1. INTRODUCTION

The idea of using a wing sail is not new, indeed the ancient junk rig is essentially a flat plate wing sail. The two essential characteristics are that the sail is stiffened so that it does not flap in the wind and attached to the mast in an aerodynamically balanced way.

These two features give several important advantages over so called 'soft sails' and have resulted in the junk rig being very successful on traditional craft and modern short handed cruising yachts.

Unfortunately the standard junk rig is not very efficient in an aerodynamic sense, due to the presence of the mast beside the sail and the flat shape which results from the numerous stiffening battens.

The first of these problems can be overcome by using a double skinned sail; effectively two junk sails, one on either side of the mast. This shields the mast from the airflow and improves efficiency, but it still leaves the problem of a flat sail.

To obtain the maximum drive from a sail it must be curved (or cambered), an effect which can produce over 50% more force than from a flat shape. Whilst the performance advantages of a cambered shape are obvious, the practical way of achieving it are far more elusive.

One line of approach is to build the sail from rigid components with articulated joints that allow the camber to be varied (Ref 1). This approach is claimed to give a very good performance, but suffers from the practical disadvantage that the sail area cannot be reduced by reefing.

(On large vessels, where the rig provides sail assistance contributing only a fraction of total power, this may not be a limitation, but for small vessels designed to exploit sail power to the full, some form of area reduction appears to be vital).

The alternative of a sail which has both camber control and provision for reefing has proved to be a very difficult specification to meet with a practical seagoing solution.

Many extremely complicated systems have been proposed, which whilst they may have worked for their enthusiastic inventors, have not been sufficiently practical to attract wider attention.

The first practical solution to this problem has come from an unexpected quarter. The Cumbewrights had a simple objective, to build the cheapest boat that would take them safely across the Atlantic. They started with no preconceptions and little knowledge of boats or the sea. They talked to people, listened and learnt. Their solution was a 32' catamaran with a wing sail - a wing sail with camber control which they called the Tunny Rig. They realised their ambition, crossing the Atlantic last year without problem. Since then they have proceeded via the West Indies to the Panama canal and so to the West Coast of America.

Their voyage has proved the practicality and seaworthiness of the rig in its prototype form, and their basic concepts are embodied in new versions of the rig being developed by Gifford Technology. This development has taken place over the past 18 months and has now reached a stage where a production prototype is being tested and commercial applications are under serious consideration.
2. PRINCIPLES OF THE TUNNY RIG

The Tunny Rig is an aerofoil wing sail made from a set of shaped battens connected by panels of sail cloth (Fig 1). The battens wrap around the mast, thus forming the aerofoil section, and can be collapsed one on top of the other either for reefing or clearing away the sail.

For almost two thirds of their length the battens are rigid frames, made from thin section timber. The final third of the length comprises detachable, flexible extensions to the main frame, interconnected only by a single tensioned line.

The camber control comes from two lines, one from the end of each flexible section, which are fastened to a cross member in the front part of the batten. By differentially tensioning these lines the batten is warped one way or another, the degree of warp being limited by the tension line joining the flexible extensions.

In the full rig these control lines are tensioned by a common line running down through the sail to over Centre levers on the lower batten (or boom).

3. TUNNY RIG DEVELOPMENT

Building on the Combewrights' original concept the rig has been developed in two phases, comprising the manufacture of a 28m² sail for initial practical appraisal followed by an 18.2m² sail for direct comparative evaluation against other rigs.

Much of the first stage was reported in Ref 2, notably the selection of the aerofoil section for the sail and the simplification of the internal mechanism.

The section chosen was the NASA GA(W)1, a recent product of research into aerofoils suitable for light aircraft. It proved ideally suited to the Tunny Rig for several reasons:

- Relative insensitivity to surface roughness
- Thick section with thickness carried well forward
- Camber largely concentrated in small proportion of the trailing edge
- Good lift to drag ratio coupled with high maximum lift coefficient
- Good aerodynamic properties retained in low wind speeds, i.e. low Reynolds numbers

Figure 6 (from Ref 3) shows the basic lift characteristics of the section at typical sailing boat Reynolds numbers. Figure 2 shows its superiority in terms of maximum lift over other typical sections, in the practical condition of aerodynamically rough surfaces.

The first development rig of 28m² area was built using this section and fitted to a catamaran trials boat (Fig 3). Extensive trials were carried out last summer in a wide range of wind strengths and a great deal was learnt about the general handling characteristics and practicality of the rig.

The positive features demonstrated are:
Low sheet loads. A direct result of the sail area being aerodynamically balanced on the mast as in the junk rig.

Evenly distributed loading. Since the sail does not rely for its shape on being set between attachment points where loads are highly concentrated, the sheet and aerodynamic loads are evenly distributed so reducing the weight and quality of sail cloth required as well as the complexity of manufacture.

Insensitivity to sheet position. Because the sail is self supporting it does not rely upon the direction of the sheet lead for its shape. Consequently the sheet can be taken to points which do not obstruct operation of the boat and which fit best with the overall deck layout, rather than dictating the layout as with many soft sail rigs.

Absence of flapping. The sail cloth is supported by the Tunny battens so does not flog when being raised or as the sail is tacked.

Practicality of reefing. Again in common with the junk rig reefing is a quick and effective process.

Ease of handling. The light sheet loads mean that the 28m² sail can be tended single handed without the need for a winch. Its docile behaviour when hoisting or lowering also makes life much easier for small crews.

Power tacking. An unexpected feature was that because the sail retained drive even when very close to the wind, tacking was a much more reliable process than is normally the case on a catamaran. Provided the sheet was freed off (contrary to normal practice) as the boat was put into the wind the sail would drive the boat round and through the wind.

Close wineded. The lower drag of the rig coupled with its stable shape allows it to be carried very close to the wind.

Camber effective. Trials conducted with and without camber in the sail demonstrated an improvement in drive resulting from the application of camber.

Stern power. By pushing the sail out into a reverse mode the craft can be sailed astern quite simply.

Life is not all gain however and there are of course some negative points about the rig. Compared to, say, a Bermudian rig, the Tunny Rig will always be heavier, though further development and the incorporation of more refined structural details could well reduce the margin considerably.

The other problems which were found on the first rig were largely specific to that particular rig and were rectified for the next 18.6m² version.

Excessive structural weight. In the absence of reliable loading data the Tunnies and the sail cloth were made greatly over strength and thus the rig was much heavier than necessary.
NASA GA(W)-1 Section

Effect of Surface Roughness and Reynolds Number

Effect of Section Shape on Maximum Lift Coefficient

Figure 1

Figure 2

TUNNY RIG ON SANDSKIPPER

Figure 3
Creasing of sail cloth. Due to deflection in the top batten (gaff) the top panel set badly towards the trailing edge. Also it proved impossible to completely eliminate creases around the leading edge, even when extreme halliard tensions were applied.

Over complex lacing. The sail was laced to the Tunnies far more extensively than was necessary, making removal and adjustment very time consuming.

High camber control forces. This problem was linked to the overstrong structure which resulted in the Tunnies being stiff and difficult to deflect.

Damage to control mechanism. The camber lines were tensioned by means of levers on each Tunny. These worked well but suffered damage when the sail was lowered.

Limited rig rotation. Due to the halliard arrangement and the down haul on the boom the rig could not swing out freely to large angles. Since it was finely balanced about the mast the aerodynamic forces were insufficient to force the sail out and thus it was difficult to reduce the drive by simply freeing the sheet.

