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A Cruising Boat

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The paper discusses the trade-offs and pay-offs of designing and building big ship capability into a small cruising sailing yacht. A norwegian resuce ship hull form, large three bladed controllable pitch propeller, nickel cadmium batteries, shaft driven generator, above average horsepower, a high degree of watertight integrity, modest self-salvage capability, tug boat handling under power, low helmsman energy drain under all conditions, circumferential safety and grab rail, balanced rudder, diesel oil fired range, hot water central heating are discussed as they combine to fill the author's requirements for seaworthiness, seakeeping ability, safety, maintainability, self sufficiency and comfort at sea.

INTRODUCTION

Any aspiring cruising boat owner with a reasonable library can vicariously circumnavigate the world compiling his own compendium of cruising sail boat attributes without leaving the security of his favorite den chair.

Some will never buy. These comprise the most avid and obdurate group. A few will enter the market with quite firm convications of type, rig, acceptable accommodations and services. A still smaller number, not satisfied to judge by number of bunks, "bulkhead to bulkhead" amenities and monogrammed tea service will buy, sell and alter until they find their own right mix. Very few support their convictions with their money in a "one-off" boat.

Included among the already well known exceptions are the "Yankees", the "Wanderers" and "Angantyr". A recent exception is "THULE" so named because the years of gestation made her seem chimeric to the author's friends. Some of the thinking underlying her design follows.

HULL FORM

Until 1928 the author's experience was limited to a 14 foot international dinghy and a Charles Mower designed centerboard cruising ketch. The summer of 1928 brought a Rotary Club son exchange opportunity and personal contact with double ended fishing ketches out of Risør on the south coast of Norway. Similarly designed working yachts carried the fishing fleet doctors and managers to the coast of Greenland.

Subsequent visits to FRAM, Roald Amundsen's south polar ship and analysis of other of Colin Archer's designs kept the author's interest alive until the rescue ship hull form became better known and more widely used in the United States.

In 1951 the author met Bjarne Aas, known to him before only for his 6 meter and International One Design designs. He had done many cruising yachts, some flying twin running sails, but except by six meter sailors was little known in the United States. He kindly provided the author a set of parent lines for mulling and massaging purposes. As events developed, his son Henrik[2] ultimately assumed the responsibility for the lines and sail plan of THULE.

Figure (1) shows the long and gradual rise of keel fairing into the bow sections whose fullness results in gradually increasing buoyancy to limit plunging in head or quartering seas and, together with increasing beam above the

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[2] Mr. Henrik Aas, General Manager for Hodgon Brothers New Boat Sales and Design, Manager for John Alden Inc., Maine.

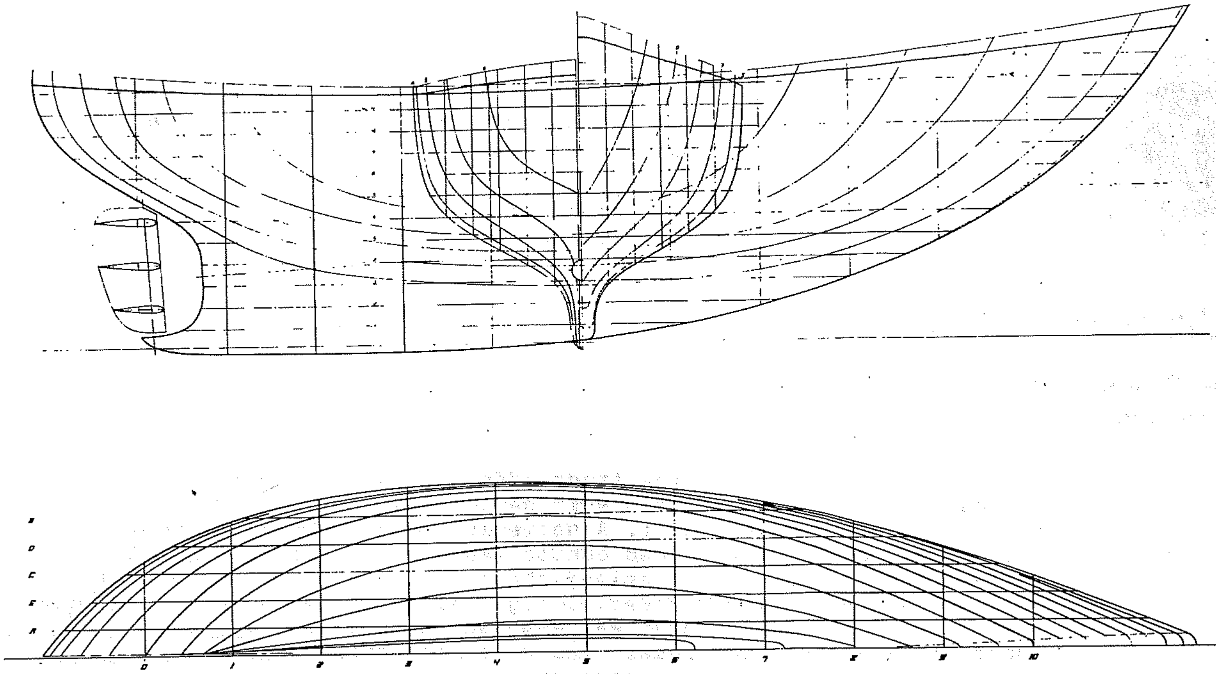

Figure 1 Lines

load water line throughout, also provides the lift to reduce the normal tendency to trim down by the bow when heeling under sail. This is a hull characteristic that can not be corrected by weight distribution.

Table 1 is interesting. It shows that at load draft the hull has little inherent tendency to change trim with increase of heel. Moreover, the ability of the hull to resist the trimming moment caused by the lift component of the aerodynamic forces acting on the sails for all practical purposes remains constant with increasing heel. For example; at 15° the boat trims by the head only 1" (25 millimeters), the trimming moment falls off only (.06 ton feet) 134 pound feet (18.6 meter kilograms); less than the helmsman shifting his position for comfort.

With these figures and sail loading data it would be simple to approximate the static effect of increasing wind velocities or direction on the boat's trim.

The freeboard, 6'5" (1.95 meters) forward, 4'(1.21 meters) amidships, and 4'10" (1.48 meters) aft with bulwarks rather than just toe or cap rails combine to keep the deck reasonably dry under all but apalling conditions. Bulwarks and proper waterways with freeing ports carry off what water does come on board quite quickly.

The after body to the load water line is not unlike many others. The use of the quite full after sections in lieu of transom stern above the L.W.L. makes the difference. An advancing wave front, encountering the rising buttocks and full water lines generates greater lift seconds earlier than an equivalent transom stern and helps avoid triping a following sea causing it to break devastatingly on board.

The enclosed volume of the entire hull is, at first glance, more difficult to use efficiently. It does not seem to lend itself to routinely preferred arrangements on any given length. The hard bilges and relatively great beam, a deep champagne glass form, necessitate a deck house to achieve head room on a boat below approximately 50 feet (16.4 meters) over all. The distribution of volume has merit.

The lines do produce an easily driven hull, great directional stability, initial stiffness, high range of stability with resultant ability to carry full working sails to force 7 Beaufort with safety and comfort.

The penultimate design carried a draft of 5'4½" (1.64 meters). The rationale then included a straight run of keel for ease in docking. A three inch half siding was simultaneously considered. Inasmuch as drydocking is almost always a planned, controlled operation these considerations were thrown out in favor of grounding and self-salvage considerations; the former at least being unhappily always a disturbing and normally overlooked certainty, the latter usually given short shrift by both designer and owner.

Table 1 changes in static trim and trimming moment for increasing angles of heel at load draft.

