THE REDUCTION OF ENERGY NEEDS FOR FISH HARVESTING THROUGH THE USE OF SAILS ON FISHING VESSELS

Prepared for

National Marine Fisheries Service
Saltonstall/Kennedy Grant
NA-80-FA-D-0012

By

Rebel Marine Service, Inc.
1553 Bayville St.
Norfolk, VA 23503

May 10, 1983

I. EXECUTIVE SUMMARY

A. Description of Project

The fishing industry has been hurt by rising fuel costs. This study was undertaken to determine the fuel savings that might occur if sails were used on fishing vessels as an auxiliary means of propulsion. Attention was also paid to vessel safety, crew efficiency and "come-home" capabilities as they were effected by the use of sails.

A boat was designed, built and equipped for sail assisted fishing operations. Data was collected during sea trials, test runs and actual fishing operations. These data were analysed with the help of the Virginia Institute of Marine Science to determine the fuel savings and the economic viability of the configuration. Assessment of the observations of crew performance and vessel safety were analyzed.

B. Findings

The monitoring of Norfolk Rebel performance in sea trials, on fishing trips and during routine operating conditions yielded over 1,500 observations under varying conditions of wind, sea and sail configurations. Results of analysis of sea trial data and summations of observations taken during fishing operations indicated a representative overall fuel savings of six percent with certain periods of operation showing savings of 20 to 45 percent. The fairly low payback rate by the sail rig as seen in this study may be enhanced by more experience in the offshore fishery and by greater attention to wind patterns in selecting the fishing grounds for each trip. Since the overall savings is heavily dependent on the proportion of transit time in a fishing trip, this multi-purpose vessel would be more competitive in a region requiring longer travel to the fishing grounds.

C. Benefits

The benefits to the fishing industry include lower fuel costs, ability to stay out longer, increased safety for vessel and crew and decreased engine maintenance costs.

II. INTRODUCTION

The rising cost of fuel has steadily eaten into the profits of people operating fishing vessels. The increase in fuel prices has not been countered by a corresponding increase in the off-vessel price of seafood. The gross tonnage of seafood brought to the dock has declined over the same time period. These economic factors, combined with higher interest rates, have sharply cut into the profits of fishing vessel owners and operators.

An individual fishermen can have little effect on interest rates, fuel prices, or seafood prices, but control of fuel consumption is within his power. One potential way to reduce fuel consumption is by the use of sails on fishing vessels. The vessel operator can increase his profit margin by decreasing his fuel consumption if the means used have a sufficiently good payback.

III. PURPOSE

A. Description of the Problem

The purpose of the project is to determine the effects of sail-assist for fishing vessels with attention to two areas: how is vessel safety and crew efficiency influence and what fuel savings accrue to the operator.

B. Original Objectives

The original objectives of the project were as follows:

1. Achieve a significant reduction in fuel consumption. For project purposes, a "significant" reduction will have been achieved if fuel needs are reduced by 20% or more.

2. Demonstrate the feasibility of utilizing wind power to reduce fuel consumption without additional manpower needs.

3. Demonstrate additional value of sailing capability to bring vessels suffering mechanical failure back to port, thereby eliminating the need for energy-intensive rescue operations ("Come home capability").

4. Demonstrate that designing and equipping a vessel for sail-assist contributes to the overall safety of the vessel and the crew.

5. Demonstrate that reluctance in the fishing industry to adopt and apply energy-saving measures can be overcome through this example.

6. Demonstrate that reduced engine use through sail-assist substitution reduces engine down time and maintenance.

IV. APPROACH

A. Description of Work

1. VESSEL DESIGN AND CONSTRUCTION

Rebel Marine Service, Inc. commissioned the design of the *Norfolk Rebel* by Naval Architect Merritt Walter of Rover Marine, Inc. Both firms are located in Norfolk, Virginia. The design parameters established by Rebel Marine included:

- Vessel to be used for fishing, towing and cargo.
- Vessel to have good performance under sail and power.
- Vessel to have short mast height and large sail area.
- Accommodations to be adequate for up to six crew members.

The resultant "TUGANTINE^R" specifications (see Appendix A) are as follows:

Length on Deck . .	51.5 feet (15.7 meters)
Beam (maximum) . .	15.2 feet (4.6 meters)
Draft (light) . . .	5.5 feet (1.7 meters)
Nominal Sail Area .	1400 sq. feet (130 sq. meters)

The lines for the vessel were computer-processed by Mr. Walter to determine righting angle and tons-per-inch immersion, and were computer-lofted for ease of construction. She was designed to meet or exceed the American Bureau of Shipping scantlings.

Arrangement of the vessel includes an insulated fish hold amidships with a volume of 800 cubic feet (23 cubic meters), capable of holding about eight tons (seven metric tons) of ice and fish. The area forward of the hold is given to the crew's quarters which are sufficient to accommodate four or more crew members. Aft of the hold, amidships and in the area of greatest beam, is the galley, main salon, captain's cabin, and head with shower. Farther aft is the engine room, and in the stern a large lazarette for equipment storage. Fuel and water tanks are built into the box keel. There are five watertight compartments. The *Norfolk Rebel* has a capacity of 900 gallons (3400 liters) of diesel fuel and 350 gallons (1325 liters) of water.

The *Norfolk Rebel* is rigged as a gaff schooner for several reasons. It offers a large sail area for the shortest possible masts. The mast height must be less than 65 feet (19.8 meters) from the waterline because the vessel often works in the Intercoastal Waterway under bridges. A gaff rig is less efficient than marconi upwind, but more efficient off the wind. Though the *Norfolk Rebel* can work its way to windward under sail if need be, normal procedure is to drop the sails and motor upwind. Although a gaff rig is more labor-intensive, the initial cost is lower than for roller-furling marconi rigs. (The "extra" labor needed for the gaff rig has no effect on the *Norfolk Rebel's* complement because four or five people are carried for fishing trips and only two are required to raise, lower or reef the sails.) The masts are raked aft so that no backstays are necessary; a backstay would hamper fishing operations and prevent the vessel from performing tows.

Construction of the vessel was conducted under the direction of Howdy Bailey, Master Builder, of Customs Unlimited (Norfolk, Va.). All welds in the steel plate hull were ground and checked for pin holes. The completed hull was then sandblasted and painted with Devoe's inorganic zinc system to prevent rusting. The vessel was launched on May 22, 1980. Subsequently the wiring, interior, and engine were installed, followed by the masts and rigging. Outfitting the vessel and equipping it for fishing took a total of one and a half years. The difficult economic times and subsequent reduction in available towing and salvage work resulted in cash flow problems which delayed the final fitting out for fishing operations.

The vessel is equipped to undertake two major types of fishing: longlining for swordfish and bottom-fishing for snapper, grouper or sea bass. Longlining equipment includes a hydraulic reel with level winder, holding ten to twelve miles of mainline. Three to four hundred hooks are spaced evenly along the mainline, with a ball every three hooks and a high flyer every mile. The bottom-fishing equipment consists of four electric and two hand reels, each equipped with a heavy sinker and from two to six hooks.

In addition, the test vessel carries an extensive array of electronics to aid her in navigation, fish-finding, and performance monitoring. For navigation, the Norfolk Rebel is equipped with an Epsco C-Nav XL Loran coupled to a C-Plot II plotter. There are an Epsco FO-2 radar with 32-mile range, two Epsco RT-78 synthesized multichannel VHF/FM radiotelephones, and a Ritchie 6-inch steering compass.

Fish-finding equipment consists of a Epsco CVS-888 color video depth sounder and a Wesmar 165 color scanning sonar. There is also a Dytek sea water temperature gauge.

Primary to the performance monitoring are a Datamarine apparent wind speed and direction indicator and a Datamarine knotmeter/log unit. A Fleet Facts fuel flow monitor shows the fuel consumption rate and the total fuel used. The Loran C gives vessel speed over the bottom.

2. PERFORMANCE MONITORING METHODS

The performance of the Norfolk Rebel was monitored for the assessment of the use of sails as an auxiliary power source for vessels engaged in coastal fishing operations. Observations were made of crew performance and vessel performance during sea trials and during normal fishing operations. Descriptions of the data collection methods follow.

a. Crew Acceptance and
Vessel Handling, Safety and Seaworthiness

Observations were made during sea trials, fishing trips and during routine free-running transits to assess the crew's acceptance of sail-assist, the vessel's ease of handling and the effect of sails on safety and seaworthiness. Interpretation of these observations was done with explicit reliance on the captain's judgement and experience in the handling of vessels of this type.

b. Estimation of Representative Fuel Consumption

Four tasks made up this portion of the project: (1) data collection, (2) data editing, (3) error assessment and (4) data correlation.

(1) Data Collection. Data logging sheets were set up to record the date and time of observation, apparent wind speed and direction, vessel speed through the water, vessel speed over the bottom, engine speed, fuel consumption rate, sail configuration, sea conditions, and "remarks". The "remarks" column was used for noting the amount of ice and fish in the hold, plus other factors likely to influence the vessel's performance.

Vessel speed, engine speed, wind speed, wind direction and fuel consumption were measured electronically, displayed by instruments and logged by the pilothouse watch. All other parameters were estimated by the pilothouse watch.

Controlled sea trials were conducted jointly by RMS and VIMS personnel in Willoughby Bay (Norfolk, Virginia) at various times between December 1981 and August 1982. This body of water was chosen for its minimal tidal currents and good protection from wind-generated wave action. Trials were conducted under various conditions of wind speed, sail configuration, and engine speed. During these "controlled" sea trials, the observations were logged at frequent intervals (thirty to ninety seconds) while the vessel was running prescribed courses. Since the sea trials were dedicated completely to the testing of the vessel, as opposed to operations during which data logging was auxiliary, the sea trial data provide the most consistent and precise data in the set. Three hundred twenty four data points were collected during these "controlled" sea trials.

Data acquisition on fishing trips was done at regular intervals as demands on the pilothouse watch would allow. Observations were also collected under free-running conditions whenever possible. This set of observations provides information on a much broader range of operating conditions, but has less precision because of the involvement of the watch in other activities, because of the varying individual interpretations of the readouts of the instrumentation and because of the variability of the conditions under which the observations were made. During routine vessel operations, 1209 observations were logged.

The observations were keyed into the VIMS Prime 750 computer from the data logging sheets and reformatted for access by a standard statistics and graphics package.

(2) Data Editing. Correct transcription of the data was checked by visual comparison of each entry against the original logs. Typographical errors were thus reduced.

