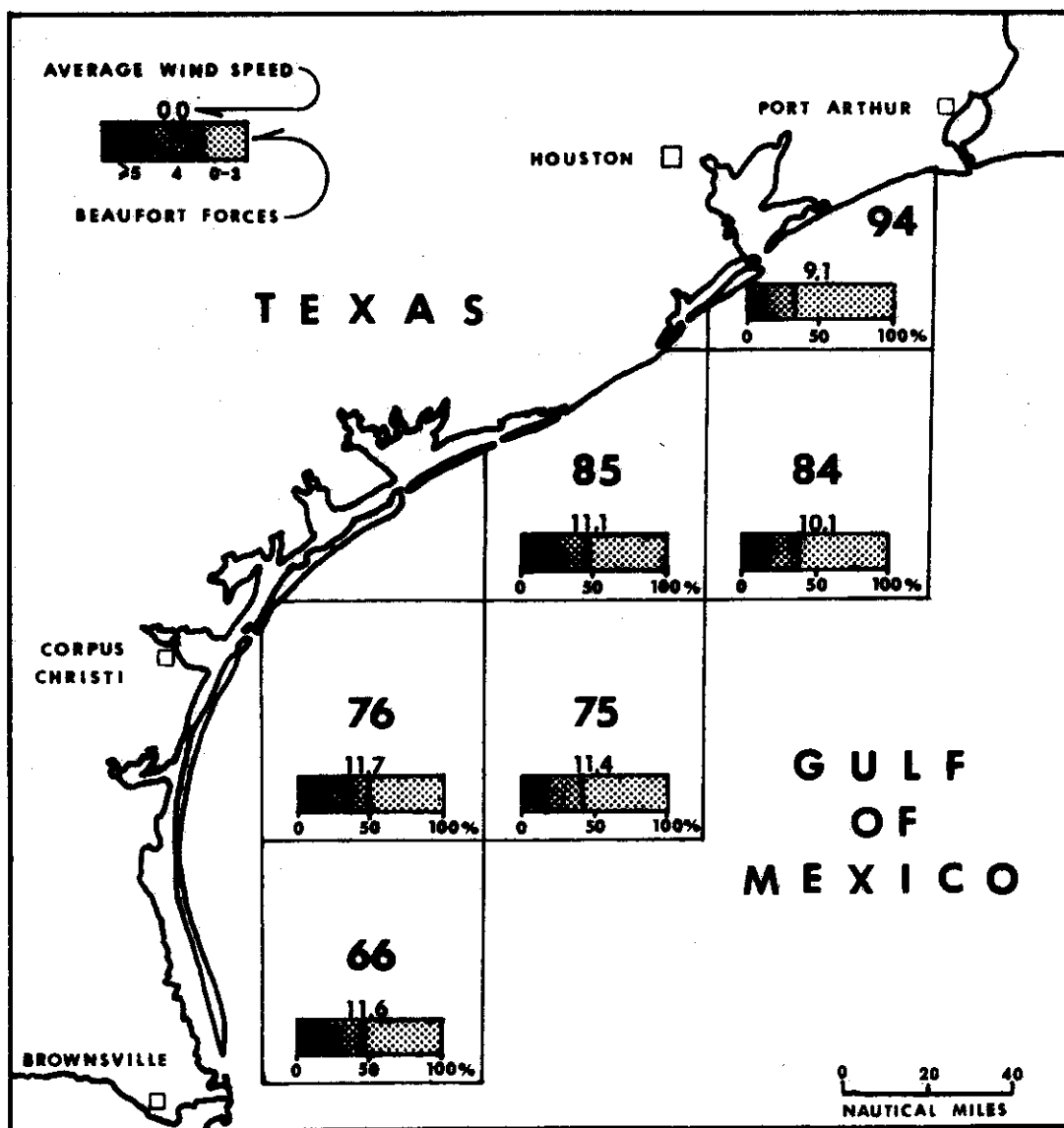


Figure 8 Annual catch of all shrimp. Modified after Osborn, Maghan, and Drummond.