Heel in degrees	Trim by the head in inches	Trim by the head in millimeters	Moment to trim 1 inch in foot tons	Moment to trim 25 millimeters in meter kilograms
0.0	00	00	1.07	332
2.5	.02	.51	1.054	327
5.0	.11	2.79	1.04	322
7.5	.31	7.87	1.029	319
10.0	.46	11.68	1.02	316
15.0	1.03	26.16	1.01	313
20.0	1.84	46.74	1.00	310
25.0	2.83	71.88	0.97	301

If take to the ground on an ebbing tide one must, an easily shelving flat sand beach is to be preferred. However, this is not the rule. A straight keel with substantial half siding may, in trying to conform to the bottom as the waters recede, generate a hairy situation particularly if it hangs up and later lets go. It seems more prudent to design to make the best of whatever misfortune befalls the boat. THULE will come to rest at about 45° if the water drops away entirely. During grounding or refloating on a subsequent high tide the deck at side will not be immersed.

Grounding is at best a lonely situation, when far from assistance, discouraging if not alarming. The author has been there. Normally one can assume the boat has way on when grounding and will skate on her sloping keel until friction and the rise of the center of gravity combine to halt her by absorbing the energy of translation. If this occurs in mud or even soft sand, small problem; but for rock, shale, coral or hard sand a rocker keel line is helpful. It permits changing the attitude of the boat with the facilities on board as well as enabling the boat to be slewed with a light kedge or, if water depth still permits, even with the engine and rudder.

This reasoning led to dropping the keel line 3" (75 mm) below the original base to provide a continuously curving surface to the bottom.

Groundings also occur dragging anchor or backing down to avoid what seems to be more immediate, or at least recognizable danger, ahead. In line with this reasoning, the keel terminates in a very heavy skeg which carries the lower rudder bearing. This skeg can take the impact of the boat's grounding and pounding without jamming the rudder. The trailing edge of the rudder, as can be seen from Figure 1, falls within the extended upward sweep of the skeg for additional rudder clearance when dragging to ground on a rocky ledge or steeply shelving beach.

RUDDER AND STEERING

The rudder itself is very sturdily constructed. Aside from its heavy framing and plating with commensurate attention to strength and details of suspension, the solid stock 2.56" (65 mm) extends through a grease lubricated hull bearing and stuffing box above the water line to an upper bearing at deck level where a squared end can accommodate an emergency tiller. If extensive rudder damage should be incurred necessitating the removal of the rudder it can, with inconvenience, of course, be done afloat by unbolting the mating palm arrangement fitted in the flow lines under the counter.

Although 9.69 ft.^{2} (0.9m^2) in area the rudder has slight positive buoyancy in the intact condition and can be handled by one man either in or out of the water.

The rudder is streamlined with the maximum thickness at 20% of the chord length. It is also balanced, perhaps too well balanced if the usual concept of "feel" is applied. A rudder with quadrant and cable moved hard over to hard over with 4 turns of the steering wheel normally would be expected to have "feel", a numbing amount in heavy going.

For a cruising boat it is not an overriding or even desirable requirement. Most helmsmen on long passages and even on short watches ease the load on themselves by braking the steering wheel, thus by choice removing inherent responsiviness and, "feel". At least on the wind, they balance the boat with the rig, the rudder essentially amidships, and carry on "no hands" making only minor adjustments thereafter as needed.

Some kind of relief from the demands of the helm is indeed very welcome; wind vane steering, auto pilot, or both. The usual outboard wind vane rig was considered but even with the very low torque demands of a balanced rudder seemed an awkward arrangement and vulnerable at best. It was mentally shelved in favor of a Flettner Tab actuated by a small wind vane with a servo shaft through the rudder stock. This lent itself very well to the hull construction and configuration of the rudder. The linkage within the rudder seemed the Achilles heel.

Inasmuch as motoring is not only a windless alternative but moreover a great boon in lumpy windless weather, an auto pilot releases the helmsmen and reduces him to the role of a sometimes lee helmsmen and lookout under both sail and power.

Manhandling a tiller or a wheel with the usual rudder "with feel" under hard going can be an enervating experience in itself. No less so with an auto pilot. It becomes an energy consuming hog which, when added to navigational lights, refrigeration and communications requirements, either requires unreasonable energy storage capability or a continuously running auxiliary generator.

The balanced rudder permits efficient use of an auto pilot. The battery drain is so limited that the 24 volt auxiliary generator need be lit off only one hour in twelve and this dictated by navigation lights, refrigeration and freezer requirements.

The auto pilot even under worst conditions flushes the ammeter indicator only momentarily off the peg. On the wind with the rig balanced the power consumed is miniscule, with the wind aft or on the quarter, acceptable; much less than a VHF receiver monitoring channel 16.

THULE uses a Sharp and Company (English) auto pilot. This rugged unit (THE MATE) was a natural for fishing trawlers, coasters and other commercial boats. Its simplicity, rugged compactness and sensitivity of control makes it especially suitable for yachts.

THULE always carries a watch on deck. Under these conditions wind vane steering as opposed to auto pilot has no particular merit. Even under single or short handed cruising conditions "off course" (or "off wind") alarms can be plugged into the pilot, again making wind vane steering more of a refinement than a necessity. As an adjunct to an auto pilot wind vane steering does make sense.

An ancillary component manufactured by Sharp provides the wind vane input. The auto pilot serves as its servo mechanism. The input is essentially a Brooks and Gatehouse wind indicator feeding signals to the auto pilot control box in the same fashion as does the compass course selector.

The auto pilot with or without a vane controlled servo mechanism is the best helmsman on board. The control box can alter the sensitivity of the drive to allow for yaw, general sea conditions, vary the rudder angle used to hold course, or easily use the rudder as a trim tab by offsetting the electrical zero point when the boat is carrying helm. Furthermore, the vane can be at the mast head level, a shroud or anywhere convenient.

THULE does not carry a wind vane but is fitted to receive one. The whole would make a tidy, dependable package facilitated in THULE's case, by the balanced rudder to conserve electrical energy and by the controllable pitch propeller driven shaft generator to generate it.

CONTROLLABLE PITCH PROPELLER AND
SHAFT DRIVEN GENERATOR

In order to provide the maximum performance under power under all conditions, aground to free running, plus full feathering for sailing a controllable pitch propeller was used. The shaft driven generator is a fringe benefit.

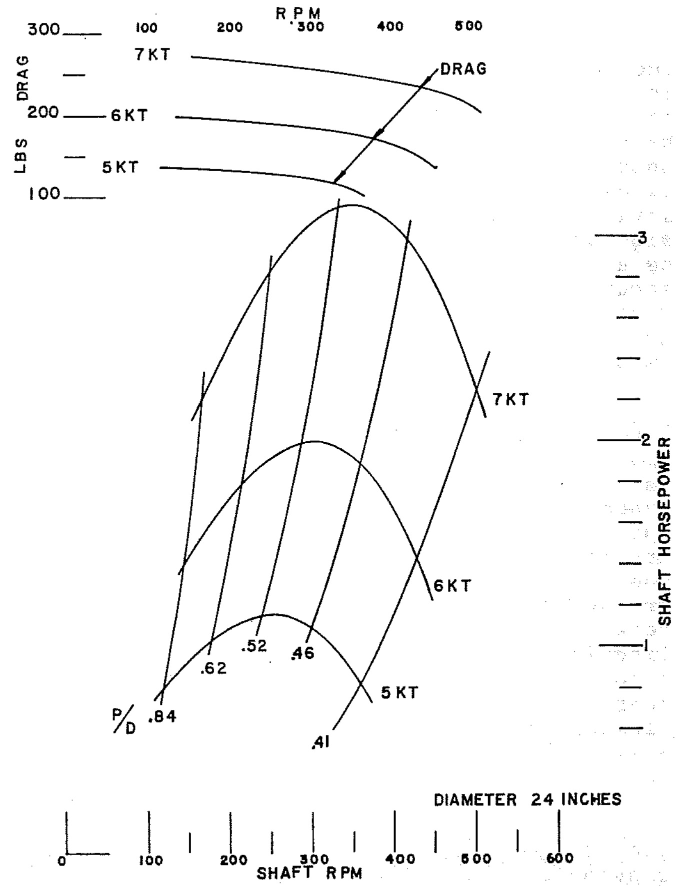

Figure 2 Dragging Propeller Curves

The curves shown in Figure 2 are based on data from the David Taylor Model Basin. A pitch-diameter ratio of about .50 indicates the optimum possibilities of torque extraction for a 24" diameter 3 bladed propeller.

