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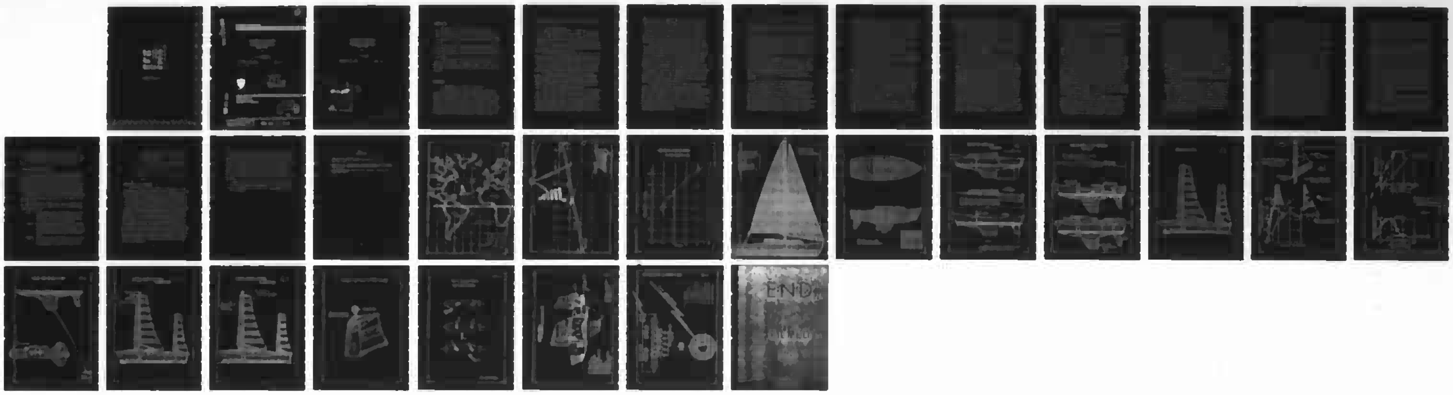

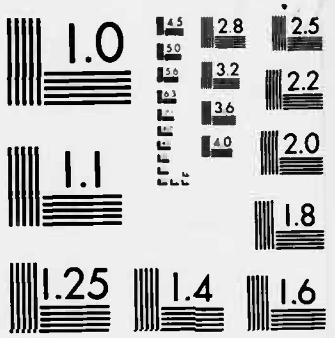

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Princeton University

THE CONCEPT OF AN UNMANNED TRANSATLANTIC SAILING BUOY

(NOAA'S ARK)

by

T. E. Sweeney

AMS Report No. 1358 May, 1977

**Department of
Aerospace and
Mechanical Sciences**

THE CONCEPT OF AN UNMANNED TRANSATLANTIC SAILING BUOY

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INTRODUCTION

Oceanographers, hydrodynamists, marine biologists and other scientists have become most interested in obtaining hard data concerning the conditions of our seas. These include both horizontal and vertical motions of the currents, the temperatures of both the water and the ambient air, along with air pressure, wind velocity and wind direction.

In the recent past these matters have begun to be quite carefully studied by the use of free drifting buoys which acquire some of the desired information. These buoys transmit their position and data by novel and sophisticated means that are generally in existence for other reasons.

Even more recently there seems to be a desire for a data scan - in this case transatlantic by a moving or sailing buoy capable of making good a prescribed course within reasonable tolerances and also capable of acquiring and transmitting significant data on a short time interval.

[illegible] capable of accomplishing these tasks

DISCUSSION

A. The Problem (as posed by Dr. Kirt Bryan)

The task presented is indeed a formidable one. That is, the concept of a vessel capable of sailing, unmanned, across the North Atlantic Ocean and in the process of so doing is also capable of very frequent transmissions of data important to oceanographers and meteorologists. The cost of such a craft is, most certainly, not trivial; however, it is mitigated by the existence of satellites in orbit for other reasons but of extreme importance for this matter. It is furthermore claimed to be economical because of its probable long life. How to design, build and operate such a vessel is the basic problem. The ability to transmit the primary data is considered to be rather well established by the success of past and present free-floating buoys.

B. The Proposed Solution

In order to meet the requirement of a water speed of 4 to 5 knots it is immediately obvious that a hull shaped like a buoy would not be desirable, but rather it should be a more conventional configuration such as a small yacht. The data collection and retrieval method is another problem, as are the navigational and communication procedures. Other considerations must also be carefully treated to insure success in the venture. All these matters are systematically, though briefly, discussed in this section.

First, consider the problem as posed. A more or less constant latitude voyage across the North Atlantic Ocean with the further constraint of the termini of the passage(s) being the Canary Islands on the eastern end and "somewhere in the Carribean" on the western side of the sea. For the purposes of this study, St. Croix (U.S. Virgin Islands) has been selected as the western terminus for quite valid reasons that will be discussed in some detail later in the section.

The scheme as originally presented is shown sketched in Figure 1. It will be seen that the constant latitude requirement has been somewhat relaxed to be within approximately a ten degree range. This allows the Canary Island of Las Palmas and the Virgin Island of St. Croix to be the points of origin and arrival of the vessel. This is shown in larger scale in Figure 2.

It will be noted that in both Figures 1 and 2 a schematic buoy with a conventional sail attached is used to represent the sailing craft. This is, of course, not a sound proposition as is indicated by the graph of Figure 3. Here it is seen that an approximate twenty foot water line length is required of a fairly sophisticated hull shape to make good the desired 4 - 5 knot hull speed. How to accomplish this task appears to be a quite straight forward matter. A suggested procedure is shown in subsequent figures, but before further discussion of the hull shape some consideration must be given to the matter of the selected speed/length ratio of the hull. The value of this parameter of 1.0 was determined from Reference 1 as a most conservative number. For example, an America's Cup boat would have a speed/length ratio of approximately 1.4, while the necessarily more practical Bermuda racer would not be greater than 1.1. Therefore a conservative value of $Vs/\sqrt{L}$ has been assumed as stated above to be approximately 1.0. For the boat to achieve a hull speed in the 4 to 5 knot range the water line length is defined as shown on the graph.

Since sailing yachts are of a fairly highly advanced shape and are commercially built in moderate to high production quantities it is quite natural to select a suitable craft from the literature. This has been done but the boat selected was chosen by a most cursory examination of those available. It is not intended that the Bristol 22 is necessarily the optimum hull to work with. It is, however, quite typical of those hulls available and is, perhaps, enhanced by the design skill of its originator (Mr. Halsey Herreshoff). Figure 4 and 5 have been prepared directly from the advertising literature since the dimensions of the boat are very close to those considered necessary to accomplish the task. It will be noted that the design water line length (D.W.L.) is 19.5 ft., but this length will grow as the gross weight of the vessel increases. Even so, the original length would indicate a hull speed of approximately 4.4 kts.

Figures 6 and 7 indicate how, in an approximate manner, such a modern fiberglas yacht is put together from two basic parts. Figure 6 shows the breakdown of the hull while Figure 7 shows necessary but modest modifications to the components and the general configuration when combined. The resultant hull as shown on the bottom Figure 7, while not very appealing to a yachtsman's eye, is most certainly rather advanced from a buoy designer's point of view. In any event the configuration does seem to possess all characteristics necessary for the successful completion of the task. In this regard some comments are in order relative to the altered hull:

a) Note that it is intended that the vessel would be completely sealed.

b) 1000 lbs. of iron ballast have been added to the keel and advantage has been taken of this to increase the aspect ratio of the keel. In a similar manner the rudder has been increased in both aspect ratio and area.

c) An additional bulkhead has been added forward to reinforce the main mast step and a completely new bulkhead has been added aft mostly for torsional rigidity. More than this, a mizzen mast step has been added aft which makes the "sailing buoy" into a ketch rig. It will be noted that the proposed new topsides is completely faired to make the craft more compatible with the elements. It will also be noted that the new decking is fitted with three watertight flush hatches for access to the machinery below.

d) The modifications suggested above are intended to best convert a commercially available hull into a most unique sailing ship. For example, the planned operation of the craft includes the ability to be "knocked down" under storm conditions. Thus the ship may lay on her side for prolonged periods and when the storm abates it would come aright and sail on. All on-board gear is designed for such severe attitudes and conditions and this has greatly influenced all hull modifications.

Just as the hull is rather unusual in appearance, so too is the sail plan as shown in Figure 8. These sails are characterized by the concavity of the leech. This particular shape produces strong chordwise tension in the sail which, in turn, yields performance superior to other more conventional configurations. At Princeton the sail is known as a Sailvane and is a derivative of the Princeton Sailwing. The latter device has been the subject of a great deal of research and development and has served as a very successful wing for special purpose aircraft over the past decade and a half. The essential difference between the Sailwing and the Sailvane is that the former is composed of two membranes and the latter has but one. The Sailvane is better described from data of Reference 2. From Reference 2 it is clear that the Sailwing is much superior to the Sailvane in aerodynamic performance, however the latter device is far superior to a conventional sail as shown in Figures 9 and 10 and offers an advantage over the Sailwing by virture of its single membrane. This single characteristic is responsible for its selection as the motive power for the sailing buoy in that when "knocked down" there is no closed sail envelope to fill with water which would inhibit its capability to restore itself to the normal sailing mode. To further emphasize this point it will be seen on Figure 9 that both the mast and the leading edge fairing are filled with expandable plastic for floatation purposes.

Figure 9 shows a polar diagram comparing the performance of the Sailvane and a more conventional sail. Of principal importance are the tangent lines A and B shown on the graph of Figure 9. The steepness of the slope of these lines is an indication of how close the vessel may sail to the wind. This is not the only criteria for sailing "close hauled" but it is certainly an important one.

Why the Sailvane has this superior performance can be seen from the curves of Figures 10 and 11. First it should be noted from Figure 10 that not only is the lift performance at any angle of attack much greater than the conventional sail but, more importantly, the sailvane has the capability of passing through the region of zero lift without luffing. This single characteristic is of extreme importance when the Sailvane is used as a wing for an aircraft and of considerable importance when used as a sail for a fully automated sailboat. The latter point can be appreciated when one considers a "hove to" mode during storm conditions. In this case the Sailvane can be told to go into a zero lift attitude without the self destructing sail luffing that would occur with a conventional sail.

The performance of the Sailvane in comparison with the conventional sail as shown on Figure 9 is best described by the curves of Figure 11. Here it can be seen that the Bermudian sail can achieve a maximum lift to drag ratio of approximately 4.5 while the sailvane can approach a value of 20. This then is the explanation for the slope of the lines A and B of Figure 9. Implicit in this discussion of the sails and their relative characteristics is that, for this application, the Sailvane is not intended to be either reefed or furled - it will have to live with the elements and be periodically replaced (perhaps every 2 to 3 years). This, however, is cheap fuel.

So far the discussion has dealt largely with the hull shape, how it would be modified and how it would be propelled. This is so because it is the greatest deviation from conventional free drifting buoys. However, it becomes essential to consider other aspects of this technical adventure. Of equal importance is the technique of data collection, of navigation methods and of the overall problem of handling this simple-yet-sophisticated vehicle.