Figure⁹ 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

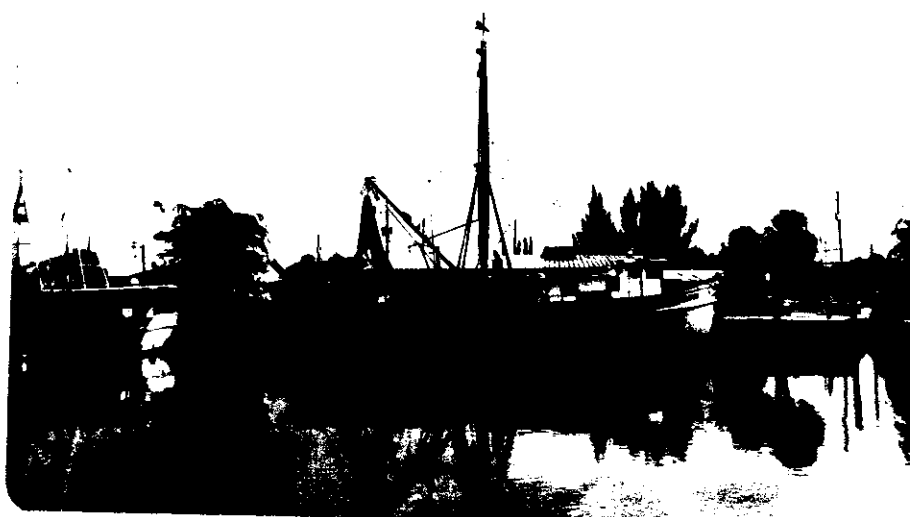
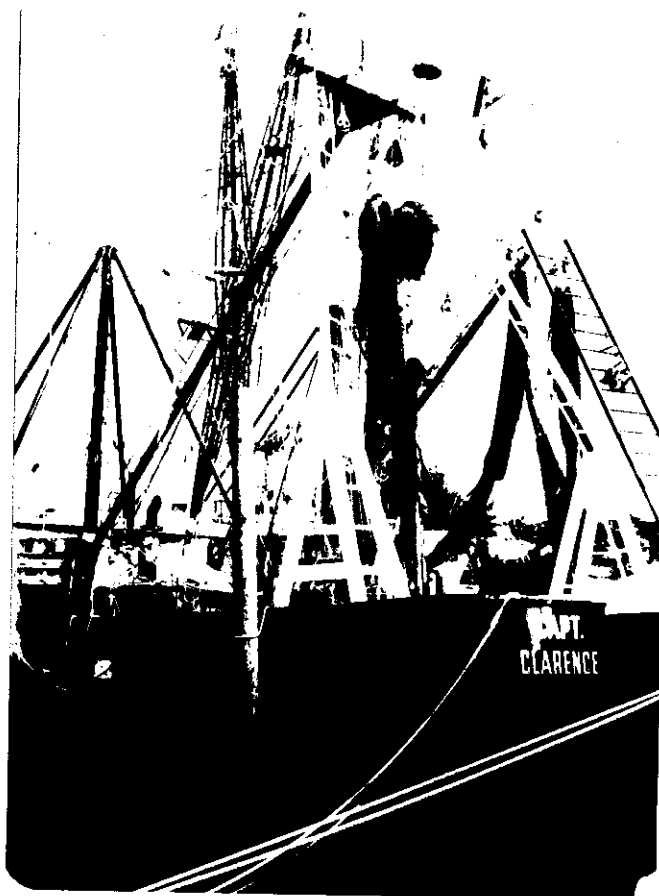


Figure 11

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

LDA	LWL	OAB	DISPL.	Payload	Hull Draft
23 ft.	21 ft.	13 ft.	4500 lbs.	1.0 tons	1.75 ft.
29	26	15	8500	2.02	1.7
36	33	18-20	15400	4.02	1.75
46	42	25	31724	8.03	1.49

Notes: LDA 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

$W_S = 2500 \text{ LBS}$

Figure 12

$R_T/W_S [\%]$

$L=19.2 \text{ Ft. DLR} = 159 \text{ L/B}=2.5$

$L=38.6 \text{ Ft. DLR}=19.5 \text{ L/B}=17.9$

$V_S/W^{1/6}$

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) $C_P = .59$
 $P_{FE} = 800 \text{ LBS/IN.}$
 SCALE: $3/8" = 1'0"$

JOHN W. SHORTALL III, N/A

CURVE OF HALF-AREAS
 FULL LOAD - 15,400 LBS
 24' L CW, FT.