The stern tube and thrust bearing losses were not known but, assuming one to two horsepower, the useful net appeared disappointingly low even at the indicated optimum pitch ratio; moreover, it fell off rapidly as the pitch ratio increased. One can conclude that use of a fixed propeller designed for maximum free running propulsive efficiency has little merit when used alternatively for power generation.

In order to minimize parasitic losses

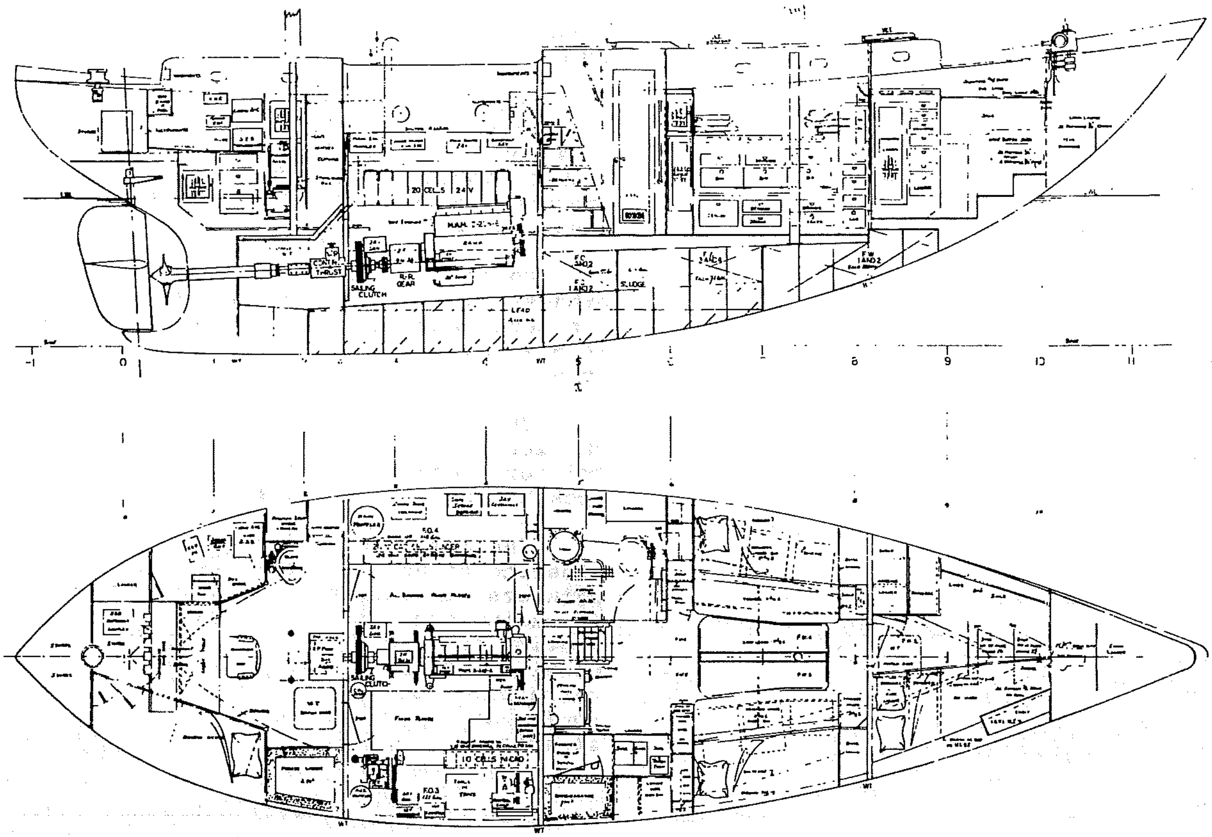

Figure 3 Arrangement and Profile

it was necessary to isolate the reduction gear box. A reduction gear box with a disconnect clutch and lubricating oil pump both on the output shaft was a non-standard unit thus inordinately expensive; a standard box could be delivered without the reverse gear at slightly increased cost. Inasmuch as a standard reduction-reverse gear box could be furnished at list price off the shelf and a propeller configured to permit full reverse to full feather required a hub 7" longer than the standard 90° range feathering wheel and would interfere with the propeller aperture and rudder configuration, the standard reverse-reduction gear box was chosen for reverse as well. Thus the standard reverse-reduction gear box driving a 90° range controllable pitch propeller through a simple high torque mechanical disconnect or sailing clutch between the pitch control cum thrust bearing housing and reverse-reduction gear box itself comprise the system. See Figure 3.

The pitch control box as well as the reverse-reduction gear are fixed to the engine girder extended. The main diesel itself however is mounted on rubber vibration mounts. The coupling between the units is a standard moulded rubber coupling.

In summary; the afterbody lines of the norwegian rescue ship hull form lend themselves to accommodating the large slow turning high torque controllable pitch propeller which gives good thrust under power, minimum drag when sailing feathered and adequate torque under water-milling conditions to drive a shaft driven generator under sail.

The shaft driven generator is a Leece Neville 100 amp BuOrd type generator with a standard voltage regulator. In practice this appeared to be the Achilles' heel of the system as first fitted. It was in fact the author's design oversight. If the battery was completely charged the demand on the generator was low and the shaft driven system provided the small trickle charge with no difficulty at speeds down to about 4 or 5 knots. If the battery was even slightly discharged the voltage regulator demanded the maximum output the generator was capable of. This setting although actually 50 amps proved sufficient to stall the propeller shaft at any wind velocity under about Force 6 or 7. This wind and the usually accompanying sea conditions are not conditions that one seeks if one can avoid them; certainly not merely to charge batteries. This confirmed the fear that the parasitic losses were in fact between 2 and 3 horsepower and that even with the reduction gear isolated the amount of power actually available for electricity generation was very low indeed.

Leece Neville engineers made available

a manually variable current controlled regulator with its parent alternator. These will be installed this winter and will permit varying the battery charging current to whatever the wind conditions will support without stalling the system. This, assuming a minimum current output of 5 amperes, would still permit a replenishment rate sufficient to carry the boat.

Some loss of speed is inevitable. The relative importance of this loss depends on which end of the speed-power curve the boat is operating.

Further refinement of the system might include redesign of the back faces of the propeller blades. In large propellers the expense rather renders the pay-off an unnecessary fillip. Where propulsion itself is only a convenience, the principal could be applied to trailing propellers in smaller sizes, powering a low capacity generator whose output is purely to float a battery-auto pilot-cum-wind vane system such as is understood to have been fitted into at least one of the last group of single-handed trans-Atlantic British racing entries.

OTHER PROPULSION CONSIDERATIONS

The capabilities of the controllable pitch propeller for emergency towing of others (THULE carries a 40 fathom 3/4" nylon towing hawser on a reel aft in addition to a similar reel forward as a stand-by anchor rode) or self-salvage are real assets. Large thrusts can be generated at low speeds of advance (high slip). If a modest 30 lbs. of thrust per shaft horsepower were assumed to be the conversion factor, the combined thrust or pull of 2 anchors to beach gear tensioned by the hydraulic capstans fitted plus an estimated 70 HP being available (power available less double hydraulic pumps) and assuming a bottom coefficient of 1.0 a Force of 20% (3 tons) of the displacement would be available for salvage without outside help. This of course assumes that the propeller would remain reasonably immersed.

In the usual grounding or extreme sailing situations the main engine soon becomes useless when the boat lists beyond 15-20°, either because of standard engine oil sump design, silting of the cooling system or loss of sea water suction as the tide runs out.

