An Analysis of Sail-Assist in Today's Fisheries

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ABSTRACT

For centuries fisherman around the world have used sail powered vessels to harvest the seas. In a very short period, following the development of the internal combustion engine, fishermen in most developed countries converted to mechanically powered vessels. Until the early 1970's when fuel prices soared all over the world, especially in the developing nations, there wasn't much need or desire to return to the day's of sailing fish boats.

With the advent of modern thechnology in both materials and design, sail may well find appropriate application again in commercial fishing. To be more precise, we should say sail-assist, as fishing vessels powered solely by sail would be not feasible in today's fisheries since most of today's fishing gear requies some power sources. Time is also valuable so an engine can help keep the vessel on schedule during periods of light winds.

In today's economy, the only certainty is that everything will go up on price. This is especially true of petroleum products. Between 1973-83 world oil prices have risen 6-10 times. This combined with the fact that fisherman in most areas must be prepared to travel futher and further in order to catch enough fish to make a profitable venture, would seem to indicate that sail does indeed have a place in today's fisheries.

In this paper we will attempt to make valid comparisons of the initial cost of motor vessels vs. sail-assited vessels and a comparison of the cost to operate and maintain their propulsion systems.

INTRODUCTION

Reports on sail assistance technology tend to skirt the issue of commercial viability, and when it comes to the application of sail assistance to fishing vessels, the situation tends to be even more confused. This confusion appears to arise from the lack of actual practical applications of the technology and the absense of commercial experience in the operation of sail assist applications. The purpose of this paper is to present an assessment of the potential for application of sail assist, both in vessels designed as sail boats and vessels retrofitted with sails.

Sail assist for fishing vessels must be divorced from the romance usually associated with sailing ships to the part and environmental cosiderations, and based on hard economic analysis. To receive maximum benefits technology must be developed to exploit the required charcteristics of fishing vessels rather than adapting fishing technology for application on sailing vessels.

The world fishing fleet has experienced a continued increase in operating costs over the last eight to twelve years without an equivalent increase in the price received for their products. Fuel has been the major component of rising production costs. Several areas exist for reducing fuel expenditure (Table 1).

Table 1. Selected areas for fuel cost savings.

Area	Potential savings %
Speed and power reduction	20
Improved propulsion systems	20
Improved auxillary power systems	3
Improved hull design	3
Improved fishing gear	25
Selection of fishing methods	20
Alternative energy sources	30
Fish forcasting	?

SAIL AS AN AUXILIARY POWER SOURCE

One solution to the above problems involved the reintroduction of sail as an auxiliary power source. We say auxiliary here because sail alone tends to limit access to the resource, both temporarily and geographically. As an auxiliary, sail simply enhances profitability of existing fishing operations. Although there has been considerable discussion of the sail assist concept, much of it has centered on the reuse of historical hull forms and sail plans.

Effective reintroduction of sail should utilize the extensive body of engineering data available if an efficient hull form, and a workable sail plan, are to be combined into a functional fishing platform for use in today's fisheries. Sail does have to overcome a negative image within the fisheries associated with the idea that it is old fashioned and labor intensive. Some of this may be overcome by application of the significant technological advances which have come from modern equipment which has been develolped through electronic and hydraulic engineering.

By using a more modern hull form when designing new vessels, it is possible to have a very efficient sailing hull form without loosing cargo capacity. There are also several positive side effects of sailing vessels: 1) in the event of a mechanical breakdown the vessel is still able to return to port under its own power; 2) sailing vessels are inherently better sea keepers than motor vessels; 3) when fishing with engine running or when motoring in light or dead air the sails tend to limit rolling without using fuel consuming "Flopper Stoppers". Also because of their more efficient hull form the vessels require less horsepower from their engine to drive them to hull speed.

