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WARSHIP DESIGN IN THE ROYAL AUSTRALIAN NAVY - SOME DESIGN ASPECTS & A LOOK TO THE FUTURE

BY B.L.ROBSON B.E.(N.A.); M.R.I.N.A; M.S.N.A.M.E.

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CORRECTIONS TO PAPER -

The following corrections to the paper are necessary:

1. Page 16 - Second last line on page should read High thickness to chord ratio in lieu of low thickness to chord ratio.

2. Page 55 - Last paragraph first line: After added resistance add "below $V/\sqrt{L}$ of 1.4".

3. Page 57 - First paragraph fifth line: Head seas should read following seas.

4. Page 57 - First paragraph sixth line should read maximum bow motions.

5. Page 59 - Second paragraph fifth line: Pitch motions should read Heave motions.

6. Page 62 - Fifth paragraph third line should read - increased speeds in lieu of speed length ratio.

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by B.L.Robson*, B.E.(N.A.); M.R.I.N.A; M.S.N.A.M.E.

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* Senior Naval Architect, Directorate of Forward Design Department of Navy, Canberra.

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INTRODUCTION :

It is the author's intention in presenting this paper to highlight some of the major aspects involved in the design of the modern warship. Emphasis is therefore placed on those aspects unique to surface warship design & which are rarely encountered in the design of merchant ships. Each of these aspects has been developed to a point where it has been possible to make some predictions regarding future trends. It is hoped that these predictions will raise some lively discussion & perhaps provide topics for future papers where the individual aspects can be treated in greater depth.

The paper is divided into four sections. In the first section, the surface warship is defined & a brief summary of the the design progression procedure as adopted by the Department of Navy is presented. The following two sections treat the design aspects which are influenced by the operational environment & the performance requirements. The final section looks at the development of some recently conceived ideas for warship design.

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Acknowledgement is made to Vosper Thorneycroft & Littons Industries for the use of the sketches shown in figures 31 & 29 respectfully, & to Brown Bros for figure 6.

THE WARSHIP & THE DESIGN PROGRESSION PROCEDURE :

The Warship :

The warship can be defined as a mobile platform capable of delivering to a specified area of operation, in the course of performing its assigned mission, a means of inflicting or assisting in the total or part destruction of an enemy.

The following are some of the missions that can be assigned to a warship.

a. Escorting Convoys.
b. Coastal & Riverine Patrol.
c. Submarine Hunting.
d. Engage enemy aircraft.
e. Engage enemy ships.
f. Shore Bombardment.
g. Launching & Directing Aircraft.
h. Troop Transport.
j. Collecting Intellegence Information.
k. Minesweeping.
l. Replenishment of other warships.

In performing its assigned mission or task the warship can therefore be engaged in the following types of warfare.

a. Anti-Submarine Warfare. (ASW)
b. Anti-Air Warfare. (AAW)
c. Surface Ship Warfare.(SUW)
d. Naval Gunfire Support. (NGS)
e. Amphibious Warfare.
f. Mine Warfare.

Being engaged in the above types of warefare the warship is exposed to certain enemy attacks & must therfore be designed to survive after damage has been inflicted by the enemy. The types of attack to which the warship is exposed are as follows.

a. Underwater Attack. (Contact & Non-Contact)
b. Abovewater Attack. (Blast & Mechanical)
c. Chemical Attack.
d. Biological Attack.
e. Radiological Attack.
f. ElectromAgnetic Pulse Effects.

The warship must also be designed to reduce the risk of early detection & to detect an enemy at the maximum possible range.

The methods adopted for detection, whether it be by the warships own sensors, the enemies sensors or homing weapon devices, are as follows :

a. Noise Signature.
b. Infra-red Signature.
c. Magnetic Signature.
d. Pressure Signature.
e. Visual Observation.
f. Electronic Emmission.

The effectiveness of the warship is therefore a measure of the following properties :

a. Weapon & Sensor Payload.
b. Weapon & Sensor Effectiveness.
c. Ability to proceed undetected.
d. Speed of weapon delivery.
e. Range of operation.
f. Degree of ship control.
g. Ability to survive & function after damage.

The Design Progression Procedure : Having defined the warship, an appreciation of the design progression procedure adopted by the Department of the Navy is essential to understand just how the warship design comes into being.

Normally the designers first involvement with a new warship design is when he is asked to comment on a set of Draft Naval Staff Requirements. The N.S.R. document is prepared by Naval Staff & outlines the operational requirements for a warship that may be needed to perform a strategic task. All requirements are contained in the N.S.R. document under the following headings :

Function.
Concept of Operation.
Major Characteristics.
Special Requirements.
Complement.
Cost.
Compatability with other navies & Logistic Facilities.
Target Date.

Upon receipt of the draft N.S.R. the designer undertakes conceptual investigations to prove the feasibility or otherwise of the requirements.

A number of outline designs are prepared during the conceptual investigations which may completely or partly meet the proposed requirements. The output from the conceptual investigations provide naval staff & the designers with a basis for decisions on the feasibility of the proposed N.S.R. & answers the following questions.

a. whether there is an existing design available which will meet the N.S.R.
b. Whether there is an existing design available or being developed that could be modified to meet the N.S.R.
c. whether the N.S.R. & an existing design or design being developed should be modified to achieve an acceptable compromise.
d. whether a new design is required & if so, the ship concept that will best meet the N.S.R.
e. first estimate for ship design & construction.
f. the most practical means of ship design & procurement.

An iterative procedure follows until an acceptable outline design & N.S.R. are evolved.

Fig 1 depicts a typical outline design sketch which has been developed during the conceptual investigations. This figure is intended to illustrate the depth to this this stage of the design is taken. In developing this outline design the following ship characteristics were determined & studies undertaken ;

First estimate of principal dimensions.
First estimate of displacement.
First estimate of hull form parameters.
Internal space analysis.
First weight estimate.
First powering estimate.
Main propulsion plant layout.
First fuel capacity estimate.
First stability check.
Weapons, sensors & aerial configuration.

Following approval of the N.S.R. & approval to further develop the design, the design enters the <u>Sketch Design Stage</u> which is the second stage in the development of the design.

During the sketch design stage, further studies are conducted which are in greater depth than previous studies. These studies are intended to identify the major problems involved in meeting the N.S.R. & to establish the best means of solution. Normally these studies do not involve experimental work. The studies are carried out in sufficient depth to :

a. establish that the proposed ship design is feasible & warrants further development.
b. identify high technical risk areas.
c. permit selection of types of major systems & equipments.
d. update first estimate of design & construction costs.
e. provide preliminary particulars of the proposed ship for the preparation of the sketch ship characteristics document.
f. provide a basis for follow on design activities.

During the sketch design stage, the features determined during the previous stage are validated or revised. This requires a second estimate of weight, powering, stability etc. Also basic investigations are made in the following areas :

Seakeeping.
Strength.
Subdivision.
Survivability, Vulnerability, Protection.
System Trade-offs.
System Interfaces.
Ship Effectiveness.

On completion of the sketch design stage, an updated general arrangement drawing is prepared & the follow on design philosophy established for guidance during the next stage of the design. The draft sketch ship characteristics which describes the main features of the design are also prepared in conjunction with the sketch design.

Following the endorsement of the sketch ship characteristics & approval to develop the design further, the design enters the third stage in its development which is called the Preliminary Design Stage. During this stage, the sketch design is extended in depth with the aid of model experimentation, mock-ups & where necessary some research to :

a. establish that the design of the proposed ship, its systems & equipments are practical & within the limits of present technology.

b. enable selection of, & initiation of procurement action for major equipments & systems with long lead times.
c. provide particulars of the proposed ship for the draft ship characteristics.
d. provide a basis for the detail design contract if this method of design procurement is intended.
e. update design & construction estimates.

In the preliminary design stage many of the design tasks are repeats of tasks carried out in the previous design stage. These tasks however are more detailed.

The preliminary design stage is considered to be completed when the following drawings & studies are finalised & the information required for the draft ship characteristics is available. The list of drawings & studies is as follows :

General Arrangement.
Lines.
Hydrostatic Curves.
Appendages Drawing.
Midship Structural Section Drawing.
Structural Profile & Decks Drawing.
Weight & Centre of Gravity Estimate.
Stability Studies.
Ship Model Experimentation.
Powering Estimate.
Preliminary Propeller Design.
Tank Capacity Calculations.
Endurance Calculation.

Once the preliminary design & the ship characteristics are approved & finance commited to the project, the design enters the next phase of design which is known as the Detail Design Stage. The detail design can be done "in house" or by contract. The purpose of this stage of the design is to :

a. fully specify the ship & all of its systems & equipments.
b. enable procurement of all important materials & equipments.
c. enable the preparation of a contract package for ship procurement.

The contract package which is issued to the shipbuilder for ship construction tendering action contains the following information which is dependant on the design responsibility given to the shipbuilder :

General Arrangement Drawings.
Lines Plan.
Midship Structural Section Drawing.
Structural Profile & Decks Drawing.
Compartment Layout Drawings.
Appendages Drawing.
Machinery Space Layout.
Diagramatic Sketches of the major systems.
Equipment list.
Building Specifications.

Having awarded a contract to a shipbuilder for the construction of the ship, it is his or his subcontractors responsibility to complete the final stage in the development of the ship design. This last stage is called the Working Drawing Stage & deals with the preparation of all working drawings necessary for the ship & all of its components to be manufactured & follow on ships produced.

It should be made clear at this point that the procedure for ship acquisition as described above has only considered the technical aspects. The overall procedure is much more complex which at times leads the author to believe that a few miracles are necessary in making any new design a hardware reality.

Ship Acquisition Procedure :

By adopting the existing administrative procedures laid down by the Department of Navy & the acquisition procedures specified by the Australian Government, it can take as long as five years from the time of approving the N.S.R. to the completion of a prototype patrol boat & at least ten years for a destroyer.

Fig 2. shows a typical ship acquisition programme which clearly demonstrates where the acquisition time is consumed. Such a series of programmes are normally prepared during the conceptual investigation stage of the ship design.

As can be imagined, there are many ways by which a ship can be acquired. It is therefore essential that all options are considered during the conceptual & sketch stages of design & equated to target dates & rescources to arrive at the most suitable method. Some of the options are listed below:

a. purchase an existing ship from overseas.
b. ship built overseas to an overseas design.
c. ship designed in Australia & built overseas.
d. ship built in Australia to an existing overseas design.
e. ship designed "in house" & built in Australia.
ship designed & built by contract in Australia.

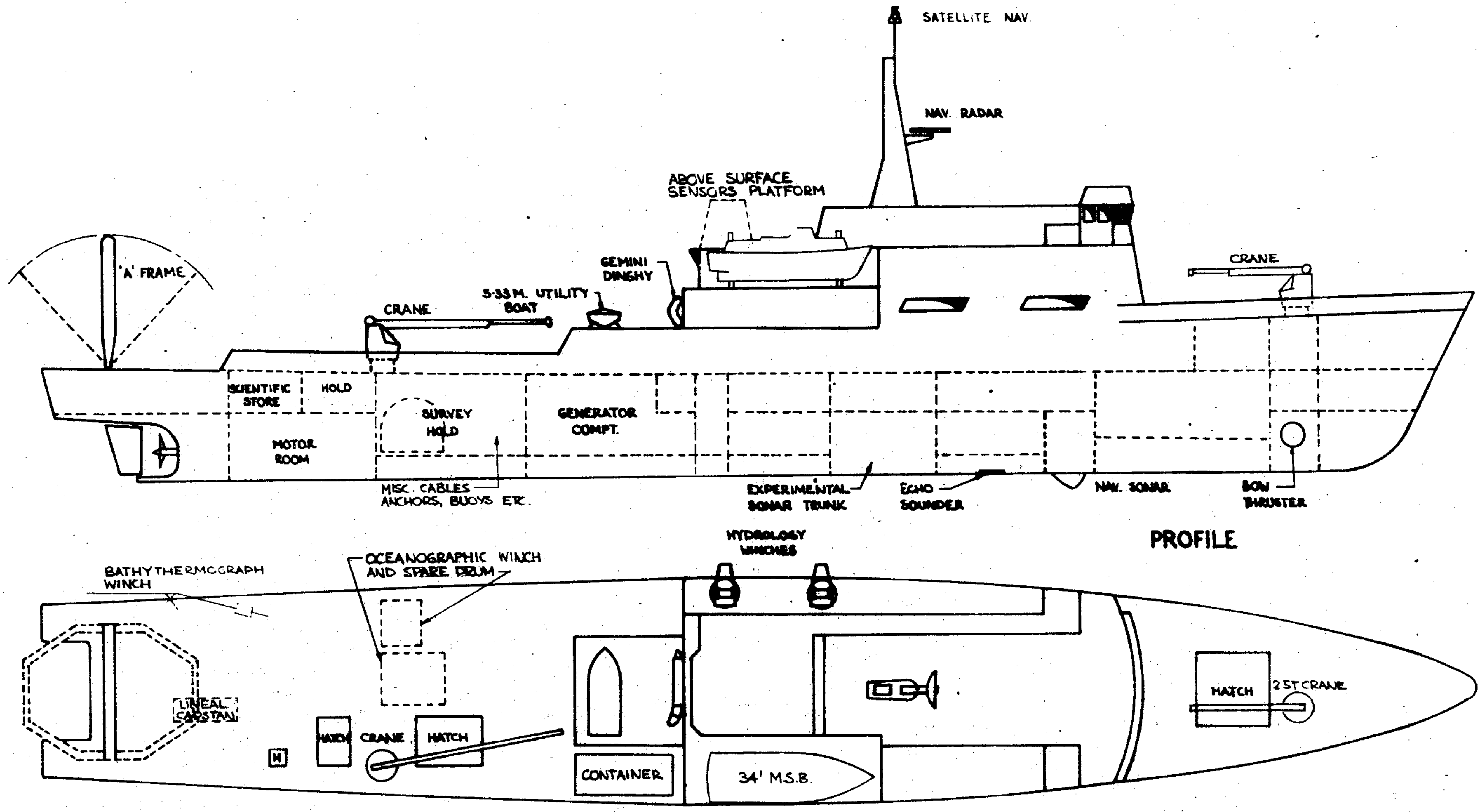


FIG. 1.

TYPICAL OUTLINE DESIGN SKETCH PREPARED DURING THE CONCEPTUAL INVESTIGATION STAGE.-

TYPICAL DESTROYER ACQUISITION PROGRAMME.

ACTIVITY.	DURATION MONTHS.
DESIGN.	
1. RECEIPT OF DRAFT N.S.R.	0
2. CONCEPTUAL DESIGN STUDIES & N.T.S. COMMENTS ON DRAFT N.S.R.	6
3. APPROVAL & ISSUE OF N.S.R.	5
4. SKETCH DESIGN & DRAFT SKETCH CHARACTERISTICS.	8
5. ENDORSEMENT OF SKETCH CHARACTERISTICS.	4
6. PRELIMINARY DESIGN & DRAFT SHIP CHARACTERISTICS.	12
7. ISSUE OF APPROVED SHIP CHARACTERISTICS & APPROVAL OF PROJECT.	6
8. DETAIL DESIGN & PREPARATION OF SHIPBUILDERS CONTRACT PACKAGE.	18
9. CALL TENDERS FOR WORKING DRGS.	6
10. EVALUATE TENDERS FOR " "	4
11. NEGOTIATE & AWARD CONTRACT FOR DRGS.	3
12. WORKING DRGS.	24
LONG LEAD ITEMS.	
PROPULSION MACHINERY	
13. MACHINERY SPECIFICATIONS.	4
14. CALL TENDERS.	4
15. EVALUATE TENDERS.	4
16. NEGOTIATE OFFER UNDER SEAL.	3
17. PLACE ORDER.	0
18. SUPPLY MACHINERY.	37
WEAPONS & FIRE CONTROL SYSTEM.	
19. PRE ORDER ADMINISTRATION.	8
20. PLACE ORDER.	0
21. SUPPLY SYSTEM.	44
BUILDING (DOCKYARD.)	
22. DOCKYARD ESTIMATE.	2
23. BUILDING PROGRAMME APPROVED	2
24. DOCKYARD PREPARATION.	6
25. CONSTRUCTION OF 1ST VESSEL.	48
26. FOLLOW ON CONSTRUCTION.	42.

ASSUMPTIONS.

1. PRELIMINARY & DETAIL DESIGN 'IN HOUSE.'
2. WORKING DRAWINGS PREPARED BY CONTRACT.
3. CONSTRUCTION BY DOCKYARD.
4. LONG LEAD ITEMS & EQUIPMENT PURCHASE IN ACCORDANCE WITH PRESENT PROCUREMENT POLICY.
5. UNFUNDED P.O.S ISSUED FOR TENDERING. L/LEAD ITEMS.
6. WORKING DRGS PREPARED IN CONJUNCTION WITH CONSTRUCTION

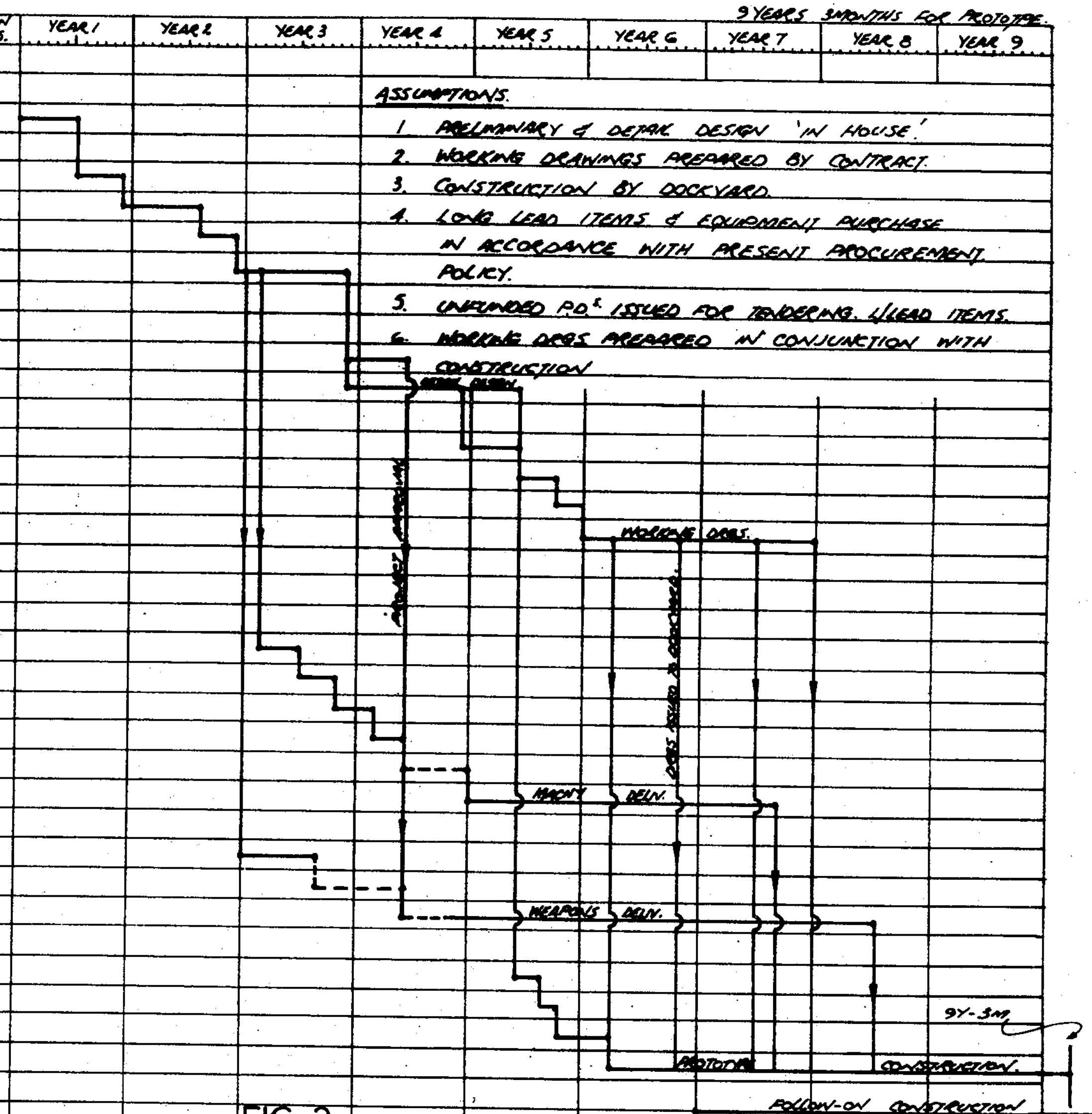


FIG. 2

DESIGN ASPECTS ASSOCIATED WITH THE OPERATIONAL ENVIRONMENT :

Rather than rely on the sheer might of weapon payload, the warship designer must aim for the best balance of the properties which determines the overall effectiveness of the warship. These properties have already been listed in the previous section of this paper. This section of the paper looks at some of these properties which are associated with the operational environment. The relevant design aspects are presented under the headings of Detection Countermeasures & Warship Survival. The next section of the paper deals with those properties which are associated with special performance requirements.

Detection Countermeasures :

Ship Silencing : From the design standpoint, the challenge of ship silencing is (a) to reduce the noise source level, (b) to reduce the input to the ships structure, (c) to increase the transmission loss, & (d) to decrease the efficiency of conversion to sound. In order to achieve any of these goals, the characteristics of many systems throughout the ship need to be compromised.

There are basically three terms used for noise, these are (a) Radiated Noise, (b) Self Noise, & (c) Airborne Noise. Generally, the introduction of any one particular noise reduction measure will have a beneficial effect on all three types of noise, but the extent of the benefit to each type will vary from case to case. The definition of each of these terms is as follows:

Radiated Noise is the noise which is transmitted through the water to a point remote from the ship. Its intensity & frequency determines the detection range of the ship, the liability to actuate acoustic mines & the range at which homing weapons are attracted.

Self Noise is the noise or vibration interfering with & prejudicing the performance of the ships own underwater detection equipment.

Airborne Noise is the noise which can increase the underwater noise level by transmission from the source, through the air to the ship structure & thus to the water.

The principal sources of noise can be conveniently grouped under the following headings :

a. Propulsion - including main & auxilliary machinery & propellers.

b. Hydrodynamic Features - including rudders, stabilisers, & any other appendage or opening.
c. Distributed Turbulence - boundary layer noise.
d. Sonar Dome Turbulence - as effecting self noise.

Table 1 roughly summarises the principal sources of noise, its frequency band & ship speed in their order of impertance.

Table 1.

Ship Speed. Knots.	Frequency Band. KHz		
	1 (low)	1 - 20 (medium)	above 20 (high)
Low Speed (12)	Machinery. Lines.	Boiler Room.	Boiler Room.
Med Speed (12-20)	Propellers. Lines.	Propellers. Boiler Room.	Propellers. Boiler Room.
High Speed (above 20)	Propellers. Stabilisers. Lines.	Propellers. Stabilisers. Hydredynamic features.	Propellers. Stabilisers. Hydrodynamics.

Machinery Noise : The prime source of machinery noise is the main propulsion system & the auxiliary machinery, diesel machinery generally being noisier than turbine machinery. However in steam turbine ships, boiler room noise is also a prime source of noise.

In accepting the challenge of reducing machinery noise, the designer is faced with a number of noise reduction options which must be considered on a cost basis. These options are (a) reduction of the noise at its source, (b) issolate the source from the ship structure & (c) adopt a technique of external hull cladding or provide a blanket of air bubbles over the external surface of the underwater hull. Depending on the noise level requirements, a combination of these options may be necessary.