These possibilities were minimized by the fitting of a deep engine sump which permits continuous full power operation to a 40° list. The sea suction problem is minimized by using a transverse sea chest piercing the hull port and starboard permitting main engine operation even beyond where the propeller would become ineffective but the hydraulic power plant still available for beach gear tensioning.

MACHINERY SPACE

The engine room is bulkheaded and sound proof sheathed. The insulation is glass wool.

The main engine is a Motoren Werk Mannheim (M.W.M.), 6 cylinder, four cycle, 84 H.P. at 3000 R.P.M. diesel of German origin. Each cylinder has its own head and push rod operated valves. The fuel system is Robert Bosch as is the governor.

On the factory test stand the engine exhaust gas temperature and manifold depression were recorded and the fuel racks set at 84 H.P. at 3,000 R.P.M. (The engine is capable of 96 H.P.)

On builders trials the conditions were duplicated by varying the propeller pitch at the corresponding propeller revolutions and locking the pitch indicator pointer.

The mechanical pitch indicator on the steering stand requires only the matching of pointers to duplicate the proper pitch. This is manipulated from full feather through operating to zero pitch by using the trim tab wheel of an Edson Stand. An electrically operated interlock prevents starting the engine while the propeller is feathered or at excessive pitch.

A large Ahead-Back R.P.M. indicator is included on the cockpit instrument panel as is an exhaust gas pyrometer indicator. Cooling water temperature is similarly monitored.

A 2.81:1 ZAHNRADFABRIK (ZF) water cooled, hydraulic reverse-reduction gear box drives a HUNDESTED MOTORFABRIK (DENMARK) Size VP3 (680 mm) 26.7" diameter 3 bladed propeller through a high torque, manual disconnect clutch (sailing clutch) and a HUNDESTED propeller pitch control box and thrust bearing assembly.

On the outer (after) housing of the disconnect clutch are mounted the sheaves to accommodate the "V" belts driving the 28 volt shaft driven alternator.

The stuffing box and stern tube bearing are conventional and are lubricated by small scoops directing water from the sea into the stern tube ahead of the bearing. These must be kept free of barnacles by routine cleaning and painting.

The main engine drives the usual service pumps in addition to anchor windlass and capstan hydraulic pumps and a large capacity, self priming centrifugal bilge pump.

A Volvo MD1 diesel powers a 100 ampere 28 volt alternator and a 35 ampere 12 volt alternator. The boat is piped to receive a small hydraulic pump for auxiliary use but there being no apparent need it was not installed.

A 1/3 H.P. GRUNERT water cooled compressor cools the 4 ft.^{3} (113 liters) freeze locker and 7 ft.^{3} (198 liters) cold locker.

Constavolt 24 volt and 12 volt units are supplied 220 volt A.C. from an isolation transformer so switched that it will accept either 110 or 220 volt shore power. At sea, 500 watts of 110 volt A.C. is supplied by a manually frequency controlled (CARTER) rotary inverter. All switchboards are of the breaker type.

The mufflers are both wet and have butterfly valves to isolate from the sea as required.

A cathodic protection device (CAPAC) is in continuous operation and is 100% effective. Great care must be exercised in maintaining the integrity of the electrical system. Two anodes and one reference electrode are used. The imposed voltage (0.940V) can be monitored from the navigator's chair.

The Auto-Pilot is housed in an open box structure depending from the engine room access portable plate in the cockpit deck. It is clutched to and drives the main steering jack shaft.

A fresh water pump, sump pumps for galley and shower (diaphragm pumps) sea water pump, 9" diaphragm hand bilge pump, electric bilge pump (diaphragm) and all liquid filling and suction manifolds complete the array.

All components are easily accessible for maintenance under way or replacement if necessary. A comfortable supply of critical spares and tools are stowed in the engine room.

ENERGY STORAGE

One can cruise as Captain Slocum or Captain Voss did but the author even if at a younger age and semi-qualified does not choose to do so. Therefore, the largest single engineering problem becomes the conserving and storage of energy or, in simpler terms, the battery capacity, dependability, long life and low maintenance. Despite common misunderstandings about nickel cadmium batteries, their size, weight, and cost and utility for yacht use, they have overriding merit.

Perhaps the increasing use of nickel cadmium batteries in small sizes and types will focus attention on their ability to hold their charge or not suffer injury by remaining discharged and will draw attention to their merit for yacht use. Emergency power for european built ships, locomotives, industrial equipment has always favored nickel cadmium batteries. The apparent weight and bulk of nickel-cadmium batteries rather blinds one to their very meritorious qualities not the least of which is low maintenance cost and life of the boat life.

Completely separate batteries both as to type and capacity are used for ships service power and engine starting. In order to avoid the temptation of using the starting batteries for other purposes and to permit larger energy storage capacity for a given volume they should also be of different voltages. 12 volts for starting is the common practice and in this case is provided by 10 nickel cadmium cells of high current drain capability and modest capacity, 110 ampere hours. The voltage in the charged condition is about 14 volts. Completely separate (in no way cross-connected) is the 24 volt ships service bank of 20 cells of high capacity 230 ampere hours at a nominal drain rate (7 hours). The imposed voltage during charge is 28 to 29 volts and can be 20 or less in the discharged condition. This possible large voltage variation requires the entire electrical system to be capable of tolerating it. For example: the types of lamps used, 28 volt bulbs for navigation lights, compass and other important lights.

The usual run of low load intermittent duty (sump, fresh water, sea water, bilge) pumps will accommodate this variation without complaint. However, more heavily loaded motors such as the refrigerating compressor will draw more current, overheat as they slow down and plunge the batteries more rapidly to lows of 16-18 volts if neglected. The batteries are not damaged, the motor may be. Prudent boat operation as in most situations prevents these things from happening.

At first glance equivalent capacity in a nickel cadmium battery system seems to be obtained only at the expense of great weight and space. This is a common misconception. Actually the weight differential for the 24 volt ships service batteries is only about 5% higher than the equivalent capacity of lead acid batteries. In the case at hand 596 lbs. as opposed to 568 lbs.

For the 12 volt starting system the differential is less favorable, a good 50% weight premium being paid for the use of nickel cadmium batteries for starting purposes. This too is quantitatively no big penalty.

If optimum packaging is specified, overall volume, although not a standoff is at least acceptable. In this case, by using nickel cadmium assemblies of 2 cells per crate and racking the crates athwartships the bank was only 2" wider but shorter than the wood crated lead acid equivalent.

In the writer's opinion the advantages of long life, ease of maintenance, dependability, safety, complete imperviousness to extremes of heat or cold, no loss of electrolyte at extreme lists outweigh even the commonly assumed disadvantages. In THULE the two battery sets are mounted in battery banks let into the two fuel oil day tanks outboard in the engine rooms (see Figure 3). A sacrifice of only a few gallons of fuel was necessary to accommodate the nickel cadmium selection over lead acid.

The initial cost, however, is high unless one considers that one set of nickel cadmium batteries will last for the life of the boat. Assuming only 20 years, 5 sets of lead acid batteries would be needed. When viewed from this life of type point of view the cost is highly in favor of nickel cadmium.

Conservation of electrical energy is important on any boat but singularly so on a long range independent cruising sail boat.

Bunks, heads, galley and chart desk are fitted with 4 watt push button, flexible neck lamps; the normal 25-40 watt illumination lamps are only normally used under power or when along side the dock on shore power.

Under sail in daylight the refrigerating compressor is the largest single load, 11-12 amps. It runs about 8 minutes per hour in the tropics servicing a 7 foot cold box and separate 4 foot freeze box. Add the auto pilot, communication receiver, Loran and the need to run the auxiliary diesel generator is then about one hour in twelve. When motoring under no wind conditions of course there are no current use restrictions.

That the shaft driven generator would not carry the load short of Force 6 or 7 wind was a disappointment and as stated could have been avoided by better and more thorough engineering.