As understood by the author, the vital information to be collected during a transatlantic voyage is sea temperature both on the surface and at prescribed depths, air temperature, atmospheric air pressure, wind velocity and wind direction. Such information is presumably being collected now from free drifting buoys, but the problem of collecting these data from a moving buoy, while not more difficult, must be approached from a slightly different point of view. For example, the matter of determining the water temperature at depth and firmly relating that temperature to the depth is a case in point. A suggested solution is presented in Figure 12 which shows the application of the aeronautical technique of the use of a trailing bomb for these measurements. It is, of course, not really a bomb - it simply looks like one - and its function in aeronautics is to measure free stream atmospheric pressure without the influence of the body of the aircraft and these measurements must be made some distance from the craft. Its application to the sailing buoy is most logical since water temperature and depth must be simultaneously observed. The speed of the vessel will determine the arc the attaching cable will make in the water so depth cannot be accurately measured by the length of cable deployed. The static pressure vents in the side wall of the bomb will quite accurately measure depth in terms of pressure. This information, by means of an electrical pressure transducer, can be directly relayed to the vessel along with the temperature measured at that depth by means of a thermocouple in the nose of the bomb. The "bomb" as developed over the decades is quite stable about all three axis and should perform as well underwater as in free air.

Figures 13, 14 and 15 are presented to show optional mast head instrumentation for the collection of wind data - both wind direction and wind velocity. From a scientific viewpoint the scheme shown in Figure 13 is preferable; however, considering very practical operational problems it is probably the worst of the three methods so far studied. This is so because of the effect of a stormy sea upon such fragile sensors while the craft is in a "knocked down" attitude. It is felt that the hull, masts and sails may easily tolerate such a condition for extended periods of time but that the straightforward and common system of Figure 13 could not do so. Therefore, the alternative schemes of Figures 14 and 15 are presented as possible viable methods of data acquisition that would be rugged enough to withstand the rigors of the sea when "knocked down". Figure 14, for example, shows a drag sphere which replaces the tender cup anemometer of Figure 13. Also replaced is the vane type wind direction indicator, by a pair of symmetrically mounted pressure tranducers which are easily calibrated for wind direction indications. The drag sphere is shown in an enlarged sketch in Figure 15. It will be noted that it is mounted upon a short beam atop the mast which is fitted with a four arm Wheatstone bridge. It is, therefore completely temperature compensated. The technique of operation of these devices of Figures 14 and 15 are discussed in a latter section.

Prior to such a discussion the unique characteristics of the rig should be examined. First; the vessel is completely without either standing or running rigging except for the two servo controlled masts and sails. To accomplish this and to maintain minimal power requirements of the servo motors, the axis of rotation should be near the one quarter chord point of the mean aerodynamic chord - perhaps as little as 20% of this significant geometric parameter. Such a value would insure aerodynamic stability about the point of sail rotation and low moment coefficients which in turn would produce most constant torque coefficients for the servo motors to cope with.

Because these full cantilever masts are not encumbered with rigging of any sort it becomes quite possible to orient the sails in any direction relative to the hull. Such an ability opens new doors to the art of sailing. First of all the vessel should sail almost as well backward as forward, which is not important to the task being considered but the capability did exist in the past with square rigged ships.

The real importance in being able to point the sails in any direction relative to the hull is shown in Figure 16 where it is seen that, sailing with the wind somewhat aft of the beam, it can be highly advantageous to actually point the trailing edge or "leech" forward. It has also been pointed out by others that such a condition can actually be made to cause a heel into the wind when very high lift to drag ratio sails are employed. "Tricks" of this nature can become standard operational procedure with such a rig. This manner of sailing is not unknown to sailing canoe sailors nor to others experienced in yachts of similar capabilities. The important point here is that the absence of rigging is essential and this is enhanced by a servo controlled setting of the mast and sail rather than the primitive "sheet" controlled setting of this surface normally used.

Figure 17 shows an inboard profile of such a sailing buoy. The drawing is schematic except the hull and sail lines are probably close to scale. The auto-rotating rotor is also probably near scale since preliminary calculations indicate that approximately a one square foot of disc area is all that would be required to adequately charge the batteries at a hull speed of four kts. It would drive a generator or alternator through a suitable gear box which would, in turn, maintain the battery bank charge. The electric bomb winch and the bomb itself are no doubt shown out of scale (too large). So also are the servos, radio gear, batteries and compass. This license has been taken for ease of presentation of the scheme.

C. Proposed Operational Procedure

So far the discussion has dealt with the problem as posed and a suggested very general solution including some description of the unique items of instrumentation. Other, more conventional, instrumentation has purposefully not been discussed. The unique (to sailing) devices are treated in somewhat more detail in this section since they substantially affect the operational procedure of the craft. How to make a transatlantic crossing and at the same time accumulate and relay scientific data with an unmanned ship is, to say the least, a somewhat unusual task. As a matter of fact is has never been done before.

It will be noted that all of the preceding discussion and the accompanying figures do not suggest any new invention required. It is, rather, a straightforward piece of engineering which puts together the current state of the art of several disciplines.

It will be noted on Figure 2 that a plus or minus 100 mile deviation from the Rhumb line course has been permitted. This, of course, is a very generous allowance which opens the possibility of sailing the craft practically anywhere in the world covered by satellite monitoring. One procedure for accomplishing this task which seems, to the author, to be the only presently valid method is the use of the dual satellite method developed by the U.S. Navy (Reference 3) for submarines in distress. Fortunately this emergency system is seldom called upon to function so that a great deal of satellite "time" is available (again Reference 3). In essense this means that a surface craft may be interrogated by a low altitude satellite (NAVSAT) every 45 minutes. Apparently the very high speed of NAVSAT permits a most precise positioning of the vessel by Doppler effect. Since the line-of-sight range of NAVSAT is not great these signals are relayed to a sychronous satellite (COMSAT) which then transmits the signals from anywhere in the north or south Atlantic Ocean, the Caribbean Sea and the Mediterranean Sea to the Washington, D. C. vicinity. Thus the position of the sailing buoy may be carefully monitored by digital read-out of both latitude and longitude. With other vital information in hand the craft may be told what to do to make good her course.

Figure 18 schematically shows, in as much detail as is presently thought out, just how the data accumulation may be made and the necessary commands may be given. It will be noted from this figure that eleven data channels are provided for. In addition to these there are five command channels. The function of each is defined on the figure (18), and the order of operation as presently envisioned appears to have significance.

For example, a few moments prior to a scheduled satellite sweep Channel 16 would be activated which would place both the main sail and mizzen sail in the position of zero lift. This would accomplish two things; first it would orient the masthead drag sphere for proper wind velocity indication and the angle of the main mast relative to the hull would permit the wind direction to be determined when related to the ships heading (Channel 10). To physically accomplish zero lift of the sails the symmetrically placed electric pressure transducers (see Figure 14) would, through a nulling circuit, command the sail orientation servos to maintain such a condition. This would also serve in the case of storms - it is the "hove to" mode of the craft. If upon examination of the primary data received from the sweep the ship is reasonably on-course then the previous sail and rudder settings may be commanded. If off-course, it would be possible within a few moments to determine the new sail and rudder settings required for proper correction of the deviation. There seems to be nothing about this type of desk-top sailing that is not a valid procedure - it merely requires that the man behind the desk project his mind to the boat whenever up-dating is necessary.

Precisely how commands would be given has been a matter of long consideration. At this point, even though many aspects are as yet not throughly investigated, it appears the Bell System for talking to ships at sea via COMSAT may be the optimum method and it seems remarkably inexpensive. By this it should not be assumed that voice commands would be contemplated, but rather impulses that would cause the several servos to perform the navigator's wishes. The present commercial rate for this system is but $6.00 per minute of use and considering how few minutes would be required for up-dating the ship's trim for a transatlantic passage the technique appears most attractive. This is but another example that no new invention is required - only advanced engineering of the combination of the several vital components.

SUGGESTED DEVELOPMENTAL PROGRAM

This has been but a cursory study which has crossed several disciplines. It is obviously necessary to conduct a deeper study - not only to further define the several problems but to also look at alternative solutions to those offered here. A reasonable amount of time and effort should also be expended in a small scale (waterline model) wind tunnel model test of the configuration under all major points of sailing. This would be an effort to determine trim conditions for maximum thrust and to also determine hinge moment coefficients of both of the mast-sail combinations. Such information would enable the proper selection of "off the shelf" servo motors for the full scale craft.

These several phases leading to the logical development of the remotely controlled long range sail boat are summarized against an estimated time frame:

Phase 1 - Would include a deeper study including hull selection and the selection of all mechanical and electronic gear. Also included would be small scale wind tunnel tests of a water line model.

Phase 2 - This would include the acquisition of all standard components including the hull, the modifications to the hull, construction of the masts and sails. Also included would be ground testing of the assembled craft.

Phase 3 - It is proposed that initial tests of the ship would be in the Atlantic Ocean a short distance off the New Jersey coast. Any modifications to the final scheme that appear necessary at that time could be more easily made because of the proximity of the Princeton Laboratories from which it is proposed the vessel would be spawned.

Phase 4 - The first crossing, probably westbound from the Canary Islands to St. Croix (U.S. Virgin Islands).

A time estimate for each of these phases follows:

Phase 1 - - - - - - - - - - - - - - - - - - - 6 mo.
Phase 2 - - - - - - - - - - - - - - - - - - 12 mo.
Phase 3 - - - - - - - - - - - - - - - - - - - 6 mo.

OTHER MATTERS TO BE CONSIDERED

There are two non-technical matters to be discussed. First the problem of the ship as a potential hazard to navigation. This has been considered from several points of view. In highly congested harbor areas there is little doubt that an unmanned craft would pose a collision threat. To overcome this hazard it is proposed that the vessel, when launched upon a tranatlantic voyage, be towed far enough to sea to avoid the high traffic areas. At the terminus of the trip it would similarly "be captured" and towed into port. While at sea in the remote control mode the hazard would appear to be to small high speed yacht type boats; but not more so than some of the larger free drifting buoys. It is considered that there would be no hazard to larger vessels - as a matter of fact the hazard would be to the unmanned craft in this case. To reduce hazard under all conditions it is suggested that the hull, including the deck, be painted international orange in color and that both sails be orange and white striped. Also, radar reflectors would be fitted on both mast heads. These are, of course, inexpensive passive measures, and a slightly more complex system could be fitted. This would be the incorporation of a transponder in the system to be actuated only during periods of darkness or very poor visibility.

The second very real problem to be considered is that of vandalism or even out right loss of the vessel by theft. This is a difficult matter to rationalize and if the boat were constructed, launched and sailed in secrecy it would appear to be even greater. One alleviating ploy would be to invite an official representative from each of the major maritine nations to the launching of the craft on its first voyage. They could be given a briefing on the purpose of the experiment and an opportunity to examine, in detail, all aspects of the venture to be assured that the U.S. was not up to something ominous. This might, for example, keep the Russian Navy from picking it up out of curiosity.

There are, no doubt, other steps that might be taken that have not yet come to mind, but the important thing is that such a historic venture in the interest of science should not be compromised by fear of this eventuality.