LCB LCF

STATION SPACING
 8' 3"

BRIDGE DECK
 24"

DWL 43"
 15600 LBS
 12,500 LBS
 12"

Figure 14

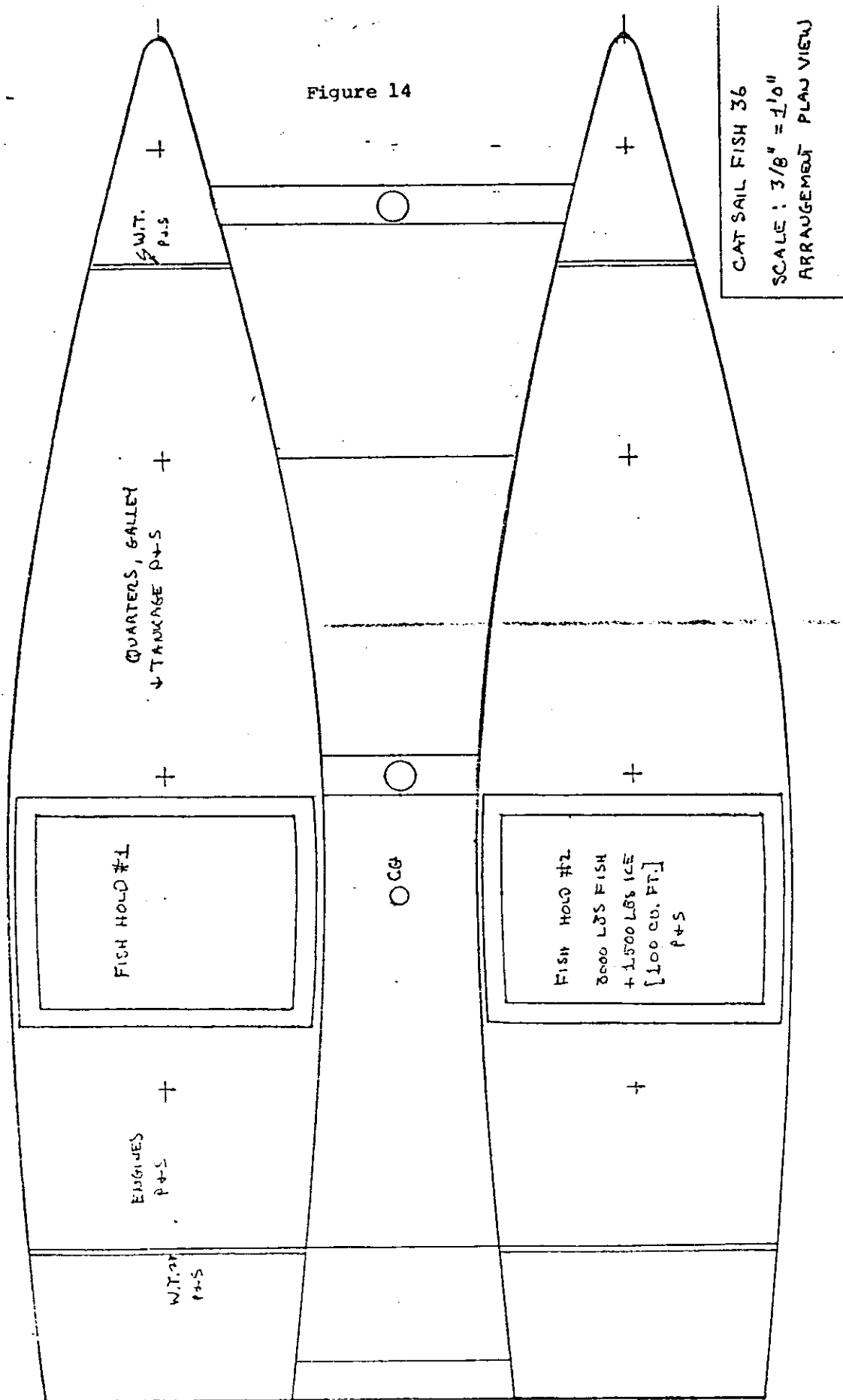
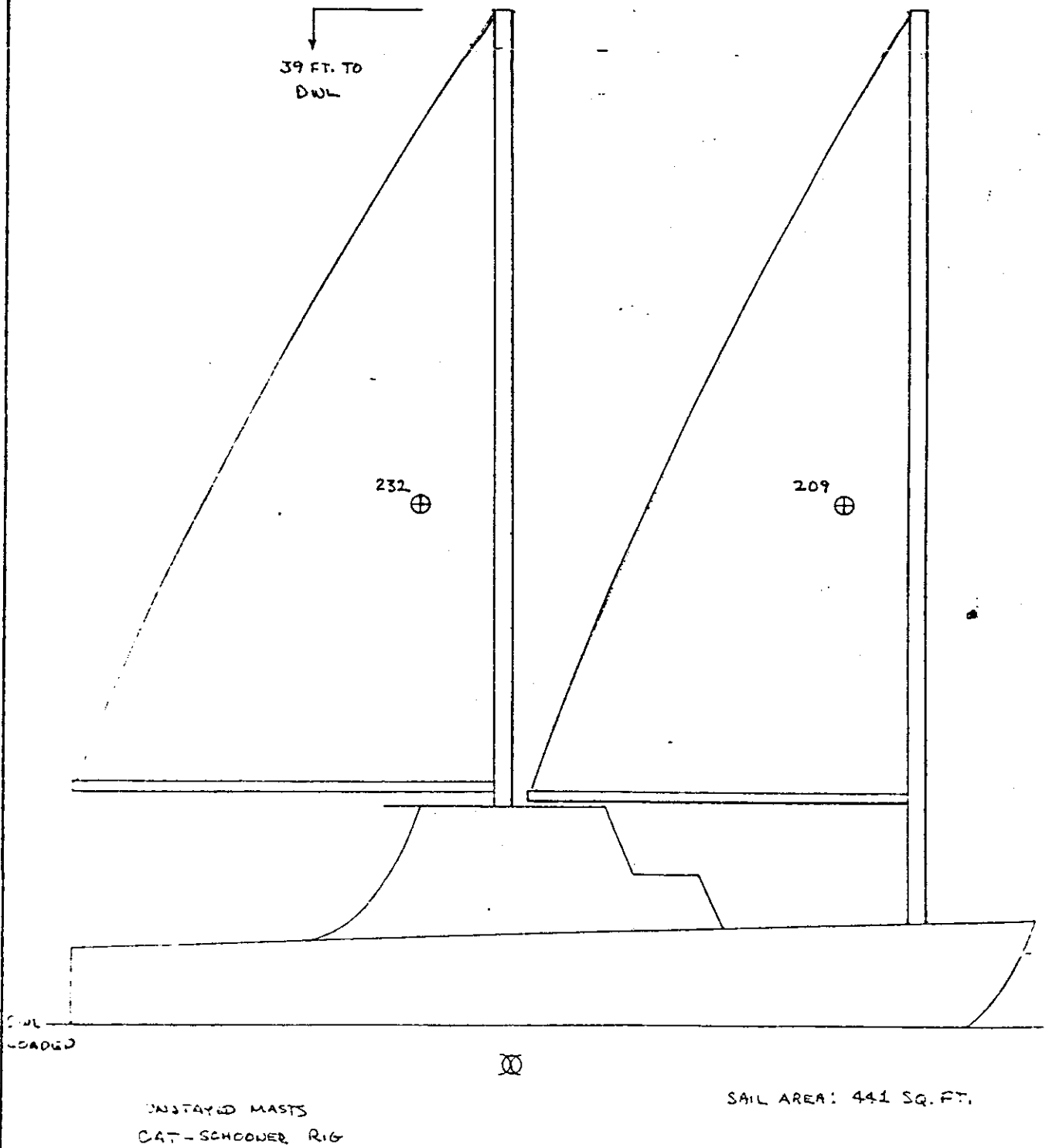