One of the fringe benefits of the variable pitch propeller not heretofore mentioned is its use in the zero pitch condition as a drogue for use in following seas.

Although the theoretical drag of the propeller when generating power is about 200 pounds at 6 knots the drag in the zero pitch condition is not known. However, on one occasion when making about 9 and a half knots with winds off the quarter Force 7 or 8 the propeller was brought from the feathered position through the operating position to the zero pitch position with almost catastrophic results. The drag was so great that the ship almost tripped. The bow was driven under green water by the overpowering wind in the sails. Only the heavy duty nature of the entire rig prevented its being blown out of the boat.

WATERTIGHT INTEGRITY

"Lasting solidity and exactness of beauty" are not necessarily conflicting requirements. Use of wood accomplishes the latter but, being in large measure a function of initial building skill and materials, skill and level of maintenance and location of boat, falls short in the former. First class wood construction is indeed a joy but expensive when the desired woods and skills are available and used. The author reasons that steel, cheaper than first class wood construction is none-the-less to be preferred to the glass he has surveyed, at least on a "one off" or true custom boat basis, and to ferro cement in any sense. Steel lends itself to maximum flexibility of arrangement, ease in sub-division, structural strength and again, with skill and use of fine wood trim, can be beautiful.

Aluminum, more expensive than steel, but less so than glass or wood for a custom built boat has the additional advantage of ease of fabrication, maximum flexibility of arrangement and ballasting and, combined with art, ship fitting and ship joinery skills produces a hull of "lasting solidity and exactness of beauty".

Although early aluminum hulls made free use of plastic fairing compounds as steel hulls did "rivet cement", the judicious and skilled use of intermittent controlled inert gas welding, with heavier thicknesses of plating permitting grinding in the way of welds reduces the need for such treatment to a minimum. Watertight bulkheads with their continuous welding, there are three in THULE, do present the shipbuilder with a challenge.

These bulkheads were not located by considerations of floodable length but rather of accommodations. Aside from the "collision" bulkhead forward they isolate the machinery space which is located under the midships cockpit.

FLOODABILITY

The author can not recall seeing a Floodable Length Curve for a sailing yacht. Figure 4 may be worth a few minutes of study.

The most apparent conclusion must be that the price of two compartment capability in a small yacht is high indeed; in this case five compartments (four bulkheads).

Accurately speaking, THULE is only a one compartment ship. If damage and flooding is incurred aft it is marginally a two compartment ship. The engine room wing tanks and the cockpit recess with the machinery probably lower the permeability coefficient to the 0.7 indicated on the diagram.

A collision at the forward bulkhead or forward engine room bulkhead could spell deep trouble.

In order to have complete two compartment capability a bulkhead would have to be located at or near where the slash appears at the bottom of the diagram, approximately 13 feet from the forward perpendicular. This makes a shambles of the main cabin lay-out and creates an unhappy area to put to good use.

The margin line was taken as 3" below the deck at side. The hull and deck house is virtually submersible. The hull is covered from one foot below the waterline with 1" (25 mm) of water excluding foam insulation.

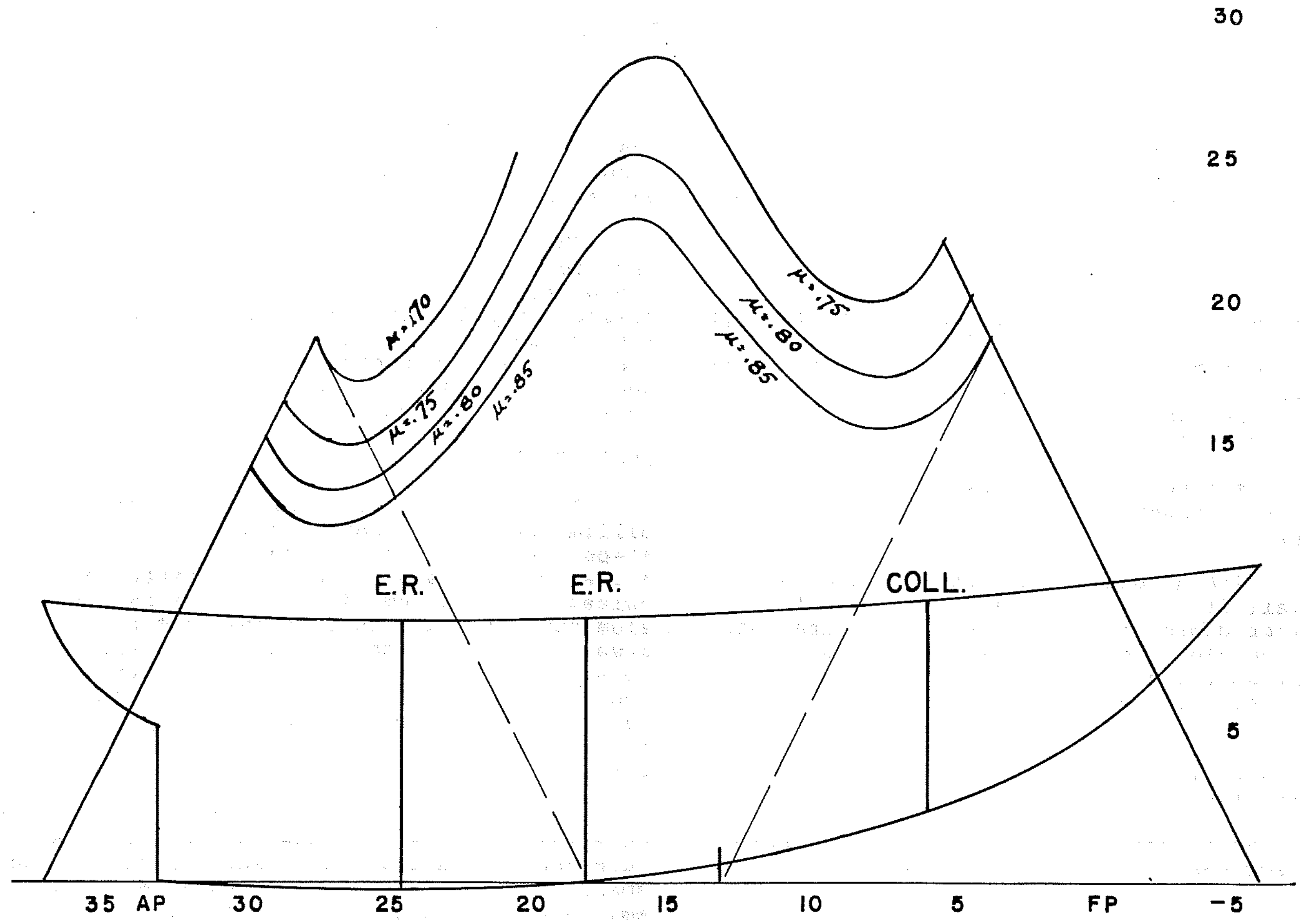

Figure 4 Floodable Length Curves

This adds the buoyancy equivalent of 3/4 ton. The assumption of an average "u" of .85 is conservative. All these inputs under touch and go conditions might lend validity to the u = .70 required to help out aft.

A transom stern would change the pug nose end of the curve slightly but not enough to invalidate the use of Figure 4 as a guide for other yachts. The following stability thinking could also apply.

STABILITY

The curves of Figure 4 are of themselves revealing. When damaged stability floodable length is also considered it is quite evident that severely damaged yachts have small chance of survival short of impractical subdivision.

With the bulkheads as located in Figure 4, one compartment capability is achieved measured by either criterion. This is certainly an improvement over "zero". It is not really prohibitively expensive in space or arrangement.

When analysed three and two adjacent compartments at one time, it isn't surprising to find that any adjacent three will cause loss by either flooding or loss of stability. As a practical matter, any two adjacent will do likewise.