Extreme data points were located by graphical presentation and by statistical summary of each of the parameters. Some data points were thus recognized as outliers and were referred back to the data logs. If the data transcription was correct, the conditions under which the observation was made were inspected. If the conditions were appropriate for the data group being examined, the observation was left in the data set as a normal deviation. In some cases, observations were found which were not representative of normal vessel operations, e.g., instances of towing a sea anchor or another vessel. These data points were removed from the data set.

(3) Error Assessment. With specific quantitative knowledge of the errors associated with a series of observations, an analytical derivation of the precision of the observations can be made. Without such knowledge, the estimation of precision and, conversely, the estimation of uncertainty must be done statistically.

Analytical quantification of the errors in the observed data was not attempted for two reasons:

> There was no capability for precise calibration of the sensors and readouts of the instruments used in determining vessel speed, wind speed and direction, fuel use and engine speed. The assessment of the stability of the instrumentation had to depend on the crew's experience with the vessel and her performance.
>
> The observations depended a great deal on the individual who was logging the information. The high rate of variability in several of the parameters required an "optical averaging" of the instruments' readings. In the cases of fuel use and vessel speed, digital readouts with half-second updates left much to the interpretation of the observer. Additional interpretation was involved in the assessment of the amount of ice and fish in the hold, as well as the type (chop or swell) and height of the seas in which the Norfolk Rebel was working.

Statistical quantification of data precision was used for this study. Difficulties arose here also because of the many variables inherent in the wind-sea-vessel interaction and the relative sparseness of the data set.

In addition to sail configuration and engine speed, motor sailing performance depends heavily on three environmental parameters: wind speed, wind direction and sea state. The collected data were not continuous across the whole range of values for any of the recorded parameters. If a comparison was to be made by selecting one value of wind speed, one value of wind direction and one value of sea state, there were not necessarily any corresponding values for vessel speed and fuel consumption.

Instead of specific values for these environmental parameters, ranges of wind speed, wind direction and sea state were established to provide larger sets of data for each desired comparison of sail configurations. Although this method did provide more data points, it also introduced additional uncertainty in the results because the slightly different conditions over the sample contributed to variations in the observed performance. An attempt was made to select regimes or ranges of wind and sea conditions within which the vessel performance would vary as little as possible. The groupings of wind and sea conditions are shown in Table 1.

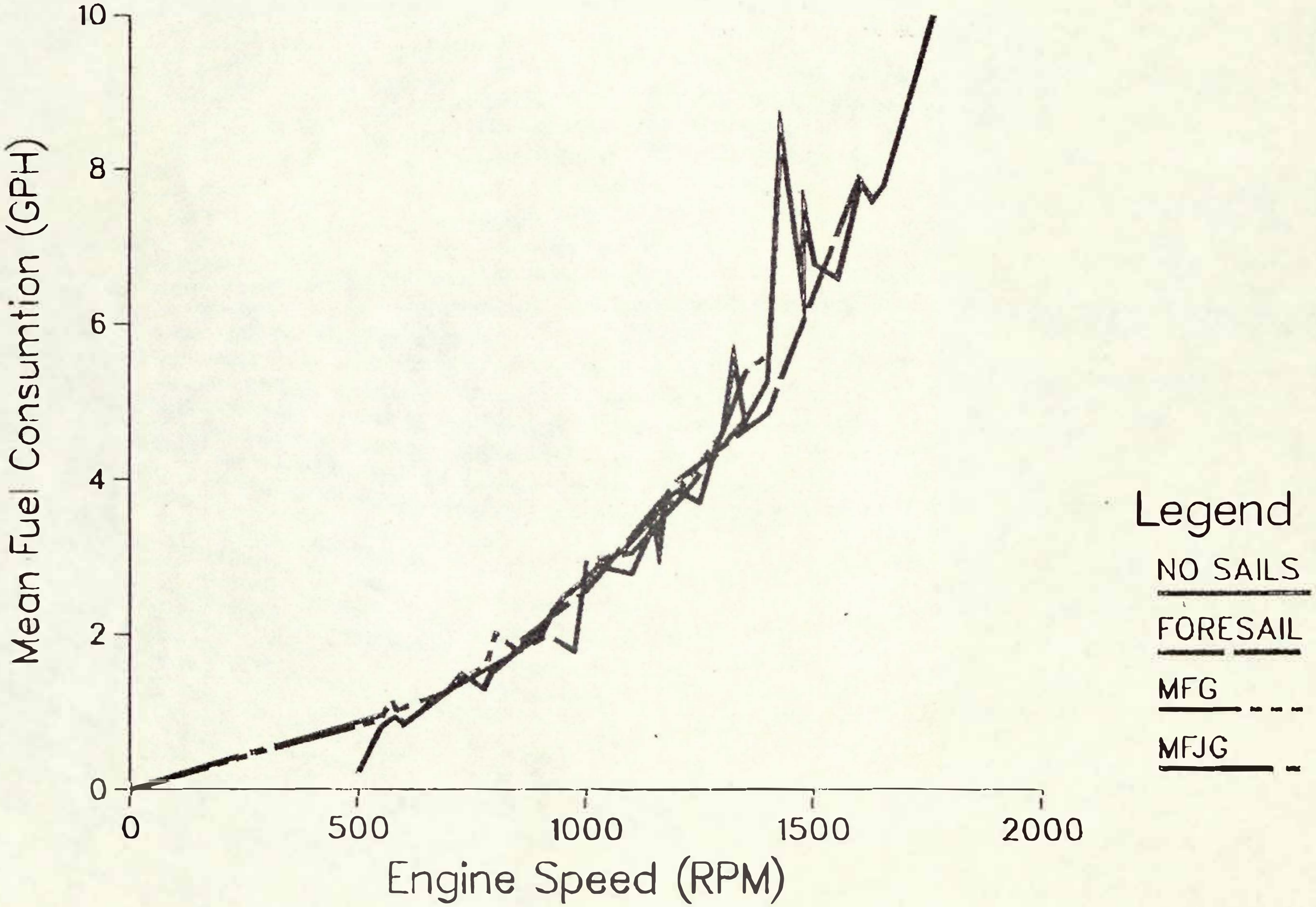
Table 1.
Grouping of Wind and Sea Conditions
For Sea Trial Analysis

Apparent Wind Speed (knots)	5-9	10-16	17-21	22-26
Apparent Wind Direction (degrees)	0-49	50-150	151-180	
Wave Height (feet)	0-3	3-6	6-9	9-12

Observations were logged for all the conditions encountered. Winds speeds encountered during fishing trips were predominately in the range of 8 to 16 knots. For simplicity, the presentation of the sea trial data will be limited to winds of the 10 to 16 knot range. Winds of less than 10 knots are of lessor importance in fuel savings and winds of greater than 16 knots were not often seen during the sea trials.

(4) <u>Data Correlation.</u> The following parameters were found to be significant to fuel consumption within the resolution of the study: vessel speed through the water, wind speed and direction, engine speed, sail configuration and sea state. The data show a fairly steady relationship between fuel consumption and engine speed regardless of sail configuration or vessel speed. Figure 1 shows this relationship for several sail configurations. Because of this behavior and because the primary interest is in the amount of fuel needed to get from point A to point B regardless of engine speed, the comparisons of different sail and motor configurations are presented directly in terms of vessel speed versus the rate of fuel consumption, independent of engine speed.

Figure 1. Engine Speed vs Fuel Use For 4 Sail Configurations



For all wind and sea conditions

Figures 2 through 5 show scatter plots of the relationship between the vessel speed and fuel consumption rate for engine with foresail; for engine with main, fore, and genoa; for engine with main, fore, jib and genoa; and for engine-only operation. The second plot in each figure shows the mean of the consumption rate at each discrete value of vessel speed. The scatter and lack of smoothness of this data do not allow simple comparisons of fuel consumption at arbitrary vessel speeds.