Lack of visual clues to sail setting. Since the sail did not flap when not set correctly it was difficult to determine visually the best sheeting angle.

No reliable measure of performance. Whilst the sail appeared subjectively to perform well it was not possible to obtain any valid comparison with other rigs by which its true performance could be judged.

4. THE 18.5m² RIG

Choice of Area

As part of a contract with the Commissioners of the European Communities (CEC) Gifford Technology had carried out a series of comparative sailing trials using four different rigs, each of 18.5m² area (Ref4). Accordingly it was decided to build a Tunny Rig of this same area which could be evaluated in the same way, thus giving a measure of its performance relative to other well known rigs.

Aspect Ratio

Having fixed the area it was also decided to increase the aspect ratio by a moderate amount to a value of 2.0. This is still far from the most efficient shape for the very best performance to windward, but a reasonable compromise for all round performance when heeling moment and structural considerations were taken into account.

Planform

Theory indicates that the elliptical planform is the best from the point of view of minimising the induced drag of the rig. Practically it is far from ideal since each Tunny must be a different length, thus greatly complicating manufacture. Similar considerations apply to a triangular shape, which is also a bad shape aerodynamically.
These lines of reasoning led to a rectangular planform, which particularly when associated with a squarely cut off tip, gives virtually the same performance as the elliptical shape. The final refinement was the cutting back of the top batten to give a small amount of taper and to eliminate the creasing in the top panel.

Using information in Refs 5 and 6 predictions were made of the induced drag for different planforms and it was found that the penalty associated with adopting the practical rectangular planform was negligible, as compared to the "ideal" ellipse.

**Detailing**

In addition to these basic design considerations a number of detail changes were made, mainly as a result of the negative features found on the 28m² rig.

**Lightweight Structure.** The size of the timber used for the Tunnies was reduced from 90mm x 18mm to 40mm x 12mm. For reasons of economy solid redwood timber was used and further weight savings could be made by using laminated timber construction.

**Lightweight sail cloth.** Cloth weight was reduced to 4½ oz.

**Lacing arrangement (Figure 4).** The number of lacings on the intermediary Tunnies was greatly reduced and a revised system adopted for the top and bottom which makes adjustment of the sail much easier.

**Detachable battens.** The flexible sections of the Tunnies were made detachable so that they could be readily replaced if damaged. They were sleeved into the sail in the same manner as conventional sail battens, so further reducing the need for lacing.

**Harp String Warping (Fig 5).** Instead of using levers on each Tunny for tensioning the warping lines a harp string approach was adopted. This does not give quite such a good mechanical advantage, but offers significant gains in simplicity and a reduction in weight.

**Floating Ribs.** To give a smooth shape around the leading edge intermediary 'floating ribs' were fitted to the sail.

**Mast Crane and Collar (Figure 6).** To ensure that the sail was free to rotate the halliard was lead from the mast head via a rotating crane and the boom restrained by small wheels bearing against a collar on the boom.

5. **THE TWIN TUNNY RIG**

In parallel with the development of the Tunny rig a 28' double hulled fishing boat was being developed for a beach fishing project in Sri Lanka (Ref 7).

For a good sailing performance in tropical conditions a sail area of 37m² was considered necessary and a design exercise was undertaken to examine the possible rig alternatives.
Lacing Details

Figure 4

Warping System Development

Figure 5

Sail Swivelling Arrangements

Figure 6
The traditional rig that could be used was the lateen, which though a practical and culturally acceptable option, was not expected to give a very good performance. Also the size of the spar required would become difficult to stow on the boat and vulnerable in surf. Similarly there were likely to be problems with spar size if other rigs such as the sprit or bermudian were carried on a single mast. Within the length of the boat the idea of splitting the rig to give a ketch or schooner layout proved impractical - the rigs would be so close together as to interfere a great deal and much of the double hulled advantage of deck area would be lost. Finally a centre line position for a mast introduced additional structural loads on the cross beams and practically precluded the possibility of using unstayed masts.

The solution adopted was to place the masts side by side, one in each hull. It was immediately apparent that this gave many worthwhile structural and layout advantages and potentially good aerodynamic performance.

Figure 10 shows that 8.5m boat fitted with two 18.5m² Tunny rigs (though the layout is not rig specific and could be made to work well with other single rigs suitable for unstayed masts).

The advantage of this layout over a single central rig are considerable:

Lower centre of effort height.

Less weight aloft giving lower centre of gravity and lower pitch inertia.

No obstruction to bridge deck for handling nets.

Absence of rigging and the associated point loadings.

Cross beams do not have to be reinforced to take mast compression.

In Figure 9 the two rigs are overlaid and the differences are visually very apparent. The other appealing features of this layout when compared to a fore and after disposed twin rig are:

Masts can be buried into the hulls and thus unstayed if required.

Close hauled performance is likely to be much better (though not quite as good for a single rig).

Reaching performance is potentially very good due to the slot effect that can be created by working the two sails together.

Down wind additional sail area can be set between the two masts.

The boat remains balanced with only one rig set, so reefing can be readily achieved by dropping one complete sail. Also the single sail rig is useful where only low thrust and fine control are required.

Most of these points are illustrated by the various insets in Figure 7 and 8.
Performance Predictions

Using a computer program specially developed for evaluating the effects of different rig and hull characteristics a series of polar performance predictions were made. Figure 9a shows three of the results obtained. Figure 9a illustrates the correlation between the theory and experimental results obtained for the bermudian rig tested on a Sandhopper trials craft during the CEC trials. It can be seen that the prediction is within the scatter of the full scale results and can thus be considered an adequately reliable tool, particularly where emphasis is placed upon relative performance comparisons.

For Fig 9a the hull data was obtained directly from trial results and rig data from wind tunnel tests at Southampton University (Ref 8).

For the predictions of the SK28 performance no direct test data was available for the hull. However, tank test data for the 20' craft of very similar proportions was available, as was full scale thrust data for the SK24, a craft even closer to the proposed SK28. Figure 10 shows these two results plotted non-dimensionally and Figure 11 is the prediction made from them for the SK28. Finally a check was made using the excellent prediction method of Gerritsma (Ref 9). Also on Figure 11 is the thrust curve measured during the CEC trials for the 13.5 HP Deutz diesel, the engine proposed for the SK28.

Rig data could not be established quite so reliably and various assumptions had to be made so that conventional aerodynamic theory could be applied.

The first stage was to construct a polar curve for an AR=2 Tunny rig. For operation up to the point of stall standard aerodynamic theory was used to correct the wind tunnel data of Ref 3 to finite aspect ratio and the planform and tip shape of the proposed rig. Then using other rig data and information from Ref 6 a drag coefficient of 1.2 was deduced for the foil set normal to the flow and a smooth curve fitted between that point and the stall point. This approach may not give a very reliable estimate of the foil performance just beyond stall, but the prediction program indicated that the optimum angle for the rig seldom exceeded the stall point except on direct down wind courses. Thus the errors resulting from the inprecision are likely to be very small. The resulting rig polar is shown in Figure 12.

For the twin tunny rig a biplane correction factor was applied to the results up to the stall point (this was applied as a virtual reduction in aspect ratio and hence increase in induced drag). Beyond the stall point it was assumed that the sails were set to give beneficial mutual interaction which at large angles of attack could give a peak lift coefficient similar to that of a flapped aerofoil, i.e. around 2.4. In the down wind condition the drag coefficient was corrected to incorporate the effect of adding extra area and the vague intermediary part of the data fairied in. This result is also shown on Figure 12.