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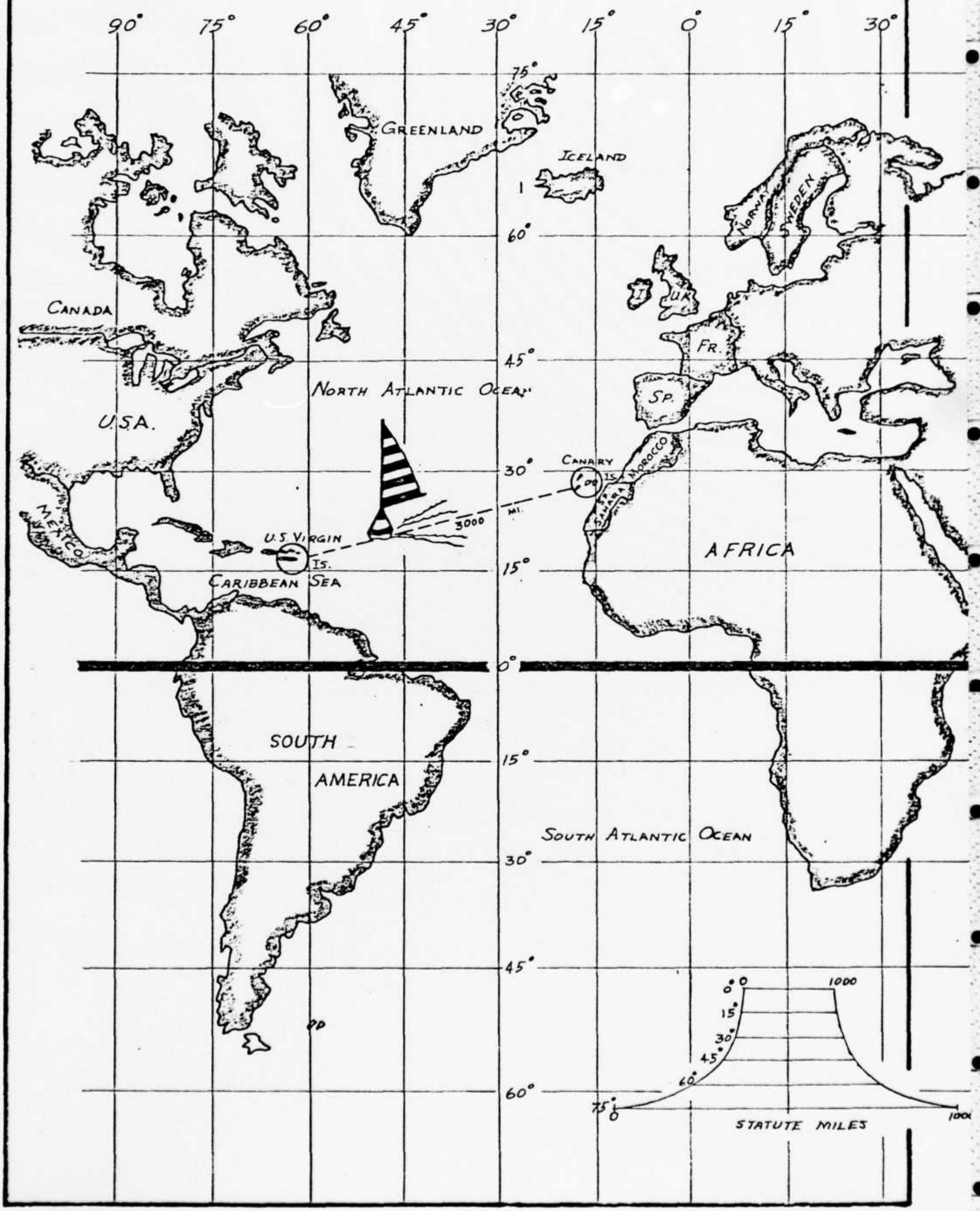
2. Maughmer, M. D., Optimization and Characteristics of a Sailwing Windmill Rotor, AMS Report No. 1297, March 1976.

3. Free Drifting Buoys, AIAA Drift Buoy Symposium, Hampton, Va., May 22-23, 1974.

FIG. 1


90°
75°
60°
45°
30°
15°
0°
15°
30°
75°
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45°
60°
GREENLAND
ICELAND
CANADA
NORWAY
SWEDEN
U.K.
I.
FR.
SP.
NORTH ATLANTIC OCEAN
U.S.A.
MEXICO
CANARY IS.
MOROCCO
SP. SAHARA
3000 MI.
U.S. VIRGIN IS.
CARIBBEAN SEA
AFRICA
SOUTH AMERICA
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15°
30°
45°
60°
75° 0 1000
STATUTE MILES

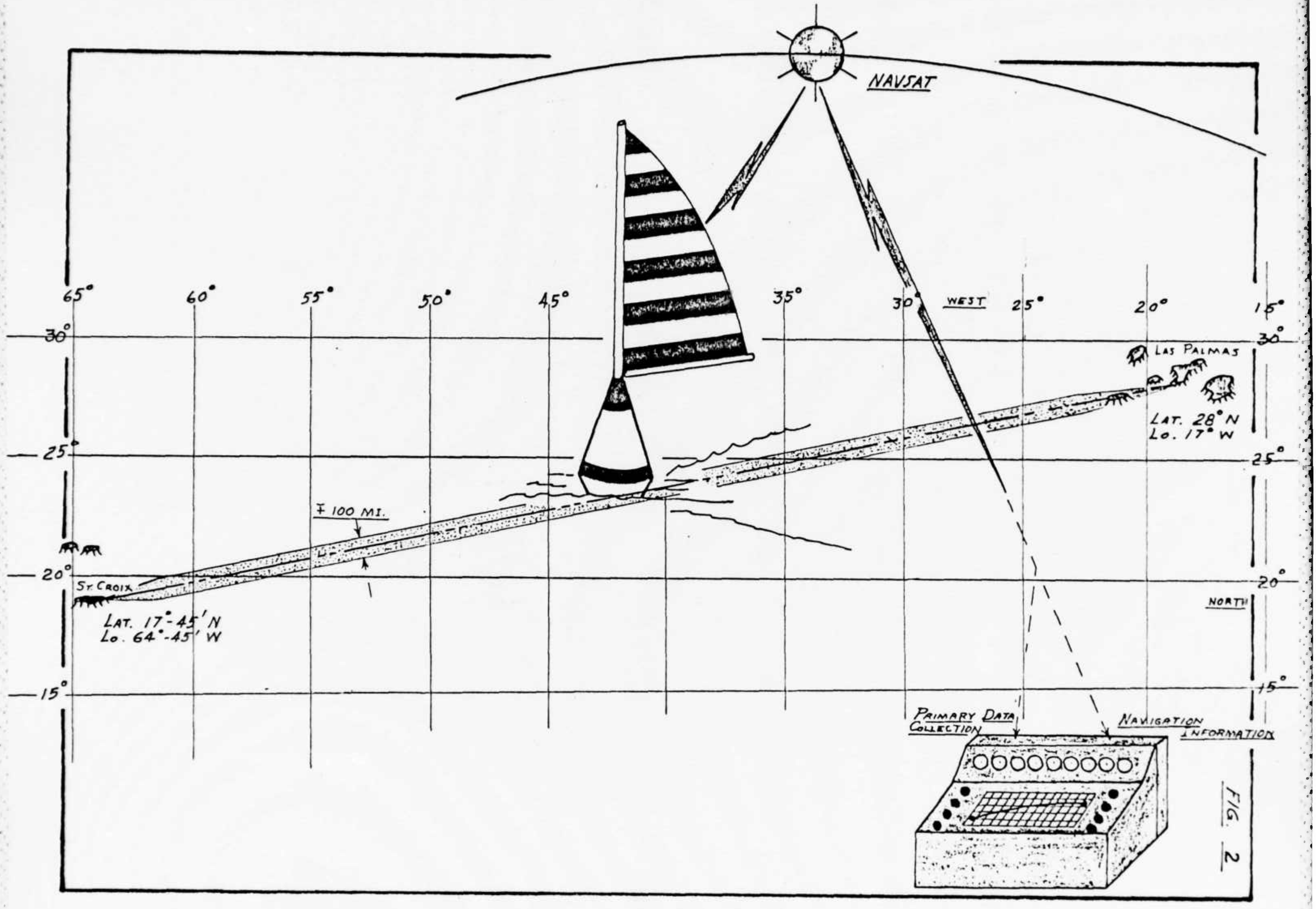

NAVSAT
65°
60°
55°
50°
45°
35°
30°
WEST
25°
20°
15°
30°
25°
20°
15°
Las Palmas
Lat. 28° N
Lo. 17° W
± 100 MI.
St. Croix
Lat. 17°-45' N
Lo. 64°-45' W
NORTH
Primary Data Collection
Navigation Information

FIG. 2

HULL SPEED Vs. WATER LINE LENGTH

Fig. 3

for Speed-Length Ratio = 1.0

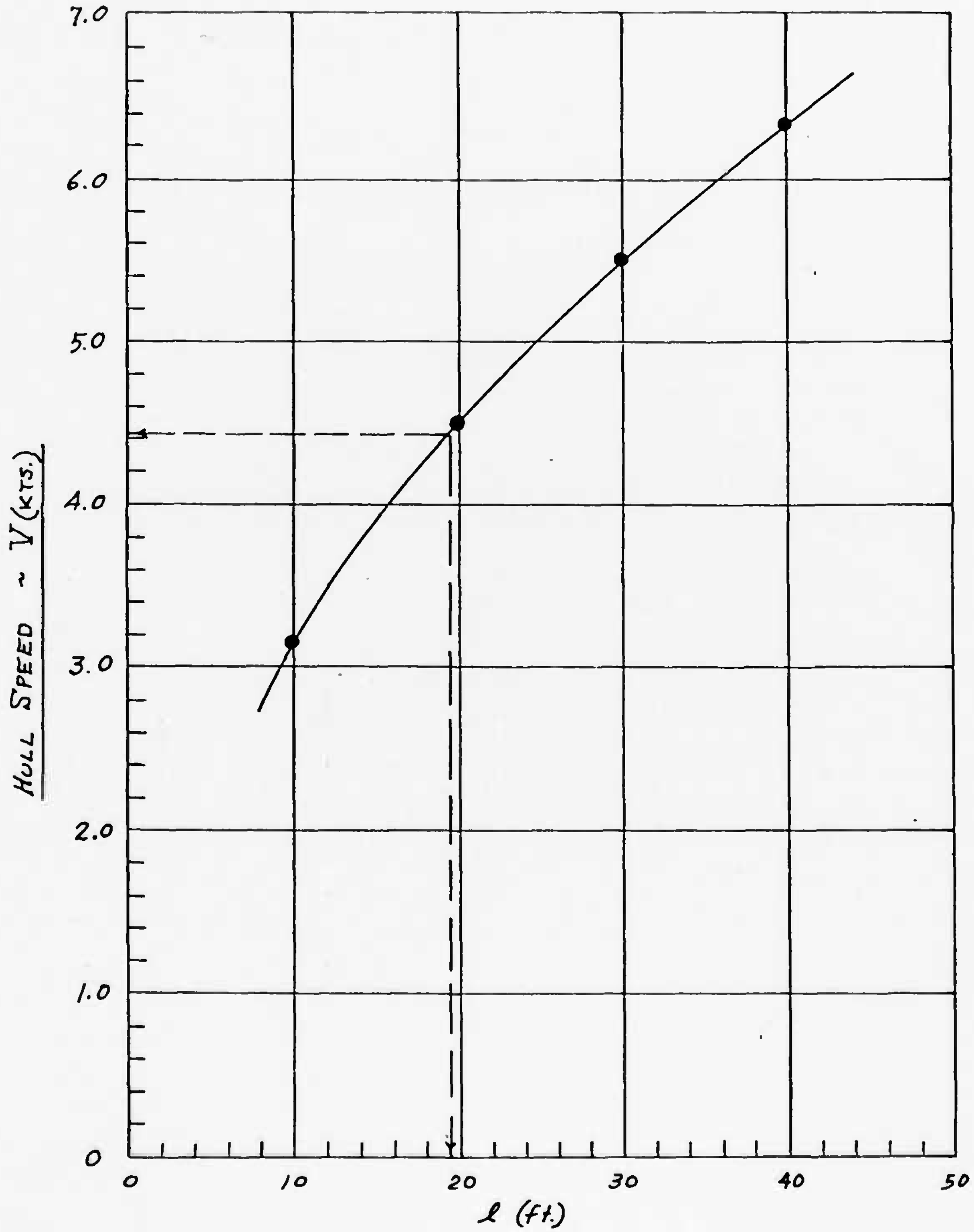


FIG. 4

Hull Profile And
Sail Plan From
Advertising Brochure

Caravel 22 Specifications
Designer: Halsey Herreshoff
Builder: Sailstar Boats
LOA 22'0"
LWL 19'6"
Beam 7'9"
Draft 3'6"
Displacement 1150#
Ballast 2650#
Sail Area 206 sq. ft.