Figure 2. Fuel Use Rate vs Vessel Speed

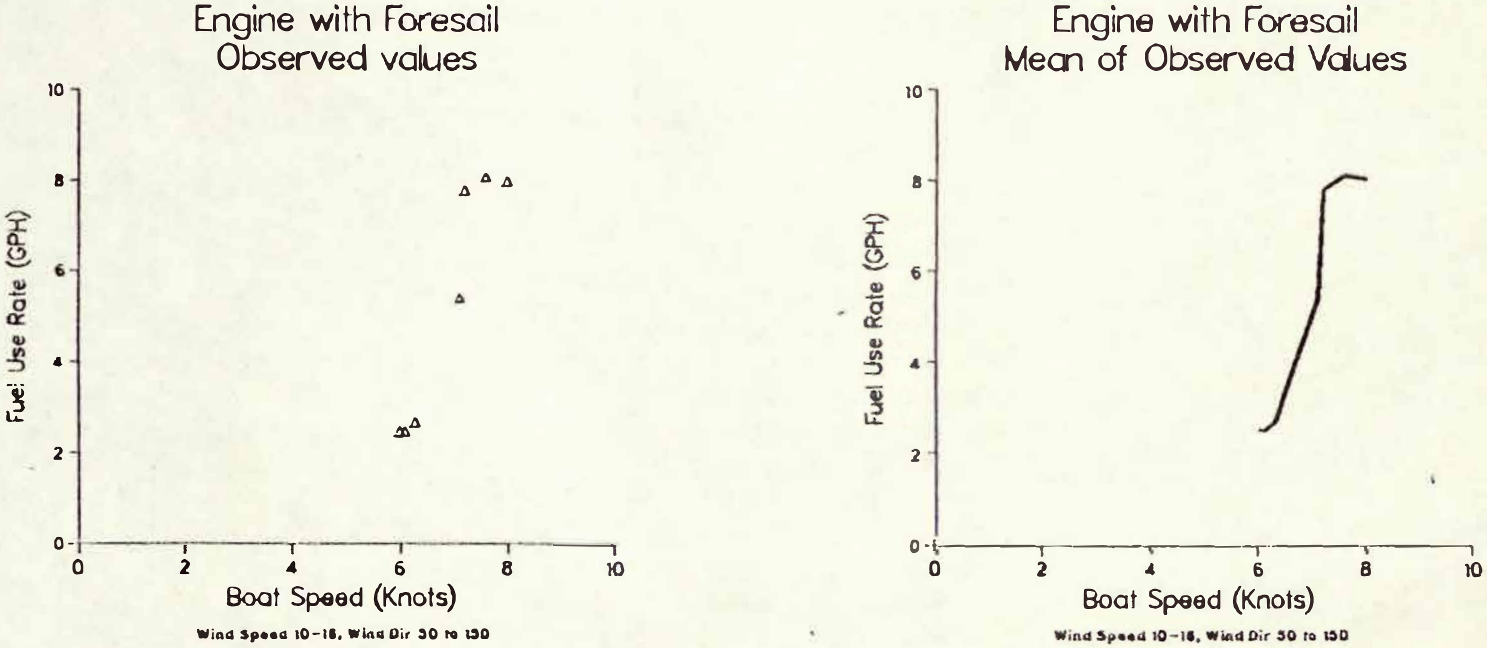


Figure 3. Fuel Use Rate vs Vessel Speed

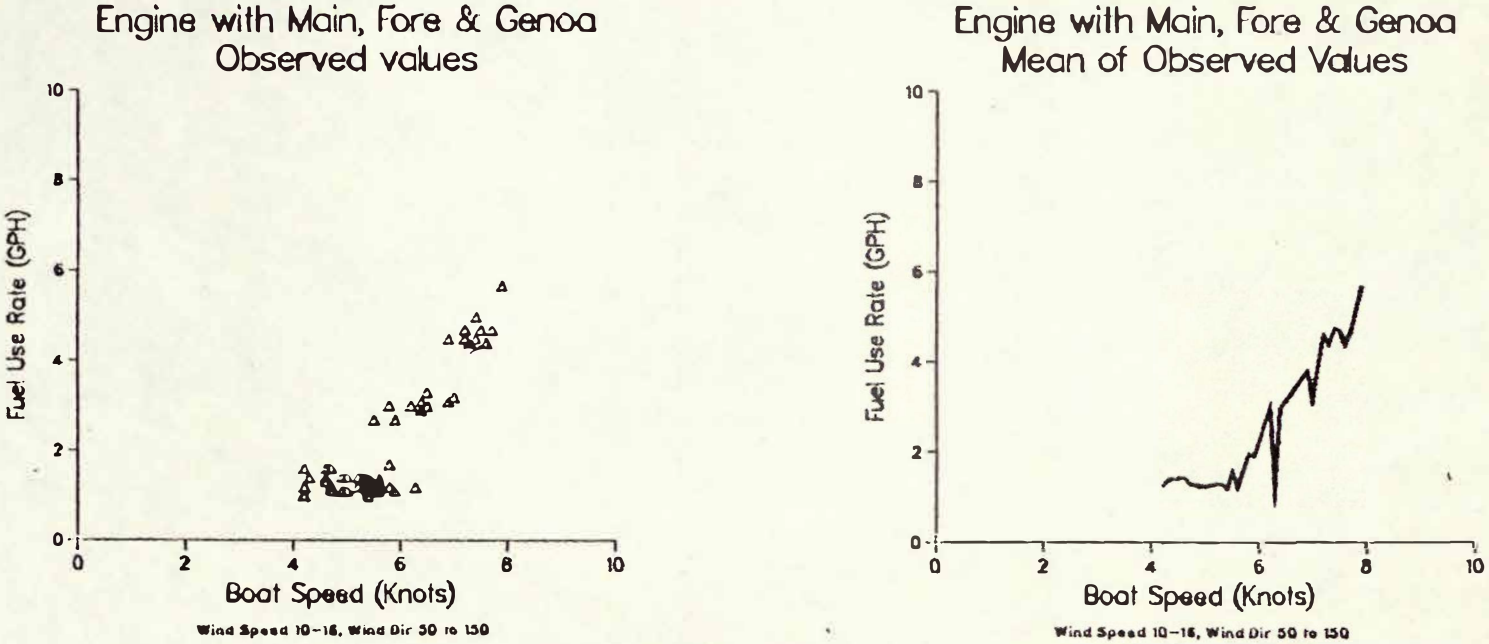


Figure 4. Fuel Use Rate vs Vessel Speed

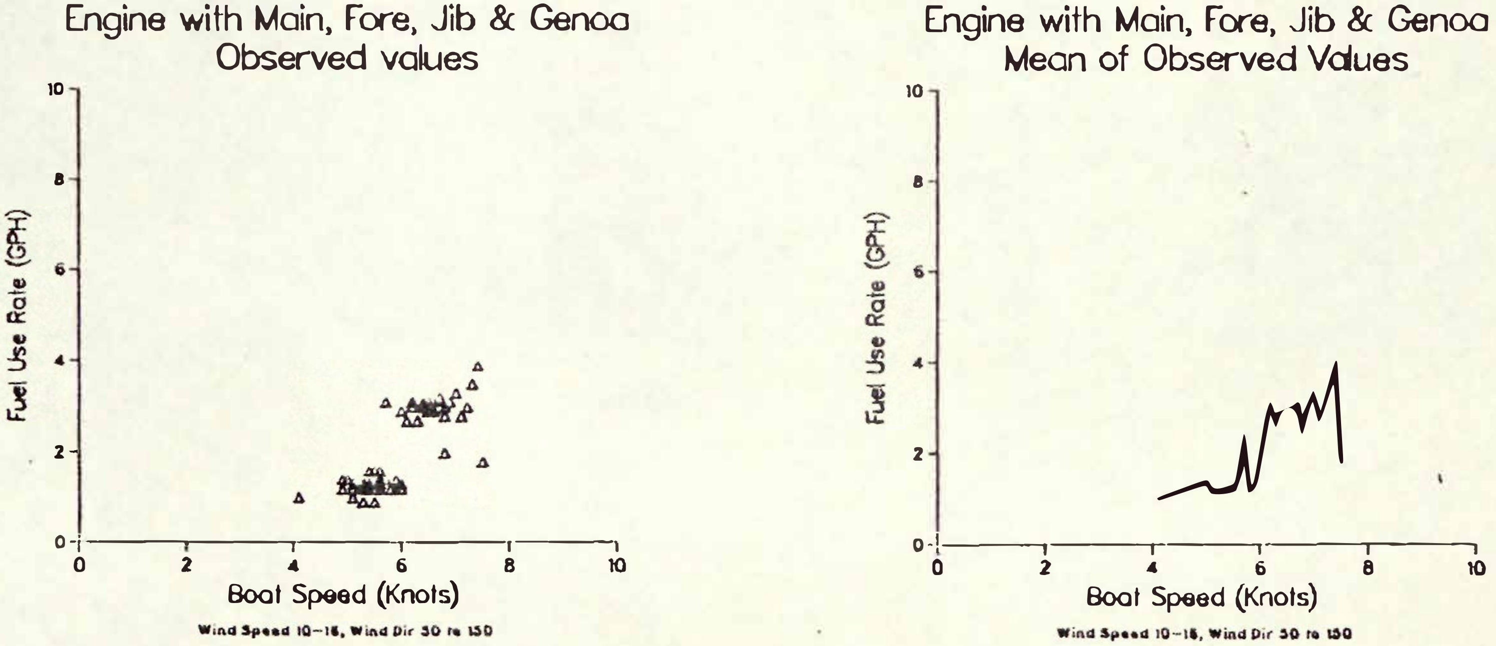
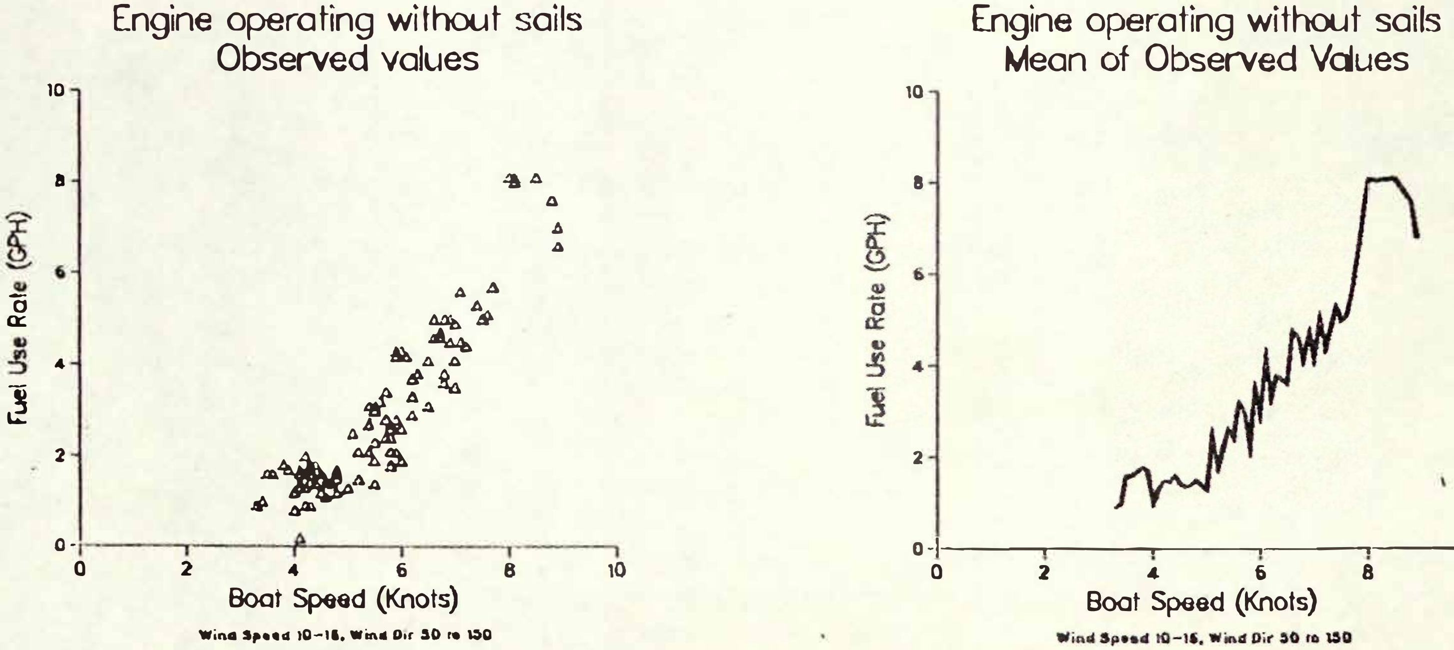