Finally using similar methods a rig polar for a Tunny sail fitted with a notional flap was also constructed.

Figure 16 shows various rig polars from other sources with the twin Tunny prediction overlaid for comparison.
Figure 9 a

Figure 9 b

Figure 9 c

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Using this data and Southampton University data for Bermudian sails (Refs 8 and 10) a range of performance predictions were made. Two of the polar curves are shown in Figure 9b and 9c and the results of the full set of runs summarised in Figures 14 and 15.

Figure 14 compares the performance of the four different rigs in 12 knots of wind (a typical tropical breeze). For each rig three different speeds are shown:

- Speed made good to windward.
- Maximum reaching speed (generally with true wind angles of 90° to 100°).
- Down wind speed (true wind angle of 180°).

To windward the Bermudian sloop has a slight advantage over the others, showing a Vmg of 4.5 knots against 4.2 for the twin tunny and 4.3 for the single tunny.

When reaching the twin tunny and the tunny with flap gave the best performance and downwind the twin tunny is fastest of all, due to the additional area assumed to be set between the masts.

On all points of sailing the speed through the water exceeds 5 knots, and when reaching it is greater than 7.5 knots. This compares favourably with the maximum speed under power of 7.8 knots and suggests that lack of speed will not be a large disincentive to the use of sail.

The results in Figure 14 are for a wind strength where even for the tall single rigs an adequate stability margin remains.

With increasing wind speed the sail area must be progressively reduced - the limiting stability point of flying a hull occurring in 19 knots of wind with the single sail rigs and 21 knots with the twin tunny.

Figure 18 compares the performance of reefed rigs. First, in 18 knots of wind a single small Tunny (i.e. twin rig with one sail dropped) is compared to the sloop rig with a deep reefed mainsail. The step function change in tunny rig area results in a slightly inferior performance, but the difference is not more than 10%.

In stronger winds (25 knots) a comparison is made of the single Tunny with a mainsail only Bermudian rig. Under these conditions the Tunny rig is superior on all points, but again the margin is small.

The single Tunny can theoretically be carried in winds of 30 knots, but the option of reefing that sail remains if continued operation under sail is required in still stronger winds.

From these comparisons it can be seen that twin Tunny rig has a good performance potential, which coupled with its convenient layout and ease of handling makes it a very attractive rig for small commercial boats.

6. ECONOMIC ANALYSIS OF SAIL ASSISTANCE

Particularly at an early stage in a project it is very difficult to make valid economic forecasts of sail assistance projects. There are two distinct (but in some senses connected) sides to the equation; on one side the capital investment and running costs for the rig, on the other
Figure 14

RIG PERFORMANCE COMPARISON
SK28 HULL TRUE WIND=12 Knots
- Speed made good
- Reaching
- Running

SAIL AREA=37 sq.m

SPEED (KNOTS)

TWIN TUNNY
BERM. SLOOP
TUNNY
TUNNY +FLAP

Figure 15

RIG PERFORMANCE -REEFED
SK28 HULL TRUE WIND 18Kts & 25Kts
- Speed made good
- Reaching
- Running

SPEED (KNOTS)

Ut=18
Ut=18
Ut=25
Ut=25

TUNNY
SLOOP
TUNNY
SLOOP

18.5m²
25.0m²
18.5m²
18.5m²

* Mainsail only
the fuel saving that will result from the use of the rig. The capital side is relatively straightforward, though maintenance costs will tend to be very dependent on actual operational conditions. The problems come when the other side is tackled. Difficult questions immediately arise:

How many hours per year will be rig be used

What is the minimum speed acceptable

Will motor and sail be used together

Will the use of sail influence the fishing strategy

Does sail allow more fishing trips to be made (i.e. say cases where fuel was previously unavailable)

The combination of all these unknowns must make very unreliable any attempt at a single answer for the amount of fuel saving that will result from the use of the rig.

Fortunately if computers are available to do the donkey work it is a simple matter to examine a range of different cases and so get a feel for the sensitivity of the economics to the different variables. From this it is possible to make reasonable judgements and answer "what if" questions.

To demonstrate this approach the ITIS/Giffords Sandskipper project in Sri Lanka is taken as a basis. Two 7.3m double hull Sandskipper fishing boats are currently working in Sri Lanka, soon to be joined by a larger (8.5m) boat. Using data from the present operation a prediction of the economic performance of the new boat was made. The method used is a full discounted cash flow over a ten year period (a conservative life for the boat). Figure 16 shows the result for a datum condition. An internal rate of return (IRR) of 96% is indicated. For more details of this prediction and the assumption with it, see Ref 7. The techniques used for the analysis are well described in Ref 11.

To investigate the potential for sail assistance the analysis was rerun for three different conditions to give a range of rates of return. In each condition the capital cost of the rig was adjusted to maintain a constant IRR.

Figure 17 shows that at IRR of 108% an expenditure of roughly Rs 500 is justified for each percentage point of fuel saving. Since the operational experience reported for other sail assist project indicates that fuel savings in the range of 10% to 30% are practical, the capital outlay on a rig can be Rs 8000 to Rs 20000. (Rs 20000 being already allowed in the datum condition). For projects where a lesser rate of return is acceptable greater capital expenditure can be justified.

No cost for the Tunny rig in Sri Lanka is currently available, but it is known that a lateen rig of similar area would cost only Rs 2000. Even assuming a fourfold price differential the Tunny rig would only have to provide a 10% fuel saving to earn its keep. Experience suggests that this will be an easy target to meet, thus giving great confidence that the twin Tunny rig could provide economic sail assistance in this project.
Figure 16

SANDSKIPPER 28 IN SRI LANKA
PREDICTED ECONOMIC PERFORMANCE

Displaced Cash Flow Analysis

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Total: 22500.00

Discounted Value: 1500.00

Capital Value: 162.35

Figure 17

Capital Value of Fuel Saving

At Constant Internal Rate of Return
REFERENCES


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A MICROCOMPUTER-BASED INSTRUMENTATION PACKAGE FOR ON-BOARD WIND-ASSIST MEASUREMENTS

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ABSTRACT

Described is an inexpensive instrumentation and data logging package applicable to performance measurements of wind-assisted commercial vessels as well as sailing yachts. Power is supplied by small dry cell batteries to a CMOS technology lap computer: The Epson HX-20. Data are logged on the self-contained microcassette tape. Sensors are used to measure and log data on: apparent wind speed, apparent wind direction, vessel speed through the water, hull leeway or yaw angle and angle of heel. Experimental runs are plotted and errors discussed.

INTRODUCTION

This work was preceded by the earlier development of a microcomputer data acquisition package using an Apple IIe microcomputer, 12 volt marine storage battery, inverter and a $4000 Cyborg Isaac plus sensors for a total instrumentation expense of about $10000. The work was concluded successfully and has been reported in detail. (1)(2) Earlier work in this field is described in References (3) and (6).

With little time or monies available, it was decided to attempt to develop an inexpensive set of instruments to accomplish the same functions... The object was to measure the following parameters aboard sailing vessels and yachts: boat speed through the water, apparent wind speed, apparent wind angle, yaw or leeway angle and heel angle. In addition, earlier work used a roll monitor from Ocean Motions Company to record metacentric height — changes in vertical center of gravity. A diesel fuel flow sensor was also obtained from that company.