The main cabin and engine room flooding combination results in instability but there might be enough left to survive at a heavy list; hardly enough to support sailing away. (Righting moment approximately 0.4 foot tons, 124 meter kilograms at 25° heel).

One can conclude that with four compartments arranged as in THULE:

1. If the hull is breached at a bulkhead the boat will survive only if the deck is truly submersible. In two of the three possibilities the boat will up-end like a nun buoy.

2. If two compartment and modest sail

away capability is desired at least five transverse W.T. bulkheads will be required. (A longitudinal sub-system is beyond practical consideration except in fuel and water tanks) or

3. Other means of providing high buoyancy and limiting free surface must be provided.

If a ship is to be truly whale, uncharted pinnacle or petit collision proof it is not beyond the realm of possibility and the current state of the art. A remote controlled or automatic foam generating system could be carefully designed and built into each compartment.

As shown in the "Knox" salvage it's messy to clean up but the boat could sail away.

With adequate attention to structural detail it might be possible to use only joiner doors and bulkheads if they are done in the old mode before yachts became cost, ballast ratio, wetted surface and weight critical cruiser-racers.

Good drainage and emergency power to serve it would be required hopefully to arrest progressive flooding.

As a last alternative; one can always follow past precedent and trust to luck.

At least in these "Years of the Whale" I doubt the bulkheading in conjunction with the energy absorbing qualities of the aluminum shell and framing would permit accidental precursors of yet one more heroic tale of survival. Such possibilities however should not be taken lightly in the design of any deep sea cruising boat.

WATER TIGHT DOORS

The watertight doors are fitted with commercial type dogs, knife edges and heavy rubber gaskets. The boat normally cruises with the forward door (6 dogs) dogged at sea, the other doors are normally carried with the dogs lightly set for quick access to the after cabin from the cabin. The head room 5'6" (1.67 m) over the engine room floor plates is adequate for access to the switchboard, pumps, engines, work bench and a rush through. The engine room doors (four dogs) have only 53" opening and are 18" wide. They are raised to provide ease of access as well as a high coaming to buy closing or dogging time in case of flooding or fire.

HULL OPENINGS

There are a minimum of underwater hull openings. All sea water service is taken from the 10 cm (4") port to starboard sea chest mentioned earlier and is strained through a duplex strainer before entering the sea water suction distribution manifold. The two head overboard discharges, depth finder, underwater log and cockpit drainage openings comprise the other hull openings.

All are secured with their own stainless ball globe valves of generous proportions. They are insulated from the hull and are easily accessible.

The one blunder with the above arrangement turned out to be the refrigerator cooling water sea suction. This was starved by taking off below the main engine cooling system raw water suction valve. This in fact limited the protracted free running speed of the boat to six and one half knots under power. It will be rerouted this winter.

SHOCK CRITERIA

The coach roof or cabin top is six millimeter (1/4") plate except in way of the stepped-on-deck mast partners where it is twice that and additionally stiffened and gussetted. A 10 cm (4") double extra heavy aluminum stanchion carries the mast compressive load to the tank top and through heavy floors to the keel. It also serves as the fresh water filling manifold routing the water from deck to the foot of the main mast to four tanks through suitable valves at its base.

The cabin top has a low profile, it has no straight lines or plane surfaces in its form and is heavily stiffened. Double dogged small 4" x 7" x 3/8" (102 mm x 178 mm x 9.5 mm) safety glass ports are fitted. The skylight is one half inch (12.5 mm) plexiglass in a heavy aluminum frame. The dogged access-escape hatches to the forward and after cabins are of heavy construction. (Sparkman and Stevens design, Rostand produced). Except for the one inch teak sliding hatch over the cockpit bridge deck THULE is virtually submersible. Even without the aluminum bulwark and teak cap rail the boat hopefully can broach and be thrown off a sea with no basic damage.

The criterion was that all compartments and foundations should be able to withstand the shock of a drop off a sea or a total capsize with no disruption of functional capability below decks.

The inertia forces resulting from such possibilites demand much attention to detail in foundation and stowage design. For example: the batteries are not merely chocked but are structurally griped with no lost motion to permit acceleration. They are comparable to the ammunition stowages in combatant ships.

HABITABILITY

An all weather capability is a comfortable asset. Heat transfer through the hull and the plague of sweating when cruising in cold weather are in great measure eliminated by the 1" foam insulation sprayed over the entire hull to one foot below the waterline. This when ceiled and sheathed as required for protection and decor lowers heat transfer and limits sweating to ports or through hull fittings not amenable to cork painting.

The engine room is insulated with glass wool and sheathed with perforated aluminum noise absorbing sheathing. Four dogged 6" (150 mm) ports are let into the cockpit well sides to the engine room. Although these can be left open in all weather two, one port, one starboard engine room air induction systems supply air via Dorade type water traps to the engine. Dogged covers are fitted at the inner ends of these pipes.

Diesel fuel is carried in four tanks not only for main and auxiliary propulsion but also for basic cooking and cabin heating. A total of 300 gallons can be carried. The Perkins "Mate" cooker is a lighter stainless version of the English AGA coal cooker. Its basic capabilities are at least the equivalent of the old coal "Shipmate". The gun type burner is completely automatic and is essentially "fail safe".

Insofar as combusion is concerned the most critical factor was the "Charlie Noble" design which proved to be gale direction critical. Plugging the windward aperature of the "T" stack solved the problem for the moment. A wind vaned, counter balanced, swivelled "Charlie Noble" head is fabricated but not yet installed.

The cooker fire box has water walls which by thermosyphon circulation heat a mixture of ethylene glycol and distilled water contained in an insulated tank in the overhead of the engine room. From this a circulating pump pumps hot fluid to radiators in each compartment as well as through the fire box water walls itself if desired. The return water temperature can control the burner while main cabin temperature can control the circulator by a suitable thermocouple and thermostat. These normally have not been required. Manual control and heat from routine cooking have proved not only adequate but perhaps have the advantage of giving one greater peace of mind.

The cooker once heated for preparation of breakfast is kept sealed by an insulated hinged cover over the hot plate and stays hot for the greater part of the morning ready for coffee, soup or egg service over long periods of time merely by lifting the cover.

A 2,000 watt 220 volt automatic immersion heater heats the primary loop liquid when on shore power. 110 volts can also be accommodated but at increased current demand. With the ambient temperature at 28° F and 2" of snow on deck the cabin temperatures averaged 55° to 60° F. The cabin could be brought higher when desired by radiant heat from the cooker with the cover open. Condensation occurs only on the uninsulated ports, hatches and skylights. Terry cloth pads suitably located kept this from being an obnoxious situation.

Immersed in the primary heat transfer liquid is a secondary fresh water heating loop which furnishes hot water for domestic use. One must use soap as opposed to hydraulic mining but judicious use of an occasional "Wash 'n Dry" or "Wipe" keeps one sweet.

The use of engine waste heat for cabin heating could have been easily accomplished. It was considered but discarded in favor of the only means available when under sail or at anchor. When under power, the main engine (shaft) driven generator renders the drain of the gun burner and circulator of no consequence.

The heat of the cooker is intolerable when used in the tropics. For hot as well as heavy weather a gimballed Primus cooker of generous proportions is swung over one end of the cooker in heavily counterweighted and heavily constructed stainless steel gimbals. An important part of the assembly is a guard rail which, utensils having been purchased to fit, confines them even under the worst sea conditions encountered.

The kerosene necessary to fire the Primus as well as to support a complete set of oil burning cabin and emergency navigational lamps is carried in two small shaped tanks under the battery tank structure on the port side. One tank holds 25 liters and the other 23 liters. These are piped through a selector valve to a diaphragm pump which discharges the oil up through a goose neck at the work bench level to a suitable container for transfer and decanting to the lamps and to the Primus.

SAILS

The rig is a conventional ketch with a modest 840 square feet of sail area. The sail inventory (by Ratsey, Gosport) is small and utilitarian comprising only a genoa, number one and two jibs, spit fire jib, storm trysail, and mizzen staysail. The main, although roller reefed is fitted with high cringles and reef points for slab reefing. The mizzen is only so fitted.