Figure 5. Fuel Use Rate vs Vessel Speed



Engine operating without sails
Observed values

Engine operating without sails
Mean of Observed Values

To smooth the data and to provide a consistent means for comparison at any specific vessel speed, curves were fitted to the observed data. The foresail sea-trial data were not analyzed further because there were not enough observations. Third order polynomial equations were initially fitted to observed data for each of the remaining sail/engine configurations. For the motor-sailing observations, the fitted curves were not well behaved in the regions of interest, so the speed/fuel relationship for each of the motor-sailing configurations was modeled by a cubic equation of the type

$$\mathrm{FUEL} = K * \mathrm{SPEED}^3 + C$$

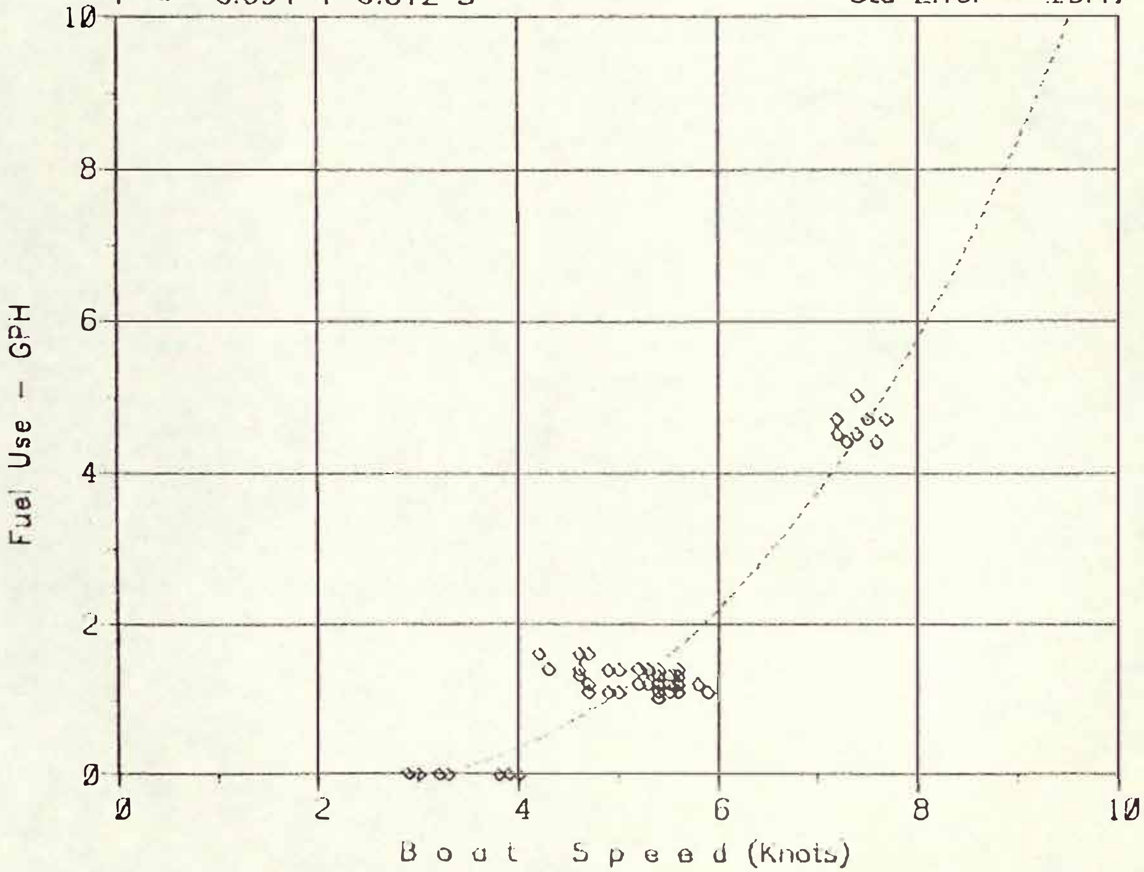
where K and C are constants determined by the fit. The curve fitting was done by a linear regression of the fuel consumption values against the cube of the speed values. A standard error of estimate (the standard deviation of the residuals) was then calculated for each set of data, providing an estimate of the predictive capability of each curve.

There were enough observations made during sea trials of engine-only operation to give a smooth third-order polynomial fit to these data. Figures 6 through 8 show the sea trial data with the fitted curves.