The current project arose as a result of information and experince gained from the U.S.V.I. Saltonstall-Kennedy funded fisheries project. Experience from throughout the Caribbean, indicated that, although many of the more developed areas were converting from sail and sail assist to pure engine powered fishing boats, this conversion was not being successful. The reasons for lack of success were various and included:

1. The small outboard powered boats, which extend the range of fishing activities, have proven unreliable and expensive to operate.
2. Larger inboard powered vessels were expensive to purchase and operate.
3. Expansion of fishing activities resulted in resource over-exploitation which made the vessels become uneconomical.
4. Increased fuel utilization created economic problems within the country in terms of hard currency necessary for petrochemical imports.

In many areas of the world where there has been serious over exploitation of the nearshore resources and where population pressures continue to increase the demand for protein, fuel has remained very expensive. This is due to inflation and foreign exchange problems. Any reduction in the use of petrochemicals can provide significant savings to both the fishermen and the local economy.

Though there is a sizeable initial investment required to purchase a modern vessel, the additonal cost of purchasing a modern auxiliary sail vessel can be well worhtwhile. Sails and rigging can add an additional $6,000-$12,000 U.S. to the cost of a 40 footer. The fact that it will require a smaller and therefore less expensive engine, may help offset some of this increase.

In analyzing the world wind data it is obvious that both pure sailing (which results in zero fuel usage) and motor sailing afford substantial fuel savings. If maximum use is made of the sails, global wind conditions suggest that most areas could benefit from the use of fishing vessels with sails. Even retro-fitted motor vessels could gain substantial savings.

The distribution of wind speeds worldwide was obtained from an expected wind curve function of the calendar days over a year. Discarding the small portion (5% of the time) during which wind speed exceeds 30 knots, ranges of equal duration are given below:

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

The mean in each range was weighted to account for the wind probability distribution of this range. These frequencies provided design requirements for sail rig in the current project.

As fish stocks have been depleted through local over-exploitation, trip lengths in time and distances of trips have increased significantly. Our own experience indicated that our fishermen traveled up to 400 miles round trip to and from the fishing grounds. They spent many hours motoring during fishing operations. All this engine time is usually at 80% throttle or more which caused more overhauls, maintenance and replacement. On the other hand, a sail assisted vessel, be it a retrofitted power vessel or a modern sailing fishingboat, can motor sail at about half the throttle, or if conditions permitted shut down the engine completely. Our experience indicated that 40% of the power requirements could be easily replaced by sail power.

REDUCING FUEL CONSUMPTION

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

Reduced weight	2%
Improved hull shape	8%
Improved hull finish	6%
Use of slow rev/variable pitch propeller	12%
Use of reaction fins	5%
Improved main engine efficiency	16%
Use of shaft driven alternator	2%
Better utilization of waste heat	2%

These improvements can easily be applied to a motor vessel as well as a sailing vessel with equally good results. All of these methods of reducing fuel consumption involve alterations or improvements in the ship and additional capital expense, in the same way as employing sail assistance. They may not all be practical or possible for each type of vessel.

If fuel consumption is the only criteria for vessel performance, then reduced speed and careful use of the throttle can show the biggest saving. A reduced speed requirement allows sail assistance to have a bigger potential as it can provide a higher proportion of the required power. However, reduced speed means longer trips which can increase crew and capital costs. The cost of capital, however, has become increasingly significant as interest rates have risen.

The Aquarian 38 S/A was designed to deal with these problems by a team of professionals that consisted of a naval architect with a history of successful yacht designs, a builder of commercial fishing vessels, a fleet operator/seafood company and a fishery biologist with experience in developmental requirements of small-scale and underdeveloped fisheries.

The design team considered that increased efficiency could be obtained in a variety of areas, and the end product should be a vessel that could be easily operated in lesser developed areas but would still have suffiecient catching power and trip capacity to be profitable in our fleet operations. The areas which we concentrated on for improvement are discussed below.