Twin roller furling running sails of small area (360 sq. ft.) are carried. These were intended for use in the trades only. (In fact the Germans call these sails "Passat Segeln" trade wind sails). They are cut flat, are small and too heavy to be of much real value in winds below Force 4 or 5.

The weight of Tyrelene is such that THULE can carry full working sails including the genoa comfortably to Force 7; with reasonable sea room, prudent use of a fisherman's reef will permit carrying full sail area with the number one jib through gusts to Force 8.

In retrospect there does not seem to be any reason to provide roller reefing. There is really no need to get the most out of the boat at all times. A slab reef the equivalent of a deep rolled reef will ease the boat at Force 8 winds. Above that the storm trysail can be bent and used on its own track instead of the mainsail if the number two jib and mizzen prove to be too much.

Although THULE is built and fitted for survival to the point of being unusually forgiving in all things when the crew ceases to function rationally, she has never yet been sorely tried. Force 9 in the narrow lanes of the Straits of Dover against an opposing wind and tide combination was handled surely and safely, if not comfortably, under power.

In this regard, the boat has a range of 1500 miles at 5 knots. This is about 12 days cruising. Inasmuch as this can be done at any angle of heel up to 40° there need be no hesitancy to use power to ease the strain when short handed or to extricate the boat from an otherwise difficult or overwhelming sailing situation. With an auto pilot and C.P. propeller one should be quite secure hove to under otherwise appalling conditions.

The twin roller furling running sails are set on a heavy stainless halliard just abaft the head stay and are set up by a LEWMAR 2C winch. This can be used as an emergency head or fore stay.

THULE really lacks sail storage capability as it is talked about in the racing fraternity. The sails are few and small. The sails that are frequently used are kept readily at hand, lashed on deck or lashed in the cockpit. The rest are in the forward cabin. Jack stays were fitted in the forward cabin to which all of the sheets, mooring lines and other working lines are made up and hung for ready access and adequate ventilation.

SAFETY RAIL

Staying on board is an important consideration for a cruising sailor. The process of creeping forward under adverse conditions, snapping a safety harness to a life line, which might part or to the standing rigging widely removed and in extremis, "portable", is eliminated in THULE.

A safety rail of heavy stainless conforming to the shape of the cabin top is carried (360°) around the entire deck. On this "track" are trolleys or runners into whose beckets a safety harness can be snapped. A "no hands" foot race can then be run about the deck in all weather. The rail also is a comfortable grab rail for hand use under all conditions.

The cross section (Figure 5) may not be best by any means. The tracks are too nar-

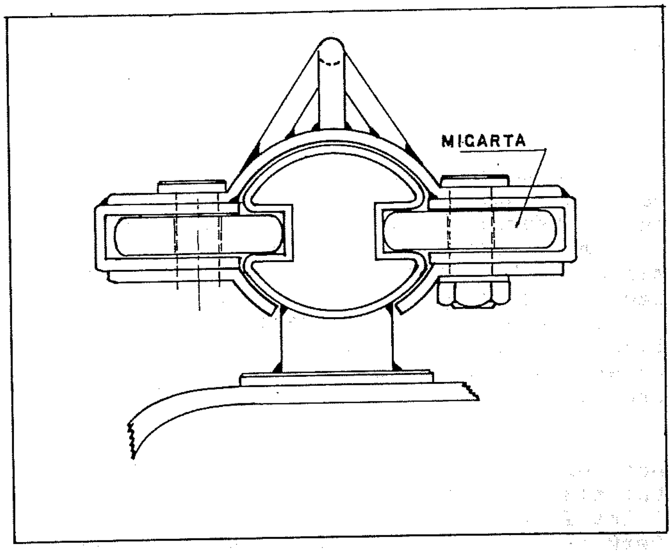

Figure 5 Safety Rail

row and shallow to carry an optimum designed runner. The merit of the section used lay largely in its being an off-the-shelf item (Pilaster stock) and therefore immediately available at reasonable cost. The forming was done by sand filling and skillfull bending using presses and heat.

STANDING RIGGING

The standing rigging is of conventional 1 x 9 stainless steel with swaged fittings, however, the turnbuckles, toggles and other hardware are hogged out of solid stainless stock. Where rubbing contact exists, to prevent the galling of threads, differing grades of stainless are used together with careful lubrication on assembly.

The entire rig is insulated from the hull to limit attenuation of transmitter energy, eliminate all above deck closed loops which might effect either radio transmission, reception or R.D.F. use and for lightning protection.

LIGHTNING PROTECTION

All stays are insulated top and bottom by carefully designed and machined toggles and lightning arresting fittings. The insulation is done with Teflon blocks and bushes. In each case a small set screw establishes a definite air gap to ground set to break down at an imposed voltage of about 120,000 volts.

Thus, normally the rig is completely insulated from the hull but upon finding itself "struck" it automatically grounds out through the hull to the sea. This is a new protective system tailored to the requirements of each ship; developed and marketed in Germany by F. Weber, Technische Vertretungen, Bremen.

FENDER RAIL

Any boat short of a dinghy can be difficult to manage with only a husband and wife team on board. A cruising boat of 15 displacement tons is particularly so in close quarters. The high power, large balanced rudder and large 3 bladed propeller are very helpful, but, there are few slips designed like ferry slips to fit your special boat.

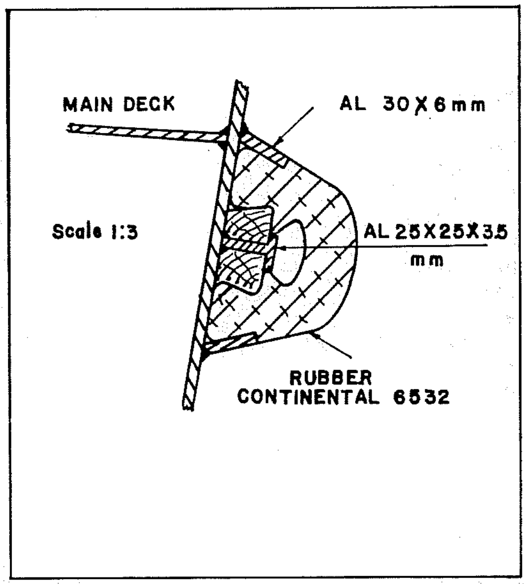

Figure 6 Rub Rail

The German sea rescue service has developed with the Continental Rubber Company of Germany a rubber fender rail which protects THULE. As seen in Figure 6 it is large in cross section but affixed to the hull without the use of bolts and screws. Short 6" teak shaped blocks are soaked in glycerine and rammed heel and toe into the bosom of the "T" bar thus locking it to the bounding flat bars and "T" bar flanges. Most piers are vertically piled and stiffened. In these cases the fender is very effective. For longitudinally fendered piers and quays it is of relatively no value. It also serves as a heavy cove strip to break the high freeboard.

COMMUNICATIONS AND NAVIGATION

A conventional communication system is carried as required by law. VHF-FM with a wide range of capability including channels 13 and 14. The former for bridge to bridge and useful to get local knowledge from tugs and inbound ships and 14 for special uses including the Welland Canal.

A 150 watt RF Communications 201M single side band receiver with a wide spread of capabilities serves as a long range transmitter and receiver. The antenna is the entire divided backstay with a total length of about 75 feet, the lead in, 3 feet below decks to the Antenna Coupler.

A Danish Sailor serves as a general purpose receiver for weather, time, curiosity and 2182 MHZ monitoring on the high seas. In conjunction with this receiver is a goniometer RDF of Debeg (Hamburg) manufacture. The actual goniometer antenna (twin loops) is mounted atop the main mast so is free of all ship oriented deviation errors. RDF bearings can be taken from below decks, easily read and directly plotted.