The source noise can be reduced by giving due consideration to the detail design of each piece of machinery or equipment eg tolerances, speed, bearing design & gear loading etc. This procedure requires the preparation of very detailed procurement specifications which can incorporate with many other noise aspects, a noise criteria level for the completed equipment.

The preparation of such specifations requires considerable effort. Also, due to the limited number of units usually required the manufacture of such equipment can be unattractive to the potential contractor & very expensive for the navy.

The noise source can be partly issolated from the ship structure by the following methods, (a) by fitting resilient mountings between the machinery & the ship structure, (b) by cladding or hooding the machinery to reduce the airborne noise transmission through the ship structure. Both of these techniques are currently being adopted on warships.

When a requirement exists for a high shock resistance as well as a low radiated noise it may be necessary to fit the entire machinery system on a raft structure which can be issolated from the ship structure with shock/vibration mountings. This is an expensive procedure which can lead to shaft misalignment problems.

In conjunction with the above methods, the adoption of internal hull damping tiles & the cladding of the external hull surface of the warship are being considered. The hull damping tiles when discriminately placed inside the ship in areas of high local structural vibration & in areas in the vicinity of the sonar transducers can be very effective. The procedure of cladding the entire underwater shell or just local areas to impede the transmission of energy through the shell to the water shows considerable potential but problems still exist with adhesion of the cladding to the shell & the additional frictional resistance of the hull.

An interesting & very promising development in very recent years is a method of supressing the underwater noise whereby the external underwater areas of the hull adjacent to the major noise source are shrouded with a concentrated screen of minute air bubbles . The bubble screenis produced by a system comprising a compressor to supply the air & a number of air emmitters contained in one or two belts girthing the ship. In looking to the future, the air bubble technique shows most promise as an economical means of supressing waterborne noise.

For future warships the need for noise supression will increase & many techniques will be required to meet the predicted target levels.

Propeller Noise : As indicated in table 1, the propeller becomes the main source of underwater noise over a wide frequency band at ship speeds exceeding 12 knots. This noise can be attributed to cavitation, shedding of vortices, blade rate effects & singing.

The modern ASW ship is fitted with special noise reduced propellers which are designed to completely eliminate or to reduce the noise produced by the various causes. The noise reduced propeller is therefore designed to delay the onset of sheet cavitation & tip & root vortices to as high a ship speed as is possible, & when cavitation etc finally occures to control its noise effects as much as possible.

To increase the onset speed of sheet & bubble cavitation & other causes of propeller noise, the following features are adopted when designing the noise reduced propeller :

a. Flow Circulation	- The radial flow circulation over the blade is selected to unload the tip & root.
b. Shockless Flow Conditions	- This delays the onset of sheet cavitation.
c. Blade Section Shape	- Selected to avoid suction peaks on blade back.
d. Leading Edge	- Particular attention paid to shape, finish, wash up & wash down.
e. Pitch Distribution	- Combination of theory, cavitation tunnel observations & full scale correlation.
f. Trailing Edge	- Special bevel applied to back of blade to eliminate singing.
g. Blade Skew	- Selected to reduce blade rate noise.
h. Number of Blades	- Five or seven blades selected to reduce blade rate noise.
j. Hub & Cone	- Designed to delay the onset of vortices.

Even with the adoption of these noise reducing techniques, the noise reduced propeller still has limitations. At present it seems impossible to delay the onset of tip vortices, back sheet cavitation, & face sheet cavitation at ship speeds in excess of 11, 12, & 20 knots respectively.

While tolerating the presence of back sheet cavitation at ship speeds exceeding 12 knots, the noise created by this phenomina can to some extent be reduced by introducing a layer of air bubbles over the back surface of the blade. The air is introduced into the water via a series of emmitter holes in the back of the blade as close to the leading edge as is possible. The air is produced from within the ship, passed down the propeller shaft, up through the propeller hub & to the individual blades through channels in the back of the blades & hence out through the emmitter holes.

With the trend towards the use of controllable pitch propellers in warships in lieu of the fixed bladed propeller & the reversing gearbox, propeller noise has increased. This is due to the increased loading on the blade due to the larger hub size & the reversing requirement for the blades & the lack of precise pitch control which is so essential to delay the onset of sheet cavitation.

Figure 3 depicts the general features of the noise reduced propeller.

Having mentioned the limitations of the conventional & noise reduced propellers it would seem that an entirely new form of propulsor will be needed in the future if the expected developments in sonar performance are to be fully exploited & homming weapons countermeasures improved. The author therefore predicts that the propulsors used in future ASW ships will need to take the form of pumpjets or waterjets. Figure 4 depicts the pumpjet propulsor.

The pumpjet is merely a rotor with a large number of blades operating in a deaccelerating nozzle. It is claimed that this type of propulsor has its vortices & all forms of cavitation supressed up to ship speeds exceeding 25 knots. However it does suffer the disadvantage of slightly reduced propulsive efficiency & considerable loss of reversing thrust when compared to the conventional fixed bladed propeller.

It is understood that waterjets capable of absorbing 100,000 SHP are technically feasible. Such systems would probably be of the two phase type & be more suited to the Surface Effect Ship & the high speed Hydrofoil where the propulsor can be mounted in a submerged pod. However much more research will be required before such systems can be made feasible for the slower monohull conventional ASW ship.

Fin Stabiliser Noise : Full scale ship trials have revealed that the active stabilising fins, so frequently fitted to the modern warship provide a source of considerable noise when at incidence. This noise covers a wide frequency band & is significant at ships speeds above 15 knots. At low frequency the noise is represented by a low rumble with associated vibration in the ships local structure. It is thought that the low frequency noise source is that of hydrodynamic flutter & possible interaction with the bilge keel. The high frequency component is attributed to cavitation of the fins. It is also thought that the cavitation effects & the vortices shed from the fin tips can have an adverse effect on the noise produced by the propeller.

Against the noise problem associated with fin stabilisers it should be appreciated that an unstabilised ship, rolling during rough weather may prove to be far noisier than a ship that is stabilised by active fin stabilisers.

Means which are presently being evaluted to reduce the cavitation noise from stabiliser fins include emmitting air along the leading similar to the principal used for noise reduced propellers. However it has been found that this technique is suitable only for reducing cavitation noise at positive angles of fin incidence.

Some form of stabilisation will be required for future warships to improve the crew & weapon effectiveness. However to reduce the effects of noise it is the author's view that the controlled passive antiroll tank will be more frequently adopted in future ships. This system of stabilisation, while not as effective at high speeds as the stabilising fin system offers a very attractive alternative if the ship's fuel is used as the transferring medium. Fig 6 depicts a controlled passive stabilising tank.

Underwater Appendages : If not correctly aligned to the correct line of flow, underwater appendages which include rudders, bilge keels, shaft brackets & bossings can become significant noise sources due to the effects of cavitation. Model experiments in the ship tank & the cavitation tunnel are normally conducted to minimise these effects.

As well as assuring correct alignment, the section shape of the appendage is selected so as to provide as wide a tolerance as is possible against cavitation at yaw conditions. This results in a section with a ~~low~~ high thickness to chord ratio & a special preparation at the leading edge.

Underwater Hull : To minimise the flow noise from the underwater hull, it is essential that abrupt changes in sections & the profile are avoided when the lines are developed & that a smooth & fair surface in ensured during construction of the ship.

Important sources of noise exist at the bow & the cut-up regions. In ships fitted with keel mounted sonar domes, it has been found that vortices intermittently shed from a square profile shape forefoot cause turbulence interference overthe surface of the dome. Also in ship yaw conditions, vented cavities have been found to flow from the water surface & the leading edge of the stem & thus producing a high concentration of air bubbles passing down under the keel in the vicinity of the sonar dome. This creates yet another source of self noise. To reduce these effects it has been found necessary to round off the stem in profile & section to a predetermined extent & extreme care is taken to ensure that the hull surface forward of the dome is kept as smooth as possible.

Due to the abrupt termination of the keel at the cut-up it is believed that cavitation takes place in this region, thus producing a noise source. Although not proven, it is thought that cavitation takes place in the core of the vortices which stream from both sides of the cut-up as they stream aft.

Sonar Domes : Transducers are fitted in sonar domes which can be located either at the bow or under the keel, well aft of the stem. The location of this dome can have considerable effect on the transducer performance. To achieve optimum performance, the effect of ship length, ship draught & the location of the obvious noise producing machinery in the forward portion of the ship must be considered during the conceptual design stages of the ship.

If a bow mounted dome is to fitted, the draught & length of the ship is selected to reduce the possibility of the dome breaking the surface of the water in rough weather. The bow mounted dome has three advantages which are (a) it can be located & shaped to reduce the hull resistance of the ship, (b) it is located in a turbulence free zone & (c) it can be located further from the noise sources from within the ship.

The main advantage of the keel mounted dome is its reduced probability of breaking the water surface in rough weather. However the keel mounted dome is located in a highly turbulent flow area of the hull & is therefore prone to considerable self noise effect caused by cavitation etc on the dome surface. Flow fences & flow channels have proven to be unsuccessful in redirecting the sweep down of bubbles from one side of the ship & accross the keel when the ship is in a yawed condition. The keel mounted dome is therefore shaped to provide the greatest possible tolerance against surface cavitation. To achieve this aim it is normal practice to conduct model experiments in the cavitation tunnel.

Infra-red Signature : Any hot or warm body emits infra-red radiation with a wavelength determined by its temperature. In a warship, the most significant source of infra-red is the hot exhaust gases from the main machinery. To a much lesser extent, infra-red is radiated from the ship hull.

Apart from keeping the quantity & temperature of the exhaust gases down to a minimum, very little can be done by the designer to reduce the infra-red effects. The adoption ofsplayed & split funnels to reduce the profile height of the radiation have met with little success by other navies.

One interesting development which will create a lower radiation profile is that of over the stern exhaust systems. This system would have the advantage of seducing the homing weapon towards the aft end of the ship rather than to the amidships area where the funnels are generally located.

Magnetic Signature : This is basically a close range method of detection used by aircraft to detect submarines & by magnetic mines as a method of actuation.

Without creating a warship built from all nonmagnetic materials, the magnetic disturbance created by the conventional warship is extremely difficult to reduce. Even if the warship is built from a non magnetic material such as aluminium alloy a magnetic disturbance is still created by the eddy currents inherent in the material.

De-gaussing can remove some of the residual & induced magnetism from the warship. However this technique only reduces the vertical component of the magnetism, it does not remove all of the magnetism in the vicinity of the ship.

Visual Observation : The visual observation range of a warship can be effectively reduced by keeping the ship profile as low as possible & by adopting some form of camouflarge. A short visual observation range is extremely important for vessels such as patrol boats which depend on their speed also for their effectiveness. A reduced profile height & area can also reduce the range of radar detection.

Electronic Emission : The moment a warship actively transmits electro-magnetic energy either in the form of radio or radar transmissions, these transmissions can be intercepted & their bearing determined by the enemy. Complete radio & radar silence is therefore the only means of eliminating this form of detection.

Passive detection is possible by the fact that radio waves can be reflected from any discontinuity. Any ship whether metal or wood presents such a discontinuity. Radar absorbing paint does not at present offer the complete answer.

The warship designer is of course unable to eliminate all sources of reflection from ship, but he can reduce them by avoiding 'radar corners'. Any wave falling on small metal objects such as ladders etc or onto a roughened surface will be scattered in all directions & will therefore not be reflected back to the transmitter/receiver. However a wave falling onto a corner made by three mutually perpendicular planes will be effectively reflected back to its origin. It follows therefore that such reflecting corners should be avoided & that any junction between the hull & superstructure & decks should be at any other angle than 90 degrees. This feature is presently being adopted for missile carrying patrol boats but has not been adopted to any great extent on larger ships.

Warship Survival.

Having discussed some of the design features required to reduce the detection range of the warship, the following paragraphs of this section are devoted to some of the design features which are required to increase the warship's chance of survival in a hostile environment.

Underwater Explosions : Contact & non contact type underwater explosions can be created by an exploding bomb, torpedo, mine or a nuclear device. Such explosions can damage the ship structure, damage the equipment inside the ship & injure the crew & could also sink the ship.

There are three kinds of damage created by underwater explosions, these are (a) mechanical damage, (b) internal flooding & (c) shock damage. If the explosion takes place against the ship side, the hull can be ruptured, internal flooding will result & shock damage will be restricted to the local area only. If the explosion takes place at a distance from the hull, depending on the distance & the size of the explosion the hull can be either ruptured, permanently deformed or remain undamaged while the effects of the shock wave will be experienced throughout the entire ship.

Before discussing some of the design aspects associated with protecting the ship from the effects of underwater explosions, the following few paragraphs give a short history of the shock phenomena & a description of the physical nature of underwater explosions to enable a better understanding of the general environment from which the warship must be protected as much as possible.

From the many reports published during & after the last world war describing the effects of new explosives & weapons like magnetic mines & severe attacks from the air, it was found that many warships had their combat capability severely reduced after there had been an underwater explosion some distance from the hull, even though the hull had not been damaged. It was found again & again that :

a. The hull remained completely of nearly completely watertight although sometimes plastically deformed.
b. The crew was generally unhurt.
c. The damage caused to the machinery & equipment inside the ship was often very severe.

The major conclusion that was therefore drawn from these reports was that due to underwater explosions occuring at a distance from the ship, the combat capability of the warship was eliminated by equipment failure long before the hull was damaged severely or a large number of crew were seriously injured.

The extent & type of damage created by an underwater explosion is related to the type & weight of the explosive charge, its distance from the hull & whether the explosion occures under the keel or to one side of the hull. For comparative purposes the term "SHOCK FACTOR" is used as a measure of potential nominal damage. The shock factor is expressed as follows :

Shock Factor $= \sqrt{\frac{W.Sin\ \theta}{D}}$

Where	W	=	Weight of explosive charge in lbs of TNT.
	D	=	Distance in feet between the charge & the closest point on the ship hull.
	θ	=	The angle between the line drawn from the charge to the closest point on the hull & the tangent drawn to the hull section at that same point on the hull.

An underwater explosion produces a very complex excitation pattern. After the detonation the primary shock wave is firstly produced which travells at the speed of sound in water. This is produced by the steep pressure pulse which then decays exponentially with time. The shock wave can be reflected from the ocean bottom as a compressive wave or can be reflected from the water surface as a tension wave making the resulting shock wave less damaging. The closer the explosion occures to the water surface, the more pronounced is the surface cut-off effect ie the water surface is broken up when the shock wave is reflected from it & water is thus thrown into the air.

At the moment of detonation, a large quantity of high pressure & high temperature gas is produced . The surge of water which is displaced by the expanding initial gas bubble is responsible for practically all of the rigid body motion of the ship. After the initial shock wave & then the surge of water the actual bubble pulse reaches the ship creating the high pressure loading on the shell. A series of smaller bubble pulses is then experienced from the later bubble contraction & expansion. If the explosion is close to the surface of the water, the gas bubble has the tendency to rise to the surface & vent to the atmosphere, if this occures, no bubble pulses are created.

For items of equipment inside the ship, the shock wave istransmitted to them through the ship structure. The structure can accenuate some frequencies while suppressing others, this leads to a shock wave which is complex & highly individualised. Shipboard shock is therefore characterised by a complex unpredictable waveform having frequencies over a considerable range.

Figure 7 depicts a typical shock wave form which was recorded during full scale ship trials. A typical pressure time pulse is also depicted in this figure.

To permit the warship to survive in such a hostile environment, its hull structure must not only support the local hydrostatic pressure & contribute to the hull girder strength, but it must also be able to resist rupture, resist permament deformation & attenuate the shock pulse to an acceptable shock factor level.

For the hull structure to withstand the specified shock effect, many structural aspects must be considered in the early stages of the ship design. This includes material, shell thickness, longitudinal & frame spacing, bulkhead design & many other details.

Details of typical watertight bulkhead structure & some typical structural connections which have proven to offer a high resistance to shock effects are depicted in fig 8. It has been found that symetrical structural sections such as the long stalk tees, now commonly used for longitudinals & frames offer considerably more resistance to shock effects than the unsymetrical sections.

The steel used for shell plating on the modern warship is normally selected on the basis of its ductility, its toughness & its high yield properties to provide the necessary protection against shock effects. The ductility of the steel provides the necessary elastic response, the toughness permits a good degree of energy absorption, while a high yeild strength extends the lower limit of permanent deformation.

Having taken the necessary measures to ensure that the hull structure has a high resistance to shock & blast effects, safeguards are also necessary to ensure that the ship remains afloat when the hull is actually ruptured & uncontrollable internal flooding takes place. An important aspect of this safeguard is the positioning of the watertight bulkheads in the ship. The criteria for damaged stability presently adopted for H.M.A. ships is based on a certain length of hit concept with the extent of internal flooding taken to the limits of the watertight bulkheads of the compartments effected. This criteria is applied throughout the entire length of the ship to encompass all possible damage conditions.

Last, & probably the most important & demanding requirement is that of the safeguards taken to protect the ships equipments & systems against the effects of shock. To provide the necessary protection the designer must first decide the following :

a. What equipments effect the combat capability of the warship & therefore need protection from shock.
b. What are the expected shock loadings.
c. What is the most economic means of shock hardening the selected equipment & systems.

Equipments which are considered to be essential for the safety & combat capability of the warship, where possible are designed to withstand the full environmental shock level condition whether solid mounted to the hull structure or resiliently mounted. In the case of resiliently mounted equipment, the combined absorption effect of the mounting & inherent strength of the equipment is considered.

Equipments not essential for the combat capability & safety of the ship need be no more shock resistant than is associated with its own inherent strength. However, for equipment in this category, a minimum inherent shock resistance of 15g is usually specified & precautions are necessary to ensure that the equipment remains in tact, although not functioning, up to the full environmental shock level.

Short of testing the first of the class to destruction it is very difficult to predict the full environmental shock levels of a new warship design during the course of the design. Approximate levels are however determined from the results of full scale ship shock trials on old ships which have reached the end of their service life. It is fully recognised that extrapolating such results to the more modern ship structure may not be very accurate, but together with the mathematical modelling technique they provide the only source of information.

When designing shock resistant equipments, there are three alternatives available to the designer. Firstly, the equipment can be designed with sufficient inherent strength when solid mounted to withstand the specified full environmental shock level. Secondly, the equipment can be designed with an inherent strength of only 15g on the understanding the difference up to the full environmental shock level can be absorbed by shock mounting placed between the equipment & the ship structure. Thirdly, a compromise of the first two methods can be adopted.

For reasons of economy, standardisation of equipment, & for the purpose of quality assurance, the Department of Navy specifies standards of inherent strength as a function of equipment weight & location within the ship. In specifying such inherent strength standards , it is possible to test the equipment on special shock testing machines or on a barge before fitting it into the ship. When the equipment is installed in the ship & depending on its location it is fitted with shock mounts which have been designed to absorb the difference in the shock loadings up to the full environmental level.

There is little doubt that the requirement to protect equipment from shock is expensive. However it is considered that for conventional ships this requirement will continue to dominate the design & selection of naval equipment in the future.

Above Water Explosions : Above water explosions can be created by a bomb, shell, missile or a nuclear device, they can be of the contact or the noncontact type. Protection is therefore required for personnel & equipment to ensure the continued combat capability of the warship.

Since the non-contact explosion in air produces a shock effect of a lower level than that of an underwater non-contact explosion it is normallyaccepted that if the equipment has been designed to withstand the under water explosion, it is adequately protected from the above water explosions.

There are two aspects of damage caused by abovewater contact type explosions which must be considered by the warship designer. These are mechanical damage & blast damage.

For the purpose of superstructure protection from blast, it is the practice to design it to withstand an over pressure representing the blast effect of a nuclear device. This over pressure design criteria is much more demanding than the normal requirement to resist the effects of wind up to 100 knots.

To provide some protection against mechanical damage for comand personnel & important communication & weapon equipment within the ship, the following possibilities are available :

a. The siting of command, communications, & control spaces within the hull of the ship.
b. Providing external armour plating protection to the above spaces if located in the superstructure.
c. The selection of structural material for the hull & superstructure to provide an inherent protection.

If the major threat to the warship is from enemy missiles, bombs & rockets etc which are directed to the abovewater portions of the ship, the command, communications, & control spaces are best located within the hull for best all round protection. Figure 9 depicts such an arrangement. The air space between the hull & the external bulkheads of the compartments, also depicted in fig 9, provides added protection against armour piercing, shells & high velocity missiles.

For the purpose of improved protection & for flooding in the event of fire it is also preferable that magazines be sited within the hull & where possible below the level of the ships waterline.

If for operational reasons, the command spaces & magazines are sited in the superstructure or on the upper decks, the most cost effective means of protection against low energy shrapnel & small arms fire is to increase the scantlings of the boundary bulkheads & decks. In warships with a steel superstructure, this could mean increasing the plate thickness from $\frac{1}{4}$" to $\frac{1}{2}$". In warships with an aluminium alloy superstucture, the initial inherent weight saving compared to steel can be considerably reduced if a comparable degree of protection is required.

With the ever increasing need to reduce topweight on warships the adoption of special alloys & sheathing can be an attractive means of providing some protection without a corresponding increase in weight. A special aluminium armour plate material is now available for protection purposes, while sheathing the decks & bulkheads with a special nylon protective felt is yet another means of providing protection.

All aluminium alloys suitable for marine structures have a low melting point & unless adequately insulated is very prone to damage by fire. This disadvantage could restrict the use of aluminium alloy for superstructures in future warships, without even considering the ever diminishing advantage of weight saving.

Chemical, Biological & Radiological Attacks : These three types of attack are presented under the single heading because the available countermeasures are very much the same. Also the term radiological attack refers to radioactive fallout for the purpose of this paper.

The only means of complete personnel protection from these types of attack is by complete issolation from the hostile environment. Since the hostile environment is the contaminated atmosphere which would normally support life, complete protection for the crew is only possible if the warship can operate in a complete closed down condition, as is the case for submarines.

Although it is possible to detect an approaching hostile chemical or radiological environment in sufficient time to manually close down, there is no such warning for a bacteria contaminated atmosphere. For complete protection the warship must therefore be designed to operate in a continuous closed down condition. Some success in this regard has been achieved by both the R.N. & the U.S.N. but at considerable expense. As can be imagined, systems which are normally operated on the weatherdeck by the exposed crew would have to be remotely controlled from within the ship & human support systems such as airconditioning would need to operate on a complete recycling principle.

At present the chemical & radiological attacks are countered by manually closing down the ship until it can steam clear of the contaminated area. A number of pressurised citadels are maintained in the ship by drawing in alimited quantity of air from outside & passing it through a special filter to provide suffiaient clean air for the crew & maintain an adequate pressure differential between the outside & inside of the ship. Special cleansing stations are situated in the superstructure where personnel required to operate systems on the weatherdecks can discard their protective cloathing & wash themselves before entering one of the citadels through an airlock. For the purpose of keeping the ship structure clean of contaminates, a saltwater prewetting system is provided which continuously washes down the structure while the ship is in the contaminated area.

If biological warfare becomes an increasing threat in the future, the surface warship as we know it today may have to undergo considerable change. It may mean that the future warship will evolve something like the vessel depicted in fig 10.

The Nuclear Electro-Magnetic Pulse (EMP) Threat : The United States & more recently the U.K. are carrying out theoretical & simulation studies on the effects of electro-magnetic pulses (EMPs) emmitted by nuclear weapon explosions. The nuclear EMPs or Gamma rays, while of short duration are known to be very powerful (covering the complete mHz & kHz frequency spectrum) & are thought to extend well beyond the range of heat & other radiation effects of a nuclear explosion.