This series of experiments was conducted to measure the first five parameters listed above and do so inexpensively with low battery drain equipment. The CMOS technology Epson HX-20 notebook computer with rechargeable, low current drain batteries proved ideal. It is thanks to Chet Swenson, Marine Engineer, whose idea this was and the generosity of Epson America Corporation, that we were provided with this beautiful small computer. Total cost including computer, analog to digital converter box and sensors was about $1600. This could be reduced to $1300 by successful junkyard scavenging to measure the first five parameters listed.

There was only time for one day of data acquisition with this new package. As in almost all experimental projects, one problem occurred which was not evident until after the experimental day: boat speed was measured but not recorded! There was no time for a repeat series of measurements, and the data presented here are thus incomplete.
EXPERIMENTAL EQUIPMENT

The series of four photographs in Figure 1 show the 19 foot modified Cougar catamaran used as a test bed for these and earlier experiments. The sensors are mounted on an aluminum pipe well forward of the sail plan in clean air and water on all points of sailing except running. See Reference (2) for a thorough discussion of this arrangement. The wind sensors shown here are from Kenyon Corporation. The wind was heavy that day—hence the double reef in the mainsail and the generally poor sail set. Figures 2 and 3 show the instruments.

The computer and analog to digital box were housed in an attache case. The coffee can contains the joystick with a plumb bob mounted on the stick. The aluminum pipe pierces the water and holds a hydrofoil-shaped foam and fiberglass instrumentation housing for the water speed paddlesensor. A two-dimensional hydrofoil blade of five square inches senses leeway angle by turning in a set of bearings and shafts taken from an old bicycle steering column. The instrumentation plate is a steel bookshelf with holes for mounting all equipment including the roll monitor not shown here.

Figure 4 presents a block diagram of the instrumentation package showing the general arrangement of computer, analog to digital box and the sensors. Note that two heel angle inputs were taken. There were two potentiometers on each of the two axes of the joystick, and signals were taken from two of these for comparison.

EXPERIMENTAL PROCEDURES

Data was acquired at 4800 baud, and it was tentatively found impossible to increase the rate. Three hours of data fit on one side of a 30 minute microphone tape, and 2400 sets of data were logged in that time. Thus, each set of data took approximately 4.5 seconds. Of that time, the one digital input: boat speed, took 3 seconds. Yaw angle, wind speed, wind direction and the two heel angle measurements each took about 0.3 seconds. Courses were sailed from zero to 180 degrees, on port and starboard tacks. Wind was gusting to 18 knots or so.

Unfortunately, there was not time to back-calibrate the wind speed sensor, so that raw data has not yet been analyzed. As noted above, boat speed was not logged due either to corroded or loose electrical contacts or to salt water entering the potted knotmeter sensor case. Cracks were noted in the potting compound after the test. In the Reference (1) and (2) tests, a strobe light was used to pre-calibrate the paddle wheel sensor.

COMPARISON WITH ANALYTICAL METHODS OF PERFORMANCE PREDICTION

There have been various successful attempts to measure or predict sailboat performance. See references (4) through (15) for examples. Data were taken from the earlier experiments (1)(2), and are plotted in Figures 5 and 6. A towing test of the catamaran test bed gave good drag figures for the fouled hull used during those experiments. A quadratic equation was fit to the data and provided resistance information for entering the performance prediction computer program. (3) Results from the computer program are shown as crosses and circles in circles in
Figures 5 and 6. The experimental data clearly show the differences in sailing this particular craft on port and starboard tacks. Most sailing vessels will sail better on one tack than the other. Although measured, leeway angle was not included here. That would shift the early part of the experimental curve to the left. Leeway angle directly reduces apparent wind angle and thus true wind angle is also reduced by the usual trigonometric relationship. (10)(11) Another shift to the left would occur from a cleaner hull bottom and more experienced helmsmanship. Pinching is clearly evident when close-hauled. Thus, the analytical and experimental curves would then tend to agree even more than is shown in the figures.

The experimental points in Figure 5 are the result of intensive statistical analysis as discussed in detail in Reference (2). Each point represents many individual measurements. The vertical bars are 95% confidence limits which give a measure of consistency in the data. In Figure 6, a sixth order polynomial was fitted to the mean data after some experimentation. (2) A spline fit might have been better. This emphasizes even more clearly the differences in the close-hauled condition as discussed above.

EXPERIMENTAL PROBLEMS AND RECOMMENDATIONS

The computer and analog-to-digital box required protection from salt water while in an open boat on a windy day. The attaché case used was helpful, but a permanent case with transparent window and an RS-232 socket in the case would be preferable. Perhaps a sealed, membrane keyboard would be an improvement. Much salt water corrosion of the mechanical parts was noted a few days after the test run. Salt water resistant materials should be used. Voltage dropping resistors on the instrumentation platform were also corroded and need to be in water tight enclosures. There was considerable noise in the signals leading to variations in data obtained when such should have been constant. The reason for this is as yet unknown to the authors. Speed of reading the digital data inputs was limited by the use of BASIC and could have been much improved had there been time to write that routine in more efficient language. A much preferable solution would be to ensure that all inputs are analog. Simple, rugged and accurate boat speed sensors have been constructed with Simerl generators and paddle wheels. (15)

There were serious problems with battery drain, although one 6 volt lantern battery was used. The analog-to-digital box uses only 50 ma. and the port will handle 6 to 24 volts. The sensors were relatively heavy current users, especially the boat speed paddle wheel, and battery voltage dropped from 6.7 to 5.35 volts after five to six hours use. The voltage dropping resistors used with the analog sensors also consumed power. The voltage drop led to erroneous readings. A separate battery pack will be necessary perhaps with a zener-regulated supply.

CONCLUSIONS

This brief project was successful in terms of proving the practicality of inexpensive computer-aided data acquisition for performance measurements of sailing craft. It is unfortunate that data was not recorded from the key sensor: that for boat speed. It was very easy to program and use both the Epson HX-20 and the ADC-1. Technical
advice from both companies was excellent as was their willingness to
discuss problems and suggest solutions. The package ran at sea for over
dive hours with no problems.

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EPSON HX-20

PRINTED

LCD SCREEN

TAPE DRIVE

KEYBOARD

RMS ADC-1

BOAT SPEED

6 V. BATTERY

ANALOG INPUTS (16)

WIND SPEED

WIND DIR

HEEL ANGLE

HEEL ANGLE

YAW ANGLE

VA

\( \beta \)

\( \theta \)

\( \delta \)

\( \lambda \)

BLOCK DIAGRAM
INSTRUMENTATION
PACKAGE

FIG. 4
Boat Speed vs. True Wind Direction

- Measured Averages
- 95% Confidence Limits
- Predicted Model

True Wind Velocity - 14 Knots

Fig. 5
BOAT SPEED VS. TRUE WIND DIRECTION

SOLID LINE - CURVE FIT TO MEAN DATA
6TH ORDER POLYNOMIAL

+ ANALYTICAL MODEL PREDICTIONS

Fig. 6
DESIGN AND TESTING OF A FISHING VESSEL WITH COMBINED MOTOR/SAIL DRIVE FOR THE ARTISANAL SMALL SCALE FISHERY OF SIERRA LEONE

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Abstract:
Rising fuel prices during the last twelve years made it necessary to reduce the fuel consumption of fishing vessels especially in developing countries. To replace gasoline outboard engines used in the artisanal fishing fleet of Sierra Leone, by diesel inboard engines of considerably lower fuel consumption, major changes in design and construction of the traditional fishing crafts were needed.
An 11 m V-bottom boat driven by a 30 HP diesel engine and a standing lug rig of 49 m² was designed and tested. From the results it can be seen that the new type of fishing boat can be used successfully in the small scale fishery of Sierra Leone.