Figure 6. Fitted Curve of Fuel Use vs Boat Speed

Engine with Main, Fore & Genoa

$F = -0.394 + 0.012\ S^3$ Std Error = ±0.47



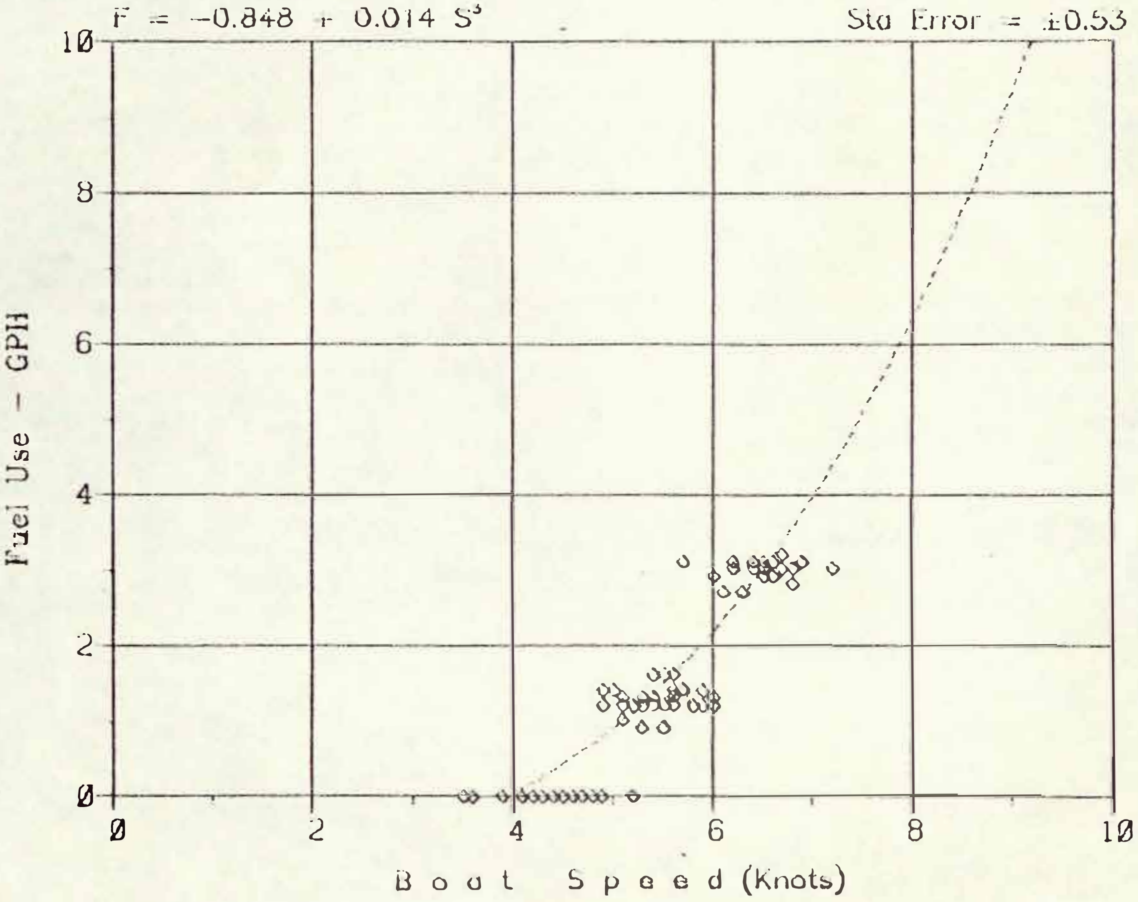


Figure 7. Fitted Curve of Fuel Use vs Boat Speed

Engine with Main, Fore, Jib & Genoa

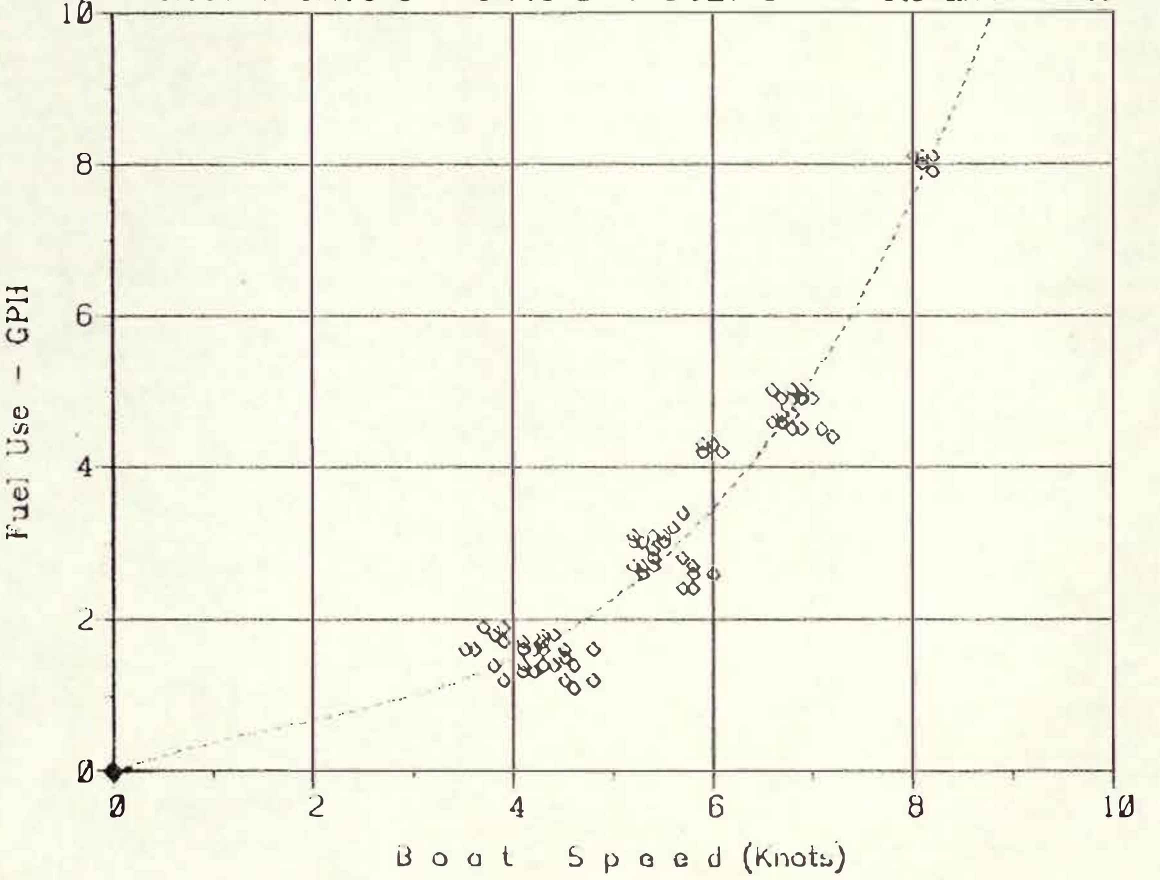
$F = -0.848 + 0.014\ S^3$

Std Error = ±0.53

Figure 8. Fitted Curve of Fuel Use vs Boat Speed

Engine Operating Alone - Sea Trials

$F = 0.001 + 0.476\ S - 0.110\ S^2 + 0.021\ S^3$ Std Error = ±0.54

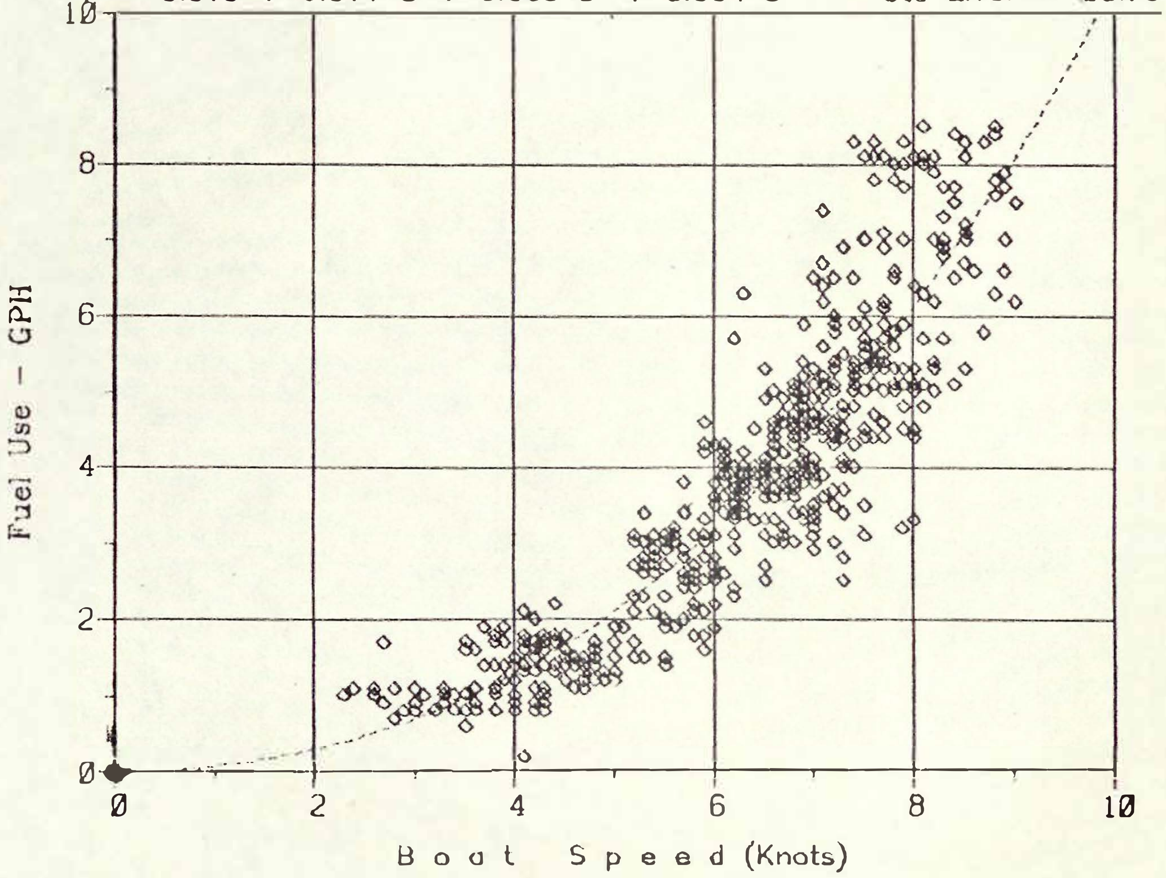


The curve in Figure 9 represents the fuel consumption relationship under power alone for all conditions. Approximately 780 readings of fuel consumption under engine alone were logged over the course of the project under various wind and sea conditions. Sufficient data were available here to generate a well-behaved monotonic polynomial. This curve was generated by a least-squares fit of a third-order polynomial to all the logged data that were representative of routine vessel operations. An additional constraint to the fit was the inclusion of dummy readings indicating zero fuel consumption at zero vessel speed to force a realistic behavior on the polynomial as it approached zero.

Figure 9: Fitted Curve of Fuel Use vs Boat Speed

Engine Operating Alone – All Observations

$F = 0.010 + 0.011\ S + 0.060\ S^2 + 0.004\ S^3$ Std Error = ±0.75



It can be seen in several instances that the fitted curves are reasonable only for certain regions of vessel speed. Extrapolation beyond the regions containing observed data should be viewed with caution. The use of these curves was restricted to the well-behaved regions.

3. USE OF SAILS IN FISHING OPERATIONS

Sixteen fishing trips were made between November 1981 and November 1982. Nine trips provided insufficient data for numerical analysis due to rough conditions and seasickness or monitoring equipment malfunction. The seven remaining trips provided 333 observations of the vessel's performance in three different types of fishing (bottom fishing, longlining and trolling).

In order to determine the savings (if any) under sail during the fishing operations, it is necessary to compare the observed consumption under sail with an estimate of engine-only fuel consumption for the same conditions.

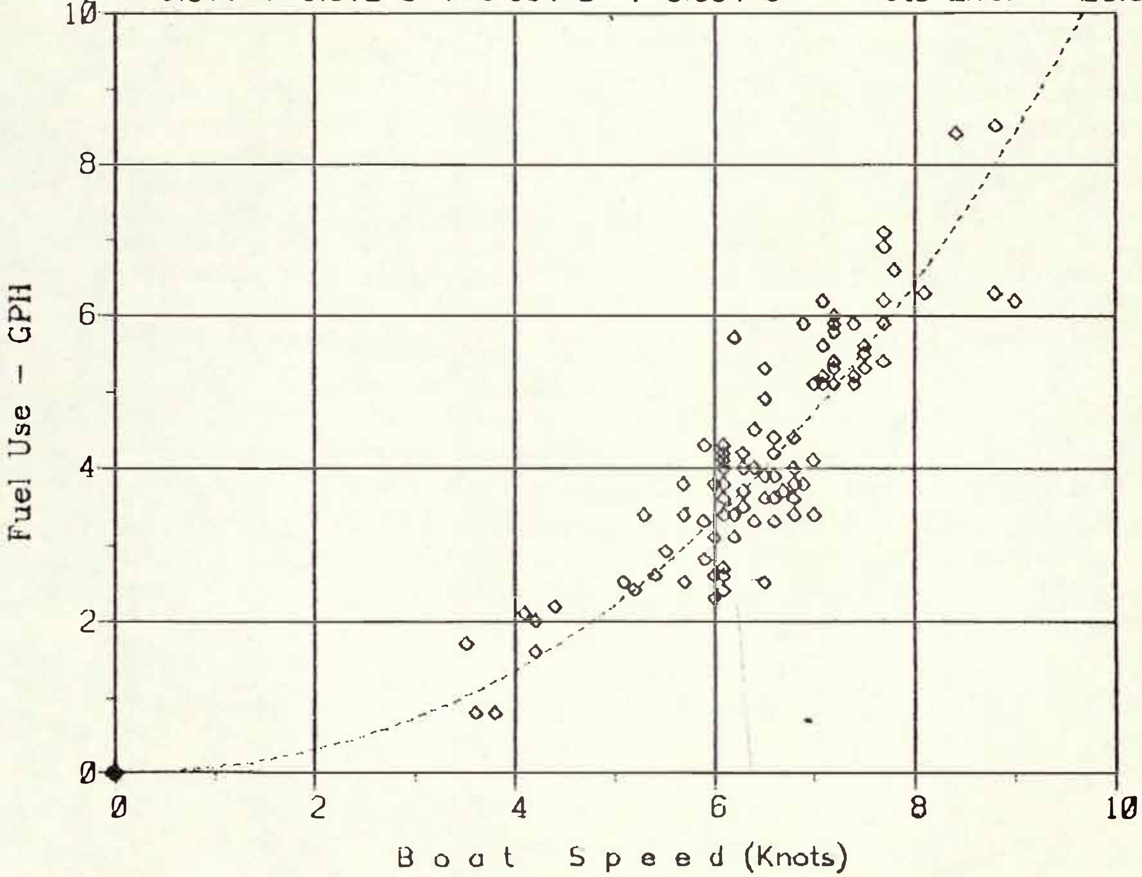
The base-line curve developed from the entire sample of engine-only observations (Fig. 9) was calibrated for the fishing trips by using it to predict fuel consumption for the engine-only observations taken during fishing trips. It was found that the base-line curve was seven and one-half percent low in predicting the average consumption rate for these observations. Detailed investigation of this behavior was not undertaken at this time, but instead an "open-water" correction factor of 1.075 was applied. This re-calibrated base-line yielded a mean residual error of 0.0 gallons per hour with a standard error of estimate of ±0.66 gallons per hour for the 192 engine-only observations in the sample.

A plot of the engine-only performance during fishing trips is shown in Figure 10 with the "open-water" base-line curve.

Figure 10. Open Water Curve of Fuel Use vs Speed

Engine Operating Alone – Fishing Trips

$F = 0.011 + 0.012\,S + 0.064\,S^2 + 0.004\,S^3$ Std Error = ±0.64



V. FINDINGS

A. Actual Accomplishments

1. CREW ACCEPTANCE, VESSEL HANDLING, SAFETY AND SEAWORTHINESS

The fishermen employed on the Norfolk Rebel, both sailors and non-sailors alike, accepted the extra work involved in sail handling because of the reduction in fuel costs and the dampening of the rolling motion of the boat. However, during runs of just a few hours or less, the time needed to raise, trim and lower all the sails was not always worth the effort, especially when there was a lot of gear work to be done on deck.