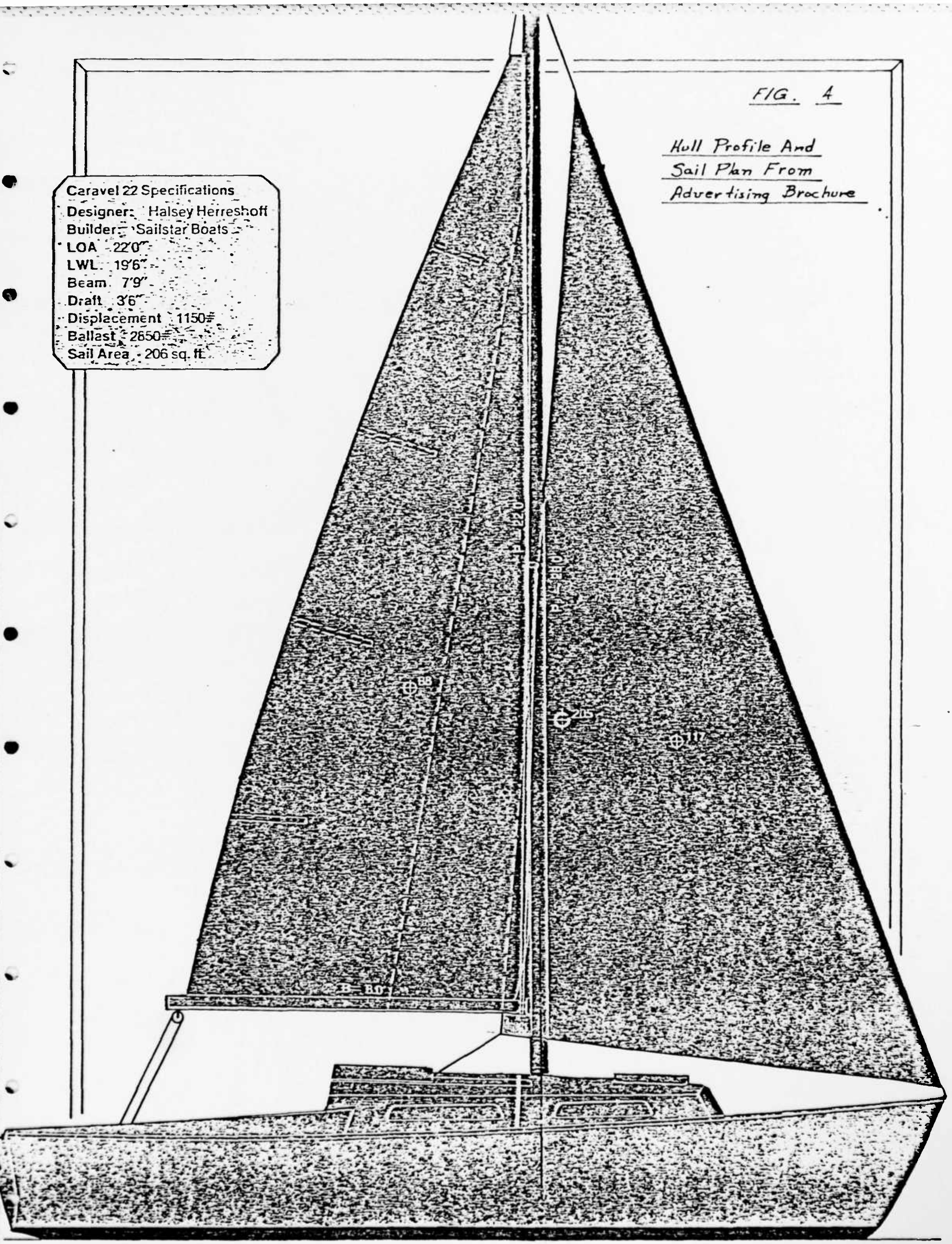
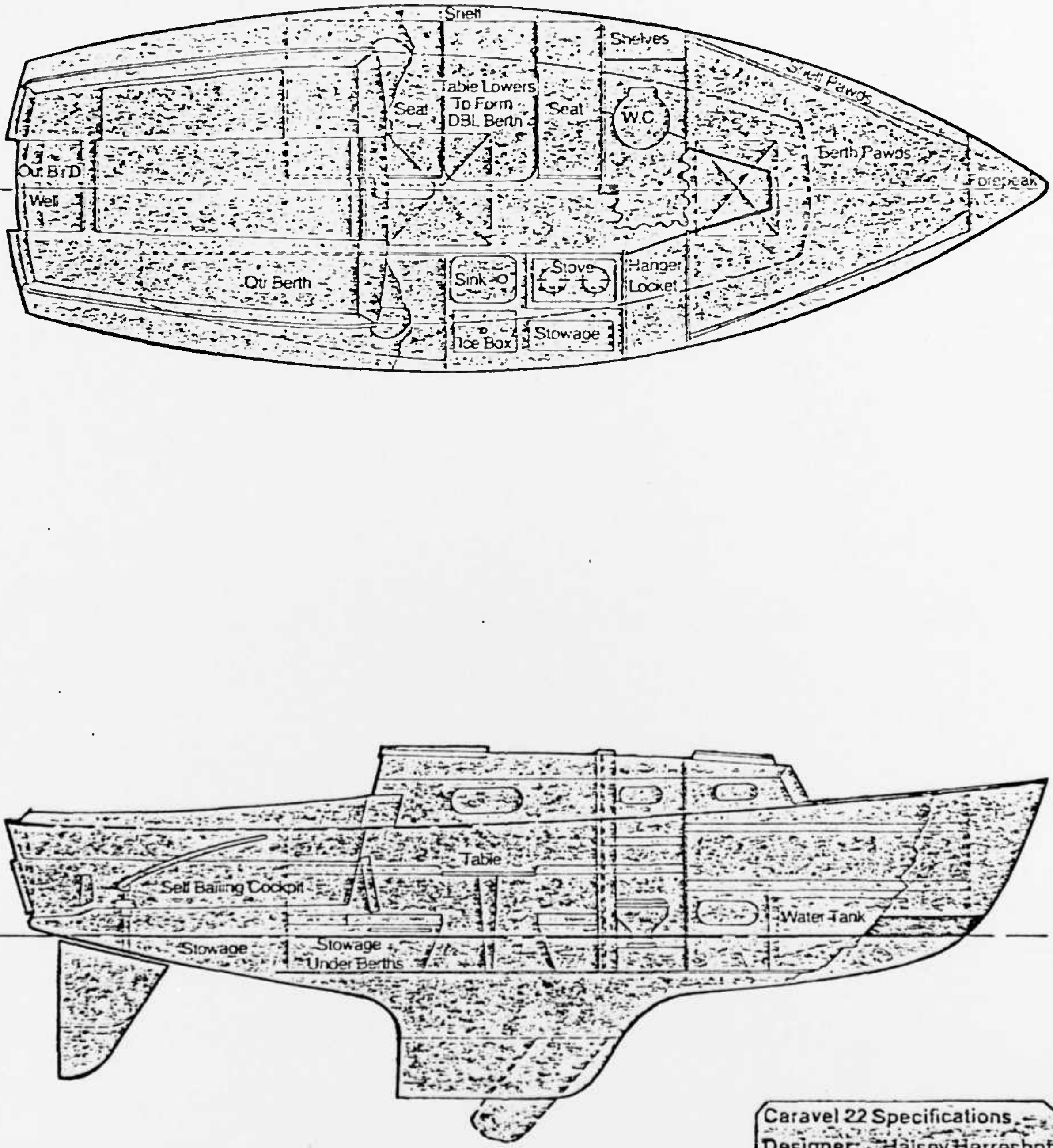


FIG. 5



Caravel 22 Specifications
Designer: Halsey Herreshoff
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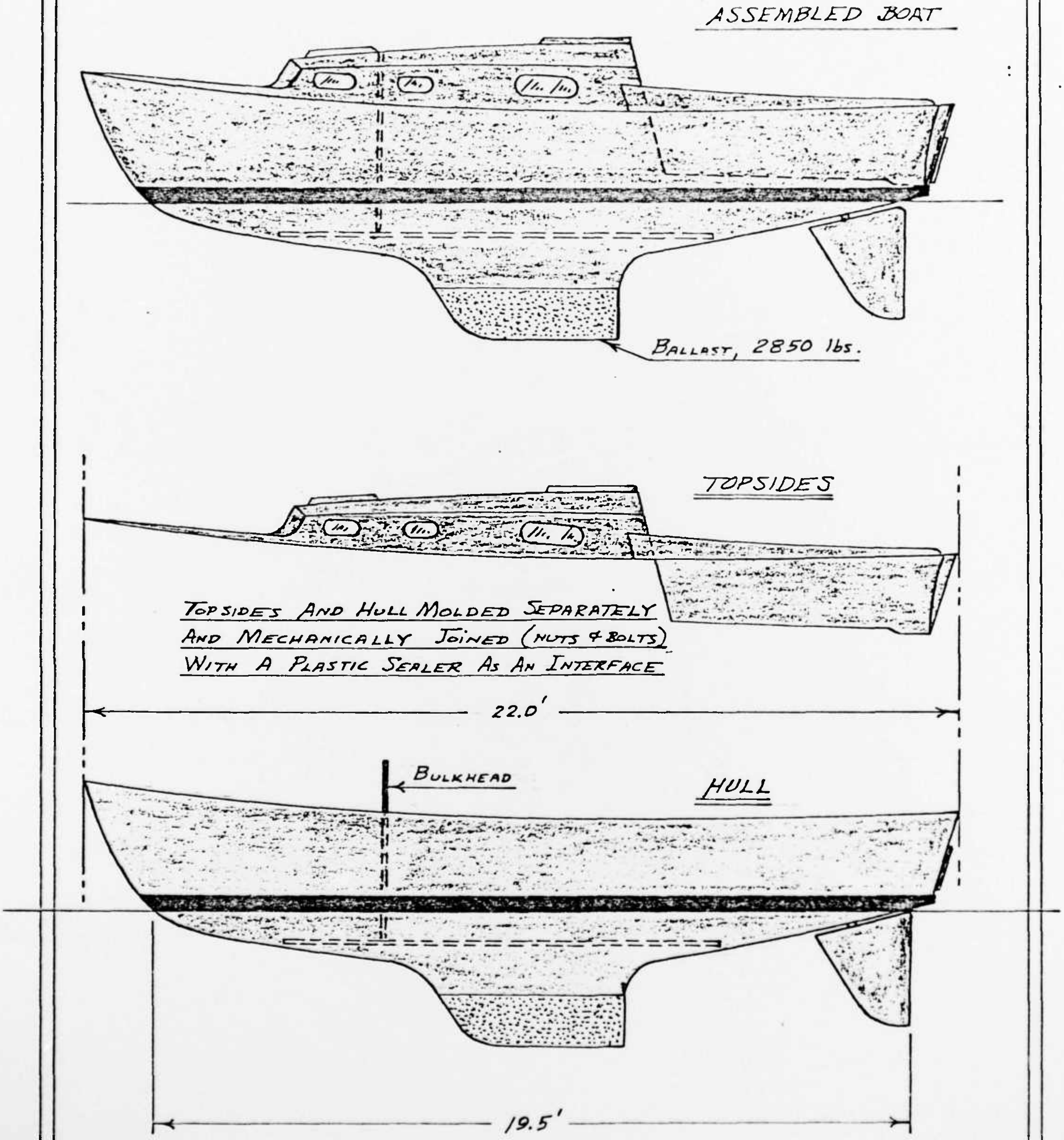
LOA 22'0"
LWL 19'6"
Beam 7'9"
Draft 3'6"
Displacement 1150#
Ballast 2850#
Sail Area 206 sq. ft.