DESIGN CRITERIA

Our other fleet operations indicated that we needed to have a 200 mile radias of operations in order to consistantly find fish. An 8 knot hull sped allowed us to have this range. The resistance curve (Figure 1) indicated that greater speeds would increase power requirements significantly. In order to provide the sail assist with enough carrying capacity to cover this range, a 6,500 lb. fish hold was included in the design requirement.

The sail assist design incorporates a shallow canoe body with a high center of buoyancy and a low center of gravity to insure a most stable hull form. By using modern hydrodynamics, and an approach using beam as a dimension towards cargo carrying capability, and an aid towards stability, we were able to exceed our original goals. With no cargo on board, the very buoyant hull form gives a slightly corky ride, which is to be expected. As load increases, stability, which is already very good, improved and the vessel becomes more seakindly. A stability analysis by USCG Cmdr. William Remley (Proc. Intl, Cong. Sail Assisted Comm. Fish. Vessels, 1983) showed that the Aquaria "has excellent ability to survive in extremis." This analysis indicated that the Aquarias were among the most stable fishing vessels yet analyzed.

The underbody configuration of the hull incorprates a low aspect ratio fin keel with a separate skeg hung rudder. The exposed shaft is supported by a "V" strut with the popeller in a clear unobstructed area for greater efficiency.

Boat speed and performance are greater than anticipated by our computer analysis. We have operated our four prototype vessels in a wide range of wind and sea conditions and on all points of sail, and have found the sailing performance to be equal to the computer projections in moderate winds and better than expected in light airs.

The boat was designed to minimize power requirements. The sail assist aspect further reduced these requirements. Although the vessel is designed for motor sailing, it is fully capable of operating at hull speed under either power source (Fig. 2).

We wanted the sail assist to be competitive in catching power with our larger vessels. Consequently, we incorporated many of the fishing equipment and electronic fish finding options, that had proven valuable on our 60 and 90 foot vessels wherever possible.

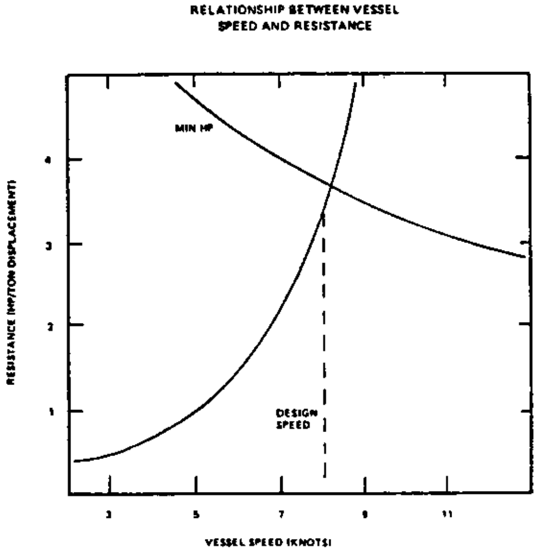

Figure 1. Speed and power requirements for the Aquaria sail assist fishing boat.