Since 1980, the Fisheries Pilot Project Tombo (FPPT), a German development aid project of “Deutsche Gesellschaft für Technische Zusammenarbeit” (GTZ), is engaged in developing the artisanal small scale fishery in Tombo, Sierra Leone.

There are two main fields of activity in this project:

1. Improvement of the fishing technology of local fishermen.

2. Introduction of improved types of fishing boats.

Local traditional fishing crafts cover a wide range from small 6m-dugouts driven by paddles to 18 m Ghana-type planked canoes driven by gasoline outboard engines with a power up to 40 HP (29.8 kW).

High fuel consumption, frequent repairs, and short life time make these outboard engines one of the most expensive parts of the fishing equipment. All these problems could be solved by introducing inboard diesel engines, but this cannot be done without major alterations in hull shape and constructional details of the traditional canoes.

For these reasons, the FPPT started the design of a V-bottom boat, based on a type which was developed by the FAO in 1974.
The main dimensions of this new design are:

- Length over all: \( \text{Lo.a.} = 10.90 \, \text{m} \)
- Length between perpendiculare: \( \text{Lpp.} = 9.85 \, \text{m} \)
- Beam moulded: \( B = 2.80 \, \text{m} \)
- Depth: \( D = 1.10 \, \text{m} \)
- Draught: \( T = 0.60 \, \text{m} \)
- Displacement: \( \Delta = 6.60 \, \text{m}^3 \)

The body plan is given in Fig. 1.

The boat is driven by a Yanmar Diesel Engine 3QM 30 of 30 HP (22.4kW) at 2600 rpm with a reduction gear of 2.21 : 1. The 3 blade propeller has a diameter of 460 mm and a pitch of 330 mm.

For the rig a standing lug sail of 34 m² was chosen with an additional jib of 15 m² (Fig. 2).

Calculating the sail area/displacement ratio

\[
T_s = \frac{2 \sqrt{A}}{3 \sqrt[3]{\Delta}}
\]

\( \Delta = \text{sail area} \)

\( \Delta = \text{displacement} \)

we find \( T_s = 3.73 \). This corresponds to values of \( T_s \) published by Timmermann [2].

Mast, boom, and yard were made out of bamboo giving high strength at low weight.

Speed tests were performed in November '83 at the Yawri Bay, south of the Freetown peninsula. The boat's speed was measured by means of a Dutchman's log and a stop watch. To measure the wind speed, a cup anemometer was available.

At full engine power, a mean speed of 8 kts was obtained at a displacement of 5.1 m³. With less displacement (3.0 m³) the speed increased to 8.6 kts. Speed measurements when sailing were more difficult because of the low winds prevailing during this time (October - December) at the coast of Sierra Leone. Only few data could be obtained which should be completed at times of better wind conditions. Sailing on a course broad reach to down wind, a boat's speed of \( v = 2.4 \, \text{m/s} \) (4.6 kts) was measured at a wind speed of \( u = 5 \, \text{m/s} \).

Rolling tests were performed to check the initial stability of the boat. With a rolling period of \( T_R = 2.5 \, \text{s} \), a metacentric height of \( \text{GM} = 0.56 - 0.65 \, \text{m} \) was calculated according to the formula

\[
\text{GM} = \frac{(\pi \cdot B \cdot C_r)}{T_R^2 \cdot g}
\]

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Cr = 0.79 - 0.85
B = 2.34 m (beam at waterline)

The last test of this series was a one day fishing trip with a local crew of 15. The crew experienced in using an 18 m outboard powered canoe, had no problems to handle the gear. a traditional ring net, aboard this new type of boat. Shooting and hauling the net was done in about the same time needed on a traditional Ghana-canoe for these operations.

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Figure 1. V-Bottom Boat, bodyplan

Figure 2. V-Bottom Boat, sail arrangement
A PROGRESS REPORT
WITH SPECIAL REFERENCE TO
A 30.5 M FISHING CATAMARAN

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1. Introduction and background

An earlier paper presented at last year's International Conference on Sail-Assisted Commercial Fishing Vessels in Florida, USA in May 1989 gave the overall background to our project, some historical information, and a broad overview of what we are trying to achieve with respect to commercial craft of all types. Since then we have consolidated rather effectively, obtained major venture capital funding and filled in many of the grey areas in our technological knowledge. We have completed the design of a nominal 100 sq. m. triplane thrust unit, which we call the Module 2, and we are in the exciting early stages of manufacture of the first prototype.

2. Aerodynamics

We decided that, even though we had a very great deal of aerodynamic information about both single and triple aerofoil combinations, we needed to build a 1/10 scale wind tunnel test model of the actual Module 2 complete in every detail. This quite large device was too big to fit into the Markham tunnel at Cambridge University Engineering Department, which we had used so effectively for most of the earlier runs, and we therefore made arrangements to test it in the large 2 Megawatt No. 4 wind tunnel at British Aerospace at Filton near Bristol. By an odd coincidence this was where I had started my aero-engineering career some 15 years before.

The model is suspended in the conventional way, Fig. 1, horizontally in the tunnel and lifting downwards, with an upstream projecting sting linked to a vertical wire controlling the model in angle as well as measuring the turning moments about the main suspension points. We have now done three separate series of tests at Filton on this model with both zero flap and full flap conditions, tail on and tail off and over a wide range of Reynolds numbers, and feel that we are getting to grips extremely well with the complex aerodynamics of high performance triplanes.

The last time that any work was done on triplane aerodynamics in any serious way was of course before the 1st World War, and we have found that to be only of marginal relevance in 1984.
The tests have confirmed that we can control the triplane very satisfactorily in the CL = 2.3 to 2.5 range, accepting of course that the triplane CL max. will inevitably be lower than the CL max. obtainable on a single aerofoil. This is because of interference between the three planes, which in some ways is beneficial, delaying stall and therefore improving the trim tolerance of the device; in other respects being detrimental, in that the actual overall thrust per sq. m. is marginally degraded. We have also simulated the storm survival case where the wingsail must weathercock in winds up to 75 m per sec, something of the order of 150 knots, neither damaging itself nor putting the vessel into any kind of danger or discomfort. The results are all quite favourable, and no modifications to the design as it progresses have been forced by aerodynamic constraints.
3. Structures

The design of the triplane has moved ahead very strongly in the months since we were writing last May, and we now have a very clear idea of the best way to build the type of structure envisaged. We have settled upon a standard 400 sq. ft. square rolled hollow section steel central spar up the middle of the centre wing, carrying the entire bending moment of the sailset, and mounting the entire triplane down onto a standard off-the-shelf slewing ring type rotating bearing, very similar to the ones which give extremely reliable service underneath small and medium-sized earth movers and diggers. This central spar is clad with streamlined reinforced plastic aerodynamic surfaces, and supports a pair of cross-axes structures which carry the outer wings, Fig. 2.