Basic Hull Lines Taken
From Advertising Brochure

ORIGINAL HULL COMPONENTS

(Breakdown)

Fig. 6

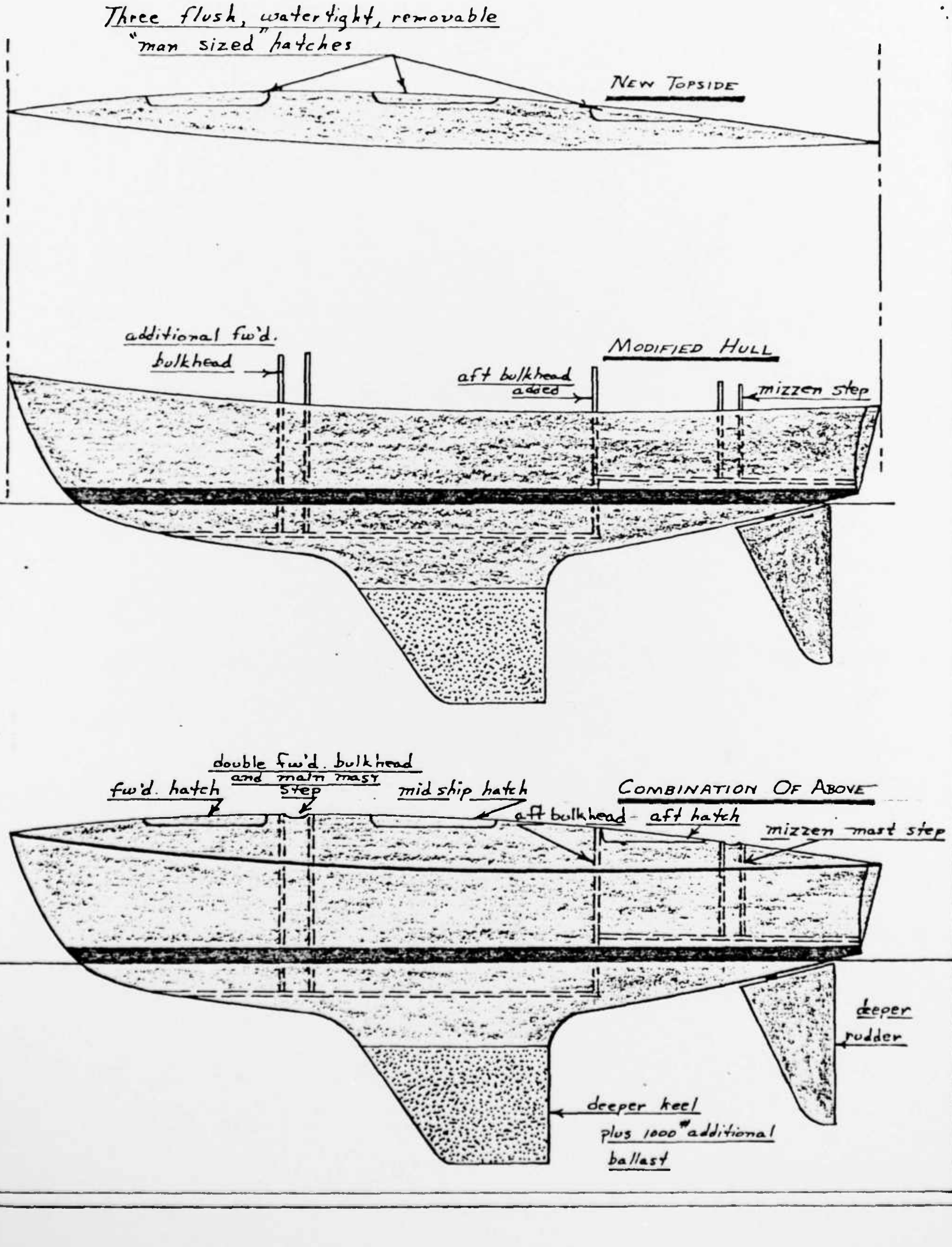


TOPSIDES AND HULL MOLDED SEPARATELY AND MECHANICALLY JOINED (NUTS & BOLTS) WITH A PLASTIC SEALER AS AN INTERFACE

A TYPICAL METHOD OF CONSTRUCTION OF MODERN SMALL FIBERGLAS YACHTS

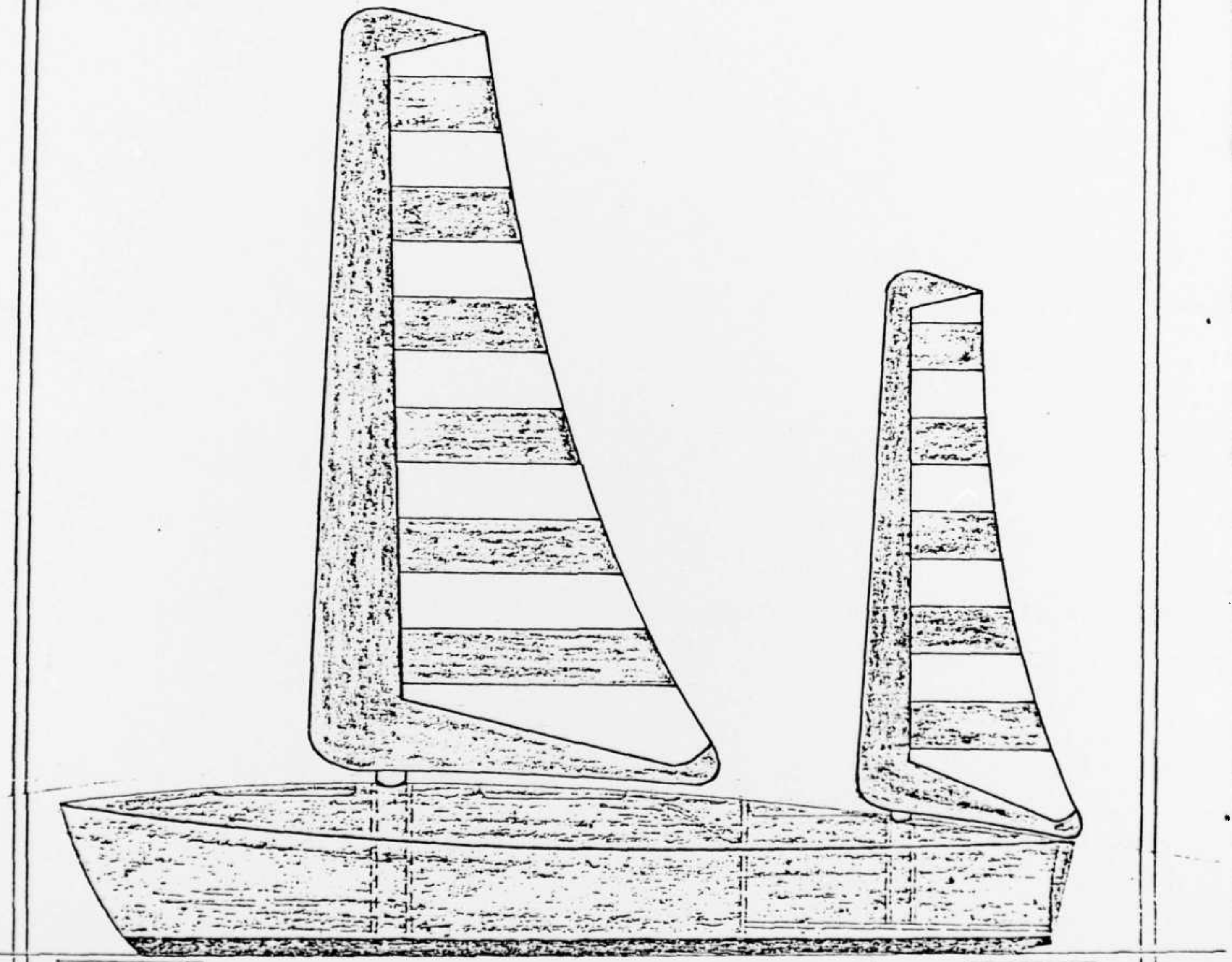
MODIFIED AND/OR NEW HULL COMPONENTS Fig. 7