A Loran A & C automatic cycle matching receiver makes any navigator lazy.

A Wempe Quartz crystal controlled chronometer and a Tamaya Sextant, chart table with 16" arm universal plotting machine, suitable charts and publications round out the "where am I" tools.

These are all located in the navigator's cabin aft. This cabin is also fitted with bunk, chart drawers, head, pullman type wash basin, book rack, hanging space, stowage drawers and, to use up the remaining oddly shaped space, a four cubic foot deep freeze. A sport fisherman's chair swivels on a heavy stainless stanchion just ahead of the chart table so one can chock oneself off very comfortably under trying conditions to carry on the business of navigating, reading, or whatever happens to be the need of the moment. Instruments are duplicated topside.

The remainder of the equipment is conventional. Brooks and Gatehouse logs and depth finders are fitted both port and starboard. The dual depth finders are particularly helpful to avoid air bubble entrainment errors. Cruising, the log on only one side is used to prevent wearing out two rotors simultaneously when only one is actually transmitting data. It was also found helpful to keep one retracted so that when the active one was fouled with sargasso weed it was only a matter of minutes before the standby could be lowered and in use.

The wind direction and velocity indicators are unusual in that they are magnetic reed switching devices. Theoretically they would transmit just as well immersed in water as they do at the mast head. By way of further description this is one of the wind direction and velocity indicating systems used by the central control stations of the European canal systems to permit them in advance to meet the differing levels of water brought about by local wind conditions. It is available from D. M. Davey Instruments Company in England. Inasmuch as the velocity indicator is actually a pulse counter it is indeed extremely accurate and dependable.

FIRE PROTECTION

The automatic and remotely controlled CO2 system in the engine room is supplemented with large CO2 extinguishers located near the access door to the engine room and at the companionway access to the main cabin for possible use around the diesel fired cooker.

DRAINAGE AND OTHER LIQUID SYSTEMS

The main drainage system consists of a sump in each of the 4 compartments piped to a manifold in the engine room. Either a normal small capacity electric bilge pump or the main engine driven self priming high capacity pump can take suction on this manifold and discharge through the cockpit scupper drain overboard fittings. The sump pump servicing the double elliptical galley sinks and the shower sump pump also discharge to the scupper overboard drains.

An Edson 9" diaphragm pump is remotely manually activated from the cockpit.

The engine room bilges can not be pumped directly over the side until the water level in the bilges achieves a depth of about 10" at which time it spills over a floor to reach the engine room bilge drain sump. In order to clear the bilges of oily water a hand pump is fitted which is discharged to a tin or bucket and carried ashore. This makes it quite an operation to dump oily bilge water over the side.

A water soluble oil bilge cleaning fluid is maintained sloshing about with a few gallons of water to keep the bilges clean. It is hand pumped every week or two.

All distribution of liquids, filling or transfer, is controlled from the engine room with the exception of fresh water filling. The fresh water tanks vent to the deck house at side. The four fuel oil tank vents join a common line which vents aft into the foot of the mizzen mast stepped on the cabin top. All sounding tubes are secured with stainless ball valves so that no fuel could be lost inboard in any attitude including capsize. Fresh water sounding tubes are capped.

Fuel oil transfer for list control or day tank replenishment can be achieved by sluicing through the filling and suction lines or by using a hand operated wobble pump located in the engine room. This pump handles about one liter per stroke. Pneumatic gauges as well as sounding tubes are used in the two deep tanks. The day tanks have well protected plastic gauge glasses as well as sounding tubes. The boat can be fueled through either port or starboard filling connections.

A sea water pump furnishes wash deck water through an outlet near the anchor windlass and one in the cockpit.

GROUND TACKLE

Anchor handling and warping of the ship in high winds and tidal currents are made easier by using a hydraulic windlass and capstan (wildcat and gypsy) fitted forward and a 6" hydraulic capstan (bollard) aft. Controls penetrate the deck so heaving or veering can be selected and speed controlled at the winch. Manual heaving with a capstan bar and pawls is also possible. The anchor can be veered under bar control or dropped and caught on the brake. A forged claw transfers the anchor cable strain when riding through legs of a stainless bridle to the heavy mooring and towing cleats forward which are bolted through the deck to headers below.

The after bollard is only controlled in speed of rotation. Each is served by a separate pump within a common housing, double "V" belt driven and clutched to the main engine.

These are powerful units with a capacity of 1800 pounds at 40 feet per minute for the wildcat and 1000 pounds at 400 feet per minute for the capstan.

The open link anchor chain is 7/16ths galvanized steel. 40 fathoms is carried. This having been struck below in Europe is marked red, white and blue in 5 meter lengths. It's a good system either in meters or yards.

ACCOMMODATIONS

The rescue ship hull form is a natural for pilot berths. These are fitted outboard with suitable grabs and lee curtains. The watch below can sleep without being involved in whatever else may be going on in the cabin. The navigator's bunk is also a pilot berth but slightly wider and more comfortable. The forward berth is not very useful in heavy weather but will sleep two in good weather. The entire boat accommodates four comfortably and five with one bunk doubled.

The entire boat is fitted with a profusion of hand grabs, pierced coamings and shaped rails so that if one is careful there is no need to be thrown about even if caught relatively unawares in lumpy seas.

A small but cosy and appreciated nicety is one head mounted so that it can be tilted and fixed to compensate for sailing heel in increments of about 5°. No more sloshing over or coming about to get on with the business of the moment.

There is a music system. The 110 A.C. power for this and the SSB tranceiver also enables a vacuum cleaner to be carried. The 24 to 110 volt inverter originally installed was a bitter and expensive disappointment, incredibly poorly designed mechanically and noisy electrically. Inasmuch as the RF201M communications equipment also depended on this power supply its malfunction and lack of dependability was a matter of great concern. After using it on the Atlantic crossing, largely for electric razor power, it was replaced by a 500 watt motor generator set with manual frequency control and built in noise filtering. This has been completely satisfactory.

OUTFIT

Although the outfit carried on board a boat is not normally the naval architect's responsibility he can and should do more than just throw it on the builder's back. Much can be included in the contract plans and specs. A few general considerations will suffice to establish patterns of thinking. Everything, stores of all descriptions have to be stowed with adequate dunnage or in compartmented lockers or preferentially, divided drawers. No matter how well stowed and dunnaged a yacht is there are times at sea when everything seems loose and sluicing back and forth. Parts drawers, small tool drawers, medical cabinets are carefully and minutely sub-divided to be best adapted for the purposes to which they were to be put. Medical stores including instruments, splints, needles and sewing gear, and a myriad of other things that are required for complete emergency care and independence requires special attention to storage and accessability. It's best thought through in the design stages.

APPENDIX I

Table 2 Characteristics

	English	Metric
Design Displacement	14.57 tons	
Design Draft	5'-7½"	1.72 meters
Design Trim	00	
Length	43'	13.1 meters
L.W.L.	33'4"	10.13 meters
Section Area Coefficient	.436	
Prismatic Coefficient	.584	
Block Coefficient	.255	
Waterplace Coefficient	.697	
Wetted Surface	424 $ft.^2$	39.4 m^2
Rudder Area (total)	19.37 $ft.^2$	1.8 m^2
Total Wetted Surface	443.4 $ft.^2$	41.21 m^2
Transverse BM	3.73'	1.14 meters
Tons Per Inch Immersion	0.61	
Center of Floation -	- 1.12' from ⊗	- .34 meters from ⊗
Center of Buoyancy Above Base	3.98'	1.21 meters
Sail Area	840 $ft.^2$	78 m^2
Station of Max Area (at D.W.L.)	18.09' (from F.P.)	5.51 meters
Beam at Station of Max Area	11.142'	3.40 meters
Max Beam Moulded	12'3"	3.76 meters
Moment to Trim 1"	1.07 foot tons	—
Moment to Trim 25 M.M.	—	332 meter killograms

Displacement Length Ratio 395

Built 1971