The use of the gaff rig on the Norfolk Rebel did not require a larger crew nor any change in watch-standing procedures. The sails can be raised or lowered by one person, but it is easier to have two people. Rebel Marine Service's practice is to have two people on watch, so this arrangement is ideal. Novice sailors were teamed with "old salts" and normally could pick up the rudiments of sail handling in just a few trips.

The mainsail and foresail are hoisted with four-part tackles, making this operation fairly easy. In addition, they are equipped with lazyjacks so that the sails stay on top of the booms when lowered. The combination gives a simple and time-tested system for making or reducing sail.

The sheets for the main, fore and staysails are also of four parts. One person can handle sail trimming for these sails in winds under 25 knots. In higher winds, the sheets may be led to winches or another crew member can assist.

When the vessel is working its way to windward, all sails except the genoa are self-tending. The genoa sheets are led to large two-speed self-tailing winches located by the pilothouse doors for easy access by the helmsman. During a tack under main, foresail and genoa, one person lets fly the windward genoa sheet then crosses to the opposite side of the pilothouse to haul in the other sheet on the new tack without going forward. When the jib is up the genoa must be led around the jib halyard.

Electric or hydraulic winches for sail handling, connected to the sheets and controlled from the pilothouse, would reduce the manpower needs under sail; however this equipment is prohibitively costly for this operation. Because there are normally two people on watch at all times, and two can handle almost any situation that may develop, manpower needs under sail were not considered excessive.

The sails on the Norfolk Rebel helped to improve her safety and seaworthiness. The sails acted to steady the rolling motion of the vessel in a seaway providing better footing on deck. This action is similar in effect to the use of paravanes on trawlers but without the underwater drag and corresponding increase in fuel consumption. If the sail-induced heel increased too much for the crew's comfort, it was easy to reef down or lower one or two sails. The vessel was very well balanced and could sail under foresail or genoa alone at a 60-degree apparent wind angle.

During rough weather the Norfolk Rebel would lay to quartering seas under foresail alone. The foresail would be sheeted in tight and the wheel put hard over to the windward side. The vessel would ride comfortably like this for hours without any need for touching the helm or running the engine.

In the event of an engine breakdown, the sails are capable of bringing the vessel safely back to port. If the Coast Guard transfers most of their routine towing duties to commercial firms, as is now under discussion, this "come home" capability may well save a sizeable sum of money for the owner of a sail-assisted commercial fishing vessel.

2. SEA TRIALS

Given the curves shown in Figures 6 through 8, it is possible to develop a theoretical average fuel savings for each of the wind and sea conditions listed. Table 3 lists several examples of the Norfolk Rebel's average sea-trial performance taken from these curves. Figures 11 and 12 show the algebraic difference between the least-squares fit of each of the 2 motor-sailing curves and the engine-only base-line curve derived from sea trial observations. These plots are restricted to the well-behaved regions of the fitted curves.

The standard error of estimate for each result is the square root of the sum of the squares of the individual standard errors of the appropriate motor-sailing curve and the engine-only curve. The standard error of estimate used here is the standard deviation of the residuals developed when each curve is used as a predictor for the set of data points from which it was derived.

Table 3.
Average Observed Fuel Use Rate (gph) During Sea Trials
In Winds of 10 to 16 Knots, Reaching

Sails In Use	Speed (knots)				
	3	4	5	6	7
Engine only	1.0	1.5	2.3	3.4	5.1
Engine with Main, Fore and Genoa	0.0*	0.4	1.1	2.2	3.7
Engine with Main Fore, Jib & Genoa	0.0*	0.0*	0.9	2.2	4.0

*Zero fuel consumption implies a sail-only configuration.

A comparison of engine-only performance curves derived from the sea-trial data with that derived from the entire set of observations indicates that the power required during the sea trials was about seven percent higher than the average for all observations. This difference may be explained in part by the additional wave induced drag exhibited by a vessel moving close to hull speed in water depths less that her waterline length.

Figure 11. Fuel Savings – Sea Trials

Engine with Main, Fore & Genoa

$F = 0.395 + 0.476\,S - 0.110\,S^2 + 0.009\,S^3$ Std Error = ±0.53

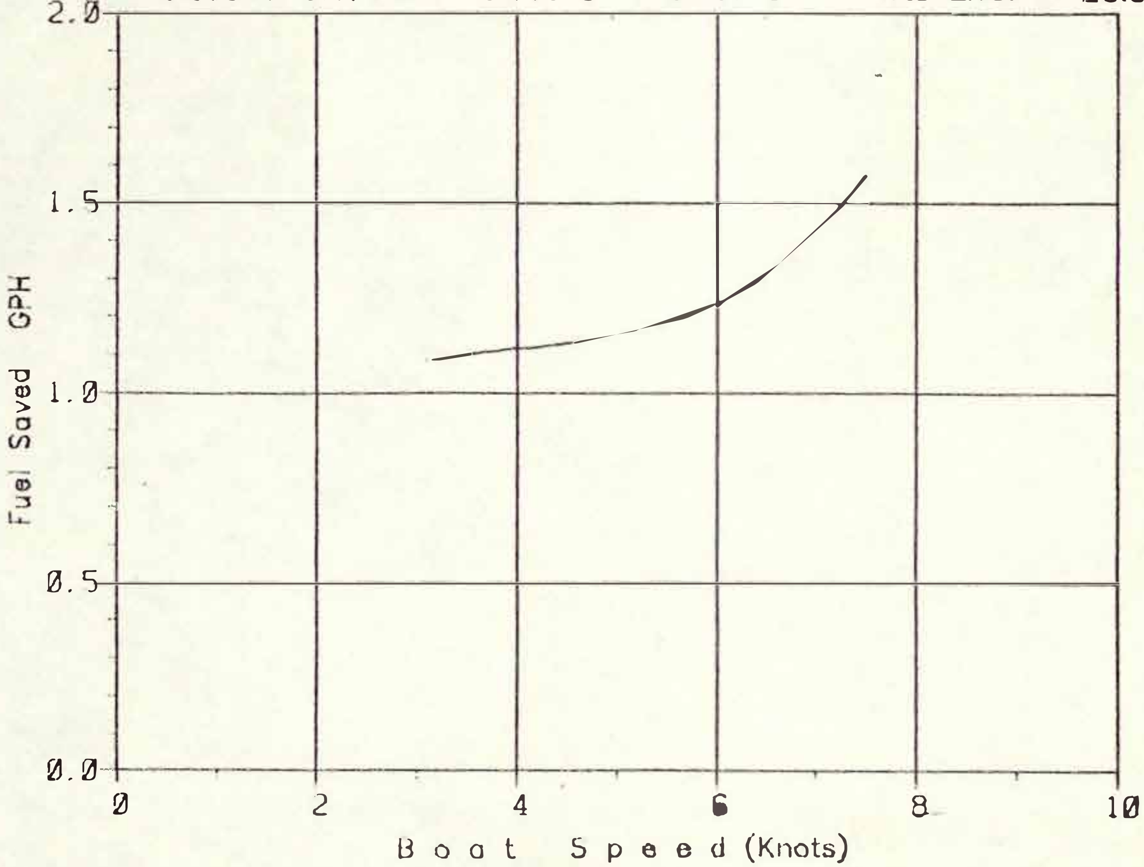
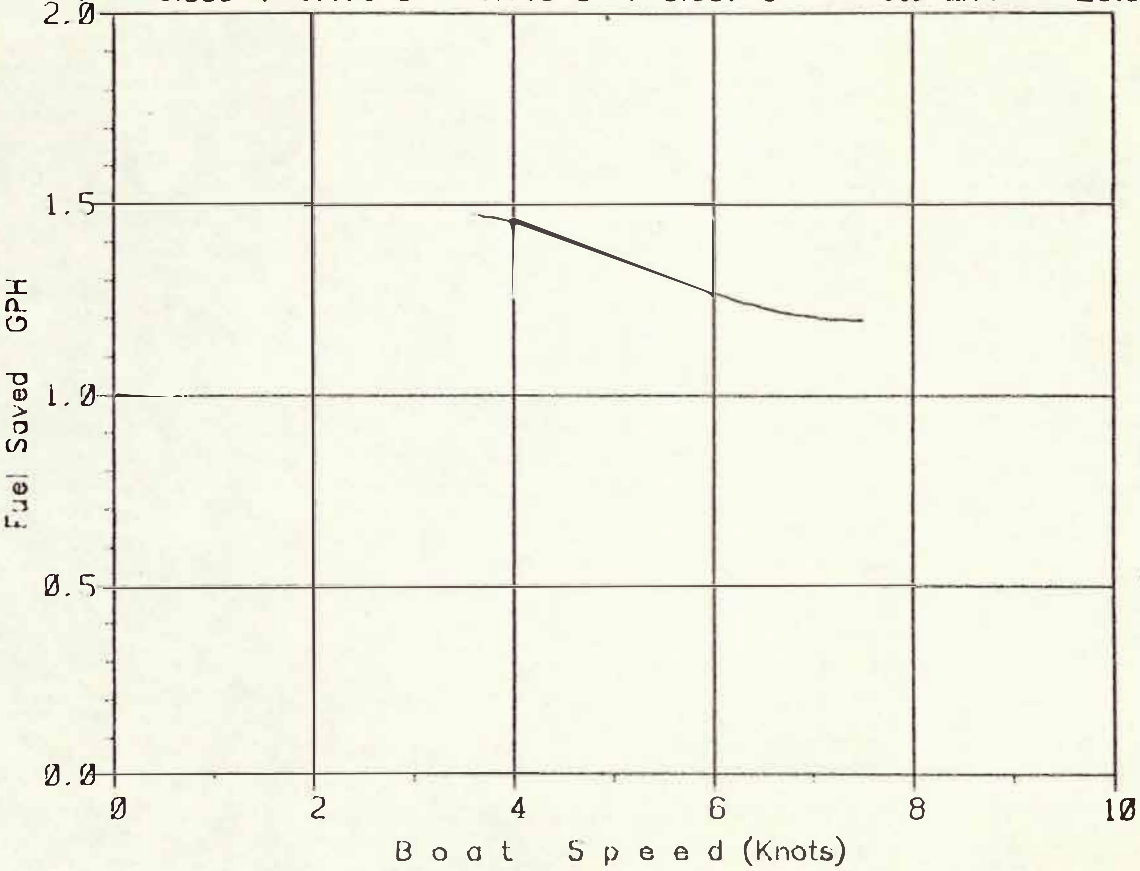


Figure 12. Fuel Savings – Sea Trials
Engine with Main, Fore, Jib & Genoa

$F = 0.859 + 0.476\,S - 0.110\,S^2 + 0.007\,S^3$ Std Error = ±0.67



3. FISHING AND SAIL USE

The fuel consumption for each observation under sail was compared with the fuel consumption predicted by the open-water base-line curve. Table 4 shows a breakdown of the results for each fishing trip having sufficient data.