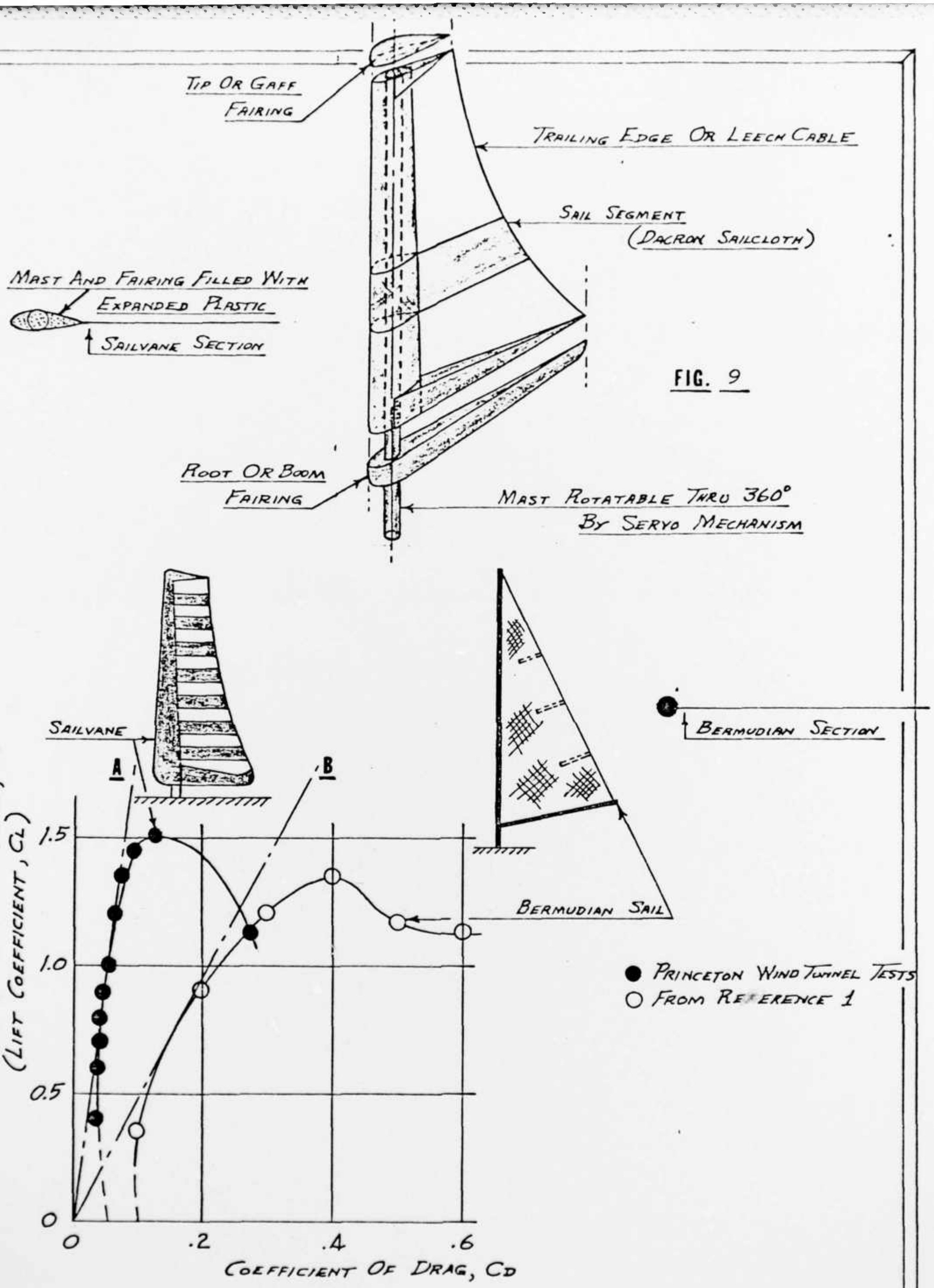
(Build-Up)



SCHEMATIC SAIL PLAN

FIG. 8

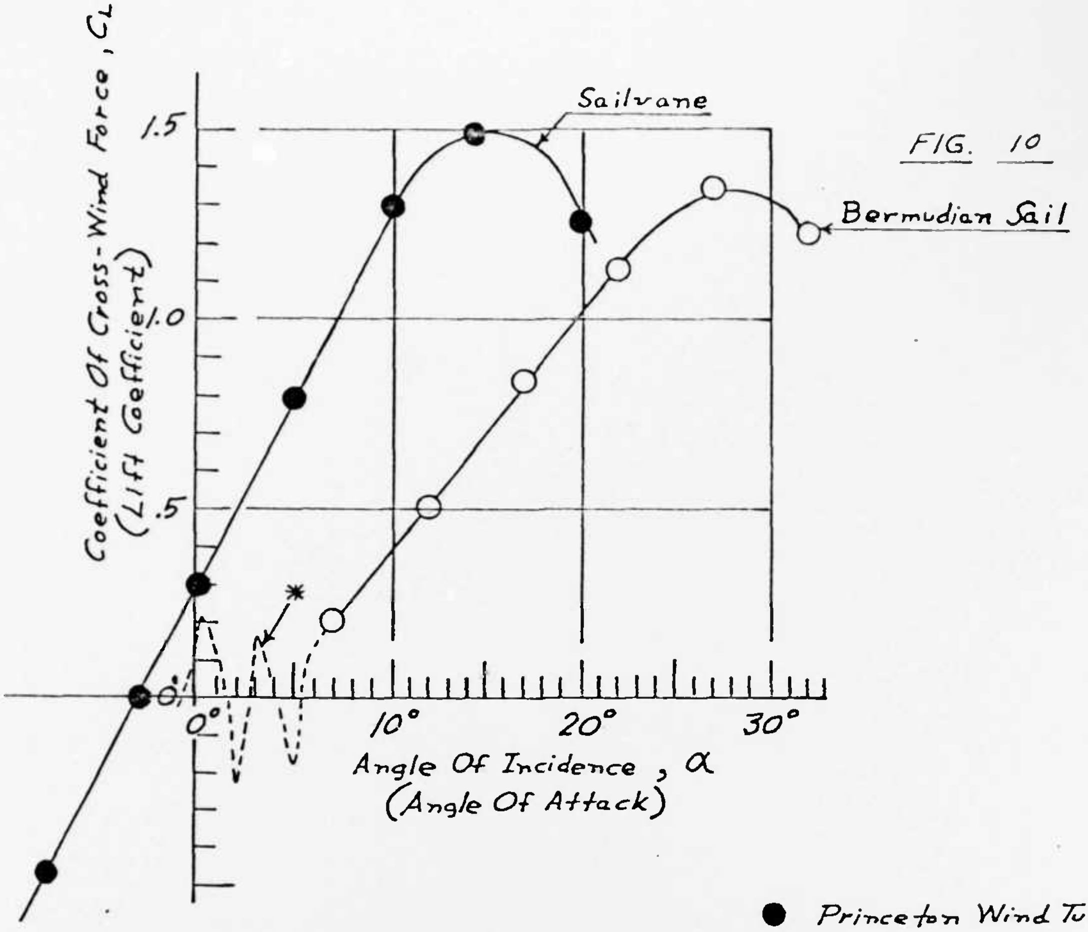




Tip Or Gaff Fairing
Trailing Edge Or Leech Cable
Sail Segment (Dacron Sailcloth)
Mast And Fairing Filled With Expanded Plastic
Sailvane Section
Root Or Boom Fairing
Mast Rotatable Thru 360° By Servo Mechanism
Sailvane
A
B
Bermudian Section
Bermudian Sail
Coefficient Of Cross-Wind Force, CL (Lift Coefficient, CL)
1.5
1.0
0.5
0
0
.2
.4
.6
Coefficient Of Drag, CD
● Princeton Wind Tunnel Tests
○ From Reference 1

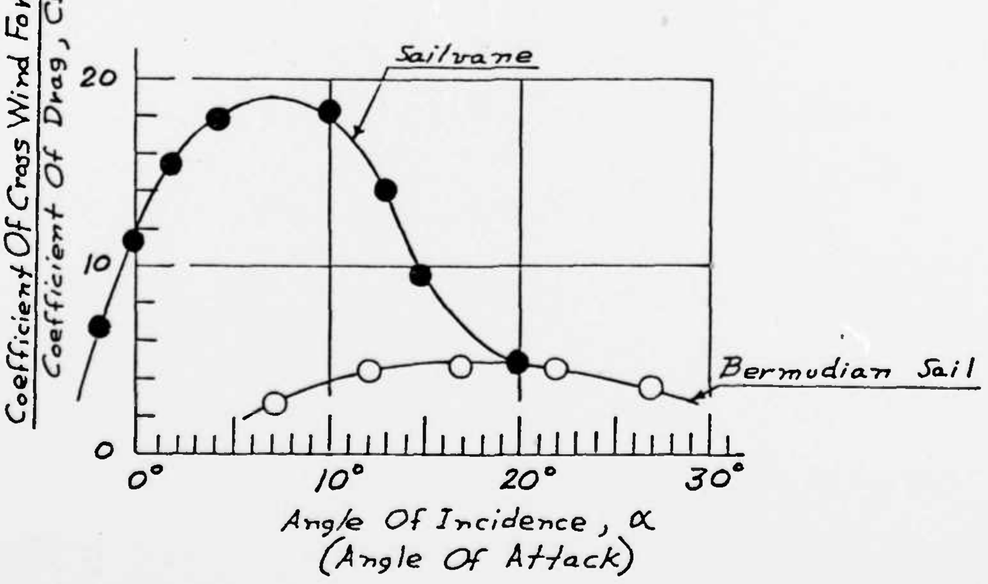
FIG. 9

FIG. 10



● Princeton Wind Tunnel Tests
○ Reference 1
* Dashed Lines Added By Princeton To Indicate Probable Luffing Mode

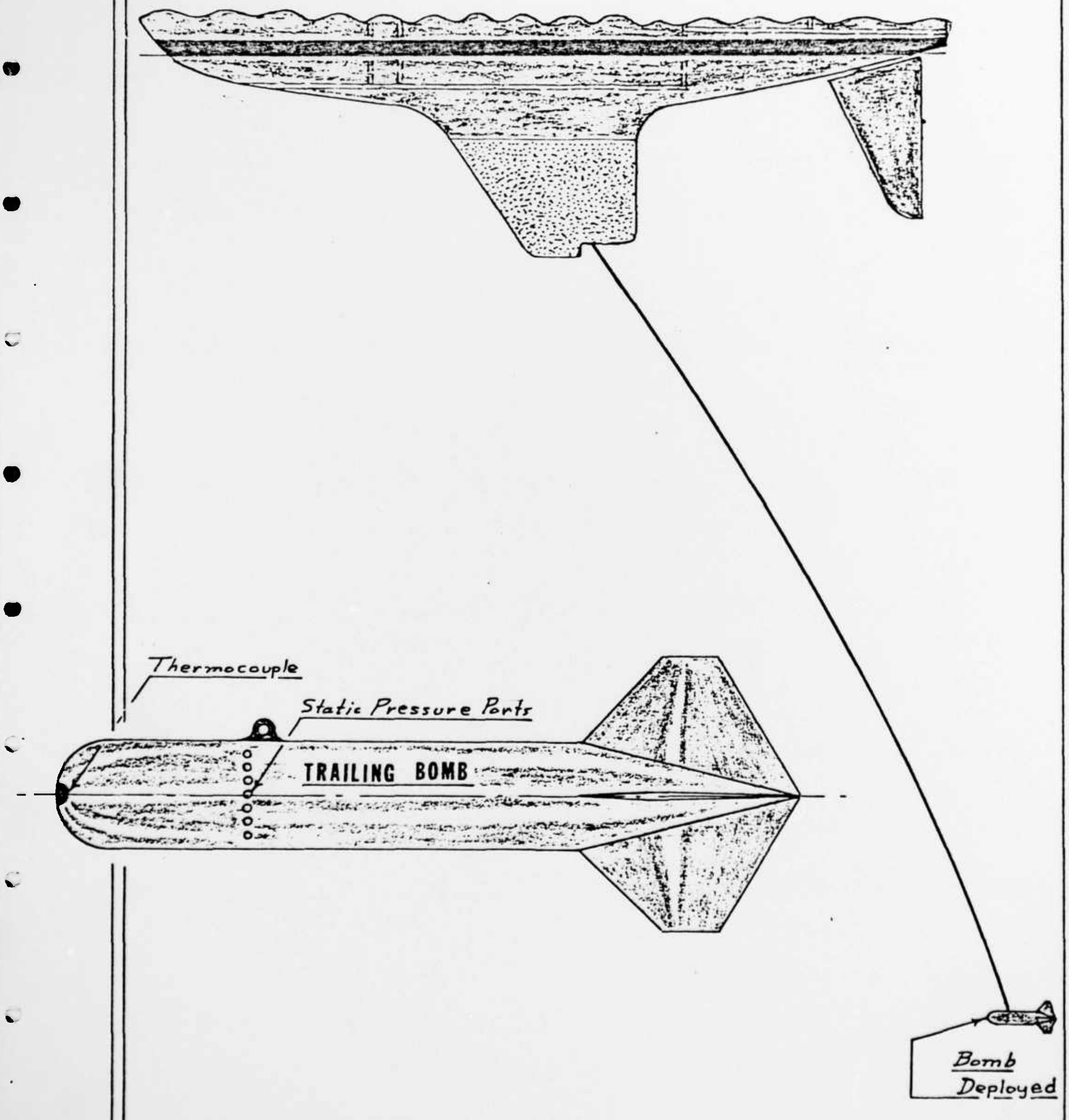
FIG. 11



REF. 1 : SAILING THEORY AND PRACTICE, C. A. MARCHAJ, DODD MEAD & CO., N.Y.