It is known that the high frequency EMPs age & destroy all unprotected transister circuits in the range, wipe out memory banks in computers, burn out aerial feeders, turn insulators into conductors & have many other effects. The result is that all types of electronic equipment within the range are likely to be disabled, this includes computers, radars, radios, line telephones, & even vehicle electrical systems. Interestingly, it appears that equipment employing old fashion valves is less effected by EMPs than modern transisterised equipment.

Electronic equipment can be protected thick steel shielding but this is expensive & complex & therefore only a few of the more important systems within the warship could be expected to be protected.

Summary of Likely Trends : In looking back over this section of the paper at the potential threats to the warship & their means of detection, it would appear that warships of the future may develop along the following lines :

a. Increased emphasis on ship silencing.
b. Development of improved propulsors.
c. Continued effort to improve the warship sonar environment.
d. A reduction in the use of aluminium alloy for warship superstructures.
e. Development of continuous close down ship operations.

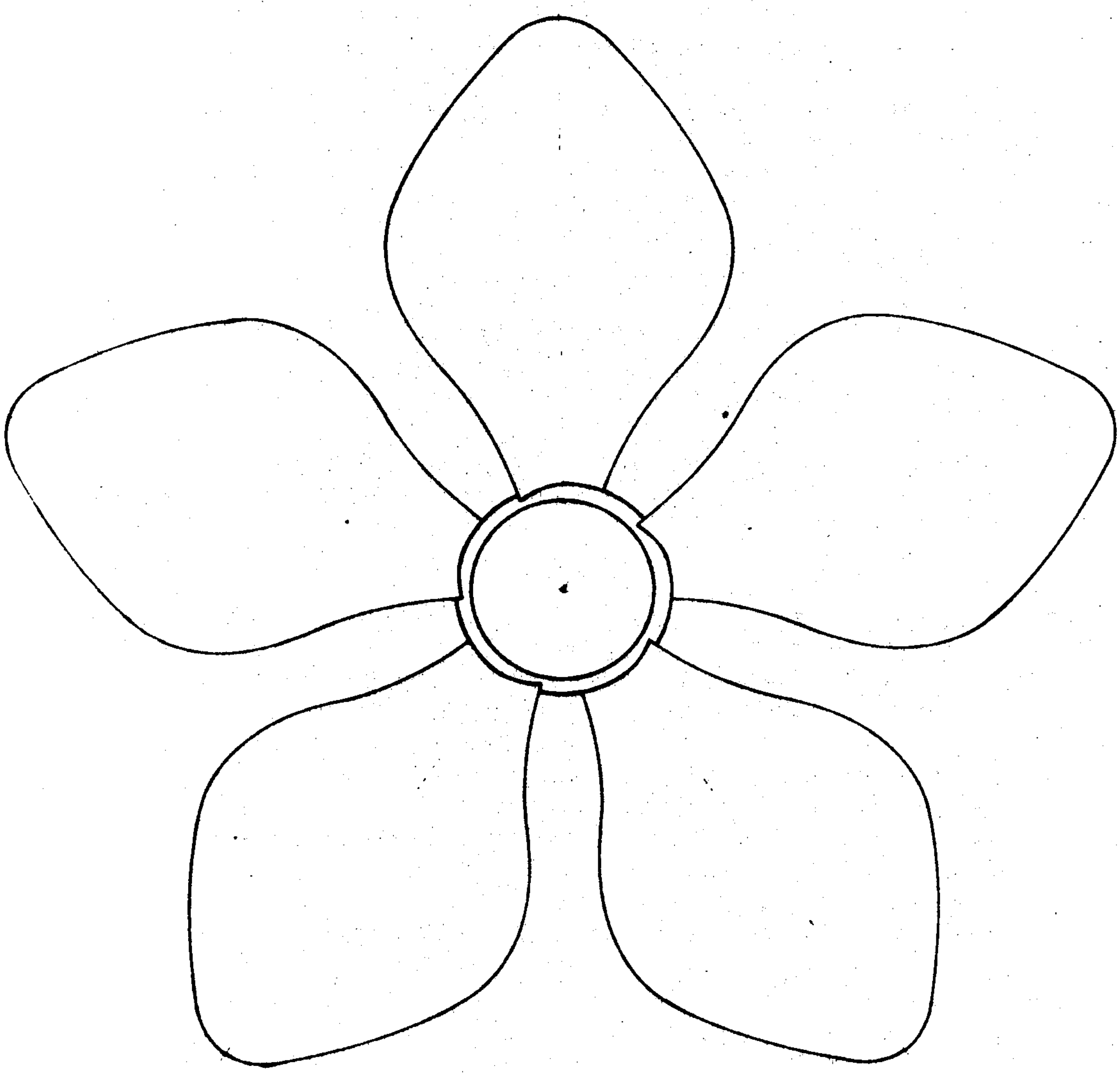


FIG. 3.
NOISE REDUCED PROPELLER.

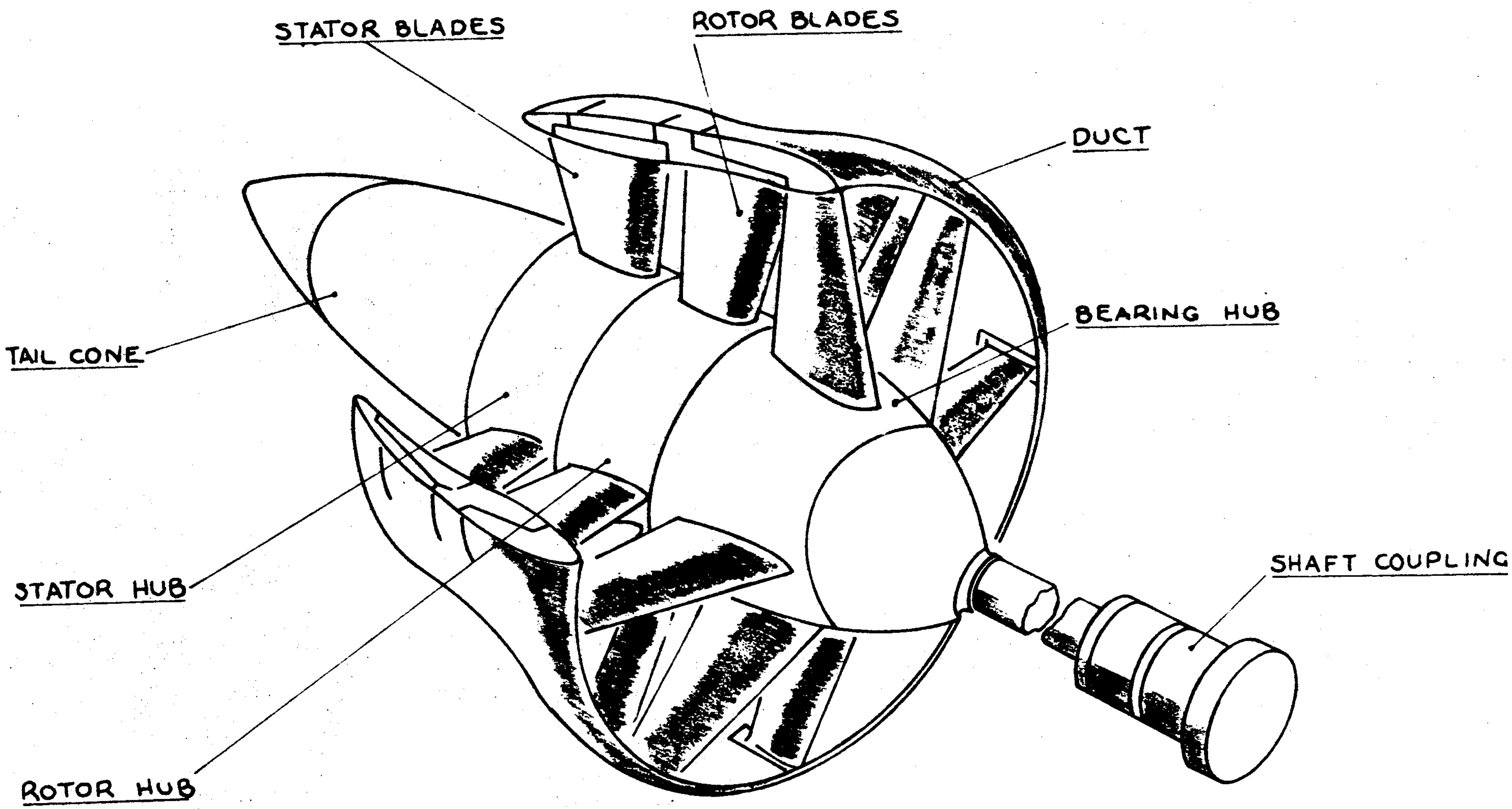


FIG 4
PUMP JET

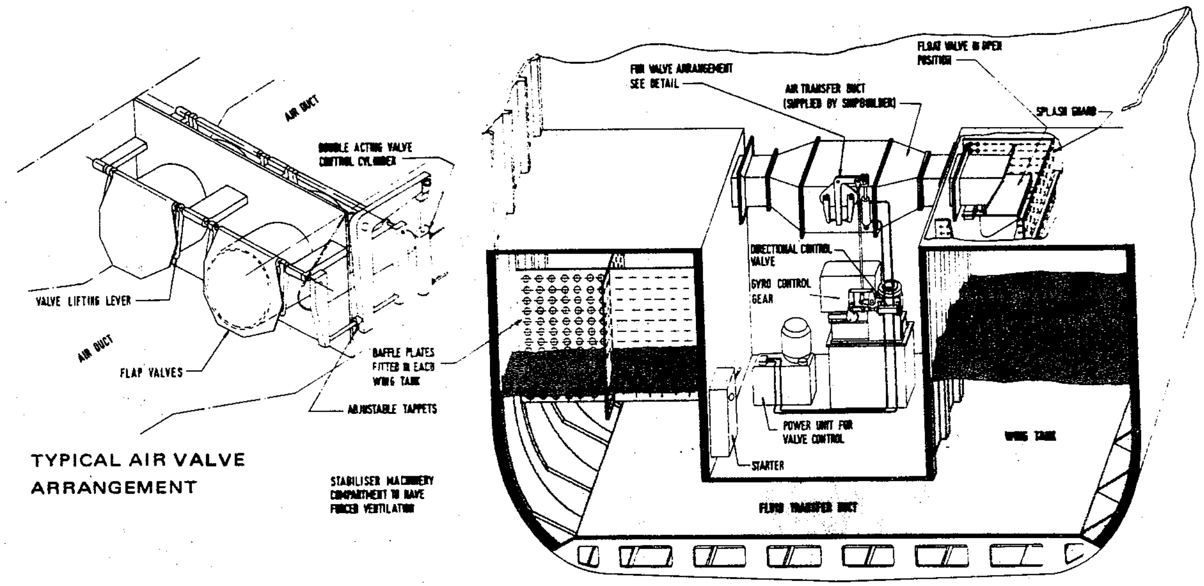
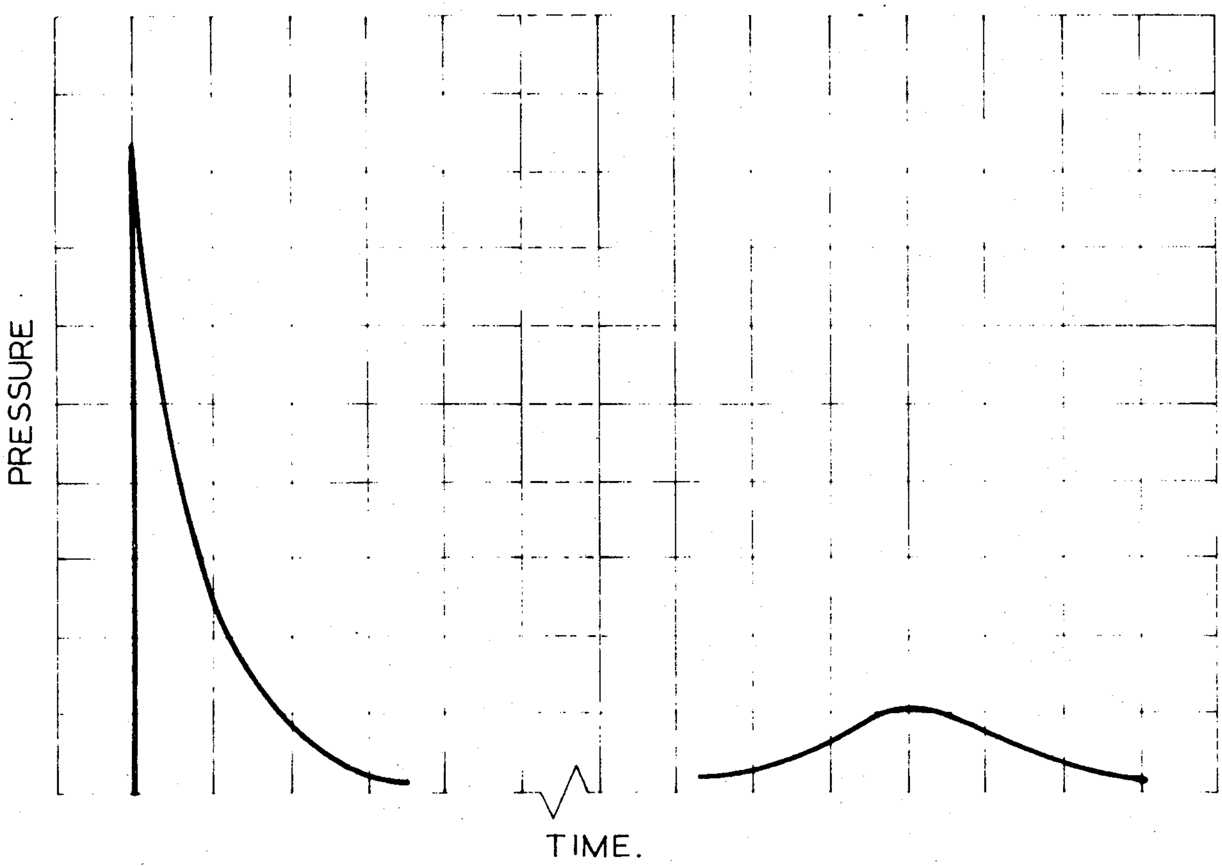
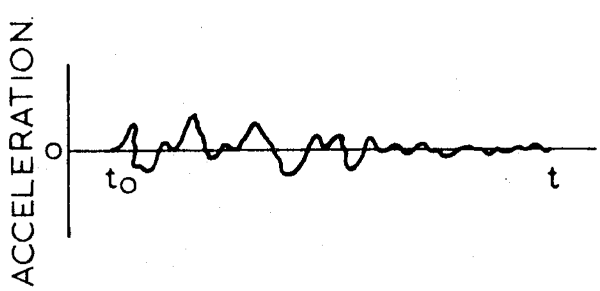


FIG. 6.

CONTROLLED PASSIVE ANTI - ROLL TANK.



TYPICAL PRESSURE PULSE.



TYPICAL SHIP SHOCK WAVEFORM

FIG 7

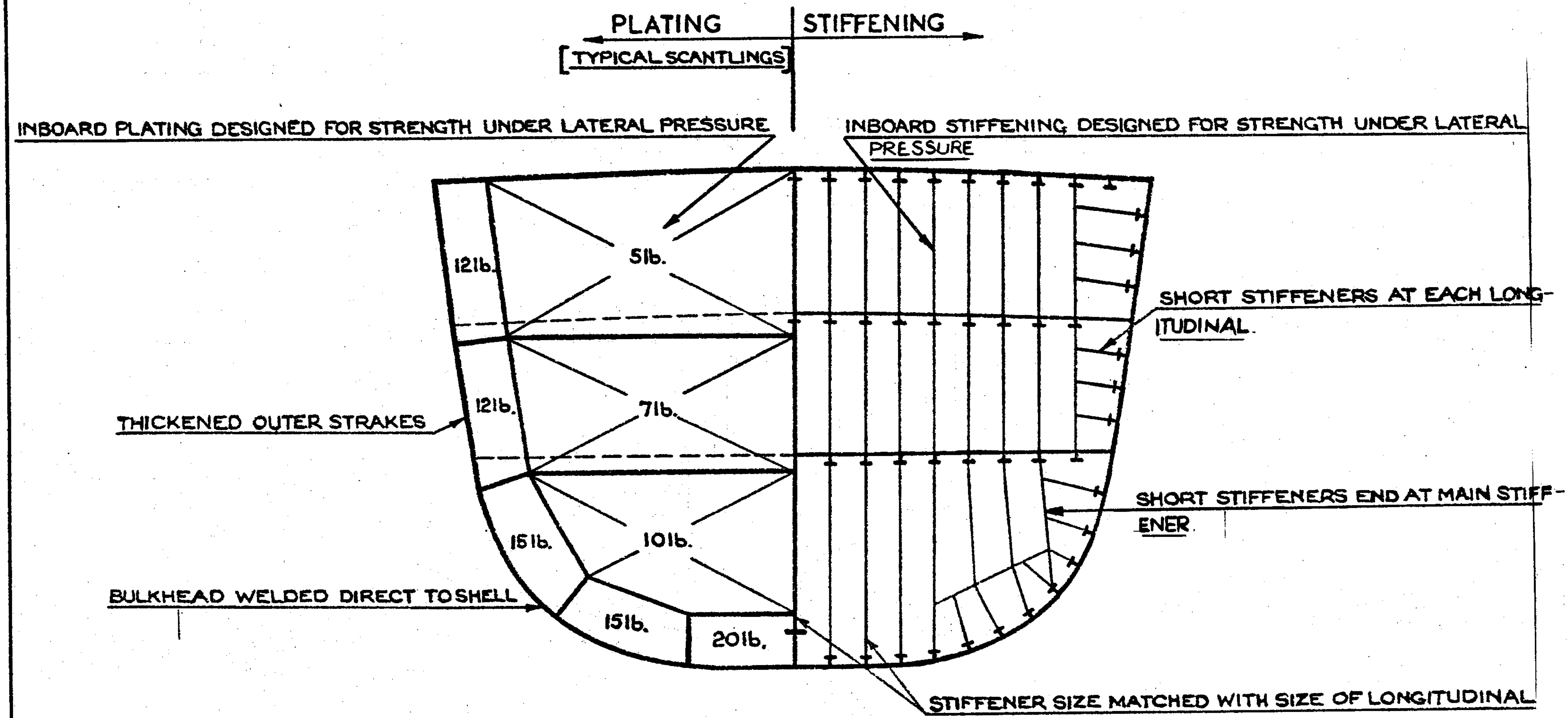


FIG. 8.

TYPICAL STRUCTURAL DETAILS.

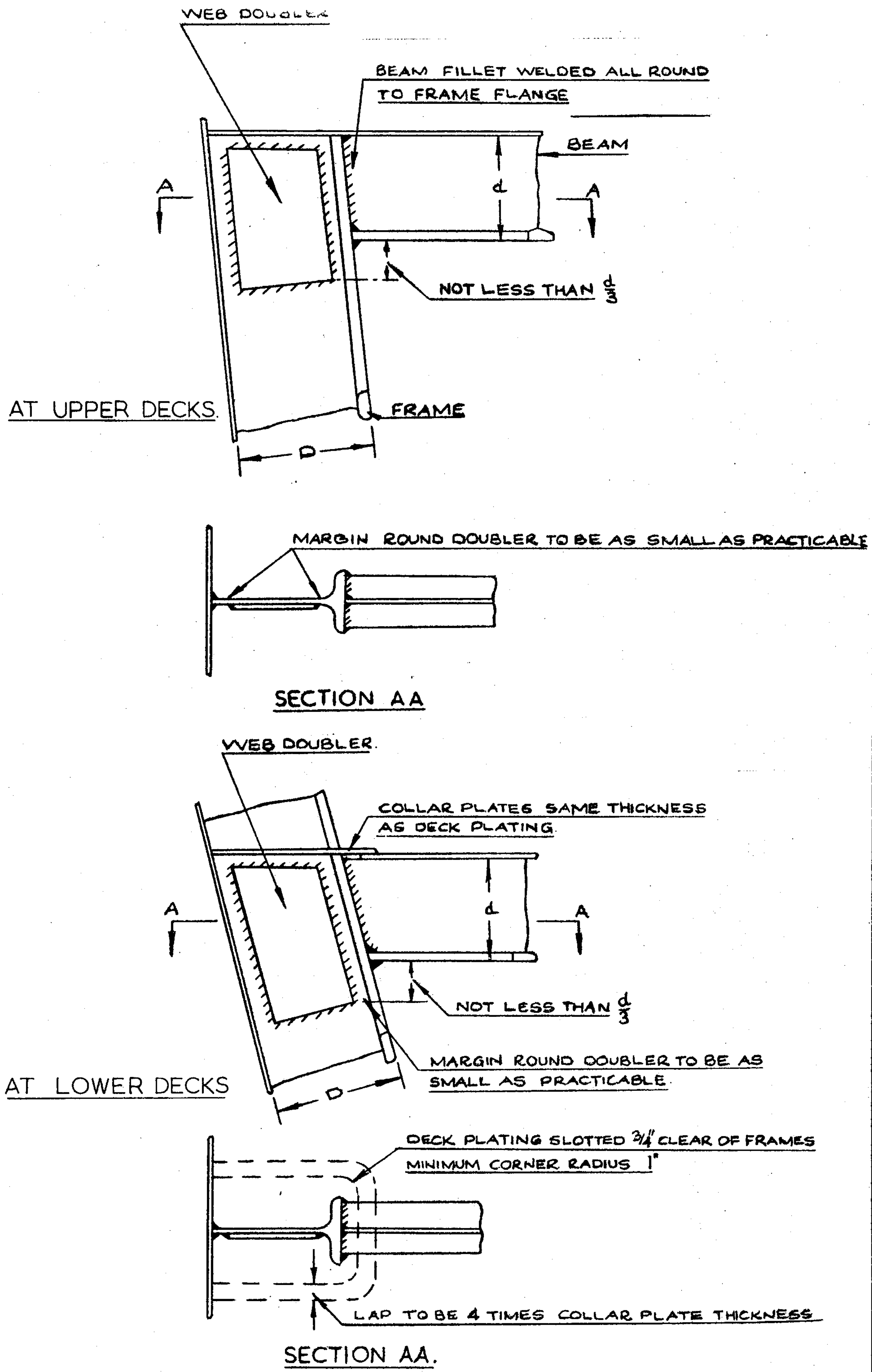


FIG. 8.
TYPICAL STRUCTURAL DETAILS.

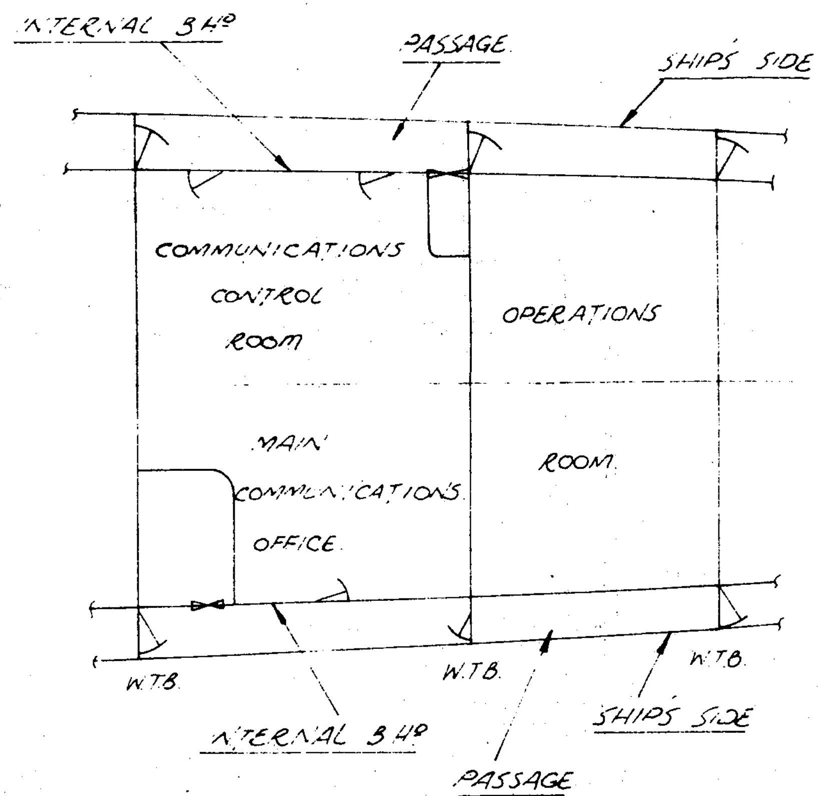


FIG. 9.