Table 4.
Trip Summary of Observed and Predicted Performance

Bottom Fishing

Trip	Sail	No. of Observ	Total Time (hrs)	Avg Winds Spd (kts	Avg Winds Dir deg)	Actual Fuel Use (gals)	Predicted Fuel Use (gals)	Fuel Saved** (gals	Fuel Saved** %)
5									
	F	8	4.1	6.0	90	18.0	24.2	6.1	25
	Head*	7	3.5	13.0	38	15.9	16.2	0.3	1
	Eng	53	25.5	10.6	26	102.7	102.6	-0.1	0
6									
	MF	5	2.5	2.6	58	13.3	15.5	2.2	14
	MFG	18	8.5	4.6	71	23.8	29.8	6.0	20
	Head*	5	2.0	2.2	16	12.9	13.0	0.1	0
	Eng	15	6.6	8.8	24	24.7	29.7	5.0	16
13									
	F	1	0.4	5.0	80	0.4	0.6	0.1	23
	MF	3	2.2	9.9	63	7.0	7.7	0.7	9
	MFG	28	15.7	8.9	67	17.5	35.2	17.8	50
	Head*	9	4.5	9.9	40	15.0	17.5	2.5	14
	Eng	1	0.5	0.0	90	0.6	0.5	-0.1	-15

(Table 4 is continued on the next page)

Table 4 (continued).

Longlining

Trip	Sail	No. of Observ	Total Time (hrs)	Avg Winds		Actual Fuel Use (gals)	Predicted Fuel Use (gals)	Fuel Saved**	
				Spd (kts	Dir deg)			(gals	%)
12									
	F	4	2.0	7.2	90	3.8	4.3	0.5	11
	MF	1	0.5	7.0	60	1.4	1.3	-0.1	-4
	FG	19	9.5	7.7	84	5.4	9.6	4.1	43
	MFG	4	1.8	8.8	66	5.1	5.4	0.3	5
	Head*	38	22.7	9.5	24	57.3	50.6	-6.7	-13
	Eng	28	18.7	1.2	11	70.5	64.5	-6.0	-9
16									
	F	4	2.1	16.2	50	9.4	8.8	-0.6	-6
	MFJ	15	7.7	13.6	86	17.5	32.6	15.1	46
	Head*	19	9.5	11.4	31	42.6	43.7	1.1	2

Trolling

Trip	Sail	No. of Observ	Total Time (hrs)	Avg Winds		Actual Fuel Use (gals)	Predicted Fuel Use (gals)	Fuel Saved**	
				Spd (kts	Dir deg)			(gals	%)
9									
	MFG	6	0.5	9.3	76	0.1	0.6	0.5	85
	MFJG	8	3.1	8.9	77	0.1	2.8	2.7	97
	Head*	16	2.8	7.6	20	6.2	6.5	0.3	4
10									
	MFG	12	7.5	6.7	90	4.5	8.3	3.8	45
	Head*	1	0.5	7.0	10	0.9	0.9	-0.0	-5

*Head - Carrying sails, but motoring upwind

**This column gives the savings for the period that the given sails are actually in use.

The average fuel savings was determined for each sail configuration used during the fishing trips. Table 5 shows the results along with the number of observations used to determine each average.

Table 5.
Average Rate of Fuel Savings During Fishing Operations
By Sail Configuration

Sails	Rate of Fuel Saving (gph)	No. of Observations
Foresail	0.7	17
Main & Fore	0.5	9
Main, Fore & Genoa	0.8	50
Fore & Genoa	0.4	19
Main, Fore & Jib	2.0*	15
Main, Fore, Jib & Genoa	0.9	8

*This figure represents 7.7 hours on a beam reach with average winds of 13.6 knots (see Table 4, Trip no. 16).

Table 6 shows the percentage of time that the various sail configurations were in use during the fishing trips from casting off to tying up, including time spent laying to and handling gear. Also shown are the accumulated fuel savings for each trip and the percent of fuel saved. Total fuel use as determined by topping off the tanks is given where available.

Table 6.
Sail Use* / Fuel Savings Profile

Bottom Fishing

Trip No.	Duration (hrs)	Sail Use (type hrs)	Overall % Sail Use	Total Fuel Used	Fuel Saved (gals)	Overall Percent Saved
5	117	F 4.1	4			
		Total 4.1	4	203	6.1	3
6	64	MF 2.5	4			
		MFG 8.5	13			
		Total 11.0	17	96	8.2	8
13	55	F 0.4	1			
		MF 2.2	4			
		MFG 15.7	28			
		Total 18.3	33	80	18.6	18

Longlining

Trip No.	Duration (hrs)	Sail Use (type hrs)	Overall % Sail Use	Total Fuel Used	Fuel Saved (gals)	Overall Percent Saved
12	129	F 2.0	2			
		MF 0.5	<1			
		FG 9.5	7			
		MFG 1.8	1			
		Total 13.8	10	206	4.8	2
16	102	F 2.1	2			
		MFJ 7.7	8			
		Total 9.8	10	212	14.5	6

(Table 6 is continued on the next page)

Table 6 (continued).

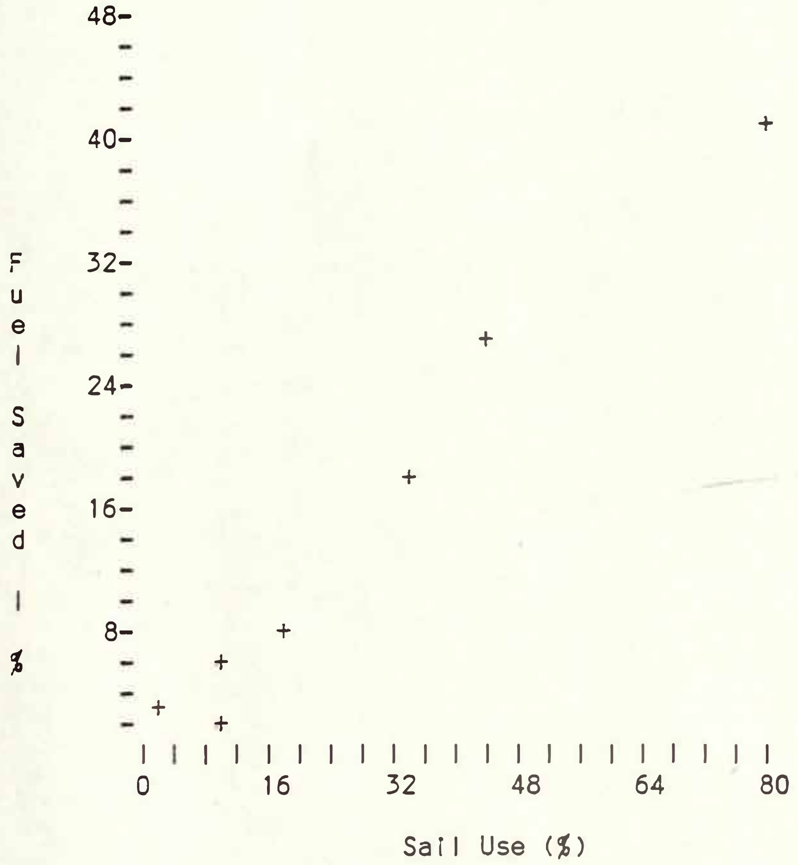
Trolling

Trip No.	Duration (hrs)	Sail (type	Use hrs)	Overall % Sail Use	Total Fuel Used	Fuel Saved (gals)	Overall Percent Saved
9	8	MFG	0.5	6			
		MFJG	3.1	39			
		Total	3.6	45	11**	3.2	29
10	9	MFG	7.5	83			
		Total	7.5	83	9**	3.8	40

*Sail use includes motor sailing and sail-only operations.**Estimation based on type of vessel operation and conditons.

Figure 13 makes evident the relationship between the percentage of time that the sails are in use and the percentage of fuel saved on a trip by trip basis.

Figure 13.
Percent of Fuel Saved vs Percent of Time That Sails are in use



B.e Discussion and Consiusionse

Two aspects of the fuel savings analysis on the Norfolk Rebel muste be examined to evaluate her performance. Both her overall savings during fishing trips and short term savings during portions of trips should be studied to best analyze the sail rig's contribution to the vessel. First, the overall savings picture will be considered.

Estimates for two short trolling trips could not be calculated due to the trips' total fuel consumption not being logged. The overall fuel savings for three bottom fishing trips range from 3 to 18 percent and for two longlining trips, 2 to 6 percent (Table 6). These rates of fuel savings are quite low.

When one examines the percentage of time sails were used on each of the trips (Table 6), it becomes apparent that this aspect of the vessel's operation is a major limiting factor in its fuel savings record. On the bottom fishing trips sails were used only a maximum of 33 percent on one trip while the other trips exhibited sail use 4 and 17 percent of the time overall. Longlining trips showed a 10 percent use of sails.

A computer analysis of the feasibility of retrofitting sailing rigs on snapper-grouper boats working out of Florida's Gulf coast ports indicates these vessels should be able to use their sails about 60 percent of the time (3). In this same study, even a conservative 30 percent use of sail-assisted power is estimated to provide reasonable fuel savings for the 400-mile round trip to the grounds. Given the obvious relationship between the percentage of time the sails were used and the overall fuel savings observed (Fig. 13), an increase in overall sail use would significantly enhance fuel savings.

Scheduling of fishing operations around offshore weather conditions would maximize the percentage of time that sail could be used. During the test period in which fishing trips were made, salvage-towing job demands on the vessel significantly restricted the scheduling of such trips. It is likely that more experience with offshore wind patterns and full-time devotion of vessel use to fishing would result in higher fuel savings rates.

Average wind speeds observed during the fishing trips made for this study were 9.2 knots. On the average, 11 to 21 knot winds are observed over the mid-Atlantic continental shelf 42 percent of the time in March and April, 46 percent from May to August and 47 percent from September to November (4). Therefore, sufficient wind magnitudes should be available during the fishing season to permit reasonable rates of sail-assisted power use.