The outer wings are of identical profile to the central wing, but have a much lighter spar structure, since they only have to support their own bending moments and communicate their thrust onto the central spar through the cross-axes. Hinged onto these three wings, the outer ones of which are set slightly forward in a symmetrical staggered configuration, so as to trim the net centre of pressure to a suitable position, are three flaps. These are all very nearly identical, although the centre one has slightly stronger hinge structures which react the hydraulic loads from the hydraulic actuating cylinders and also drive pushrods which cause the outer flaps to move in unison with the centre flap. We have two hydraulic cylinders operating the centre flap working in harness, arranged so that in the event of one failing due to a burst hose or a leaky seal the other will still be able to carry the load.

Supported downstream of this high thrust triplane is the tail vane, which is full height and is slightly longer in chord than either the main wing or the flap. It is again supported at two points by triangulated bracing struts and is again operated by two hydraulic rams for safety and reliability, even though they are considerably smaller in size and thrust rating than the ones which operate the main flaps.

The general structure of the triplane, apart from the steel central spar which we have already mentioned, consists of a reinforced plastics D-box leading edge with moulded ribs leading back from the D-box to a trailing edge in a fairly conventional aircraft style of construction, with all the lightly loaded panels covered in a specialist American aircraft covering material called Ciconite. This is a heat shrinking self primed material and we expect it to give extremely good performance at moderate cost, with the ease of repair of minor rips and defects using readily available on the spot methods.
Ahead of the triplane on a short stub pointing upstream from the central steel main spar is a balance weight which provides static and dynamic balance for the rig as it pivots and weather cocks on its free bearing, using a balancing principle pioneered by Utne in Norway in the late 1930's. Earlier in the project we believed that we would need an "upstream stalling vane" which was shown on our earlier illustrations and photographs. This is because when you fully stall this type of triplane with a downstream tailvane the vane finds itself in a low energy eddying wake from the central sail. In the wind tunnel we had found that a very slight and mirror imageable asymmetry was perfectly capable of giving us reliable in-stall drag moments as soon as the peak of the lift curve was passed, and we have therefore eliminated, at least from this particular design, the upstream stalling vane.

4. Computer System

The computer system is necessary for any economy device such as our own because for a vessel to work, whether she be a tanker or a fishing boat, she must have her crew available to do the work for which they are trained and needed. If we install such vessels an economy device which increases the crew loading, either in terms of overtime payments or actual extra crew members, then we are taking away at one sweep much of the benefit which we are able to bring to the owner and operator of the craft by fitting the economy device in the first place.

We therefore equip the wingsail with a 3 position switch for "On, Ahead"; "Off, locked and isolated" and "On, Astern" and 3 lights, one being green for "all systems on and operating"; one being amber for "a fault has occurred but redundancy is coping and the unit is still in operation"; and a red light indicating that there is a fault present which the redundancy system has not been able to correct and that therefore the system has been shut down, all vanes brought to central, and is weather cocling with small drag and no cross wind force.

The computer is based upon the well known Zilog Z80 chip, made most famous perhaps by Sir Clive Sinclair with his ubiquitous range of computers for the everyday. Fig. 9. The unit takes information from several transducers. It receives information from a vane mounted on an instrument strut extending upstream of the unit, at the angle of the wind to the centre axis of the wingsail, and it takes information from a potentiometer which reads the angle of the sailset to the centre line of the ship. From these two inputs the computer can know at all times both what the angle of the apparent wind to the sailset is and what the angle of the apparent wind to the vessel centreline is. From the angle of the apparent wind to the vessel centreline the computer decides whether to set the unit into one of four modes:-

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- If the wind is coming from within 20 deg. either side of the vessel's centreline from ahead, the computer knows that there can be no benefit obtained by switching the sailset on and it therefore either maintains the weather cocked state, or it brings it to the weather cocked state if this circumstance has just arisen.

- If the apparent wind direction is between 20 and 60 deg. to the vessel's centreline, the computer knows automatically upon which tack the vessel is and it sets the sailset up correctly for that tack and for optimum lift/drag ratio.

- If the wind is between 60 and 135 deg. to the vessel's centreline the computer sets maximum thrust.

The computer also receives information from an anemometer which tells it whether the wind is too low to provide significant energy, at 3 m/sec. or approximately 9 knots; whether it is in the working range of 5 to 20 m/sec.; and whether it is in the over 20 m/sec. range, where there is statistically very little energy available on a year round basis from these higher winds. It therefore, for a further 5 m/sec., reduces the output thrust, and after 25 m/sec. it reduces the output thrust down to zero by going to mode 1.
So we have mode 1 which is the wind ahead case, mode 2 for close reaching and close hauled on either tack, mode 3 for reaching and broad reaching on either tack, and mode 4 stalled, the spinnaker mode, for running downwind.

The next set of activities which the computer performs is the monitoring of the relative health of the various items in the system, so as to check whether the electrics, hydraulics, structure or computer are functioning as they should. In some cases there is available redundancy and the unit may still continue in the presence of a fault either at full or reduced efficiency. In the event of a fault which cannot be coped with by redundancy the computer will return all vanes and flaps to central, close everything down electrically, spring loaded pins locking all in-line for safe long-term weathercocks.

We at first thought that all this was going to be quite a difficult set of problems for a computer to solve. However, due to the advanced state of knowledge in the modern micro computer field, we have discovered that a simple low cost unit can be made up which will perform all of these functions, and which would probably have spare time to play Space Invaders in between whiles, if it felt so inclined.

5. Hydraulic System

The vanes and flaps are all moved from the central positions to their operating positions and back again, as we have already mentioned, by modestly sized hydraulic cylinders, some single acting with spring extension for locking purposes, and some double acting. These are all controlled by a set of solenoid operated spool valves arranged in a fairly complicated circuit designed to provide fail safety.

The logic of the circuit has been sketched out briefly above in the section on the computer system. The system receives a set of impulses and commands from the computer system:— for example when starting up with the wind between 20 and 60 deg. on the starboard bow, the hydraulic motor provides a pressure of 200 bar, approximately 3000 p.s.i., charging up 2 small hydraulic accumulators. The system will then hydraulically withdraw all the locking pins from the flap and vane system and push both flap and vane over to their full angles of action. Then it will allow re-entry of the flap locking pins to hold the flaps at full extension, and respond to the commands of the computer in controlling the vane so as to maintain the optimum lift/drag ratio of the main triplane, with Cl about 1.2.

If the wind direction relative to the centre line of the ship changes into the 60 - 185 deg. sector, the computer causes the tail vane to look for a different operating position, seeking now for maximum thrust.
6. Installation on 30.5m Catamaran fishing craft

We are very interested indeed in fitting an early standard Module 2 unit to an approximately 30.5 m catamaran fishing craft. Fig. 4.

Such a vessel would have about 14 metres of beam, and provide an excellent stable working platform with large deck area for handling nets and catches, a high sprint speed for getting to and from fishing grounds with minimum loss of time, while capable of completely silent and vibrationless trawling and line hauling.

We are convinced that a quiet fishing boat must be likely to catch more fish than a noisy and vibrating fishing boat beating the water with propellers, although we should of course be very happy to receive the opinions of the experts on this subject.

The installation should present no particular problems:-- we have taken a standard "Fjellstrand" design as used extensively around the Scandinavian coast and as oil rig service boats in the North Sea, and simply widened it by the addition of a parallel section to take the beam out from approx. 9 m to approx. 14 m.