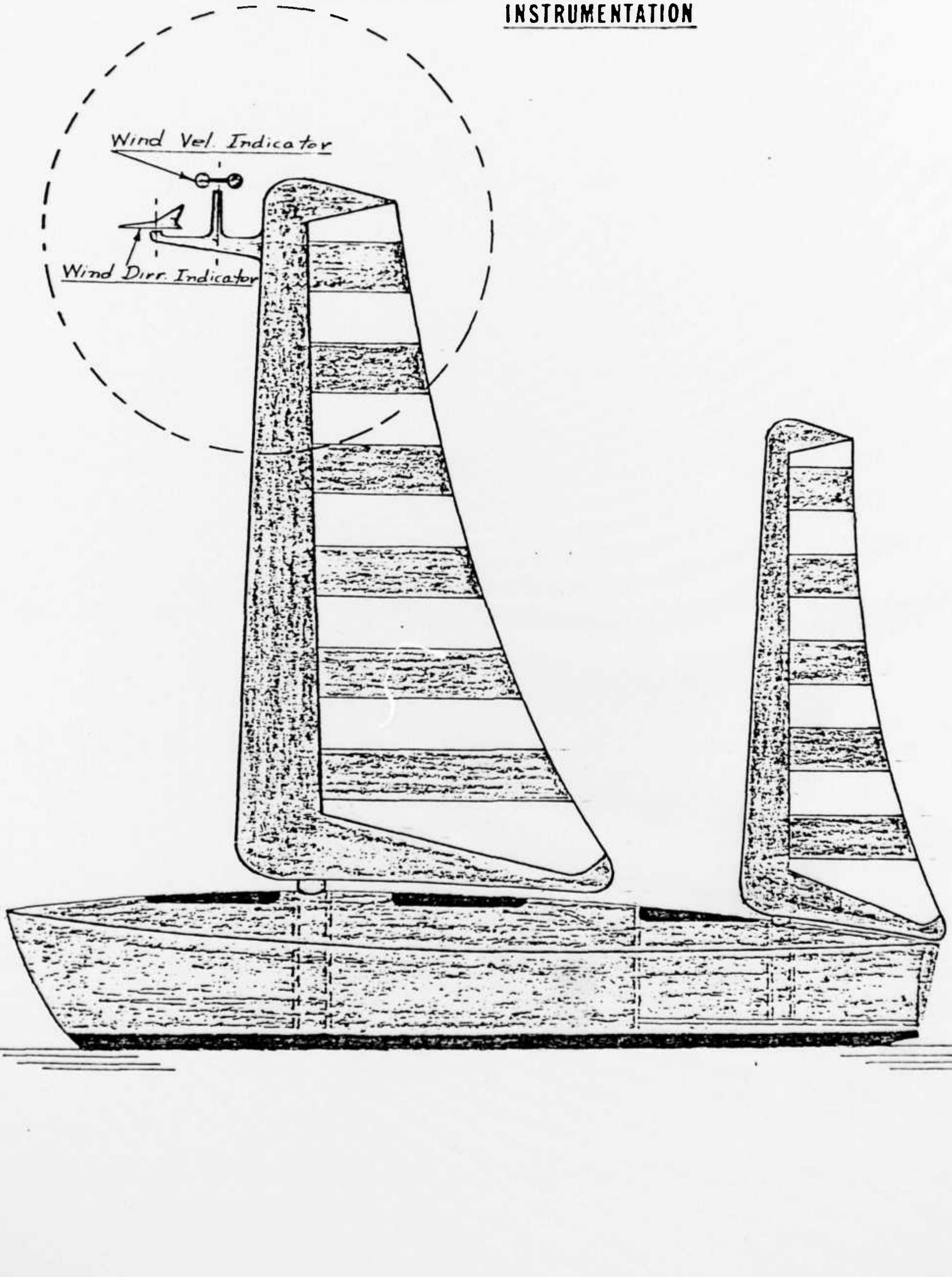
TRAILING BOMB UNDERWATER SENSOR

FIG. 12



SCHEMATIC DIAGRAM OF MASTHEAD INSTRUMENTATION

FIG. 13



SCHEMATIC DIAGRAM OF MASTHEAD INSTRUMENTATION

FIG. 14

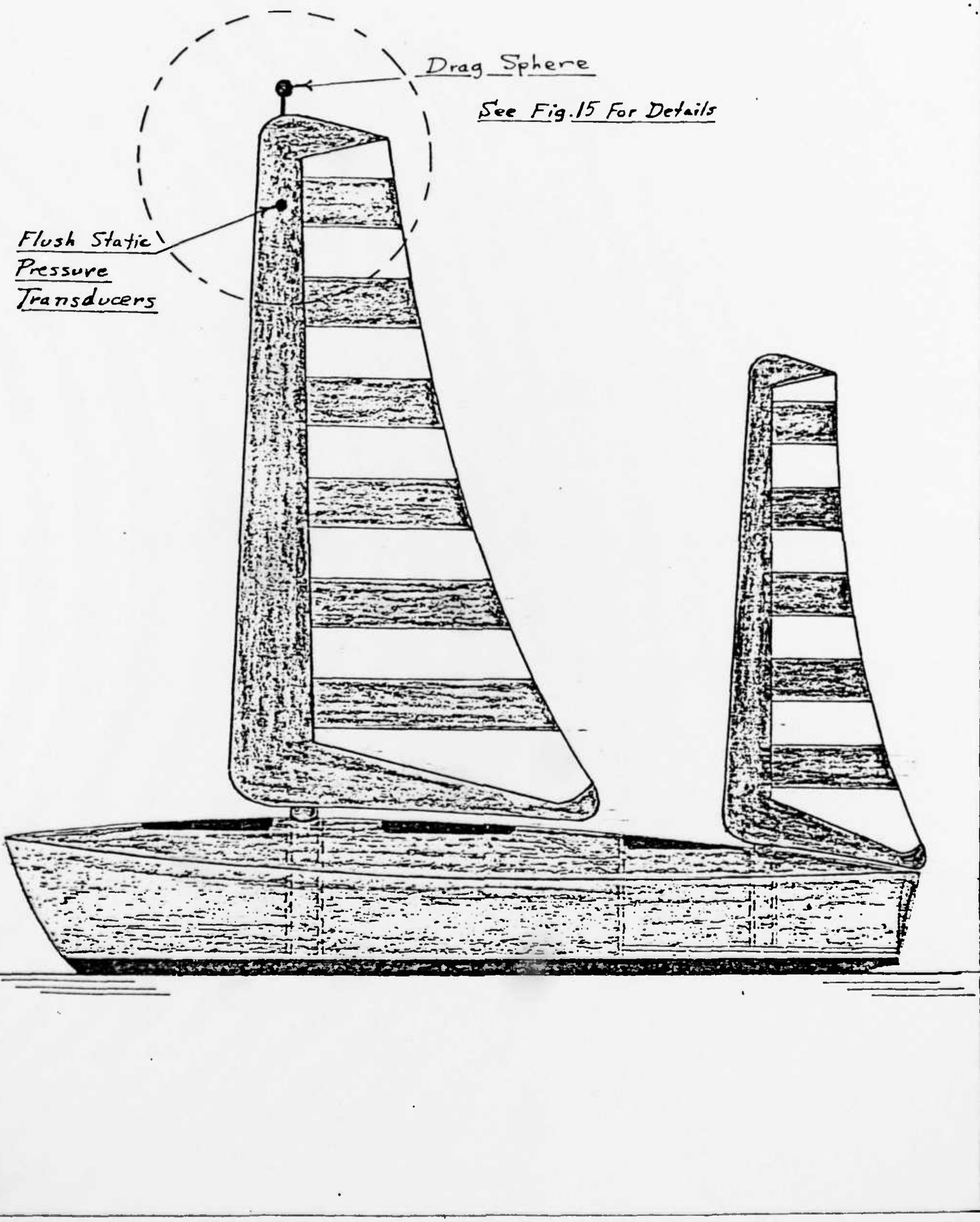


FIG. 15

ALTERNATIVE MAST HEAD INSTRUMENTATION

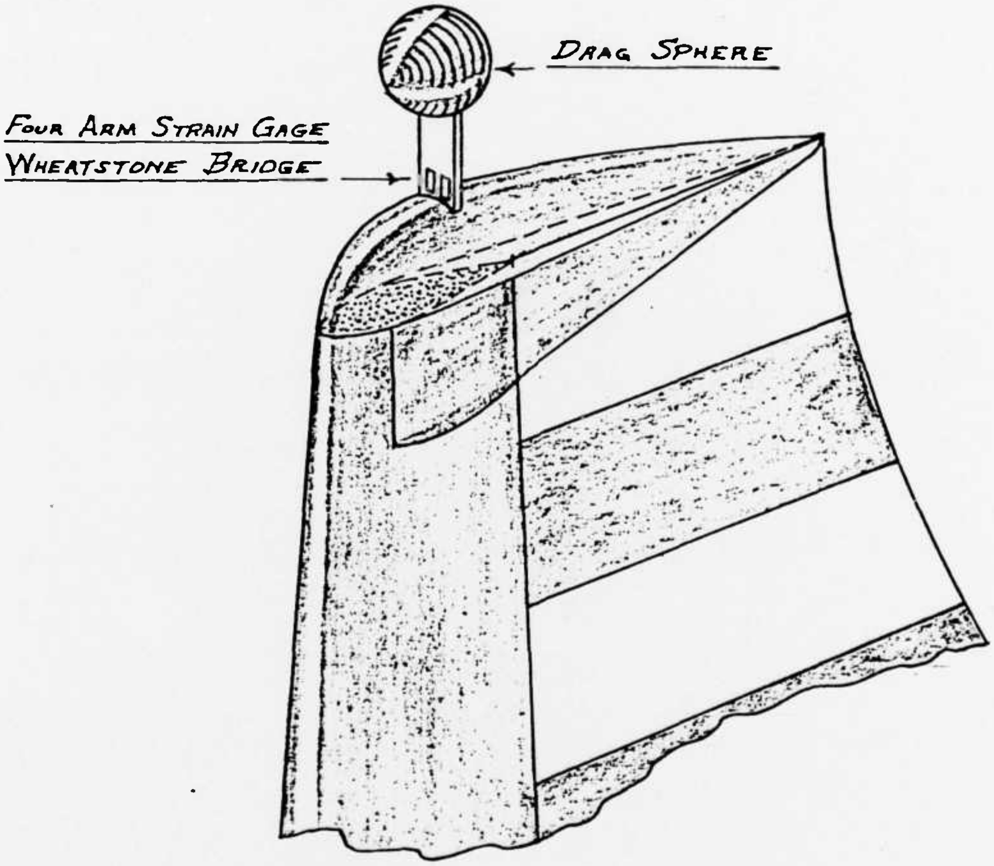
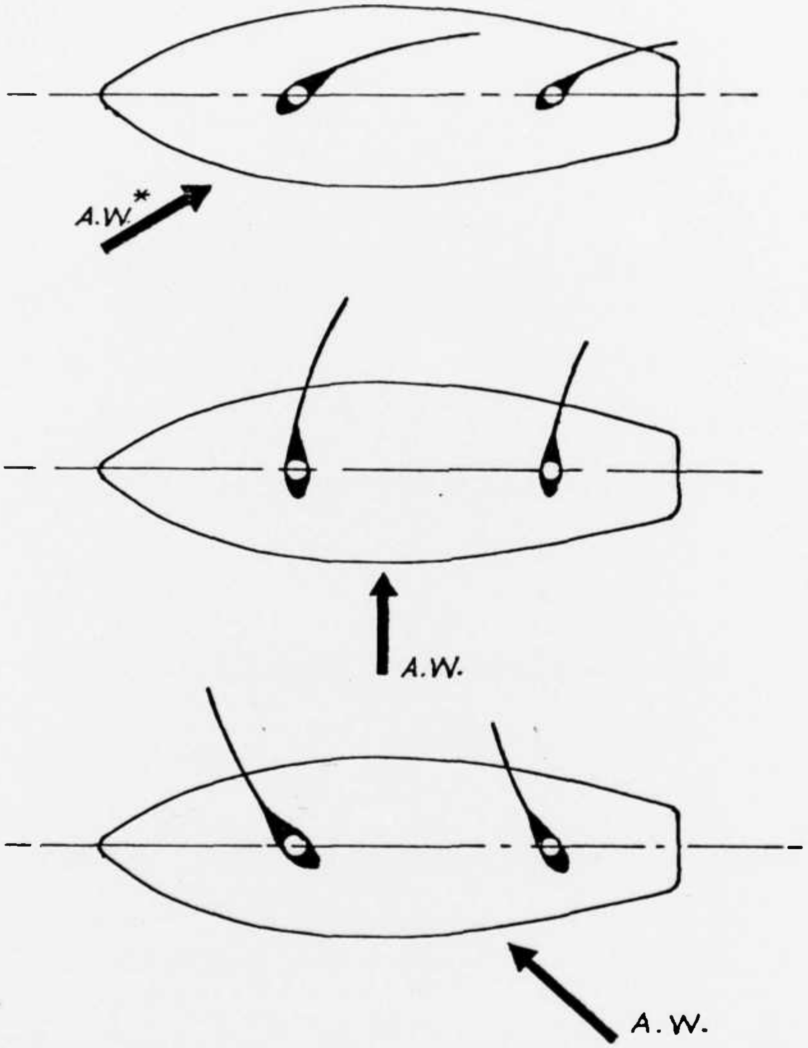