PROTECTION OF COMMAND & CONTROL COMPARTMENTS WITHIN THE SHIP

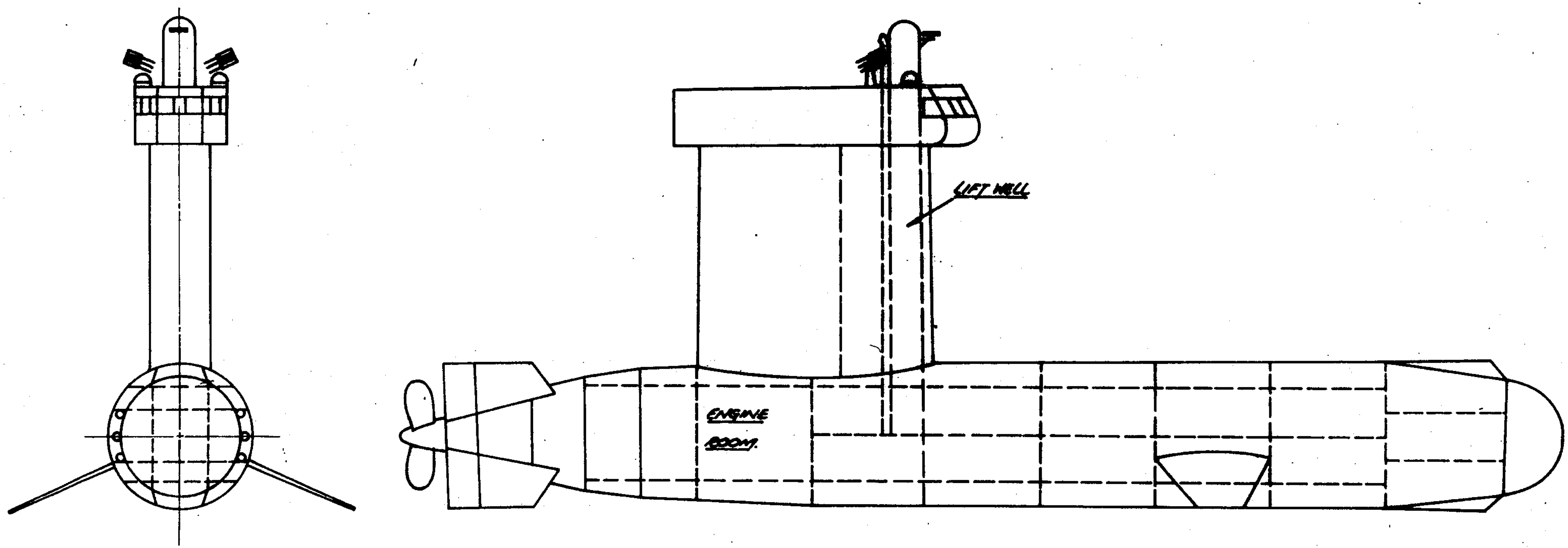


FIG. 10.

POSSIBLE DEVELOPMENT OF THE SEMI-SUBMERSIBLE.

WARSHIP DESIGN ASPECTS ASSOCIATED WITH SPECIAL PERFORMANCE REQUIREMENTS.

Some of the more demanding design aspects associated with special performance requirements are presented in this section of the paper. The design aspects which are presented under headings of the following performance requirements are related to conventional displacement type warships only. Aspects relating to dynamically supported vessels & unusual forms of displacement vessels are presented in the final section of this paper.

a. Speed & Endurance.
b. Ship Control & Manoeuvrability.
c. Seakeeping.
d. Weapons Payload.
e. Human Support.
f. Ship Support.

Speed & Endurance : Unlike the merchant ship, the warship is required to operate over a wide range of speeds. For example the modern ASW ship is expected to cruise economically at say 15 knots, hunt submarines at 18 knots & have a maximum sustained speed of over 30 knots. A typical operating profile for such a ship is as follows :

Speeds over 30 Knots	1%
22 to 30 "	10%
18 to 22 "	15%
15 to 18 "	60%
8 to 15 "	9%
0 to 8 "	4%
Astern	1%

The hydrodynamic design of the hull & propeller, the selection of main propulsion & the ammount of fuel carried are greatly effected by such an operating profile.

To date most warships have been designed to achieve speeds exceeding that of the merchant ship. However with the speeds & size of merchant ships expected to be considerably increased during the next decade, the speed of future warships can well be expected to increase if escort duties are necessary.

The hull of any ship can be designed for optimum performance at one speed & load condition only. The hull of the warship is therefore normally designed for either the full load or half condition, for maximum sustained speed in calm water & with a clean bottom. In part, this means that the hull form parameters & principal dimensions are selected to achieve minimum resistance at this condition & speed.

As the maximum speeds of warships are increased, the most economic cruising speeds can be expected to remain in the 15 to 20 Knot speed range. Therefore, for the faster ships there will be a greater degree of variance between the hull designed for maximum speed & the hull which is optimised for the cruising condition. When compared with the present & past generation warships, the faster ships will not only require more power to achieve the higher speeds as more power will be required for the cruising speed.

As an example, to demonstrate the vast increase in power required for the higher maximum speeds, the following figures represent the powering requirements for a modern 3,000 ton destroyer.

25 knots	15,000 SHP.
28 "	30,000 SHP.
31 "	45,000 SHP.
35 "	65,000 SHP.

From these figures it is obvious that an enormous price must be paid for speeds exceeding 25 knots.

When developing the hull form of a warship, it is possible, by matching the machinery configuration & performance with the hollows in the ship resistance curve to achieve some degree of improvement in economy at the cruising speed of the faster ships. This economising technique is more suitable when applied to ships with multiple engines on the one shaft. Therefore with the advent of faster ships the trend in main machinery installations may well be towards multiple engines not only to provide the power for the higher speeds but to provide a more economical cruising condition.

A typical ship resistance curve is depicted in fig 11 to demonstrate the most likely cruising speeds for such a ship. The hollows or flats in the resistance curve can sometimes be moved horizontally by adjusting the location of the centre of buoyancy & the longitudinal position of the bulbous bow if fitted.

Speeds for hunting submarines with the conventional ASW ship are not expected to exceed 23 knots in the forseable future because of the problems associated with underwater noise & the increasing use of helicopters. Also at speeds exceeding 28 knots very little gain is achieved in manoeuvring times associated with complete circle & 180 degree change in courses. Also associated with the higher speed manoeuvres is the excessive heel angles which could render weapons & sensors ineffective.

With the possible requirement for increased ship speed in the future, there still remains the problem of transfering the higher shaft horsepowers to the propulsor & thus into the water as efficient useable thrust. To avoid loss of thrust due to cavitation the conventional propeller fitted to the warship will have to be increased in area. This can be achieved by an increase in diameter or an increase in blade area ratio. Other ways of getting the power into the water while avoiding the likelyhood of bubble cavitation is by adopting multiple propellers, contra-rotating propellers, overlapping propellers & possibly pumpjets.

If the conventional propeller is adopted for ASW ships in the future & required to absorb more power than is presently absorbed, problems could be expected with noise & vibration unless precautions are taken to avoid these effects when designing the aft portion of the hull & the aft end underwater appendages.

The controllable pitch propeller is in vogue at present for the purpose of reversing the ship rather than relying on a reversing gearbox. This type of propeller with its large hub & low blade area ratio is prone to cavitation at earlier onset speeds when compared to a fixed blade propeller. However, the controllable pitch propeller has the advantage of being more adaptable to machinery installations consisting of multiple engines of the one type on a single shaft. With the expected increase in the operating range of warships, the controllable pitch propeller may survive for this reason alone.

Associated with higher ship speeds is an increase in machinery weight & space requirements & an increase in fuel capacity required for the ship. Since weight & space are at a premium in the warship, the extra power will need to come from gas turbine machinery positioned more stategically within the ship. For increased endurance, more dependence will have to be placed on the replenishment of fuel at sea.

Manoeuvring & Ship Control : Depending on the type of warship & the tasks which it must perform, the manoeuvring requirements can be very diverse. The requirements which are specified for most classes of warships are as follows :

a. Adequate directional stability for replenishment at sea operations.
b. Good ship response for taking evasive action in ASW & AAW situations.
c. Small tactical diameter with a minimum of heel.
d. Good low speed manoeuvrability for entering harbours.

Some of the above requirements are conflicting & compromises are often necessary.

Some of the requirements which are needed only for particular classes of warships are as follows :

a. Good slow speed manoeuvrability for minehunters.
b. Better than average high speed manoeuvrability for patrol boats.
c. Good directional stability for replenishment at sea supply ships.

The mathematical derivation of the degree of directional stability & manoeuvring characteristics without some form of model experimentation is not possible at present. Certain simple guide lines & empirical estimation of the characteristics of the underwater hull form & rudder area etc are therefore adopted during the sketch design stage which are subsequently verified by model experimentation during the preliminary design stages. Model experimentation for warships normally consist of a series of experiments with a free radio controlled model in a manoeuvring basin. A typical model experimentation programme consists of the following :

a. Pull-out Manoeuvres to verify directional Stability.
b. Weave Manoeuvres to test rudder response & to determine the width of the instability loop if the model proves to be unstable.
c. Spiral Manoeuvres to determine the degree of stability or degree of instability.
d. Circle tests to determine tactical diameters, speeds & hell on turns, time on turns & drift angles.

During the model testing phase it is possible to tune the ship by modifying the lines & appendage areas to achieve the specified operational requirements.

The following figures are characteristic for warships :

a. Tactical Diameter of 3 times the ship length for a destroyer to 4.5 times larger slower ships.
b. Turning rate of approximately 3 degrees per second.
c. Tactical diameters increase with ship speeds exceeding 25 knots.
d. Time on turns for speeds above 25 knots remain constant

For good low speed manoeuvrability it is the practice to provide twin propellers & rudders. The propellers rotate in opposite directions & the rudders are placed in the propeller race. For extremely good low speed control & manoeuvrability necessary for prolonged minehunting operations, minehunters are normally provided with an active rudder, a boxed rudder, secondary propulsor in the bow or a flap jet rudder.

The future trend will be towards a greater understanding of the effect of hull form & appendages on the control & manoeuvrability of warships. This will involve experimentation with Planar Motion Mechanisms in the ship model tank & rotating arm experiments to determine the relationship between & control derivatives & hull characteristics.

It is believed that the nature of control surfaces will remain almost unchanged during the next decade. More emphasis will however be placed on measuring rudder torques & bending moments during the model testing stages.

Seakeeping : The effectiveness of the warship can be considerably reduced by the influence of the ocean surface waves. In some cases the specified seakeeping requirements can dictate the type of ship, its principal dimensions & its complement.

The specified performance requirements which are related to seakeeping can be dictated by the following:

a. The operation of aircraft from the ship.
b. The need to replenish & strike down while underway.
c. Efeective weapon & sensor operation.
d. The need to sustain ship speed.
e. The survivability of the ship without severe damage to ship crew & equipment.

These requirements are normally related to a specified seastate.

When seastates & wind forces are specified in performance requirements, confusion can sometimes occure regarding the intended meaning of the specified terms. The author therefore advocates the adoption of the World Meteorological Organisation Definitions & the 11th ITTC Agreed Curve of Waveheight & Wind Speed & Related Seastates. Figure 12 & table 2 depicts these relationships.

It is unfortunate that visual observations of waveheights & instrumented data on ocean waves in the more important areas of R.A.N. operations are almost non-existent. It is therefore necessary for the Australian warship designer to use wave spectra & wave heights which have been recorded in the North Atlantic. The 11th ITTC Spectra is currently being adopted. Moves have been made to correct this situation but it will be many years before sufficient information is available for a truely statistical representation of ocean areas of interest to be made.

Some of the factors which contribute to the loss of warship effectiveness in a seaway are as follows :

a. Additional ship resistance can reduce ship speed & increase power.
b. Weapon & Sensor effectiveness can be reduced by excessive ship motion.
c. Crew fatigue due to ship accelerations.
d. Dynamic loading on ship structure & equipments.
e. Wetness & deck immersion.

It is the responsibility of the warship designer to ensure that the limits specified for the above factors are not exceeded before the limiting seastate is reached. The author is currently engaged in preparing such limits for use as a criteria for assessing seakeeping properties from ship model experiment results. Progressto date indicates that the following are representative figures :

a. Added Resistance - Not yet determined.
b. Weapon & Sensor Effectiveness - It is expected that limits for displacement & accelerations will be specified for each system, although this has not been the practice in the past.
c. Crew Fatigue - RMS vertical accelerations at $\frac{1}{3}$LBP from the bow should not exceed the levels specified by ISO as depicted in fig 13.
d. Structural Loading - The determining factor is taken as slamming & the probability of this occuring should not exceed 2%. Slamming is taken to occure when the 1/10th highest relative forefoot velocity exceeds 12 feet/sec.

e. Wetness & Deck Immersion - To allow personnel to work on the weather deck in relative safety, the probability of deck immersion at the forward perpendicular is not to exceed 20%.
f. Sonar Performance - This criteria has been taken as the 1/10th highest motion aplitude which brings the sonar dome to within one foot of the water surface should not exceed 4%.

With the ever increasing emphasis being placed on seakeeping, it has been the practice of the Department of Navy in recent years to conduct extensive model experimentation to determine the seakeeping properties of new design warships. Such seakeeping model experimentation programmes have consisted of running a ship model in the ship towing tank over a wide range of speeds & displacements in head & astern seas. Rolling experiments are also commonly conducted. Pitch, heave, accelerations, relative bow motions & rolling characteristics are measured during these experiments for the purpose of determining the necessary ship response operators which are used for predicting full scale motions in any specified sea spectra.

With regard to the design of a hull which possesses good seakeeping properties, the most dominant parameters which influence seakeeping are normally considered during the conceptual & sketch design stages of the ship. These parameters are listed below in their considered order of importance.

a. Ship Length - An increase in length can normally mean an inprovement in seakeeping.
b. Beam - The beam influences the rolling motion & can dictate the type of ship stabilisation required.
c. Draught - This effects slamming & sonar dome emmersion.
d. Below & Abovewater Form - This effects added mass of water, damping, & wetness.

Due to the increasing acquisition & running costs of warships & the ever diminishing funds, warships of the future will no doubt be smaller in size than those presently in service. More emphasis will therefore need to placed on the seakeeping properties of these smaller ships. It is also predicted that roll stabilisation systems will be required for most of the future warships.

Weapons Payload : The weapons payload is defined as the weight of armament, aircraft, ammunition, & 80% of the control, command & communication group weights. This method of defining weapons payload facilitates subsequent trade off studies which conducted with competing designs during the conceptual design stages of a warship design.

The weapons payload can account for 10 to 20% of the deep loaded displacement for a modern destroyer.

The weapon systemsfitted to a warship include a variety of gunmounts, surface to air missiles, anti-submarine missiles, torpedoes, surface to surface missiles, aircraft & numerous decoy devices. Also considered to be part of the weapon system & thus included in the weapons payload are the various types of long & short range surveillance radar & the weapons directing radar & other tracking systems.

A good compromise in siting the various wepon system components on the upper decks is essential for a good balanced design. The siting of gunmounts, missile launchers, directors & aerials therefore dictates to design of the warship above No 1 deck. The siting of these items influences the extent & distribution of the superstructure, the position & height of the masts & the design of the funnels. The following paragraphs describes some of these influencing factors.

It is essential that due consideration be given during the conceptual investigations to the siting of gunmounts to achieve maximums arc of fire. Gunmounts are therefore sited at sufficient distances from superstructures & other obstructions such as aerials, funnels, boat davits etc to achieve this objective & to avoid damage to these items by the guns own blast effects.

To protect the ships ammunition from the spread of fire from within the ship the magazines & shell rooms containing ammunition for the gun are normally located within the ship hull & below the waterline. This enables rapid flooding & offers a limited form of protection from above water enemy weapons such as missiles, rockets, small arms fire etc. With the modern rapid firing guns, a ready use magazine forms part of the gunmount & is therefore located directly under the deck. The ammunition in this magazine is protected by a thick layer of protective steel which forms the boundary of the magazine. The magazine is cylindrical in shape.

Since missiles can be directed in flight or they can automatically lock onto the target after launch, the siting of the missile launcher is not critical with regard to arcs of fire. However, certain boxed missiles are greatly influenced by relative wind velocity during the early stages of their flight. This aspect can dictate the relative angle of launch from the ship & of course the angular siting of the launcher on the deck.

Due consideration must also be given to the effect of the missile exhaust efflux at the time of launching. Launchers are therfore located in areas on the upper decks at safe distances from the superstructure, aerials & general working areas. Sometimes it is necessary to provide blast deflectors to provide the necessary safety margins against the effects of the hot gases.

Missile launchers whose missiles can be replenished at sea need to be located close to a suitable replenishment at sea position to avoid double handling of the missiles at the time of replenishing.

The long range surveillance radar aerial is normally located on the top of the superstructure or on top of a mast at an optimum height above the water surface which is dependant on the nature & frequency of the system to take advantage of the signal reinforcement from the ocean surface while avoiding the effect of wave clutter & to achieve a maximum radar horizon. Also essential for good radar performance is reduced runs of waveguides & reduced bends. This necessitates the close proximity of the radar equipment rooms to the aerials.

Due to the corrosive nature of the funnel hot gasses, the radar aerials are kept well clear of the funnel gasses. Wind tunnel experiments are normally conducted to ensure that adequate clearance has been provided.

Communications aerials are located such as to avoid mutual interference & to avoid exposing personnel to a radiation hazard.

For the reason of keeping clear of funnel gasses, the helocopter landing area is normally located at the aft end of the ship. However due to the pitching motions of the ship, theaft end location of the landing area is far from ideal.

If the exhaust gases could be exhausted out through the ships side or out through the transom, the helocopter landing area could be located closer to amidships.

The minimum size helocopter landing area is normally taken as a breadth equal to the rotor diameter & a length equal to one & a half times the rotor diameter.

Figure 14 depicts some of the features of siting the weapons payload as described in previous paragraphs.

It is predicted that weapons systems will continue to be developed at a very fast rate. A possible future development that will however cater for weapon system updates & complete changes will be that of the modular weapon system that can be simply plugged into the ship with very little effort. Such an arrangement is depicted in fig 15.

Human Support : Due to the complexity & variety of subsystems which make up the modern warship, the supporting complement far exceeds that for a merchant ship of the same size. For example, a destroyer of 3,000 tons deep displacement would require a complement of 200 to operate & maintain the subsystems efficiently.

The large complement required for warships must be fully supported from within the ship for a specified operating period. Space is therefore required for sleeping, dining & recreation as well as for laundry, washing, W.C, medical & galley facilities. Space is also required for the stowage of dry, wet & frozen provisions. The space requirements for these needs are normally determined during the conceptual design stages from approved R.A.N. allowances. As living standards improve ashore it can well be expected that warship living standards will improve in the future. This will place a greater demand on space & thus make the modern warship more space critical than at present unless special space saving design features are adopted.

One possible space saving design feature would be to group all of the human support spaces in one single area of the ship. Another possible means of saving space is to reduce the complement & provide a greater degree of system automation.

Two of the most demanding space consuming subsystems related to human support are that of air conditioning & sewage treatment plant. Due consideration must be given to these subsystems during the conceptual design stages of the ship.

Ship Support : The subsystems of the warship must also be supported from within the ship & space is therefore required for workshops, offices, & storerooms.

There are many subsystems that are unique to warships however the most demanding subsystems that require consideration during the early stages of design are as follows.

a. Replenishment at Sea.
b. Ships Boats.
c. Saltwater service for firefighting & bilge eductors.
d. Visual signalling.
e. Air intakes for Gas Turbines.

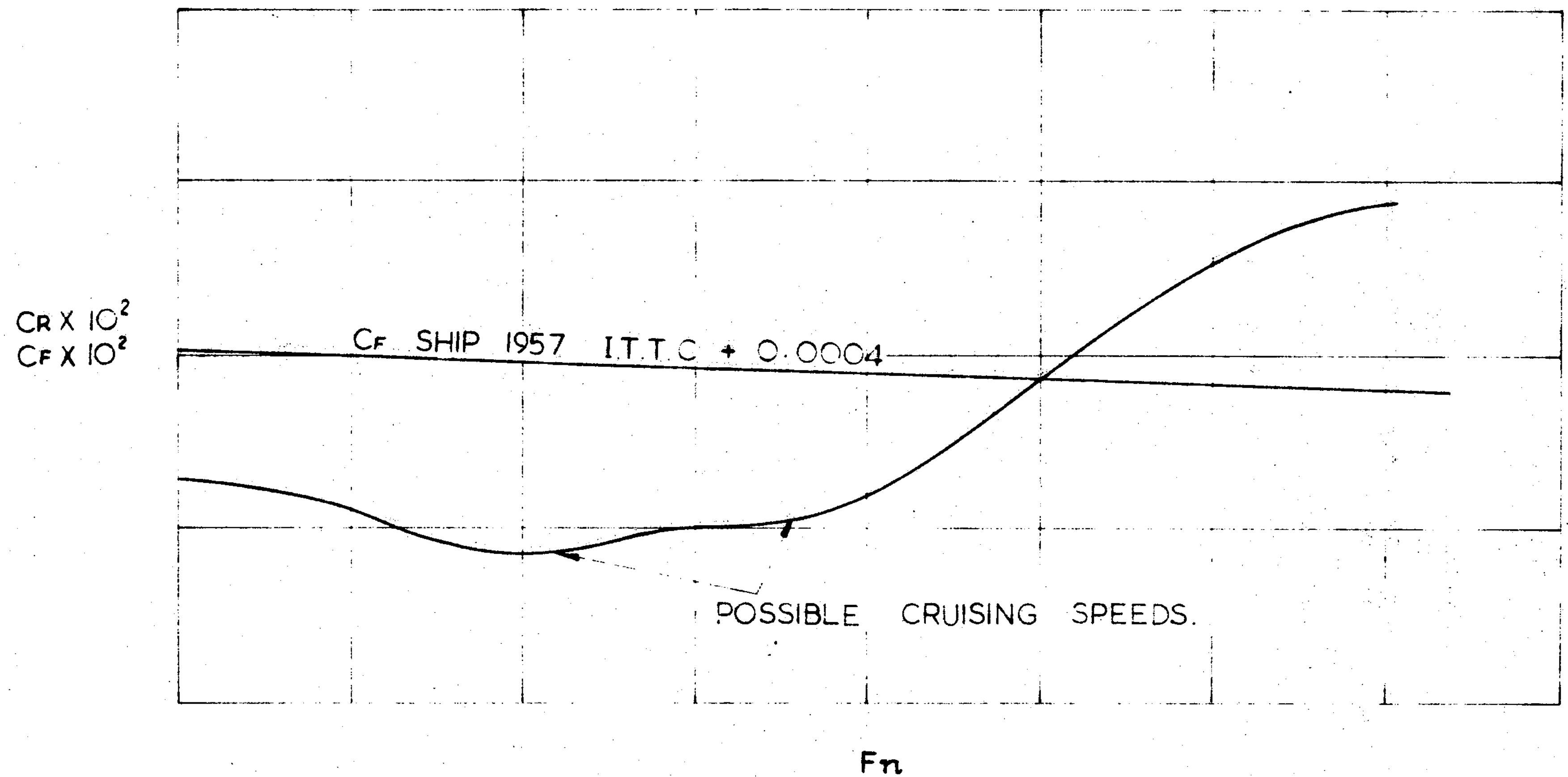


FIG.11.