We believe that this would not in any way degrade the seakeeping and other characteristics of the vessel as a power craft, be fitted with twin diesel engines and fully feathering controllable pitch propellers (a system which is already well proven in this class of vessel in any case). We believe that she will represent, either in steel or in welded light alloy a practical and cost effective vessel for medium offshore fishing purposes. We shall be very happy indeed to take this proposal, which at the moment is only at the scheme design stage, through to a stage of full analysis with any seriously interested parties.

If the wind goes round to astern, then the vane will extend to full angle to stall the main sailset.

At any time if there is a fault, or if the wind drops too low, or if it rises too high, then the electrical power to the hydraulic system is cut, main system pressure drops and hydraulic reservoir pressure is used to pull out the flap lock pins, return flaps and vane to centre, finally allowing the re-entry of flap and vane pins.

All this must be completely automatic since in storm conditions the last thing needed would be a human input to the system, especially on a small craft.

Because of the way that the system has been optimised, all the valves and components are small, at international CETOP 3 size, with 1/8 inch bore piping in most cases. The repair and replacement of elements which may have failed is therefore a modest and economical task.
We are at the moment building, as we have said, the first prototype Module 2, and by the time that this paper is presented the main triplane wing elements will be complete and the first wing ribs will be coming through from the sub contractors ready for installation and fabric covering. Figs 5 and 6.

Completion and first trials are scheduled for Mid-September 1984, and we hope that by that time we shall have made not one but many contacts among people who either attend The International Conference or who read the proceedings, so that if our products could make a cost effective contribution to their activities, then we shall not miss any opportunity to put forward proposals, have discussions, and eventually negotiate contracts.

FIG. 5.

FIG. 6.
EASILY HANDLED RIGS FOR
FISHING VESSEL SAIL ASSIST

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ABSTRACT

Once one has successfully mechanized sail handling it is relatively easy to automate it electronically.

Luff roller-furling of soft sails is the best way to set, reef and furl sails. A crane-boom whose rotation is cantilever controlled (that is not free pivoting as all booms have been) is the best way to sheet sails. Crane-booms free the rails and deck and are safe and very easy to handle.

INTRODUCTION

If the average fisherman is asked: do you want sails on your fishing boat most will answer "No!". Their negative answer is because they have never seen a truly well equipped modern sail assisted fishing boat. They do not realize how extremely little sail handling would be required. The truth is that none yet exist although right now such a vessel could be built. This paper tries to explain some important rig, sailplan, and deck machinery features of such a super-modern fishing vessel.

ADVANTAGES

A fishing vessel with sails would roll much less and thus could catch more fish in higher sea states. It could stay out in worse weather and be more comfortable and less tiring for the crew. In addition to these multiple advantages, it would save fuel and often travel faster and thus be a considerably better money earner.

MECHANIZED OR AUTOMATED

Mechanized sail handling is the first step towards automated sail handling. Once sails are mechanized it is relatively easy to automate them if one wishes. Whether or not to automate is primarily a consideration of equipment costs and maintenance versus a small amount of labor saving and medium amount of judgement obviating.
RIG AND SAIL CONFIGURATION

The basic sail system that I favor is a luff roller-furling sail whose clew is controlled by a crane-boom which may also be called a cantilevered-boom, davit-boom, or controlled-boom. As the name implies, this device is a long armed crane whose rotation is controlled at its foot or forward end so that it can never flog or get out of control. The clew of the sail is controlled by a "sheet-outhaul" which can be a single part or a multiple part tackle that goes from the clew to the tip of the boom davit. There are thus no sheets to pay out and no sheets to gather in when one tacks or jibes, for one simple rotates the crane by push button or turning a dial to the new setting. Such a device obviates overlapping sails such as genoas which really have very little place on a working sailboat because they are, first: labor intensive, second: dangerous, and third: cause a clutter.

MAINSAILS AND MIZZENS

This writer believes that it is very important that roller mainsails and mizzens roll up in the open rather than rolling into a cavity in the mast. The absence of lips and cavities in the mast assures reduced friction and wear and obviates the possibility of jamming in the mast slot or cavity since they do not exist in my systems. The rolled up sail is a few inches abaft the mast, and never out of sight or out of reach.

MAST AND RIGGING

The mast may either be cantilevered or stayed. Cantilevering permits lowering the mast in tabernacles if it is important to have this capability because of limited air-draft.

CARGO AND BOAT HANDLING

It should be noted that a really good and powerful crane can serve multiple purposes in addition to trimming the sails. While under power or while in harbor, such a crane can make substantial lifts from the water or from the shore. It can thus on and off-load gear or cargo of all kinds, and boats of any size that might be desired.

SAILS

Sails would be soft and made of the best sailcloth material available and they could be single ply or multiple ply in order to achieve the desired strength.

Sails are triangular and can be of jib, staysail, mainsail, or mizzen configuration.

Ideally all sails on a given vessel might be the same size so that the craft can carry a spare on board or shore based one for quick replacement when necessary.
ASPECT RATIO

Since the sails that are trimmed by a crane-boom cannot overlap a mast, the most convenient way of having sufficient sail area is to design and specify a tall mast or masts from the outset.

ROLLER STAY

It is our practice to use stainless steel tubing with stainless steel groove to support and roll up sails. Aluminum is considered much less suitable because of its softness, which cannot resist scratches, or deep scoring which create stress raisers. Because of aluminum’s low Young’s Modulus of ten million compared to stainless steel’s thirty million, an aluminum tube will either stretch or twist more per given tension or torque than stainless steel. Such a stainless steel tube stay is ideally configured to take torque, as well as tension. It can be shipped in 30 foot lengths and joined together by pinned spigots as is the practice of the British Rotomarine when they are supplying roller furling gear to larger vessels. We have employed more than sixteen such units and we have found them to be sound and durable on ocean going vessels.

We do not consider a combination of one by nineteen wire with sections of aluminum extrusion outside separated by plastic sleeves durable enough or of sufficiently long life. Two of these materials (aluminum and plastic) are too soft and in combination steel and aluminum invite corrosion, particularly in the tropics. The above admittedly has a price advantage for pleasure craft but lacks the durability required by workboats, that have along season, hard use and require minimum overhaul time.

THE CRANE BOOM

The crane boom can be actuated at its base by cogged gears, worm gears, hydraulic rack and pinion and various other systems. It could also be controlled by timing belt, roller chain, or cable and quadrant. Since it is a question of controlled rotation any device similar to steering gear can be applied to control the rotation of the vertical post on which the crane boom rotates. Actually, most crane technology and best practice is applicable to this fairly standard crane application.

ADVANTAGES OF CRANE BOOM

In addition to the already mentioned advantages of the crane boom, this type of sheet control greatly reduces the need for sheet winches, since a multiple part tackle of say four parts can be used, this means that a winch of one quarter of the power will do the job. Usually a headsail requires two sheets and two winches whereas the crane-boom can have one light winch of one eighth the cost of the two bigger winches.
This is of particular advantage to a commercial fishing boat for it frees the decks of headsail sheet winches and the lines at the rail that cross the deck as in older sail trimming systems.