While overall fuel savings were low for the initial fishing experiences of the Norfolk Rebel, the examination of short-period savings during trips better indicates the vessel's potential. During bottom fishing trips, 50 percent fuel savings were achieved by using the sails on a 15.7 hour run (Trip 13, Table 4). On two other trips 20 and 25 percent savings were realized over 8.5-hour and 4.1-hour runs respectively (Trips 6 and 5, Table 4). Similarly on the longline trips, runs of 9.5 hours and 7.7 hours resulted in 43 and 46 percent fuel savings respectively (Trips 12 and 16, Table 4). Even higher fuel savings were achieved on trolling trips, but these are not the types of trips commercial fishing boats (other than charter boats) make in the region.

Again as the vessel owners gain more experience with offshore sea conditions and wind patterns, they may prove able to make such runs a greater proportion of their total offshore trips and so approach an overall savings in the range of 20 to 30 percent.

In looking at typical runs made to the offshore fishing grounds out of Chesapeake Bay for longlining and some wreck fishing, such runs are usually in the range of 70 to 75 miles. If the vessel could achieve overall fuel savings of 25 percent on runs to and from these grounds at a cruising speed of seven knots, then a savings of approximately thirty dollars per trip could be realized (at fuel prices of $1.20 per gallon). If 20 such trips per year were made, then an annual savings of about $600.00 would be accrued. This amount of potential savings indicates that unless considerably longer trips were the rule in the mid-Atlantic region, payback on the sail-rig investment would occur at an unacceptable rate. However, if trips of twice the indicated distance were the usual case, an annual savings of about $1,200.00 would be realized and the economics of sail-assist would look considerably better.

In summary, the larger the percentage of time the sails are in use, the more savings achieved over the period of a trip. For best fuel savings, the selection of the grounds should be made with an eye to the winds likely to be encountered on the trip. A beam reach out and back is much more economical than head winds out and tail winds back. If fishing strategy could include longer trips, the economic return attributed to sail-assisted fuel savings would be enhanced. Extending his vessel's operating range without any penalty in fuel consumption provides a fisherman with the advantage of working grounds economically inaccessible to his local competition.

In a sail-assisted vessel designed just for fishing, the use of sails must be relied on for a substantial portion of the motive power. The subsequent effect on the vessel design is that the engine placed in the vessel may be smaller. This means a lower initial cost and a lower operating cost. This was not the situation for the Norfolk Rebel as her capabilities, by design, included towing and salvage work. If this type of trade-off had been possible for the vessel, then a better relative economic return from the use of sails might be realized.

This analysis of the Norfolk Rebel's performance during her first year of fishing operations indicates that even with a vessel designed for as divergent types of activities as towing, salvage and fishing, some economic savings can be realized using sail assist. As more experience is gained in the offshore fisheries by the vessel, it appears likely that greater savings can result. Since the vessel has also demonstrated ability to work on long runs both north and south of Virginia, it may prove able to compete in fisheries in these areas, unlike other Virginia boats of similar size, because such long runs maximize her sail-assisted power advantage.

C. Satisfaction of Objectives

1. SIGNIFICANT REDUCTION IN FUEL CONSUMPTION

Overall fuel savings of 20 percent during fishing operations were not achieved. However, during specific periods of operation during the study more than twice this level was shown.

2. MANPOWER NEEDS

It was demonstrated that the vessel's normal crew complement of two persons per watch was adequate for sail handling under nearly all circumstances, excepting only the most extreme conditions of wind and weather.

3. COME-HOME CAPABILITY

The Norfolk Rebel's performance with sail-only was sufficient in terms of speed and windward ability to bring her home in the event of an engine breakdown. She could sail to within 50 degrees apparent wind angle with acceptable leeway and could attain speeds of seven knots in apparent winds of 25 to 30 knots.

4. OVERALL VESSEL AND CREW SAFETY

The level of seamanship necessitated by the demands of sail handling, such as the evaluation of wind and weather required by the choice of sail configurations and combinations, enhanced the skills and abilities of the crew. The "secondary propulsion system" (sailing rig) serves as a backup, enabling the vessel to avoid a collision or an obstruction should the engine fail, improving the safety of the vessel.

5. EXAMPLE TO THE FISHING INDUSTRY

There has been a noticeable change among the commercial fishermen's attitudes toward sail assist. Lately there is less reluctance to consider sail assist as an economical option, and more pointed interest in its benefits. As a result of the Norfolk Rebel's operation, more than 200 inquiries, requesting copies of her results, have been received from members of the fishing industry.

6. REDUCTION OF DOWN TIME AND ENGINE MAINTENANCE

The overall reduction in engine use was 10 percent, based on comparison with a conventionally powered similar craft running under power 400 more hours in an average year of swordfishing (4,000 hours). This reduces the number of times that oil, oil filters, and fuel filters need to be changed. This savings translates into a $150.00 annual bonus for the Norfolk Rebel, not including the extended life of the engine and its components.

VI. APPLICATIONS

Before the fishing industry can take full advantage of the results of this study, more work should be done to clarify the savings that sail-assisted vessels may achieve.

In the event that no further work is done, the fisherman must look at this study and extrapolate the results tro cover his or her situation. The findings of this study are conservative, and a fisherman who builds a vessel specifically for fishing under sail will likely realize a greater savings in his cost of operation, particularly if his run to the fishing grounds is over 100 miles.

Fishermen and fishing vessel owners are the direct beneficiaries of this study. The findings of this study should help them in deciding what sort of new vessel they wish to build or buy next.

The fishing vessel owner needs to weigh the costs of a sailing rig, which can range from around $25,000 (for a rig like the Norfolk Rebel's) to an estimated $90,000 (for a 70-footer with electric or hydraulic roller furling). These costs can be counter-balanced by the use of smaller engines with lower initial cost and long-term fuel savings. The careful design of a sailing rig should allow the masts and booms to be used to handle fishing gear which helps to further reduce costs.

The fishing vessel owner and operator need to be trained in the use of sail-assist. While there are courses to teach people sailing, the hiring of an experienced ocean sailor for on-the-job training may work better. Learning the basics of sail handling only takes a short time, but to get a thorough understanding of sailing may take six months to a year of sea time.

VII. PROJECT EVALUATION

A. Benefits

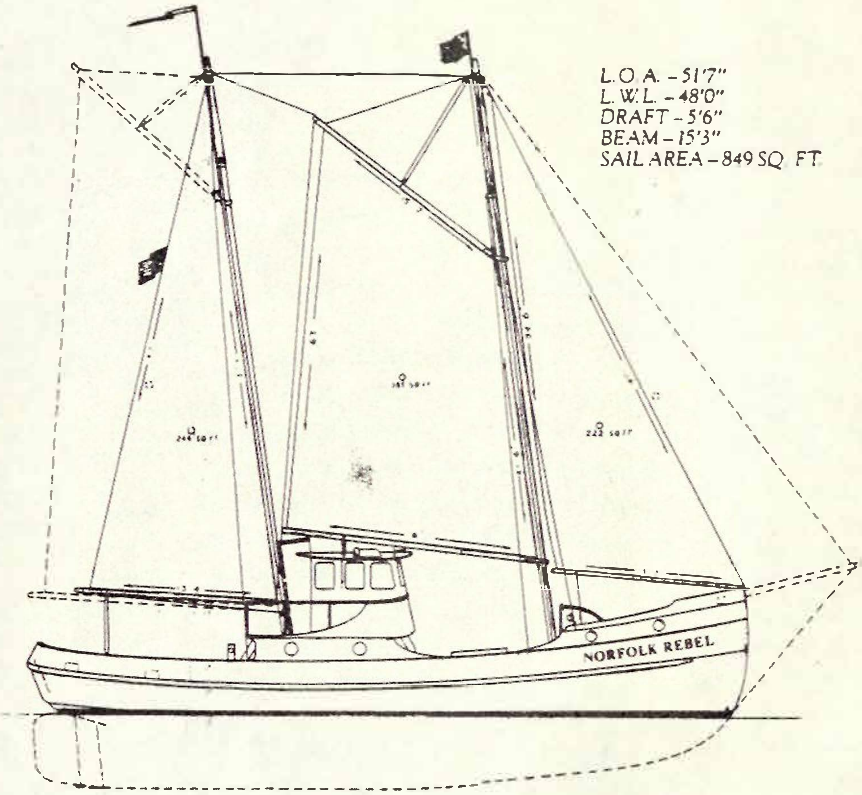
The project demonstrated trip fuel savings of 3 to 40 percent while motorsailing 4 to 80 percent of the time. Savings such as these help to cut the fisherman's operating expenses, and increase profits. Additional savings accrue from the sail-assisted vessel's ability to stay at sea longer for the same amount of fuel, if fuel capacity is a limiting factor on trip length. The sails also add to the safety of the vessel; they provide another means of propulsion in the event of engine breakdown. Savings for a 100-mile commercial tow amount to about $3,000.00, the fee for a seagoing tug's round trip to the fishing grounds. The crew of a sailing vessel must have more skill than for a conventional, motor-only craft, in order to operate the sails effectively; this should mean fewer accidents and casualties.

The roll-dampening effect of the sails has two benefits. The safety of the crew is enhanced by the slower roll. Paravanes may be used to dampen a vessel's roll, but they increase fuel consumption. Sails perform the same task, but decrease fuel consumption by 10 to 50 percent (motorsailing).

The ability to lay-to in the sea without the engine on makes the vessel safer and more comfortable, reducing the stress and fatique levels of the crew. Decreased engine maintenance costs of about 10 percent is an additional financial benefit.

B. Impact of Project on Fishing Industry

This project has a small but important impact on the fishing industry. The overall fuel savings, while low, show that through proper application sail assistance can prove to be beneficial to the fishing industry. It also provides a base-line for other studies. The greatest impact will be for those fishermen active in the fisheries which do not require a high bollard pull, such as swordfishing, trolling and wreck fishing. In these fisheries, vessels having a run of over 100 miles to the fishing grounds will benefit the most from this project.



L.O.A. – 51'7"
L.W.L. – 48'0"
DRAFT – 5'6"
BEAM – 15'3"
SAIL AREA – 849 SQ. FT.

TUGANTINE®
NORFOLK REBEL

Built for Captain Lane A. Briggs
Rebel Marine Service

Designed by Merritt N. Walter
Rover Marine

Master Builder, Howdy Bailey