HULL RESISTANCE CURVE FOR DESTROYER FORM

Code	Description of Sea	Significant Waveheight (metres)
0	Calm (Glassy)	0
1	Calm (Rippled)	0 - 0.1
2	Smooth (Wavelets)	0.1 - 0.5
3	Slight	0.5 - 1.25
4	Moderate	1.25 - 2.50
5	Rough	2.5 - 4.0
6	Very Rough	4 - 6
7	High	6 - 9
8	Very High	9 - 14
9	Phenomenal	Over 14

AGREED SEA STATE CODE

Wind Speed (knots)	Beaufort Number	Descriptive Term
Less than 1	0	Calm
1 - 3	1	Light Air
4 - 6	2	Light Breeze
7 - 10	3	Gentle Breeze
11 - 16	4	Moderate Breeze
17 - 21	5	Fresh Breeze
22 - 27	6	Strong Breeze
28 - 33	7	Near Gale
34 - 40	8	Gale
41 - 47	9	Strong Gale
48 - 55	10	Storm
56 - 63	11	Violent Storm
Over 63	12	Hurricane

BEAUFORT WIND SCALE

TABLE 2.

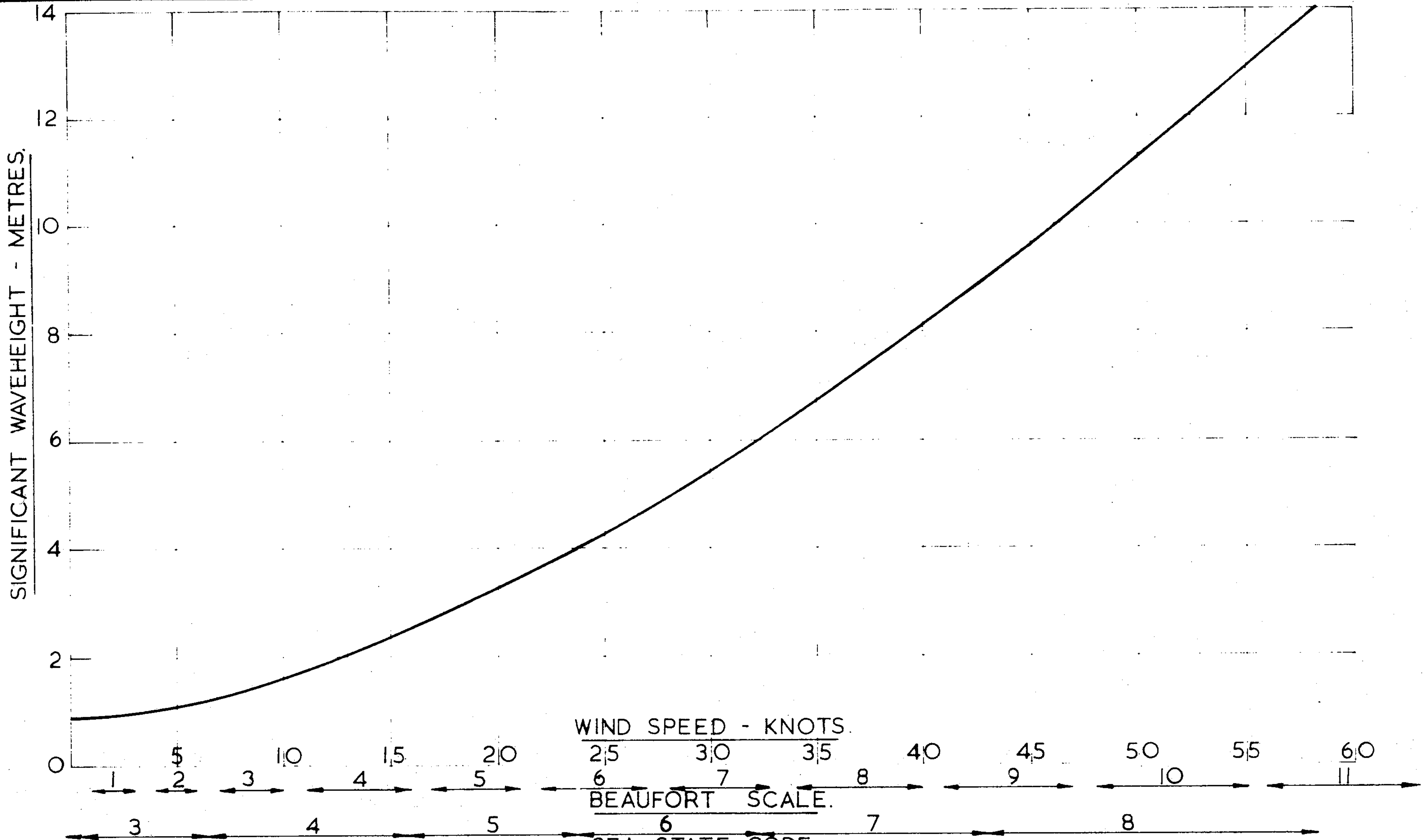


FIG. 12.

RELATIONSHIP BETWEEN WIND SPEED, WAVE HEIGHT & SEA STATE.

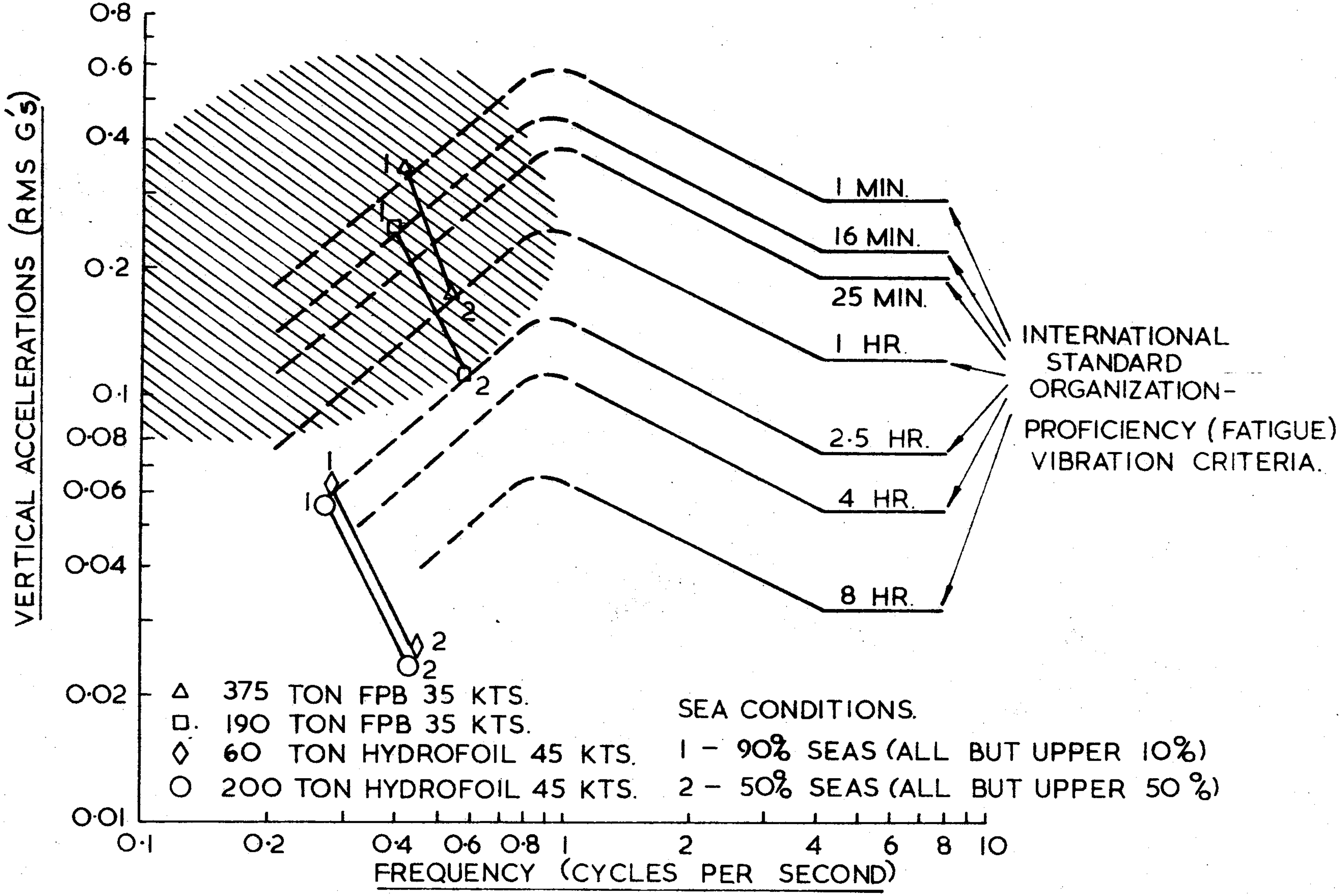


FIG 13.

ISO PERSONNEL PROFICIENCY LEVELS.

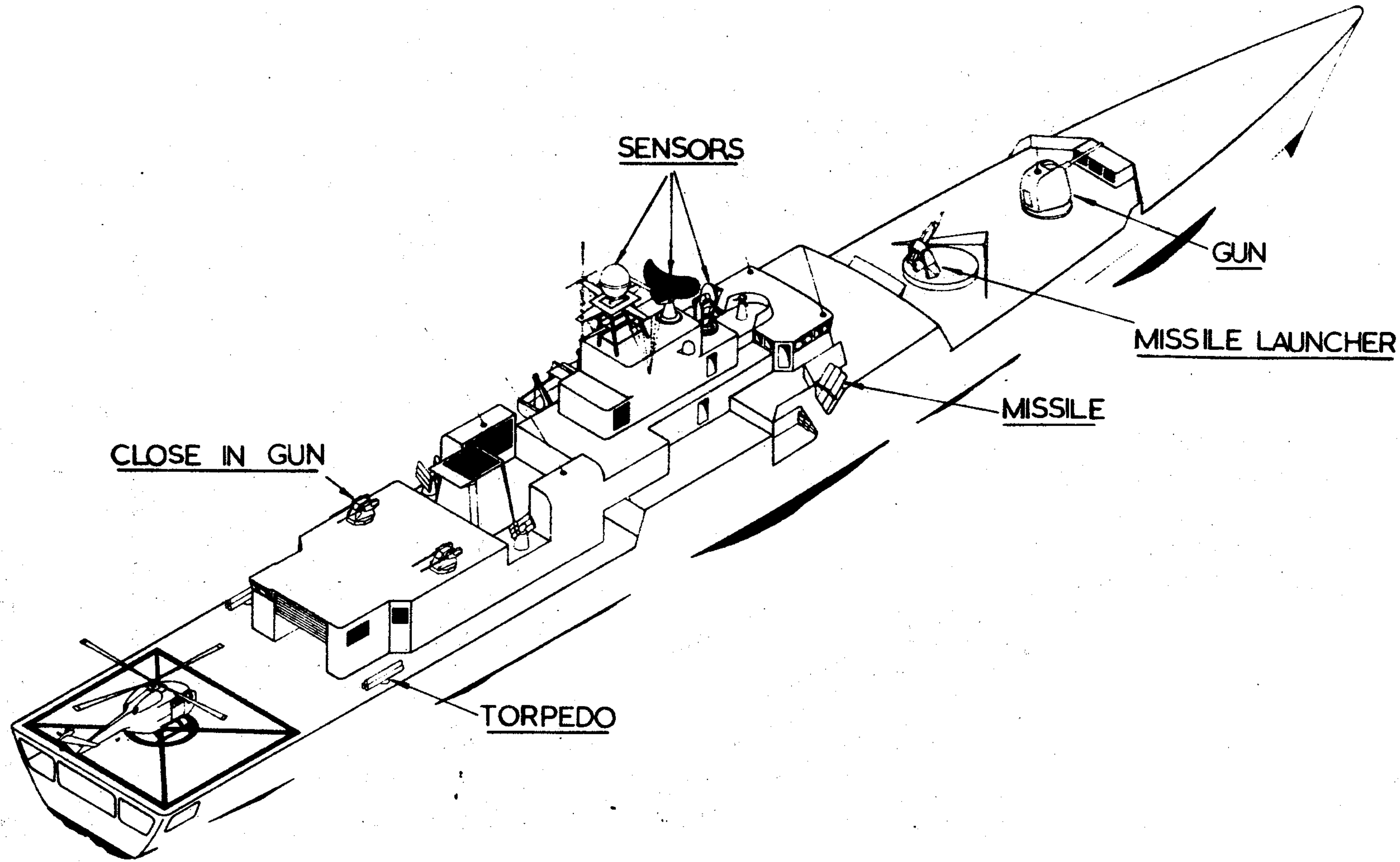


FIG.14

LAYOUT OF WEAPONS & SENSORS ON A MODERN DESTROYER.

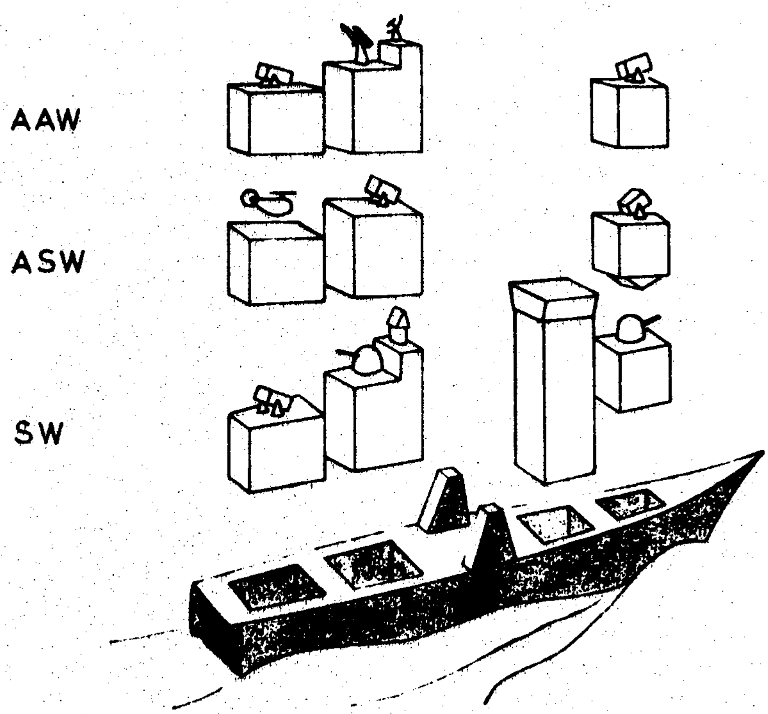


FIG. 15

MODULAR WEAPON SYSTEM OF THE FUTURE.

WARSHIPS OF THE FUTURE :

This section of the paper is devoted to describing the application & development of the more unusual types of marine vehicles either being adopted or being developed for naval applications by overseas navies.

Each type of marine vehicle is compared to the conventional monohull type displacement ship on the basis of its ability to perform the specified naval tasks associated with its speed, payload capacity, endurance, seakeeping, manoeuvrability, strength, propulsion, vulnerability, & general working features.

The types of marine vehicles considered are listed below & depicted in fig 16 :

Buoyancy Supported - Catamarans.(conventional)
Small Waterplane Area Twin Hull.
Single Hull Semisubmersible.
Slender Ship.

Dynamically Supported - Hydrofoils.
Surface Effect Vessels -
Surface Effect Ships.
Air Cushion Vehicles.

Buoyancy Supported Vessels.

The Conventional Catamaran : The conventional catamaran consists of two displacement type hulls joined together well above the waterline by a rigid bridge structure. The hulls are usually much more slender than the conventional displacement type ship & can be either symetrical or assymetrical in section. The slender hulls with waterplanes & stern configuration adapted from monohull design practice are separated by a distance which enables an advantage to be gained with reduced wavemaking resistance by avoiding wave interference between the two hulls. The individual slender hulls also offer less wavemaking resistance than the conventional single hull vessel of the same displacement. However, due to the greater underwater surface area of the twin hulls compared to the single hull of the same displacement, the conventional catamaran offers more frictional resistance. Table 3 gives a comparison of wetted surface areas of the various types of buoyancy supported vessels.

Table 3.

Wetted Surface Area Comparison.

	$S/\sqrt{\Delta L}\ /(S/\sqrt{\Delta L})_{Monohull}$
Monohull.	1.0
Conventional Catamaran.	1.4
SWATH Ship.	2.3
Multi Hull Submersible.	2.3

With high frictional resistance & low mavemaking resistance & generally possessing inferior hull efficiency elements, the catamaran is more suited to operations in the higher speed length ratio ranges. The catamaran is therefore considered to be more efficient than the conventional monohull at speed length ratios exceeding 1.4.

Figure 18 depicts the lines of an assymetrical type hull for the conventional catamaran.

It is interesting to note that up to the present time, the conventional catamaran has been operated at low speeds where the hull resistance penalty has been great. Only recently has attention been given to possible operation at much higher speeds. This development will be discussed in the sections dealing with the SWATH Ship.

The wide hull spacing of the conventional catamaran which provides a large waterplane area inertia produces a vessel with a high metacentric height, a large restoring moment & a short period of roll. These properties combined with a large weather deck area make the conventional catamaran very suitable for performing tasks requiring extensive topweight loads & open deck areas. Such tasks include Submarine Rescue, Oceanographic Research,& Minesweeping. The U.S.N. currently have vessels of the catamaran type performing the first two tasks.

Due to the added resistance below $V/\sqrt{L}$ of 1·4 of the conventional catamaran, more fuel must be carried to achieve the same endurance as a conventional monohull of the same displacement. Combining this aspect with the need for added steel weight associated with the bridging structure of the catamaran, the potential payload capacity of the catamaran is somewhat inferior to that of the conventional monohull of the same displacement.

To demonstrate this aspect, a destroyer hull of 4000 tons deep displacement with an endurance of 4000 n. miles & a maximum speed of 35 knots, has a payload of approximately 750 tons compared to 600 tons for a catamaran of the same displacement & possessing the same endurance & maximum speed. For this example, payload has been taken to represent all armament, electronics, electric plant, & all consumables except fuel & machinery liquids.

Both the directional stability & the manoeuvrability of the conventional catamaran are very much superior to that of the conventional monohull displacement type vessel. The superior directional stability is due to the effect of the two slender & deeper hulls, while the manoeuvrability is enhanced by the increased turning moments about the ships centreline created by the individual rudders & propulsors. These properties are an advantage for slow speed operation & for station keeping.

The propulsion requirements for the conventional catamaran are similar to that of the twin screw displacement type ship.

Due to the extreme depth of the individual hull of the catamaran with respect to the length of the hull girder, the first level stresses associated with balancing the vessel on the standard wave are very low & consequently hull scantlings are governed by local strength requirements. Consideration is therefore given to the bending moment loads, the vertical shear loads & the torsion loads on the cross structure. Maximum bending moment & vertical shear loads have been found to occure at zero ship speed in beam seas, while maximum torsional loads occure at zero speed in quartering seas. Water impact loads on the forward under portion of the cross structure are also of considerable importance when designing the structure of the conventional catamaran.

Apart from the effects of assymetrical flooding, the the inherent ability of the catamaran to withstand damage is very much the same as the monohull.

The catamaran is known to possess a low pressure signature due to the low wavemaking resistance making it ideal for minehunting operations where the liklyhood of actuating a pressure type mine would be greatly reduced.

As discussed in previous paragraphs, the rolling motions of the conventional catamaran is very stiff & thus creating severe accelerations at the deck level. However, with regard to pitch & heave motions, the catamaran responds to waves very differently to that of the monohull. The catamaran experiences more severe bow motions due to the small invicid damping effect offerred by the slender hulls. This property is clearly demonstrated in fig 18. It should also be noticed in fig 21 that in ~~head~~ following seas the catamaran experiences its maximum bow motions ~~operators~~ at a higher ship length to wavelength ratio than the monohull, & combining this with a representative sea spectra it is apparent that the catamaran will reach resonance in smaller seastates when compared to the monohull. Note also from fig 21 the effect ship speed has on the bow motion of the catamaran.

It is concluded that the conventional catamaran has a doubtful future because of the problems associated with added resistance & seakeeping which have subsequently been partly overcome with the the SWATH ship.

Small Waterplane Area Twin Hulled Ship : The Small Waterplane Area Twin Hulled Ship (SWATH) or Semisubmerged Ship as it is sometimes called consists basically of two torpedo like hulls which are submerged to a depth of from one to two diameters & attached to an above water platform structure either by four widely spaced struts or by two continuous struts. The term SWATH ship has generally been restricted to the four strut concept,while the two strut concept has been normally referred to as a semisubmerged ship. Basically the performance of both types are the same, although the semisubmerged ship will offer more friction resistance & may be somewhat stiffer in its rolling motions. However for convenience, both types will be referred to as SWATH ships in the following paragraphs. Fig 19 depicts both types of the SWATH ship.

The main advantage of the SWATH ship when compared to the monohull is its superior seakeeping properties, both at rest & underway. Other advantages include its reduced wavemaking resistance at high speeds, its large open deck areas in its large abovewater platform, its suitability for hull mounted sonar, its improved propulsor efficiency, its greater topside weight carrying potential & its potential for a near level ride in high seastates. The SWATH ship also offers the potential for cheap modular construction which can be joined afloat.

The main disadvantages which are related to the conventional catamaran such as poor seakeeping, high deck accelerations & high hull resistance have been overcome with the SWATH concept.

The main disadvantages of the SWATH ship is its increased structural weight due to its relatively dispersed design form, its large draught, its need for ballast control over platform height & trim & its need for additional dynamic control surfaces.

The hydrodynamic design of the SWATH ship to minimize hull resistance throughout the operating speed range is very complex. This is due to the fact that the great bulk of the ships volume is under the water & superimposed on this bulk are the vertical struts which penetrate the watersurface & can have a strong interaction effect on the main bodies. When the two hulls are combined together to a catamaran concept, their hydrodynamics are further complicated by both displacements & wave interaction effects.

Fig 20 depicts some interesting comparisons of hull efficiency between the SWATH ship, the Conventional Catamaran & the Monohull ship. Basically this figure shows that the SWATH ship has some resistance advantage over the other forms at speed length ratios exceeding 2.0. This can be explained by the SWATH ship having a greater underwater surface area (table 3) & thus frictional resistance which is the dominant form of resistance at lower ship speeds. At higher speeds however, the SWATH with its submerged hull well below the surface of the water offers very little wavemaking resistance which is the dominant form of resistance at the higher ship speeds. Due to the uniform boundary layer & increased wake effect the propulsive efficiency of the SWATH would also appear to be greater than other ship forms.

Although the payload potential of the SWATH ship is greater than that of the conventional catamaran, it still does not approach that of the monohull operating at speeds up to 40 knots. This is due to the increased structural weight necessary for the SWATH compared to that of the monohull of the same displacement.