SAFETY FEATURE

Loose-footed luff roller-furling jibs usually have a high clew to minimize re-leading the sheet as the crew moves forward during reefing. This high clew creates a dangerous flogging sheet problem. On the davit-boom the sheet is very short and does not flog since it is never loose. As reefing commences the lead slides forward automatically thus keeping the sheet lead relatively short and free from flogging and being a danger to the crew. The long lead from a high clew to the rail of a normal completely loose footed sail creates a true hazard and people's heads and other parts have been flogged by these high clewed jib sheets. I have seen a man with glasses get a bad cut across the face as his glasses were ripped off him by a flogging sheet and it could have been considerably worse. I am sure that this hazard repeats itself a great many times per year as high clewed jibs are becoming more and more popular for the above named reasons.

Thus the benefits accrued by crane-boom include: lower costs, because of substantially reduced number and power of winches, much less cluttered decks, safety from flogging sheets, substantial labor saving, and mechanization which is easily automated.

COSTS

In fairness it should be admitted and stated that the crane boom is itself expensive, requires deck reinforcing and takes up some space on deck a few feet aft of the mast or stay that it serves.

It is hard to say whether the initial cost of a crane boom cancels out the cost of the multiple sheet winches needed for a loose-footed headsail but I would estimate that they fairly well cancel each other out. On the other hand, there can be no doubt that a cantilevered boom would quickly amortize its initial costs and maintenance because of the substantial labor saving.

BREAKTHROUGH IN SAIL HANDLING

The crane boom is surely the one single greatest contributions to commercial sail since luff roller-furling and reefing which has been progressing for over 70 years. Crane-booms are still extremely rare but in this writer's estimation they are very promising and they have an excellent future. We should be seeing a great many more crane-booms on larger vessels. They are so convenient and safe that they will probably also be used on moderate sized, and large yachts to minimize crew requirements. The idea of fixing a point in space by the tip of a crane is certainly not new, but up to this point it was considered too expensive and too much weight compared to restricting swing by a sheet at the after end of booms.
The main reason that this author recommends cranes now is that labor is expensive and a swinging boom, free pivoting at this forward end is dangerous and labor intensive to control by conventional sheet, not to mention foreguys, boom vang, and topping lifts.

CONCLUSION

A sail assisted fishing boat that is equipped with external luff roller- furling sails and crane booms would be so easy to handle that fishermen would accept them. They would soon see the great anti rolling feature of sail and the increase profit from fuel saving.

We propose to offer commercial fishermen air foils that appear and disappear by push-button and that are oriented by turning a dial.

Handling sail of this kind would be so simple that one would not need to go further, but making the entire system automatic has already been done by the Japanese and is relatively easily accomplished if one desires to automate electronically.

Such a mechanized sail handling vessel, be she automated or not, would eventually be popular with the fishermen and would more importantly be a more profitable craft. She could catch more fish in worse sea conditions and have fuel as well.

It is this writer's opinion that if one good one were built, that many more would follow!
It is evident from the number of papers on this subject that the interest is considerable, but the acceptance for commercial operations with wind-assist systems has been slow.

This is partly due to the fact that the economic benefits to most operators are marginal today.

We must however be ready with fully developed systems, which are practical and easy to operate, when the oil prices again will rise. The increased costs of drilling and extraction will soon necessitate higher oil prices.

20th century technology is available to apply new practical techniques to utilize the oldest method of ship propulsion, which was oars and wind power. Human oar power plus wind power was the first motor sailor.

A wind-assist system saves fuel, but equally important it provides the fisherman with a stabler platform from which to work. The reduced rolling and pitching means less energy lost in proceeding through the seas and this results in more fuel savings.

After development and design of several different approaches, which included rotor thrusters as well as wing-sails I have become convinced that for smaller vessels the combination of a roller fueled Genoa side sail combined with a small permanently installed wing-sail provides a practical means of wind-assist system.

For larger commercial vessels, such as general cargo ships and tank ships my patented "Twin-Rotor" wind-assist system would be preferable, because of reduced overall size. This system is described in US Patent #4,398,395, which issued August 16, 1983.

The "Flexi-Sail" wing-sail was first tried in a small lake with a radio controlled 3 foot long model shown in figure 1.

Then my 24 foot Ulrichsen Sea skiff was equipped with a 36 ft² wing-sail after two parallel plate keels and a sailboat type rudder had been added. The metacentric height was unchanged and also the displacement, because a 660 LB 100HP gas engine was exchanged for a Volvo-Penta 23 HP diesel of approximately half the weight. The Volvo engine was kindly furnished by Volvo-Penta.
The experience with the $360^\circ$ fully rotatable wing-sail system is that the hinged jib-sail to the main wing-sail enables the boat to point higher than what is possible with a soft sail of equal area. The wing-sail is easy to control and can, because of the modest sail area, remain mounted in all kinds of weather.

The same boat with a flying bridge installed would have less stability and considerably higher drag.

Rolling and pitching was reduced and the boat goes through waves more smoothly, in fact higher speed can be maintained in choppy seas without discomfort compared to a boat without wind-assist system. This was evidenced by observing the inclinometer onboard.

At 5 to 6 knots boat speed in a 20 to 25 knot wind speed the fuel saving approximated 50% with the engine delivering about 4.5 to 5 HP and the propeller shaft running at 1050 RPM. It is impossible to obtain such fuel savings with a 36 ft$^2$ wing-sail from wind propulsion effort alone. Therefore the energy saving from smoother travel through the seas accounts for the difference. This has also been observed by the Japanese in comparing identical vessels, where one was equipped with wind-assist system and the other ship was identical, but without sails.

![Figure 1. 3 foot long wing-sail equipped test model](image)
After tests with the wing-sail and also "Twin-Rotor" systems on the boat shown in figure 2, I have developed the approach for commercial fishing vessels and other smaller vessels, to use a combination of furled soft sails and a permanent wing-sail system.

For transport to and from fishing grounds both the Genoa side sail and the wing-sail system would be used. A conventional sail boat will sail as fast with the Genoa and the wing-sail as is possible with the standard main sail and jib of about 10% larger sail area.

Figure 3 shows a 25 foot test boat with which I will conduct tests during the summer and fall 1984 to determine the interaction between the wind-assist system and the side sail in various combinations with and without engine power.

In figure 4 I show the relative position between the Genoa and the wing-sail system. The air pressure decreases in three steps. The highest pressure is on the windward side of the wing-sail and the air pressure is further reduced on the lee side of the wing-sail and lowest on the lee side of the Genoa.
Sailing modes:
Genoa and wing-sail for passage.
Wing-sail alone for fishing and steadying.

Figure 1.

Figure 2.
This testboat is equipped with a swing keel and can be operated as a rotor sailer with the keel up and as a full rigged sailing ship with the keel down.

One should also keep in mind that for commercial use motor sailing is safe and makes sense. 3 HP of engine power added to 210 ft² of sail is equal to a sail area of some 330 ft² for this test boat. With 330 ft² of sails this boat is unsafe in winds over 8 m/s, but would be safe and fast with 3 HP or more plus the wing-sail and the Genoa, which will furl as determined by wind strength. The side drift is also reduced by the addition of engine power.

A Fisheries Inspection Vessel of 150 feet length shown in figure 5 is large enough to take advantage of the reduced overall size of the "Twin-Rotor" system, which I have also tested on the Sea Skiff shown in figure 2.

In conclusion today I want to mention that we have seen many different approaches to wind-assist systems. It is apparent that quite a few researchers work independently without much knowledge of each other.

If we all work together—Researchers, Designers, Operators, Financiers and Fishermen in at least exchange information, we will be able to reduce net cost of the catches.

The upcoming WIND-TECH meeting in 1985 in Southampton, England, is a step in the right direction.