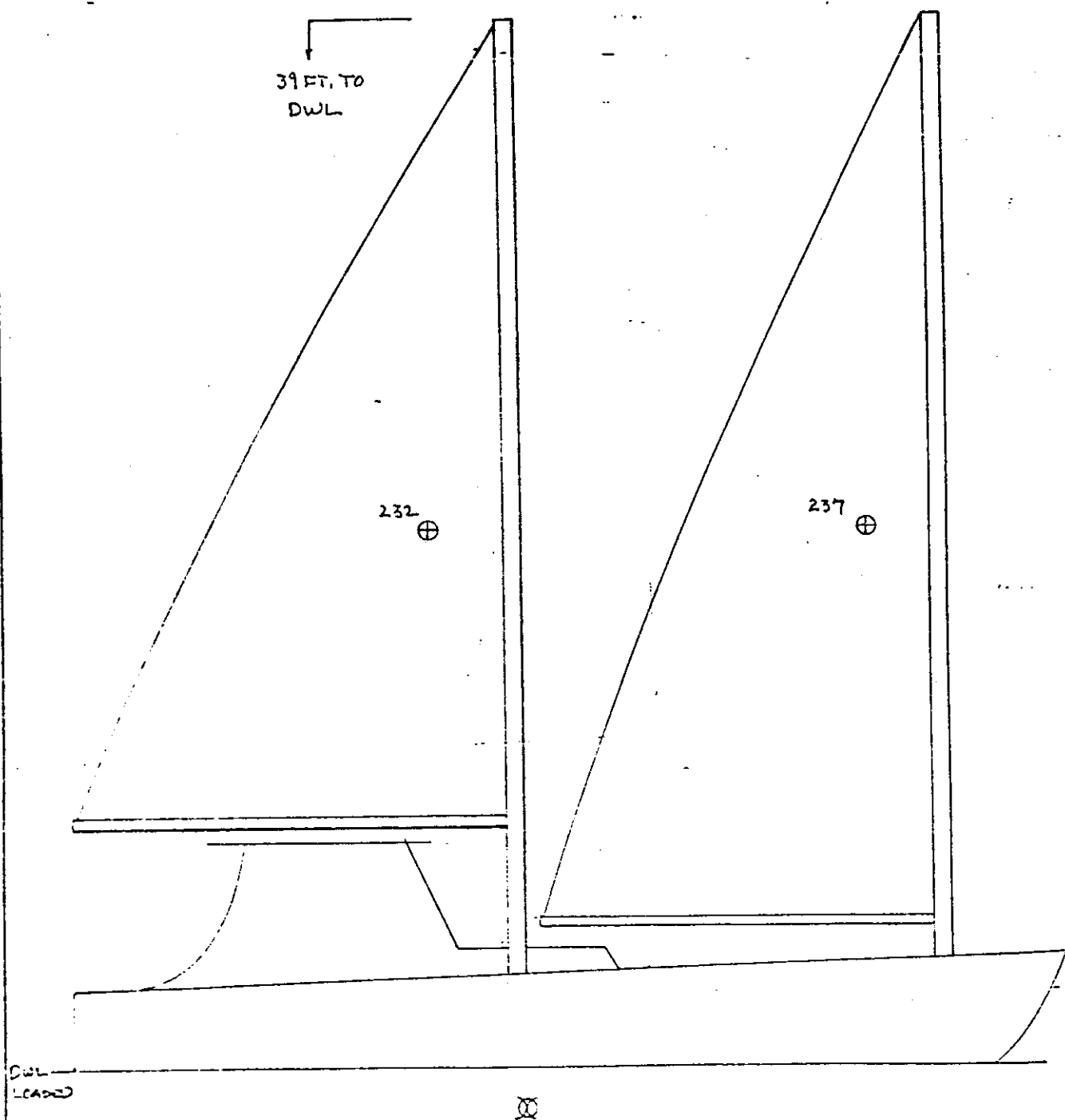
Figure 15



CATSAIL FISH-36
 LCA - 36'0" LWL - 33'0"
 DISPLACEMENT: 25,400 LBS
 DRAFT: 3'0" (LOADED)
 SCALE: 1/4" = 1'0"