In the last decade or so, naval ships have become area or volume critical rather than weight critical as their payloads have become less dense & therefore efficient operation has been hampered by the lack of adequate deck space, both internal & external. In dealing with monohulls, space, displacement & cost have been nearly synominous. It know appears however that the space so greatly needed can be obtained without a great sacrifice in performance or cost by using the SWATH concept, providing structural & other weights can be retained at a tolerable level.

In high seastates the SWATH ship is able to maintain speed with almost negligible increase in resistance. This property of the SWATH ship is clearly demonstated in fig 20 as acomparison to the monohull.

In head seas, the pitch & heave motions of the SWATH ship are far superior to that of the monohull even without making use of the various control surfaces for dynamic lift. In following seas however the reverse is the case & extreme heave ~~pitch~~ motions can occure which are greater than that of the monohull & the conventional catamaran. Typical response operator curves for following seas are depicted in fig 21. Similar response operator curves for head Seas are depicted in fig 18.which shows the superiority of the SWATH in head seas.

The roll resonance of the SWATH is somewhat lower than the monohull but not as low as the conventional catamaran, this property is depicted in fig 21. The rolling characteristics of the Swath can however be partly controlled by active fins & therefore poses no major problems.

It is thought that the reduced motions of the SWATH ship is partly due to the fact that the surface waves have very little effect on the major portions of the hull volume because of its deep submergence.

With regard to strength considerations for the SWATH ship, the same structural aspects as discussed for the conventional catamaran generally apply. In addition to these however, the connections between the submerged hulls & the struts must be given particular attention .

Propulsive performance of the SWATH ship can be expected to be superior to the monohull & the conventional catamaran. This is due to the fact that the propulsors are more readily wake adapted to take advantage of the boundary layer inflow. Contrarotating propellers & propellers in nozzels are particularly adaptable to the torpedo like underwater hulls of the SWATH ship. Such propulsors could also be expected to create less underwater noise thus making the SWATH ship ideal for ASW operations.

Free running model experiments have shown that the SWATH ship has large turning diameters & a small degree of outward heel. The experiments also showed that the SWATH could steer a straight course with only one propulsor operating.

The general working features of the SWATH ship are similar to those of the conventional catamaran. It is therefore considered that the SWATH ship is ideal for the following tasks, (a) ASW, (b)Seaborne Aircraft Platform, (c)Minehunter or Sweeper & (d)Oceanographic Research.

It is predicted that the SWATH concept will be further developed during the next decade & will eventually replace the monohull for many tasks. Already, the Dutch are operating the"DUPLUS" as a general work ship for offshore drilling operations. It is also understood that the USN have completed feasibility studies for a 2000 to 5000 ton Swath ship & propose to let a contract for the detail design & eventually the construction of an experimental prototype.

Single Hull Semisubmersible Ship : The various forms of the single hull semisubmersible ship are depicted in fig 22. These forms are as follows :

a. The Single Hull Semisubmersible.
b. The Semi Submarine.
c. The Shark Form.

Very little data is available on these forms & it is thought that almost no research is currently being carried out on these forms. However, this section of the paper would be incomplete without some reference being made to them.

The single hull semisubmersible ship is merely an adaption of the SWATH ship. It consists however of only the one torpedo like underwater body. The main advantage of this form is its reduced frictional resistance when compared with the SWATH & therefore is more suited to the slower speeds, than the SWATH, it is also more efficient at the higher speeds. Its static transverse stability is inferior to that of the SWATH but still adequate for most tasks. Without the assistance of dynamic control surfaces the heave & pitch motions could be expected to be greater than the SWATH. The low speed manoeuvrability would also be somewhat inferior to that of the SWATH, this is due to the adoption of the single propulsor.

Apart from a reduction in volumetric capacity in the bridge structure, all other characteristics of the single hull semisubmersible are similar to the SWATH ship.

The single hull semisubmersible ship shows promise for application to the tasks of the conventional patrol boat & the high speed seaborne aircraft platform. It is considered that the upper speed limit of the single hull simesubmersible ship will be limited to speeds which introduce cavitation on the struts & control surfaces.

The Semi Submarine is a near surface submarine which need not depend on nuclear propulsion for extensive underwater endurance. This type of craft maintains a permanent connection with the abovewater environment via a long surface piercing strut & can therefore employ lightweight relatively inexpensive air breating systems.

A further advantage of the Semi Submarine is its exceptionally long pitching & heaving periods in head seas. High speed operation in stern seas is however restricted to moderate seastates.

Unlike the single hull semisubmerged ship, all of the living, working & operational spaces in the semi submarine are contained in the submerged hull. This is necessary due to the limited transverse stability of the semi submarine, which is only capable of supporting a small conning bridge on the top of the surface piercing strut. All sensors & weapons must therefore be carried in the submerged hull. Weapons such as underwater launched surface skimming missiles would be ideal for use in the semi submarine.

The large draughts of the semi-submarine would be detrimental for operation in harbours & therefore some form of deballasting system is required.

To achieve a hull efficiency approaching that of the conventional destroyer, the main hull of the semi submarine would have to be submerged at least $1\frac{1}{2}$ times the diameter of the submerged hull. Fig 23 depicts the relationship of speed & power of the destroyer & the semi submarine.

As already discussed in previous sections, the threat from nuclear, chemical & biological effects is very difficult if not impossible to counter with the conventional surface ship. However the semi-submarine provides the same extent of protection against these threats as the conventional submarine at a much reduced overall ship cost. Therefore if the semi submarine is to be further developed, it is predicted that it will be developed for the sole purpose of providing protection from these threats.

The Shark Form Ship is basically a semi submarine with a much larger & continuous strut piercing the water surface which appears to be a slender ship shape form above the water. The shape & location of the strut is determined so as to cancel as much of the wavemaking resistance created by the submerged as possible. The Shark Form Ship therefore offers high speeds & small motions in seas & a limited topweight potential.

The shark form has problems with excessive running trim & it is therefore necessary to have a trimming & ballast system which occupies valuable space in the submerged hull.

It is predicted that the shark form ship will develop no further than the existing paper exercise because of its inherent limitations which have now been overcome with other types of vessels with the same advantages ie the SWATH ship.

The Slender Ship is basically a lengthened destroyer form with beam & draught reduced to maintain the same displacement. The increased length associated with the constant displacement has the duel effect of decreasing the wavemaking resistance & increasing the ships natural periods for pitch & heave.

Because of the augmented loadings associated with the increased length & the rduced beam, a greater fraction of the displacement of the slender ship is devoted to the structure than is the case for the conventional destroyer of the same displacement. The ability of the slender ship to carry topweight is also restricted by its limited inherent static stability.

Although predictions were made in previous sections of this paper that destroyers will become longer & slimmer in the future due to the increased speeds ~~length ratios~~, they will not reach the stage of becomming a slender ship. Alternative options would appear to be more practical. The future of the slender ship is therefore in doubt.

Dynamically Supported Vessels.

The state of the art with regard to dynamically supported vessels that have been designed to perform military & naval tasks is depicted in fig 24. This figure contains the envelopes of speed & size in which each type of dynamically supported vessel operates.

The speed range in which each type of vessel operates is as follows :

a. Medium Speed Planing vessel	30 - 40	Knots.
b. High Speed G.T. Planing vessel	40 - 50	"
c. Hydrofoils.	45 - 60	"
d. Air Cushion Vehicles.	50 - 65	"
e. Surface Effect Ships.	50 - 80	"

Also clearly evedent in fig 24 is that the trend towards higher speeds have produced the smaller type of vessels.

Hydrofoils : Many new developments in hydrofoil design have taken place over the last decade which has made the hydrofoil concept more attractive for naval application. These developments include ventilated foils, height sensors, aircraft type control systems & waterjet propulsion. Most of these features have been incorporated in the N.A.T.O. PHM designed in the U.S.A by Boeing. This vessel is depicted in fig 25.

Compared to the conventional monohull displacement type vessel, the hydrofoil offers the following advantages for naval application.

a. High speed in severe seastates.
b. Exceptionally good manoeuvrability at speed.
c. Good stable platform for crew & weapons.

The disadvantages of the hydrofoil are :

a. Its high acquisition cost.
b. Its poor weapons payload capacity.
c. Its poor endurance when foilborne.

The hydrofoil is well capable of operating at speeds in excess of 60 knots, however these higher speeds dictate the use of special supercavitating foils which must be manufactured from exotic & expensive materials. This factor has been the main reason for limiting the speeds of the hydrofoil to 60knots. For speeds below 40 knots it is possible to adopt the simple subcavitating foils, while for speeds ranging from 40 to 60 knots, special delayed cavitation type foils are necessary which are still considerably much cheaper than the supercavitating type.

The hydrofoil is a much more efficient vessel when compared to the conventional displacement type vessel & planing vessel at speed length ratios exceeding 2.0. This advantage is evident in fig 26.

The ability of the hydrofoil to maintain its high speed in severe seastates is demonstrated in fig 27.

The good seakeeping properties of the hydrofoil when foilborne is due to its ability to fly over the ocean waves. The extent to which the hydrofoil is influenced by the ocean waves is determined by the operation of a bow foil mounted wave height sensor. This sensor can be adjusted to allow the hydrofoil to either fully platform the ocean surface or to fully contour it. Intermediate conditions are of course possible also.

When compared to the displacement type vessel, the motions of a hydrofoil in a seaway are of a very much lower magnitude in all planes. This applies for all directions of seas. The hydrofoil is therefore a good stable platform so essential for efficient operation of the crew & weapon systems.

Although the hydrofoil has a limited foilborne endurance, the overall endurance of the vessel can be increased by extensive operation in the hullborne condition. For the hullborne condition the foils can be made to retract clear of the water, thus making the vessel a conventional displacement type with all of its advantages & disadvantages, or the foils can be fixed & dragged through the water. In this later condition the vessel offers more resistance but due to the added damping effect of the foils, hullborne motions in a seaway are less than those of the conventional displacement type craft.

In an enveavour to increase payload capacity, the hydrofoil is constructed from lightweight materials with lower safety factors. Together with the sophisticated structure, its high performance aircraft derivative type gas turbine machinery, its unique propulsors such as waterjets, its foils & the number of more expensive sensor & control systems, the hydrofoil has proven to be very expensive. Production run craft have proven to be twice the cost of the conventional displacement craft of the same displacement, while prototypes can be as much as four times the cost.

Progress in hydrofoil technology leads to two possible philosophies of employment for hydrofoil craft. The first envisions hydrofoil ships with sufficient foilborne & hullborne endurance to perform some of the escort duties associated with destroyer type ships. The second would employ small highspeed hydrofoils with a limited endurance & deployed from either a mobile support base or a fixed base close by.

In the first instance, the need for sufficient endurance dictates that the hydrofoil ship would need to have a displaeement ranging from 1000 to 1500 tons. With this size hydrofoil ship, studies have indicated that payloads with emphasis on equipment for the ASW task & currently mounted or being developed for the conventional destroyer, can be modified for use in the hydrofoil ship. It is readily apparent that the capability of the hydrofoil ship to tow sonar systems, to manoeuvre rapidly, & to increase & reduce speed rapidly in severe seastates would provide screening forces with greatly improved capabilities to detect & destroy enemy submarines. The requirements & a sketch of a possible hydrofoil ship is depicted in fig 28.

At the same time there would appear to be functions that could be performed by small highspeed hydrofoils either shore based or supported from a mobile base. Such duties presently being carried out by the conventional missile carrying patrol boat could be better performed by the small hydrofoil. The TUCUMCARI & the development of the N.A.T.O. PHM substantiates the USN faith in hydrofoil deployment.

It is predicted that despite the high cost of hydrofoils their future is assured for naval deployment. It is also predicted that as more & more hydrofoils become operational & further expertise is obtained in their design & building, their cost will decrease.

Surface Effect Vessels : The two types of surface effect vessels which will be discussed in this paper are those more commonly known as the SURFACE EFFECT SHIP & the AIR CUSHION VEHICLE. While both types depend on dynamic support from air under their hulls, the SES has rigid sidewalls with a skirt at the forward & aft ends, & the ACV is fully amphibious with a flexible skirt around its entire perimeter.

The SES offers the advantage of very high speeds in reasonable seastates. However, unlike the hydrofoil, its speed is considerably reduced in severe seastates.

The endurance, payload capacity & manoeuvrability of the SES are inferior to that of the hydrofoil, however development of this type of ship has only taken place over the last few years & very few experimental vessels are available for true comparison. The USN has recently launched two 100 tons SES's & it is understood that conceptual studies for a 2000 ton SES have recently been completed.

A concept of the 2000 ton SES for the USN is depicted in 29. It is claimed that this craft will be capable of speeds up to 100 knots, however the practicability of such a concept must be doubted if reasonable endurance is required. It is envisaged that such a ship would require 100,000 to 120,000 SHP to achieve 100 knots & over 1000 tons of fuel would be required for an endurance of 1000 miles at 100 knots.

The development of the ACV in the USA & the UK would appear to be on a less ambitious scale with regard to size than that of the SES. The most attractive advantage that the ACV has to offer for military applications is its amphibious capability. This advantage has lead the USN to develop two prototype Amphibious Assault Landing Craft(JEFF A & JEFF B). The character istics of both these craft are shown in fig 30. Also depicted in fig 30 is a concept for possible larger ACVs suitable for escort duties.

As an assault landing craft the ACV has the following advantages :

a. Reduction in the vulnerability of the landing force by decreasing the time it takes for the assualt vessel to transit to the beach & deliver its payload.
b. Increased flexibility in selection of landing sites.
c. Inherent resistance to underwater explosions.
d. High speed for taking evasive action against enemy attacks.

The main disadvantages of the ACV as presently conceived is its limited range of operation & its inability to maintain speed in seas exceeding seastate 3. The hydrofoil is mush superior in this regard.

The ACV is being developed in the UK for use as a minesweeper & to replace the traditional patrol boat. The Vosper VT1 as depicted in fig 31 is an interesting development in this regard. It should be noted however that the VT1 has only a limited amphibious capability.

<u>Conclusions</u> : In concluding this section of the paper it can be confidently predicted that the future will bring with it some very demanding operational requirements which will demand the adoption of some interesting & possibly unconventional weapons platforms. The Naval Architect should therefore prepare himself for these developments & participate as much as possible in the recearch associated with unconventional concepts. If the Naval Architect fails to accept this challenge, more forward thinking professionals in other disciplines will fill the gaps that have been left by the more traditional thinking Naval Architect.

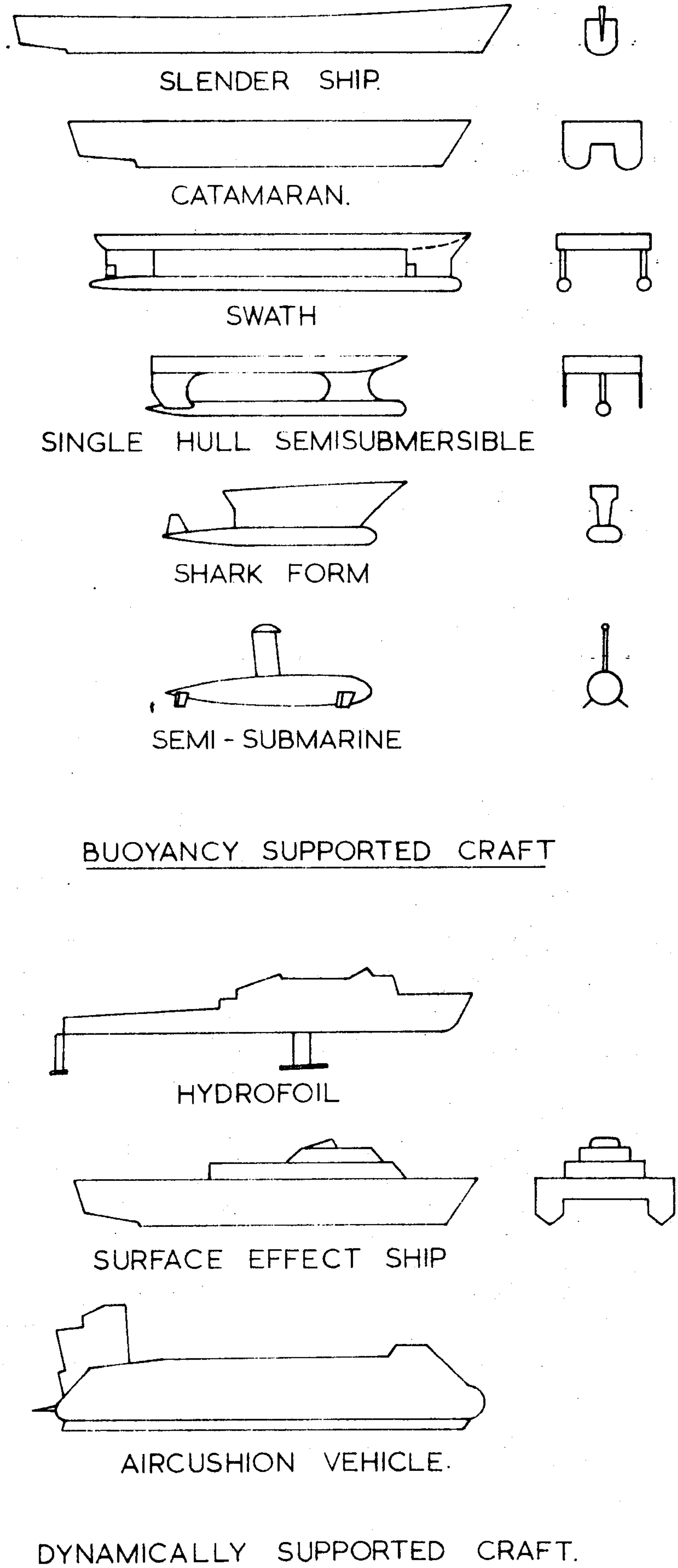
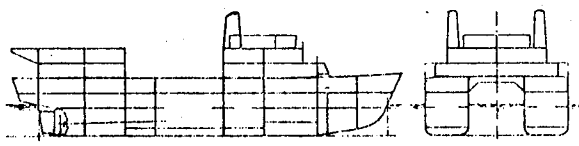


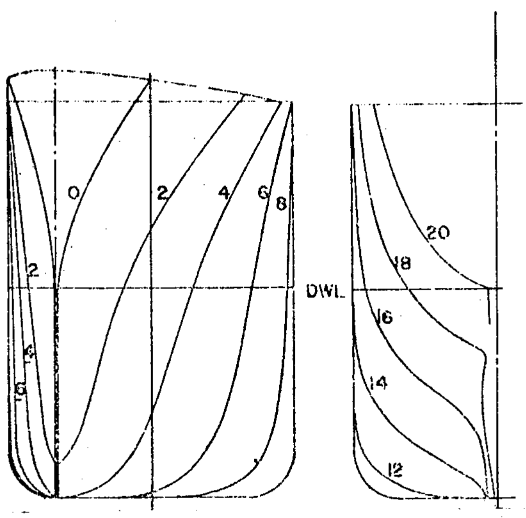
FIG 16

VARIOUS TYPES OF MARINE VEHICLES.



CHARACTERISTICS

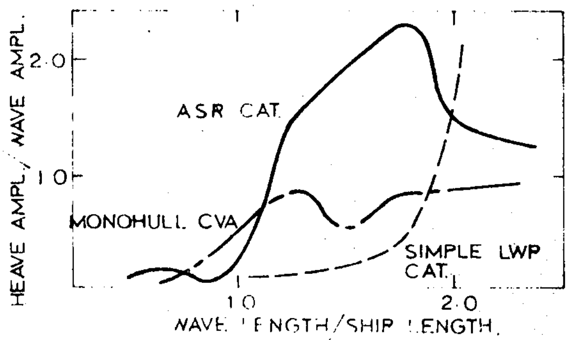
LOA .... 234'-6"	DRAFT .... 19'-0"
LBP .... 210-0"	LIGHT DISP..... 2575 TONS
BEAM (MAX.)....... 86'-0"	FULL LOAD Δ ....5200 TONS
BEAM (EACH HULL)... 26'-0"	SPEED, SUS......... 16 KTS.
MAIN DK. ABV. W.L......16-0"	ENDURANCE/13 KTS .. 10,000



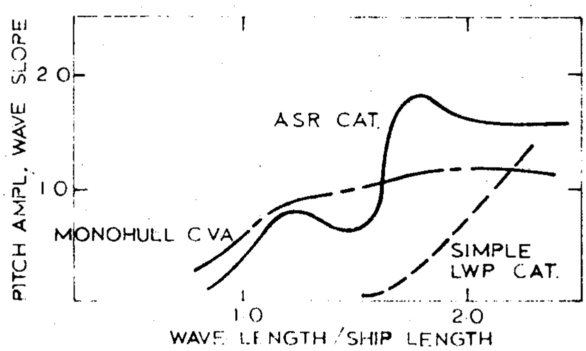
FORE BODY. AFT. BODY.

FIG. 17.

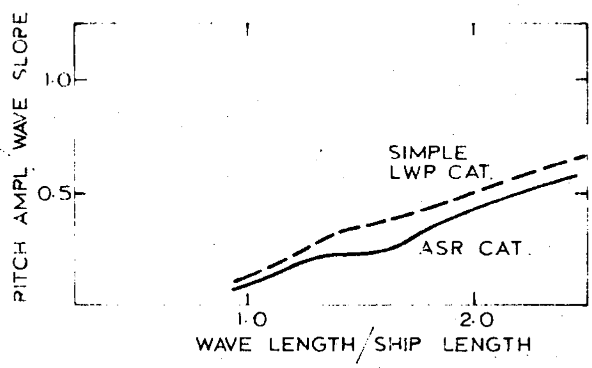
LINES OF CONVENTIONAL CATAMARAN ASR - 21.



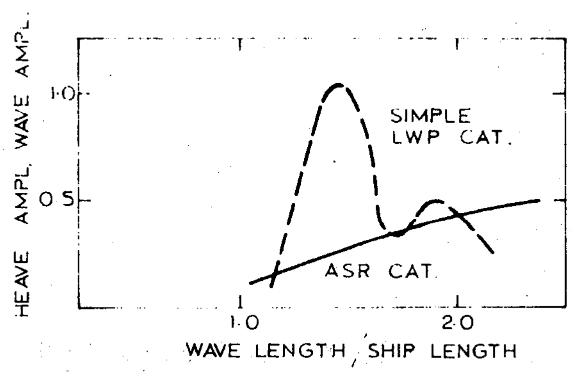
HEAVE – HEAD WAVES



PITCH – HEAD WAVES



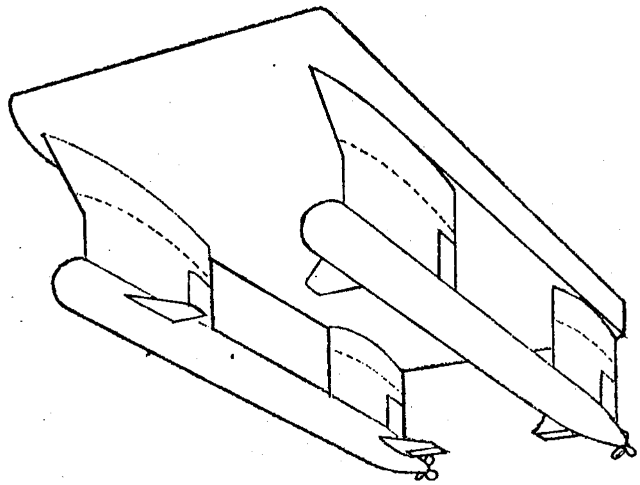
PITCH FOLLOWING WAVES.