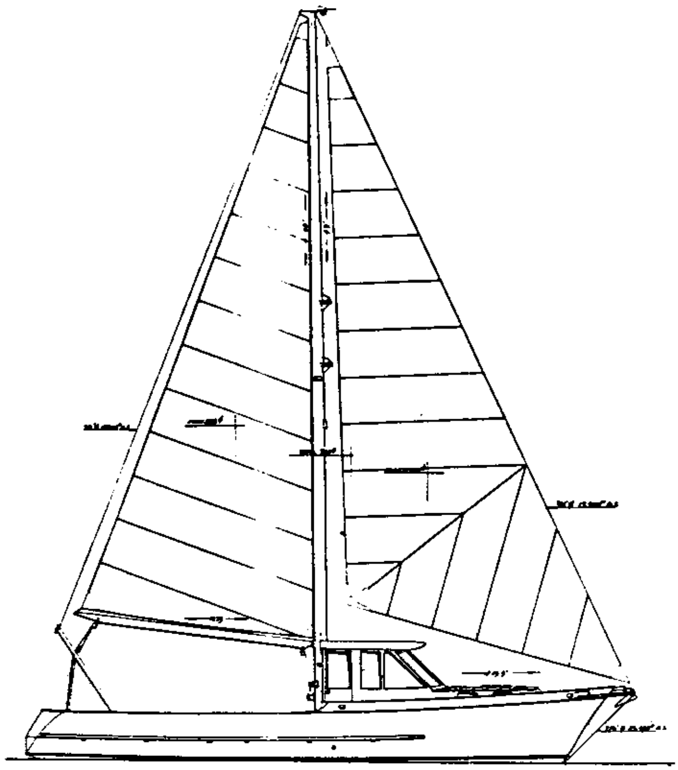

Figure 2. Aquarian sail assist line drawing.

CASE STUDIES

At this point we would like to present two case studies. One is based on the operational record of the Aquarian 38' Sail Assist. The other is an analysis of a potential conversion of a forty-four foot retrofitted power driven vessel.

Case Study 1: Analysis of aquarian sail assist performance.--The Aquarian 38's used in THE first case were part of a managed fLeet which consisted of 17 vessels including four 38 foot sail assists, eleven 60 foot trawlers and two 90 foot trawler/processors. The fleet operated in a variety of fisheries including:

1. Calico and Icelandic Scallops - one 90 foot catcher/processor.
2. Squid and Groundfish - one 90 foot catcher/processor and one 60 foot trawler.
3. Swordfish Longline - four 60 foot multipurpose trawlers.
4. Bottom Longline - eight 60 foot multipurpose trawlers and our 38 foot sail assists.
5. Shrimp Trawling - two 60 foot trawlers.

The fleet oprated in the Gulf of Mexico and the Eastern United States. One short exploratory trip was made to Jamaica in conjuction with Antillean Pride, a Jamaican canning company. Four shrimp trawlers fished in Guyana, and one of the sail assists was leased to the Virgin Island government as a fishery research vessel.

None of our captains had any prior sailing experience. They found that the boat's sailing gear could be easily handled by one person, and the sails to be well balanced in all wind and sea conditions so that steering was easy on all points of sail.

The operation of these boats provides some comparative insights into the real value of sail assist. Since these operations occurred within a diverse profit-oriented private sector fleet with common management, comparisons between vessels and fisheries may possess more validity than purely experimental data from research efforts.

Fishing performance has been the most encouraging aspect of the project. Inital trials with Aquaria I included:

1. Bottom longlining with 6 mile sets and up to 3500 hooks/day.
2. Trolling under sail and motor sailing with 6 lines. Initial attempts were made to set-up for Northwest (U.S.A.) style trolling with 15 and more lines.
3. Shrimp trawling. We successfully demonstrated that a single 56 foot shrimp net could be pulled at 2.5 knots under sail alone.
4. Surface longlining, vertical set lining, gill netting, and trap hauling, have not been tried although the boat has both the deck space and maneuverability to accomodate these fisheries.

The most convincing demonstration of the Aquarian's advantages comes from a comparison of the sail assists with the conventional diesel powered 60 foot trawlers in the bottom long

Table 2. Comparison of expenses (given as % of total revenue) between sixty foot long liner (motor vessel) and a thirty eight foot sail assisted long liner. Total expenses include bait, fuel, food and fishing supplies.

Boat	Total expense	Bait	Fuel	Daily revenue	Maintenance	Net daily revenue
60 ft. longliner	47.8	14.6	12.1	1,348	13.2	523
38 ft. S/A longliner	23.6	8.2	5.1	942	7.4	637
Ratio 60 ft./38 ft.	2.03	1.78	2.37	1.43	1.78	0.82

Notes: Total expenses include fuel, bait, ice food and fishing supplies. Maintenance expenses are not included in total expenses. Net daily revenue after total expenses and maintenance, normally divided between owner and crew.

line fishery. The sail assists produced nearly 70% of the revenue that the larger boats did despite the fact that the larger boats set nearly twice as many hooks per day. The reason for this is the fact that the Aquarias set lighter gear which was more effective. This also shows in bait expenses which were only 8.2% of the sail assist revenue as compared to 14.6% of the sixties' revenue.