JOHN W. SHORTALL III, N.A.
 PLANT HOUSE, MEDICAL - FORWARD

Figure 16



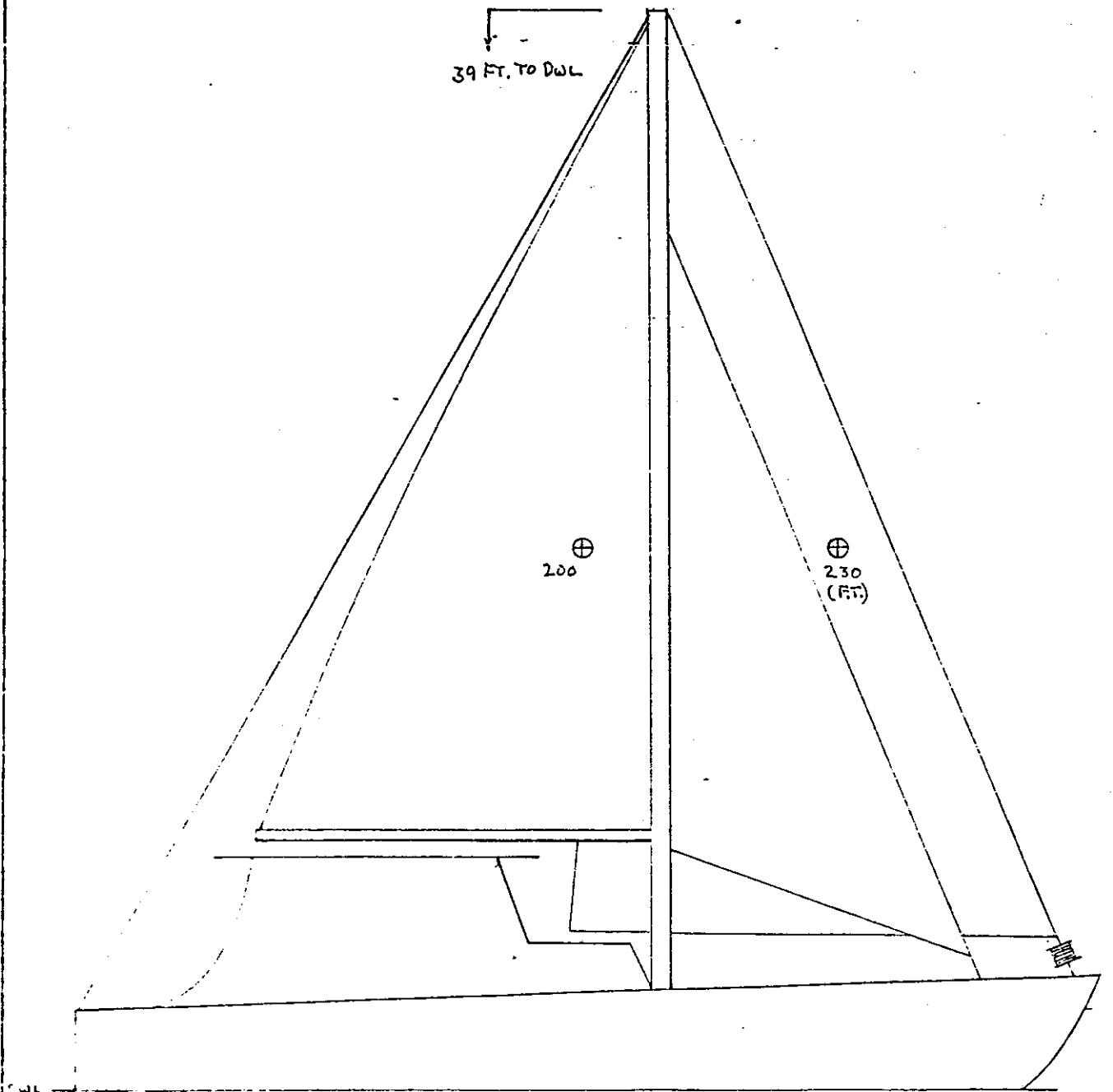
UNSTAYED MASTS
CAT-SCHOONER RIG

SAIL AREA: 469 SQ. FT.

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, N.A.
ART PILOT HOUSE VERSION

4

Figure 17



DWL
15400



STAYED MAST - CUTTER RIG

SAIL AREAS:

MAIN:	200 SQ. FT.	} 562 TOTAL
JIB:	116	
GENOA:	246	
FOREA:	230	

CATSAIL FISH-36
 LOA - 36' 0" LWL - 33' 0"
 DISP. - 15400 LBS.
 DRAFT: 3' 8" (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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