FIG. 16

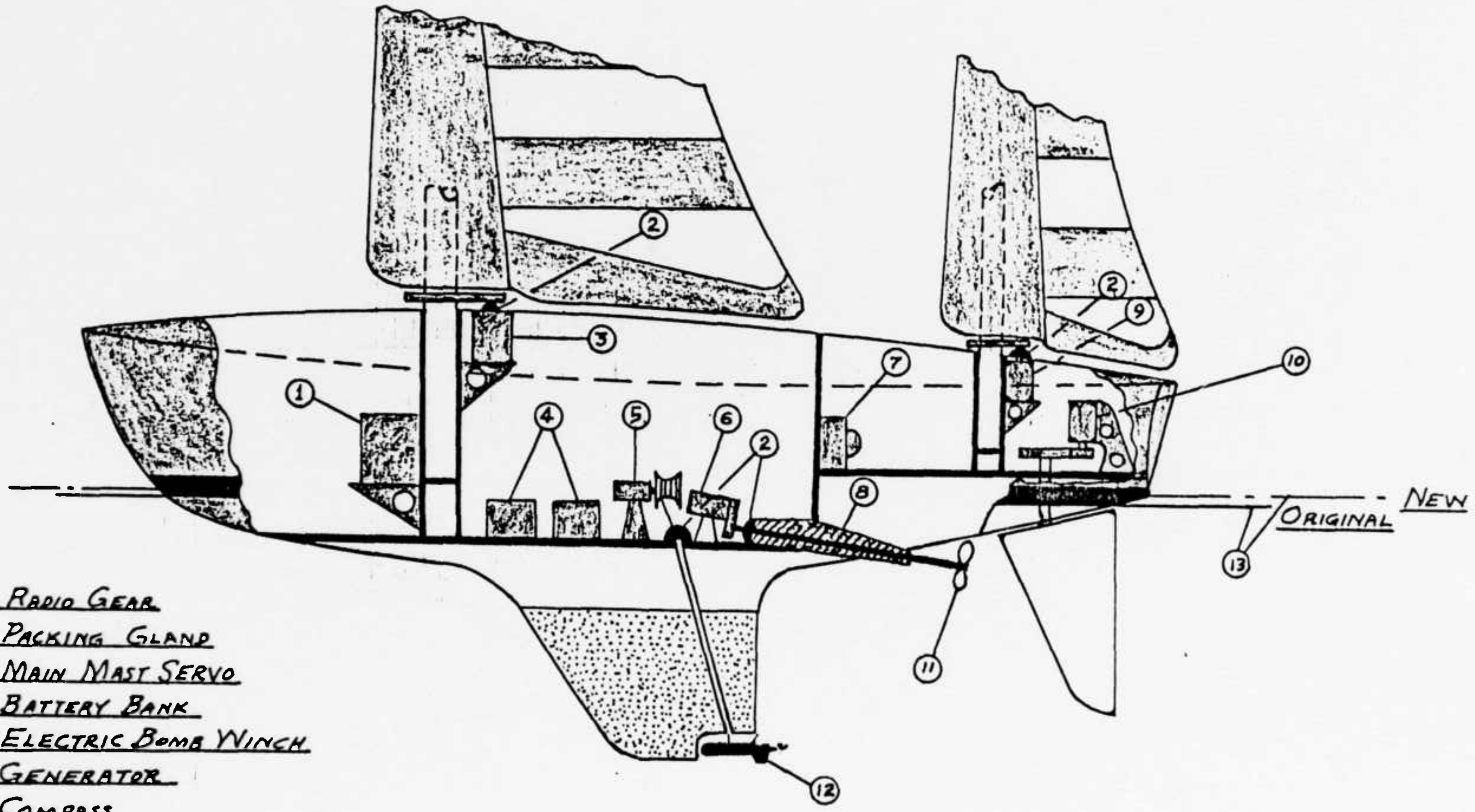
Schematic Arrangement Of Sails
for
Several Points Of Sailing



A.W.—Apparent Wind

FIG. 17

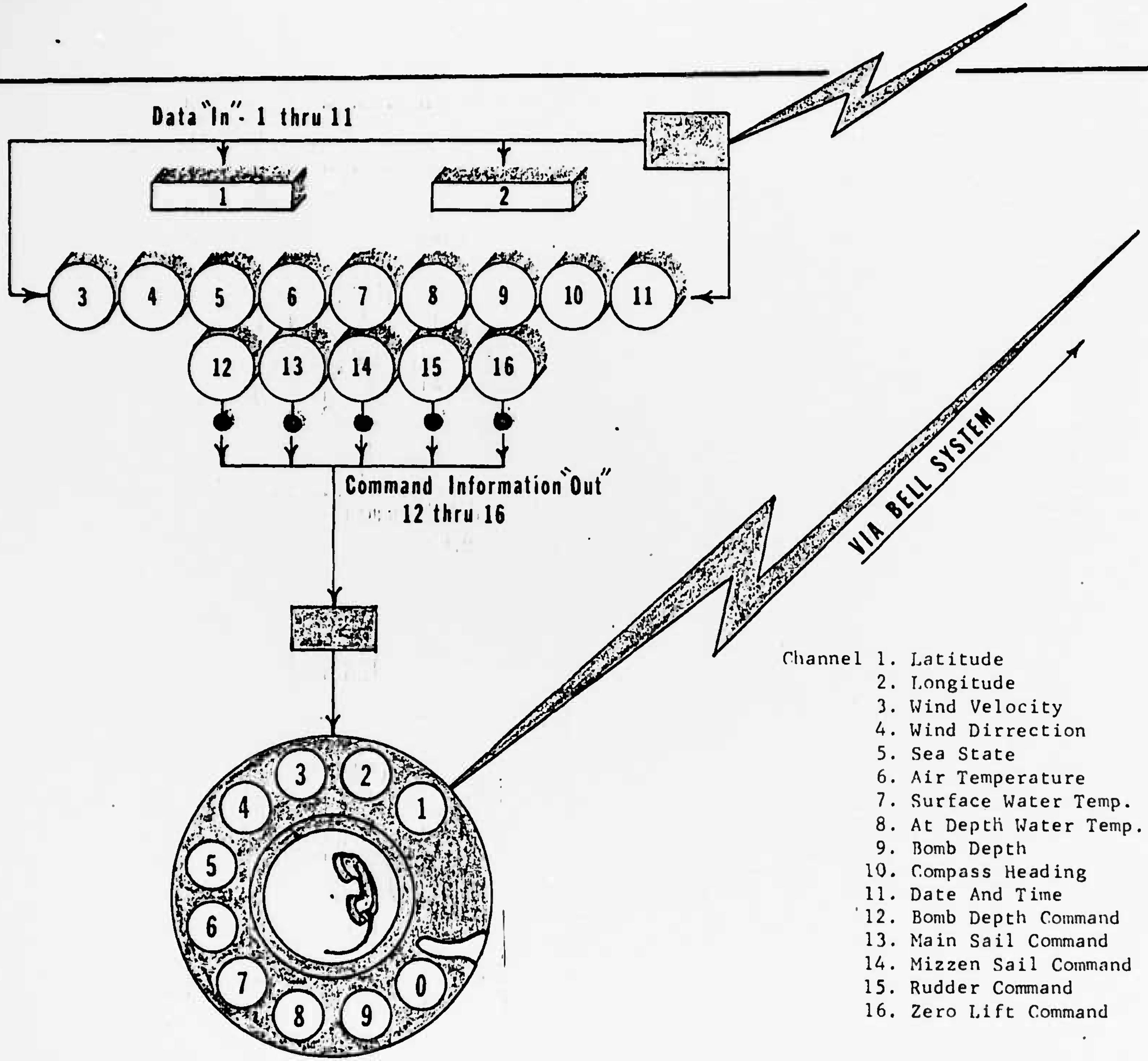
INBOARD PROFILE
(A Schematic Arrangement Of Parts)



① RADIO GEAR
② PACKING GLAND
③ MAIN MAST SERVO
④ BATTERY BANK
⑤ ELECTRIC BOMB WINCH
⑥ GENERATOR
⑦ COMPASS
⑧ SHAFTWAY
⑨ MIZZEN MAST SERVO
⑩ RUDDER SERVO
⑪ "WINDMILLING" ROTOR
⑫ TRAILING BOMB
⑬ WATER LINE.

DATA ACQUISITIION And COMMAND SYSTEMS

FIG. 18



Channel 1. Latitude
2. Longitude
3. Wind Velocity
4. Wind Dirrection
5. Sea State
6. Air Temperature
7. Surface Water Temp.
8. At Depth Water Temp.
9. Bomb Depth
10. Compass Heading
11. Date And Time
12. Bomb Depth Command
13. Main Sail Command
14. Mizzen Sail Command
15. Rudder Command
16. Zero Lift Command

END

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