Basic operating expenses (bait, fuel, ice, food and fishing supplies) only amounted to 25% of the Aquari's revenue as contrasted to 48% for the larger trawlers (Table 2). Maintenance on the larger boats was 13.2% of the gross revenue and only 7.4% for the Aquarias. The resulting daily margin (for crew and owner) was larger for the Aquarias ($637/day) than for the larger trawlers ($523/day). Additionally, because it requires fewer crew and has lower expenses, the Aquaria has greater potential for net profit.

Fuel efficiency, as mentioned earlier, was an aspect emphasized in the design project. The Aquaria's fuel costs only amounted to 5% of the total revenue as compared to 12% of the sixty foot trawlers. The sail assist vessels were also 2.5 times as efficient at converting fuel energy to fish energy equivalents (Table 3). When the Aquarias were compared to other figures from our own boats and other figures from the literature, they provided one of the most fuel efficient options available.

Table 3. Comparison of energy conversion (Kcal of fuel/Kcal of product) for selected fisheries.

Fishery	Boat length	Conversion
Northeast groundfish trawler	--	4.1
Florida spanish mackeral gillnet	--	7.8
Sail assisted bottom longliner	38 ft.	7.9
Squid trawler/processor	90 ft	15.3
Virgin Islands trap fishery	22 ft.	18.5
Bottom longliner	60 ft.	20.3
Scallop trawler/prcessor	90 ft.	39.5
Swordfish longliner	60 ft.	49.8
Shrimp trawler (Guyana)	60 ft.	191.7
Shrimp trawler (Gulf of Mexico)	--	198.0

Case Study 2: Retrofit of a 44 ft. Motor Vessel to Sail Assist.--The second case study involved an analysis of a potential conversion of a 44 ft. motor vessel to sail assist. Assumptions were made regarding the cost of installing the sails, percent of boat's propulsion from sail power, financing charges, and parameters of the fishing operations. These assumptions were made as a result of our own data on actual costs and performance from vessel construcion and operation.

These assumptions are outlined in Tables 4 and 5. Additional assumptions included engine rebuilds in the fifth and thirteenth years of the model, engine replacement in the eighth year as well as replacement of the navigation equipment in the fifth and tenth years of operation. Vessel overhauls generally run between $50 and $75 per horsepower so that by allowing smaller horsepower installations, sail assist may decrease that cost as well. The assumed fishery was the snapper/grouper longline fishery.

Table 4. Economic parameters for a snapper/grouper fishing vessel.

1.	Cost of fishing vessel $/ton	$ 6,000
2.	Engine replacement costs $/horsepower	$50-$75
3.	Engine rebuild cost $/horsepower	$25-$50
4.	Cost of mast and rigging $/foot	$ 50
5.	Sail installation cost	$ 8,000
6.	Cost of support structure	$ 800
7.	Salvage value, percent of vessel cost	10%
8.	Vessel lifetime (years)	15
9.	Fuel cost $/gallon	$ 1.30
10.	Communication/navigational gear cost	$ 6,500
11.	Down payment	10%
12.	Financing rate	18%
13.	Financing term (years)	15
14.	Inflation rate	8%
15.	Fuel inflation rate	10%
16.	Discount rate	8.5%
17.	Insurance and maintenance	5%

Table 5. Operational parameters for retrofitted sail assisted fishing boat.