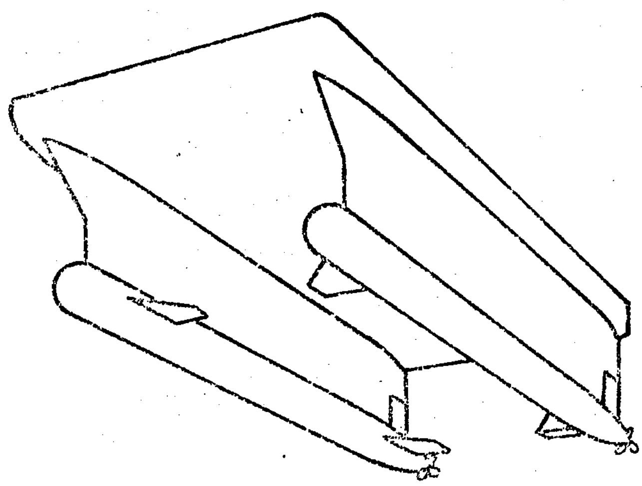
HEAVE – FOLLOWING WAVES.

FIG 18.

MOTION RESPONSE CURVES FOR THE CONVENTIONAL CATAMARAN.



SWATH SHIP.



THE SEMISUBMERGED SHIP.

FIG 19

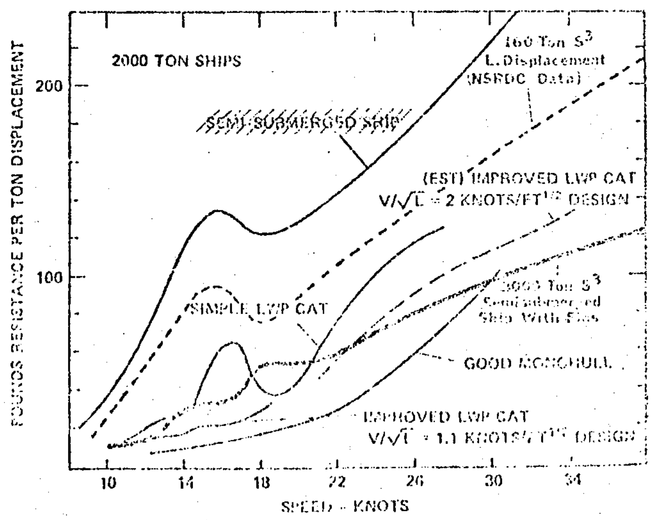


FIG 20

EFFECT OF WAVES ON THE SWATH SHIP.

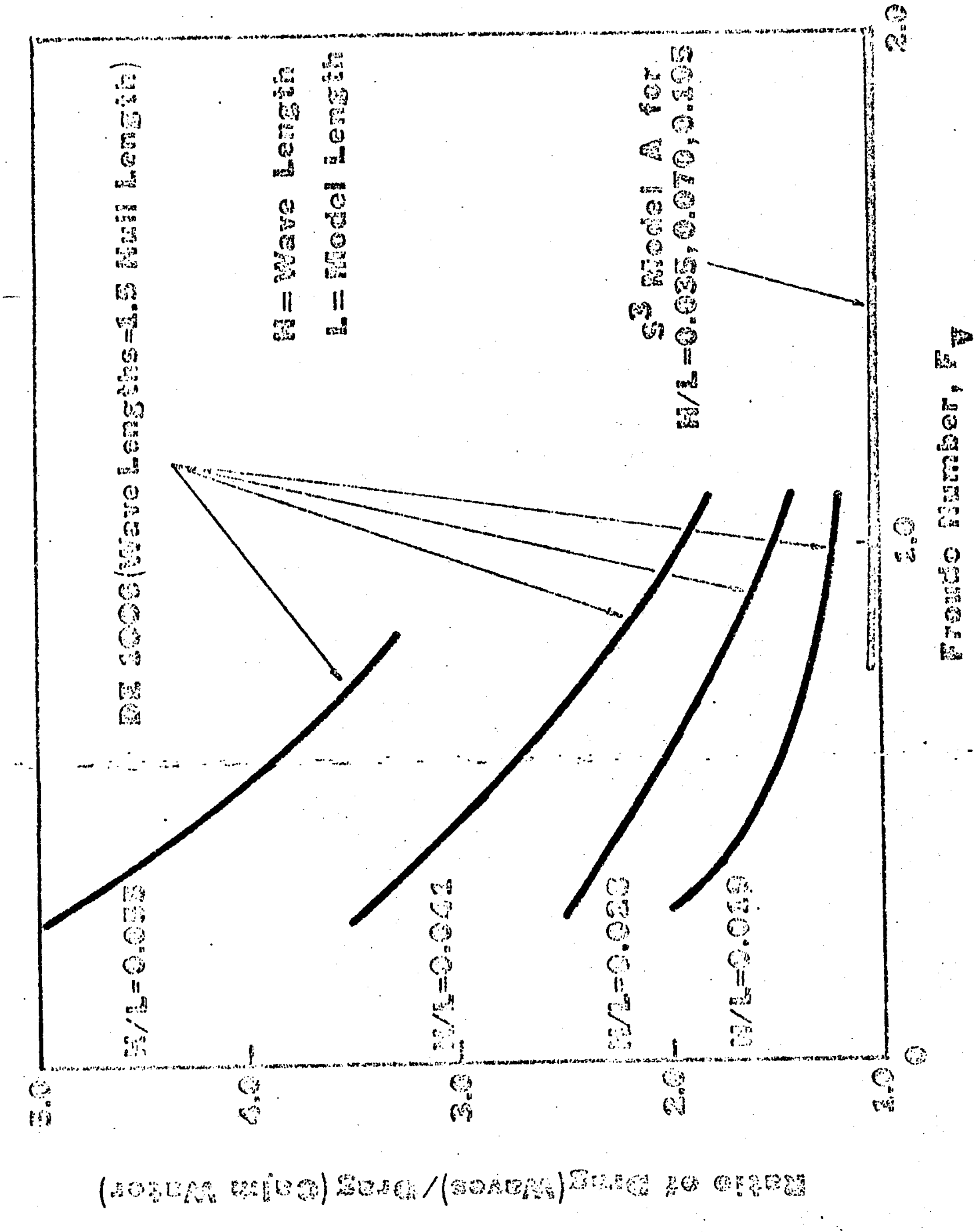


FIG 20

EFFECT OF WAVES ON THE SWATH SHIP.

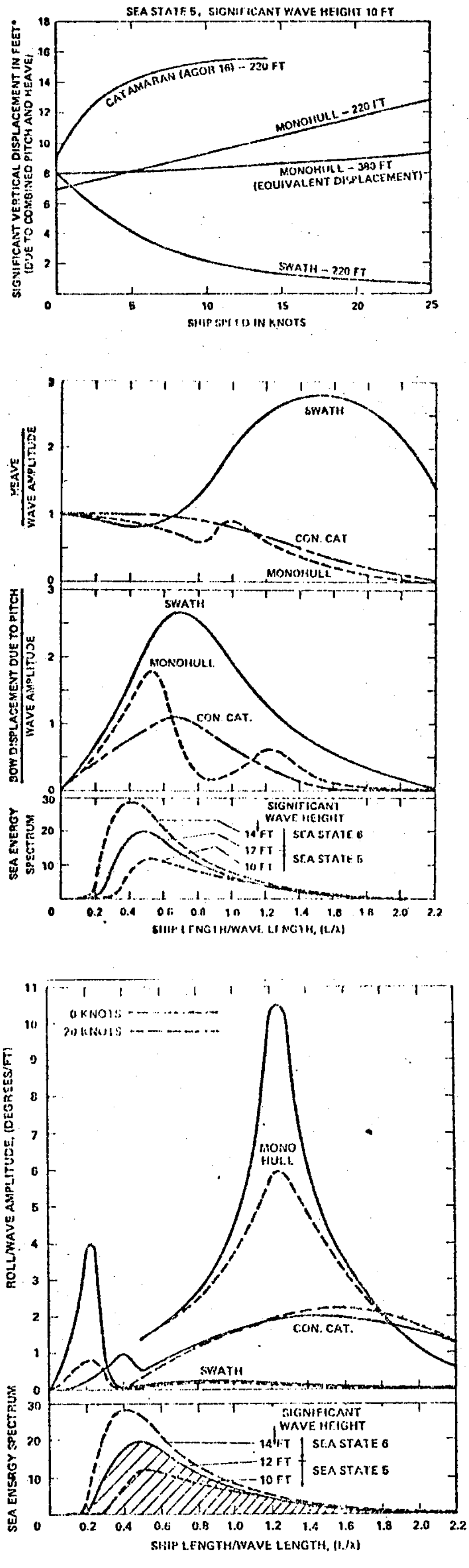


FIG. 21

SEA KEEPING PROPERTIES OF THE SWATH SHIP.

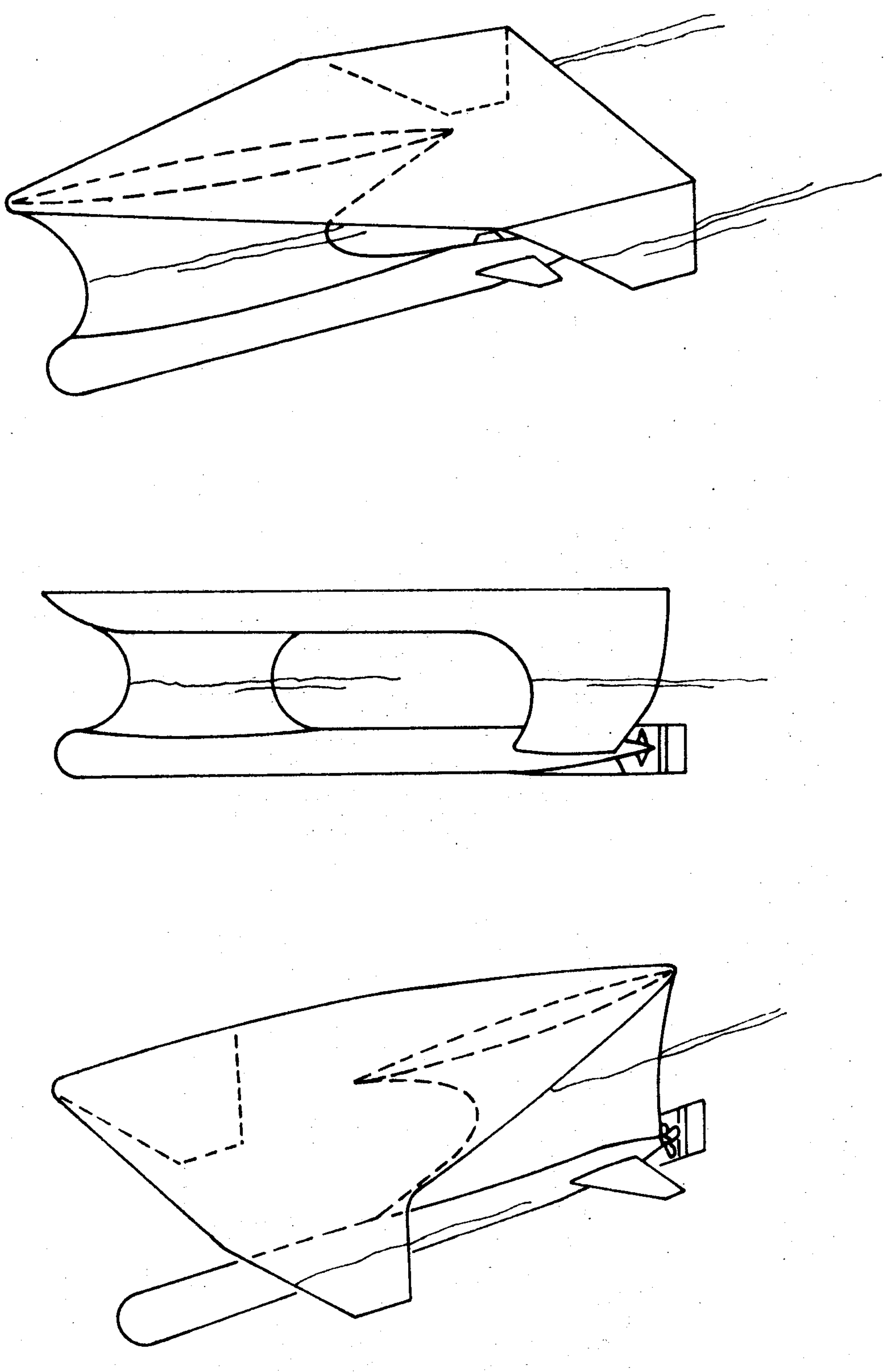
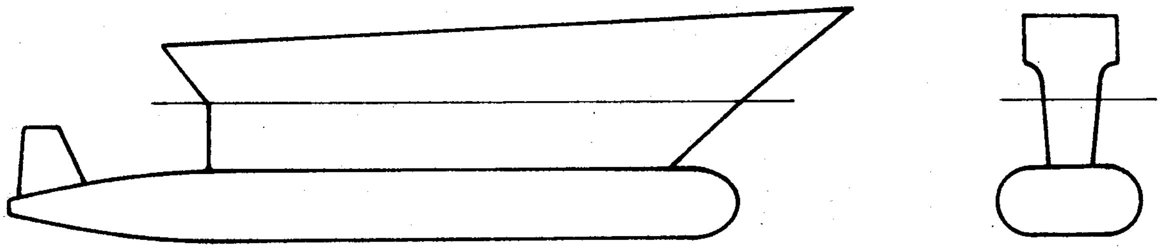
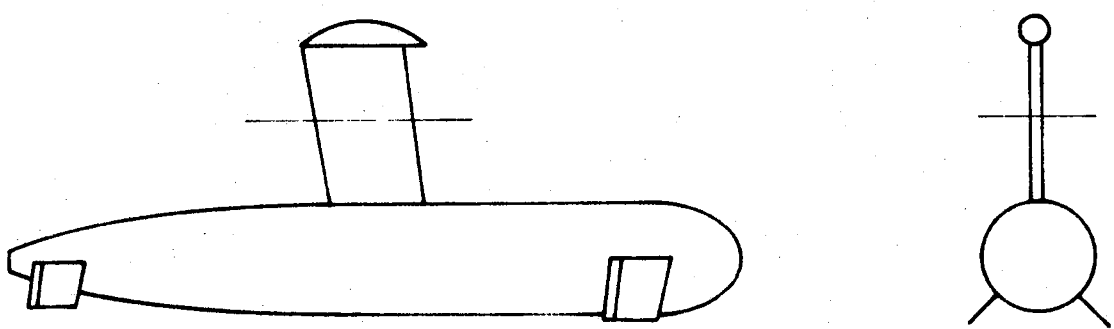


FIG. 22

THE SINGLE HULL SEMISUBMERSIBLE SHIPS



THE SHARK FORM



THE NEAR SURFACE SUBMERSIBLE SHIP.

FIG. 22.

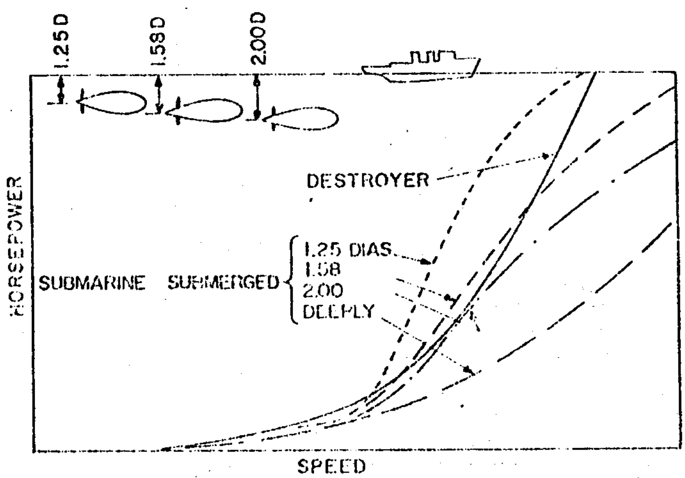


FIG. 23.

HULL RESISTANCE OF THE SEMI - SUBMARINE

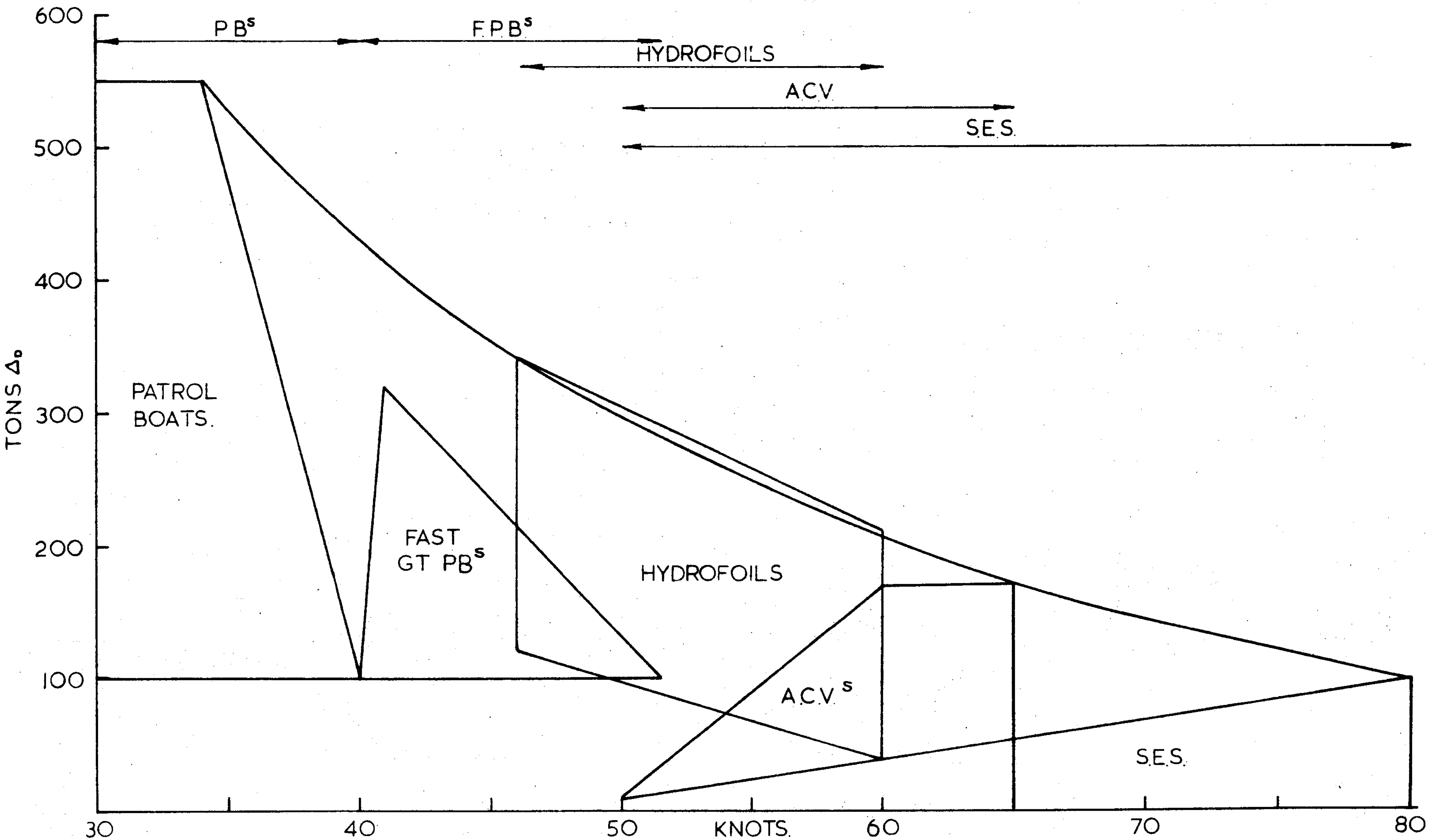


FIG 24 DYNAMIC SUPPORTED CRAFT — STATE OF THE ART.

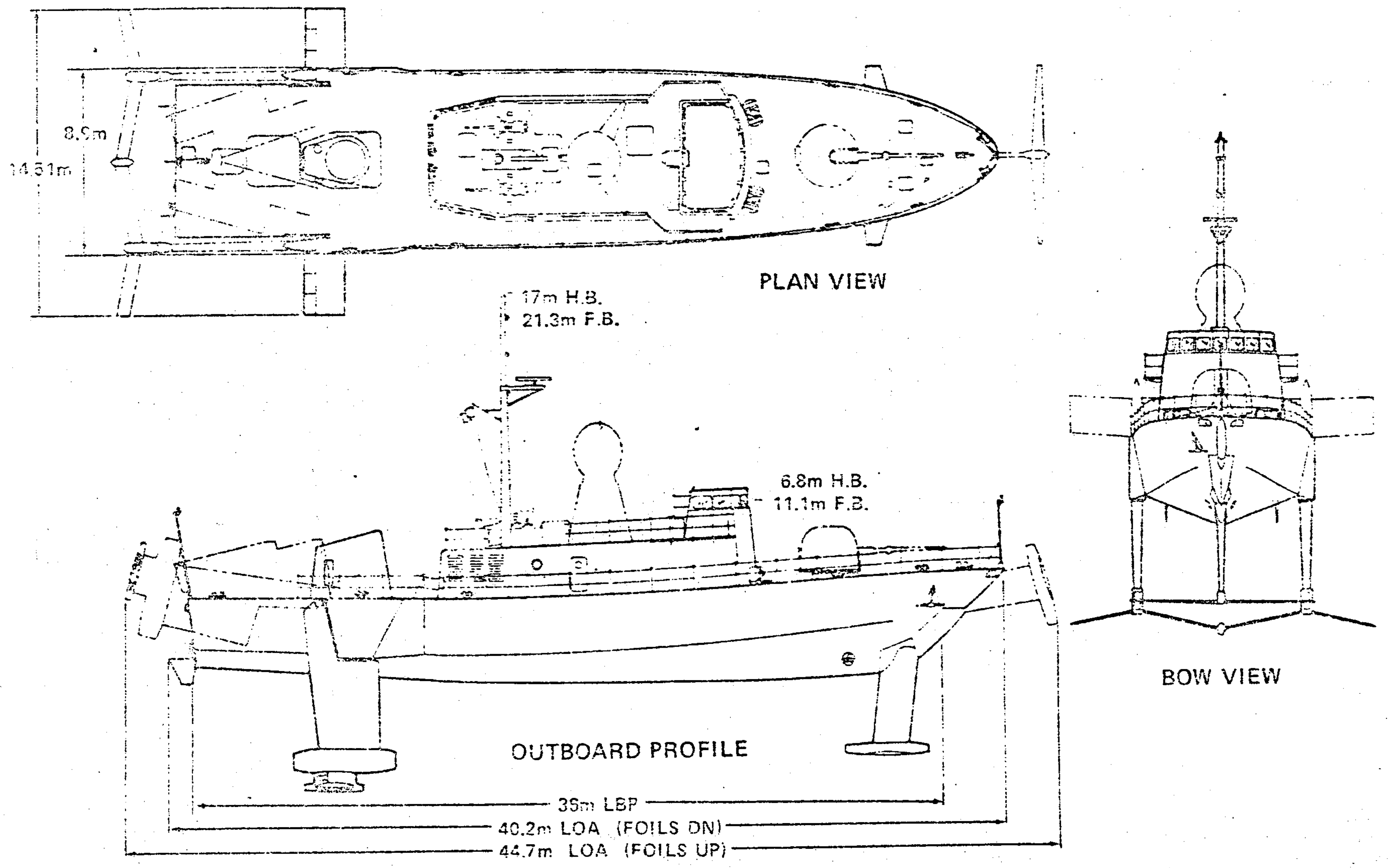


FIG 25

NATO PHM BY BOEING

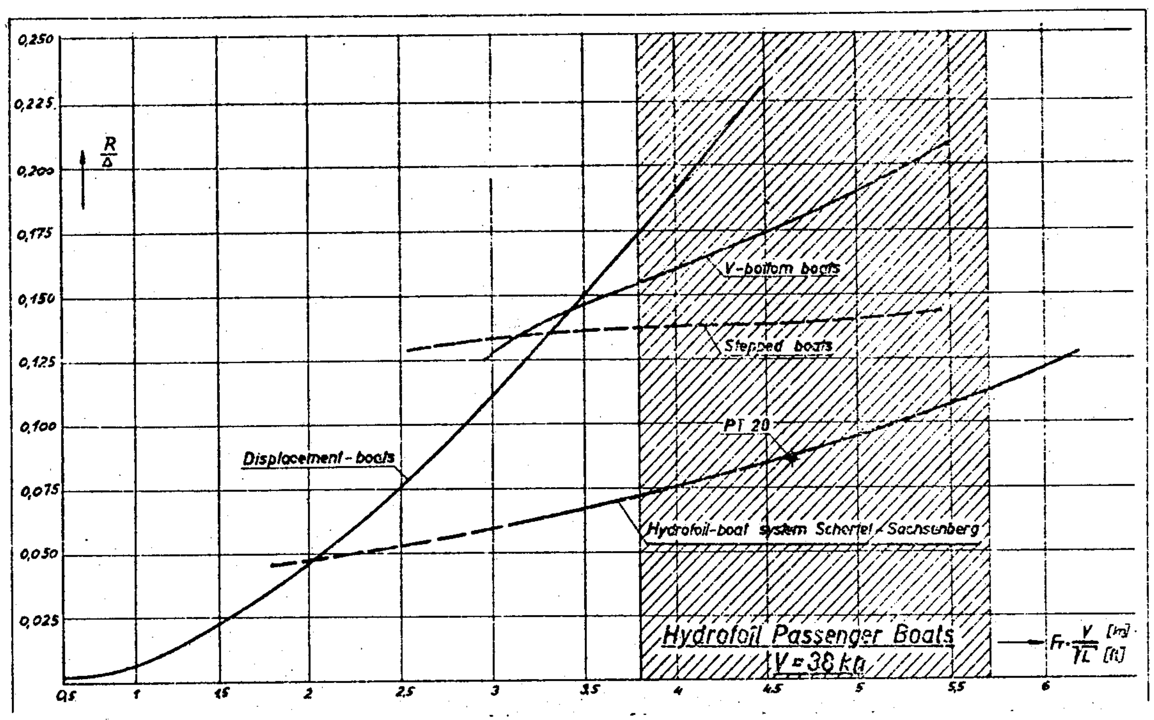


FIG. 26.