	Operational Parameters	
1.	Range to fishing vessel location, miles	200
2.	Amount of ice used per trip, pounds	3,000
3.	Duration of trip, days	14
4.	Number of annual trips	18
5.	Specific fuel consumption, gal/hr/hp	.05
6.	Vessel cruising speed, knots	9
7.	Value of catch, $/pound	1
8.	Average size of catch, pounds	3,000
9.	Cost of ice, $/pound	.0175
10.	Size of engine, horsepower	120
11.	Miscellaneous	400
12.	Catch inflation rate, %	4

Sail benefits were assumed as the percent of power replaced by sail. Thus if the annual fuel bill without sail was $10,000 and 10% of the power was replaced by sail, the savings would be $1000. The analyses were run for two parameter sets for the vessel which cost $110,000 new. In the first the mortgage payments were not factored into the net cash flow and in the second there were. The results were calculated for sail contributions between 0% and 50% to the power demand and (Tables 6 and 7) indicated that fuel savings of between $18,000 and $92,000 could be realized depending on the amount of sail replacement over the fifteen year period.

Table 6. Lifetime value of fuel saved, net cash flow and annual fuel gallonage saved versus percent sailpower, with and without sailpower, over 15 years.

With Mortgage

Percent sailpower	Fuel saved (gal/yr)	Fuel saved ($)	Net ($)
0	0	0	189,456
10	480	18,301	199,757
20	960	36,602	218,058
30	1,440	54,903	236,359
40	1,920	72,204	254,660
50	2,400	91,506	272,961

No Mortgage

Percent sailpower	Fuel saved (gal/yr)	Fuel saved ($)	Net ($)
0	0	0	630,451
10	480	18,301	640,752
20	960	36,602	659,053
30	1,440	54,903	677,354
40	1,920	72,204	695,655
50	2,400	91,506	713,956

Profitability of the entire operation was greatly affected by the mortgage on the boat. Net cash flow (= operating profit) totalled from $189,456 to $272,961 over the fifteen year period with sail use between 0% and 50%. For the unfinanced boat net cash flow totalled between $630,451 and $713,956, an indication of the interest expense. Tables 7 and 8, respectively, present data on value of fuel saved and net cash flow, given 40% sailpower for the vessel with and without a mortgage.

Table 7. Fuel saved and net cash flow, 40% sail power, mortgage considered.

Year	Fuel saved ($)	Net cash flow ($)
1	2,304	3,015
2	2,304	17,120
3	2,788	17,763
4	3,067	18,358
5	3,373	11,791
6	3,710	19,359
7	4,082	19,746
8	4,490	15,927
9	4,939	20,228
10	5,433	11,299
11	5,976	20,223
12	6,574	19,992
13	7,231	17,770
14	7,954	18,970
15	8,749	29,128
Total	72,204	254,660

SUMMARY

The economy of sail assisted fishing vessels depends on both the environmental conditions that the vessels are to operate within and the types of operations to be carried out. If wind direction or velocities are not appropirate for sail application then investment in sail technology will not contribute to profitability. If sail interfers with the efficiency of the fishing operations decreased productivity may occur whose cost may not be compensated by the fuel savings. On the other hand, investment in sail does not substantially add to the cost of the vessel and can contribute to increased profitability.

Table 8. Fuel saved and net cash flow, 40% sailpower, no mortgage.

Year	Fuel saved ($)	Net cash flow ($)
1	2,304	32,929
2	2,534	42,504
3	2,788	43,623
4	3,067	44,730
5	3,373	38,178
6	3,711	46,884
7	4,082	47,918
8	4,490	44,797
9	4,939	49,852
10	5,433	41,738
11	5,976	51,541
12	6,574	52,260
13	7,231	51,064
14	7,954	53,372
15	8,749	53,726
Total	72,204	695,665

Builder price estimates for motor vessels equivalent to the Aquarian ranged between $75,000 and $88,000. The Aquarian is now available for $94,000 after a $31,000 manufacturer's rebate.

A final point should be made that energy efficiency does not necessarily equal economic efficiency at every turn. Otherwise there would be little production of high priced products such as shrimp, scallops, and swordfish which can provide revenue in excess of the increased fuel involved in their production.