RESISTANCE — DISPLACEMENT RATIO COMPARISON OF THREE TYPES OF VESSELS

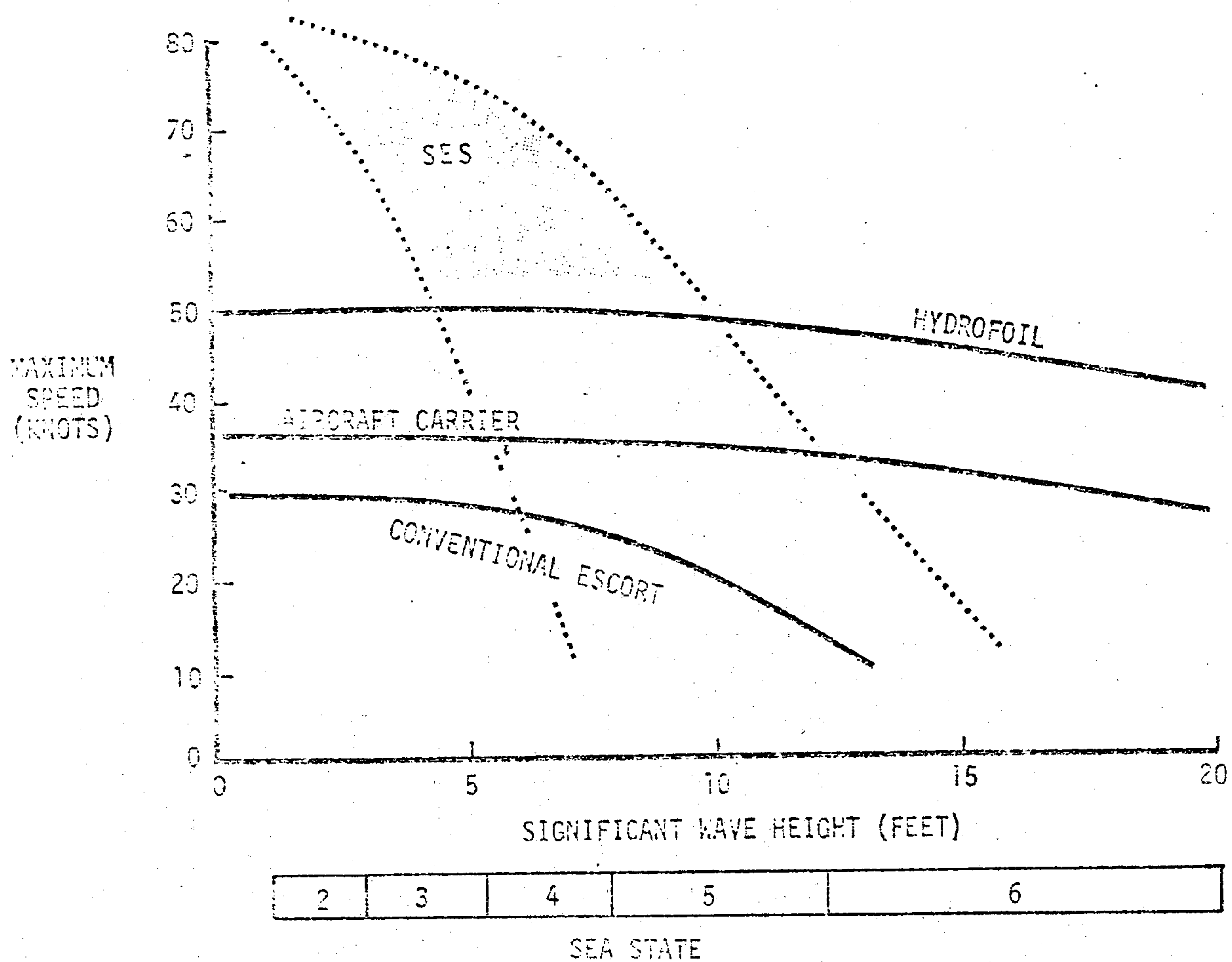
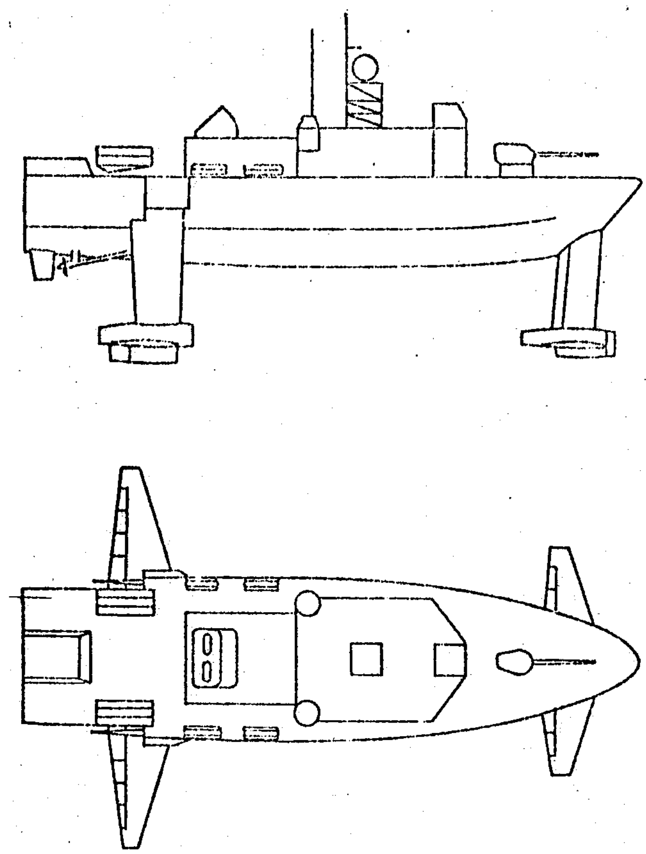


FIG 27.

HYDROFOIL SPEED PERFORMANCE IN WAVES



REQUIREMENTS

Payload ....80-160 Tons
Endurance (foilborne) ....75 hours minimum at 25 KTS or greater
Maximum Foilborne Speed ....40 KTS or greater
Gross Weight ....less than 1500 Tons
Sea State ... .5 minimum

FIG. 28.

HYDROFOIL SHIP & REQUIREMENTS.

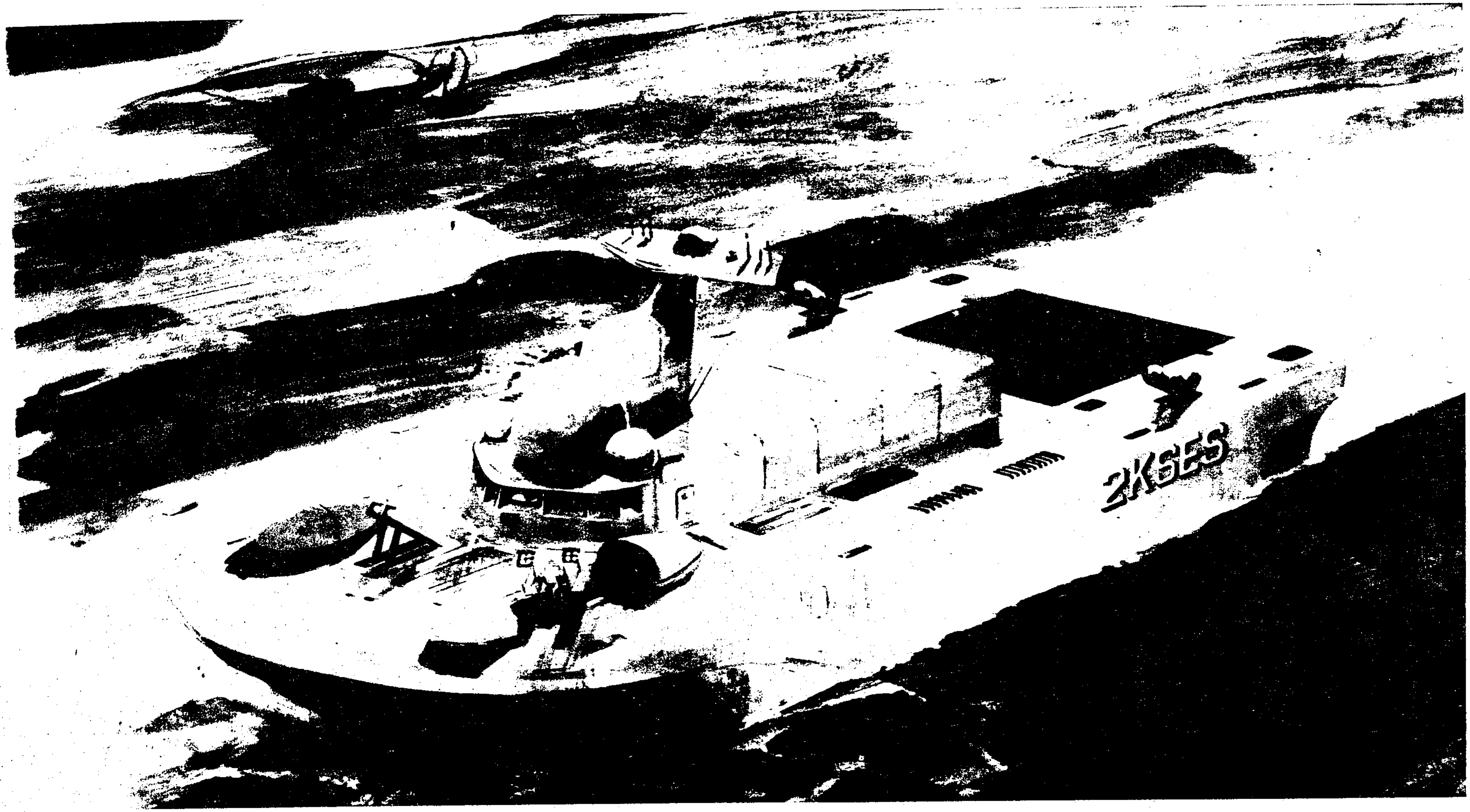


FIG 29

2000 TON S.E.S. CONCEPT.

ESTIMATED PERFORMANCE	JEFF A & JEFF B
Design speed at full load (sea state 2)	50 KTS
Range at design speed (sea state 2)	200 NM
Range at no load (max.)	300 NM
Craft speed on two engines (no load)	5 KTS
Endurance on two engines	12 HRS
On-cushion operational sea state limit	4
Surf height	8 FT
Survival sea state	5

PHYSICAL SPECIFICATIONS	JEFF A	JEFF B
Length overall	99 FT	88 FT
Height Maximum	23 FT	23 FT
Beam overall	48 FT	47 FT
Cushion Height	5 FT	5 FT
Cushion Pressure	93 PSF	101 PSF
Draft (off cushion)	3 FT	3 FT
Engines (ca 2800 HP)	6	6
Propulsors: Shrouded Props	4	2
Bow Thrusters	None	2
Centrifugal Lift Fans	8	4
Total Weight	332,900 lbs	323,146 lbs
Hull and machinery	171,700 lbs	163,066 lbs
Fuel	40,000 lbs	38,900 lbs
Payload	120,000 lbs	120,000 lbs
Crew and stores	1,200 lbs	1,280 lbs
Crew	5	6
Bow and Stern Ramps	Yes	Yes

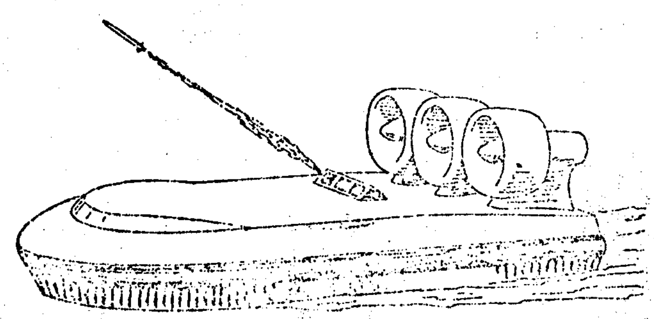
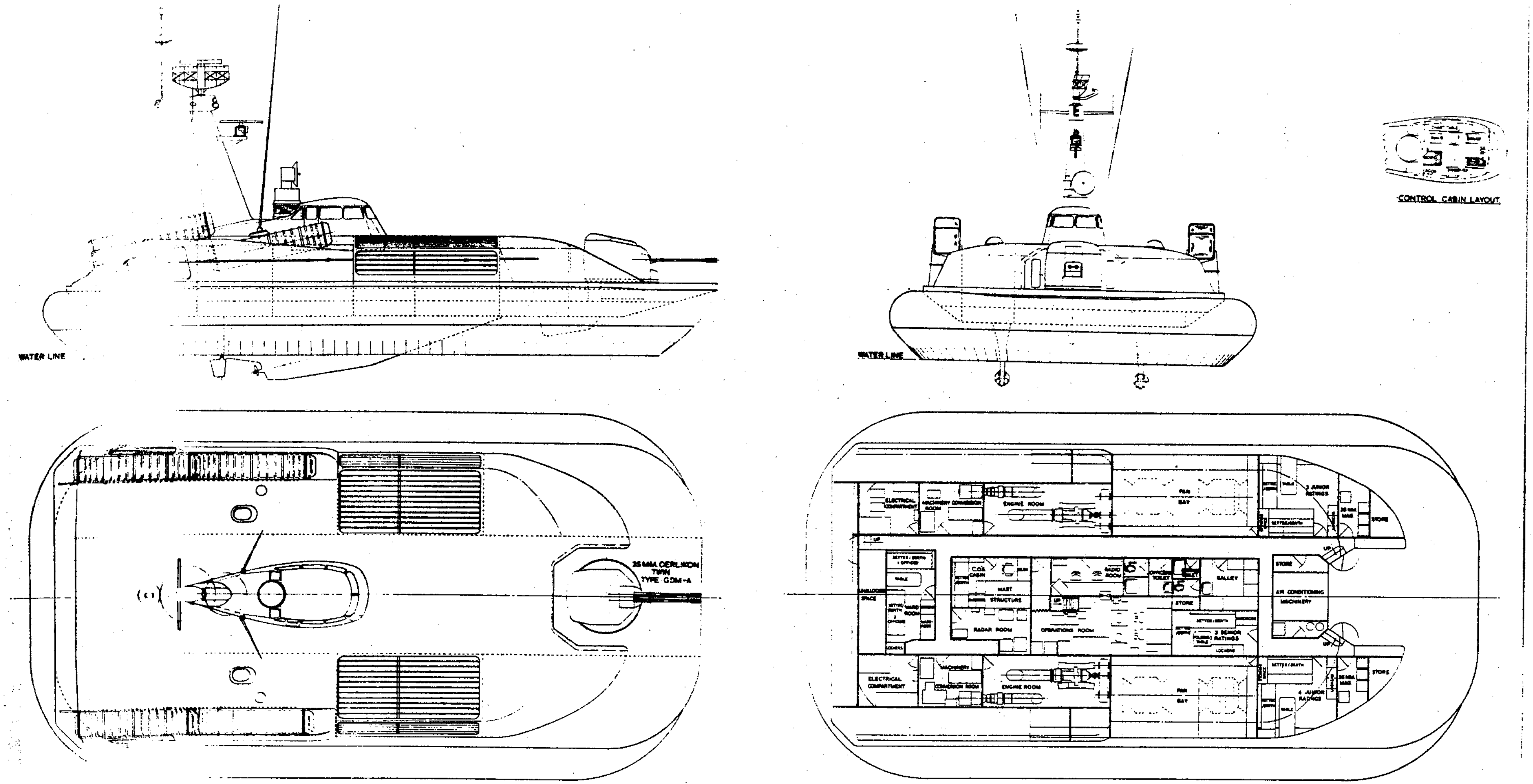


FIG 30

TABLE OF CHARACTERISTICS FOR JEFF A & JEFF B & ACV FUTURE CONCEPTS.



DIMENSIONS
Length overall. 28·05m ($93\frac{1}{2}$ft)
Breadth (hard structure), 13·25m ($43\frac{1}{2}$ft)
Draft hovering 1·07m ($3\frac{1}{2}$ft)
Draft floating, 3·05m (10ft)

WEIGHTS
Basic weight, 66 tons
Armament and crew, 24 tons
Fuel, 20 tons
Total : 100 tons
(in half fuel conditions)

FIG. 31
VOSPER V.T.I. ACV.

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THE ROYAL INSTITUTION OF NAVAL ARCHITECTS
AUSTRALIAN BRANCH

DISCUSSION AND AUTHOR'S REPLY FOR PAPER

"WARSHIP DESIGN IN THE ROYAL AUSTRALIAN NAVY-
SOME DESIGN ASPECTS AND A LOOK TO THE FUTURE".

COMMANDER N. BERLYN

I was very interested in the jetpump concept mentioned in your paper. Of particular interest was its poor reversing properties. Everytime one lands at Canberra Airport in a DC9 one can not help but notice how effective this type of aircraft and others can reverse its thrust to slow down its forward speed. Is there no similar devices available for use on warships.

CAPTAIN H. DALRYMPLE

I noticed in your paper that you did not mention the aspect of cost with regard to warship survivability. I would like therefore to raise the question of cost. Of all the demanding requirements normally presented to the warship designer I think there is great difficulty in putting a cost to these requirements and equating them to some form of effectiveness. Firstly, the operators want the best they can get and secondly the designer tries to give the best he can provide.

I wonder if you might say a few words with regard to the scope for investigating the effectiveness of say shock, noise and NBCD requirements and how the designer should take account of it.

MR. C.C. HERBERT

This paper gives an extremely interesting resume of a number of advanced comcepts currently under development throughout the world which might provide alternative solutions to the naval designers primary task in meeting certain given ship requirements. The title of the paper, however, relates to warship design in Australia and it is a little disappointing to find little reference to the real life Australian environment in which an Australian warship designer must operate.

It is no longer sufficient for a designer simply to meet his primary object of designing a ship to meet certain given requirements, although life would be much more straight forward if one could operate purely in this way. The slide shows an unusual successful instance of a marine weapons system which was designed in this ideal environment, where a definite task was given to the designer, the solution offered and accepted, the ship built and the enemy successfully engaged. This instance occurred in 1862 and perhaps has never been repeated.

Today, a designer must take into account not only the nominal requirements with which he is presented but also the industrial background within which his design must be realised, the existing and prospective financial climate and the political atmosphere which could lead to a certain type of ship being acceptable or unacceptable. He must be not only a designer, but an industrialist, an economist and a politician as well.

These considerations must affect not only his approach to the design, but the design itself, and they are particularly important to a warship designer attempting to operate in Australia. The total industrial background necessary to support a warship in allits aspects simply doesnot exist in Australia, although there are areas of strength, and the designer must accept a high foreign content in his ship or else severely curtail his design options. He must if he opts for foreign content, make improtant decisions as to whether he will limit himself to one foreign provider or shop around the market places of the world. This in itself is an enormous and complex problem, but one which the designer must bear in mind from the outset of his design.

The potential for developing forward looking concepts in Australia is limited, and while the designer must decide that a pumpjet propelled semi-submersible would provide the ideal solution to his problems, he can only tie his design to such concepts if he is assured that the technical and financial backing which is necessary for their development to be brought to a successful conclusion will be available in Australia.

This is not to say that Australian design should be confined to second rate ships, on the contary, a ship meeting the various requirements outlined could be a very good ship indeed, stripped alike of the deadwood of entrenched convention and the complexities of fasionable technology.

../2

The protracted nature of all operations in the administrative, procurement and construction areas in Australia are another fact of life which must affect the designers approach; he might consider for example that all the considerations in his design were subordinate to its being realisable within the life of a single government.

Most of those here will be deeply aware of the problems mentioned and of many similar ones. Australian design of warships is a non-starter unless these problems are squarely stated and tackled. I believe that all of those who have been concerned with ship design in Australia would be extremely interested in any observations the author might be able to make on this practical aspect of warship design in Australia, and the way in which the designer can best ensure that his ship will win its first, most dangerous battle - the struggle to be built.

COMMANDER J. BEWS

I was very interested in Mr. Robson's paper, but I was a bit disappointed in the disregard of the submarine as a possible future trend for more warship applicatons. I would like to bring to the notice of Mr. Robson that the likely trends mentioned in his paper can all be met by the submarine. Can I have some comments by the author on this aspect.

MR. D. PICKETT

I have read with interest your comments on new concepts and technologies in the paper and I have noticed that there had been no contribution to this knowledge by Australia and you have stressed the point of Australian dependence on overseas technology. This type of information is very expensive, given the funds, what line of ship research would you suggest could best develop the design potential of Australian ships.

Also in your paper, you mention that there is no information available on ocean wave spectra in Australian waters. How can one design a warship for Australian waters without this information.

MR. J. SIMMONS

These days, everything seems to be equated to cost whether it be for a merchant ship or a warship. In your paper you stated that displacement can be related directly to cost and I find this some what confusing. With all ships, if we decide to make it a bit bigger, someone comes along and decides to fill that space with a new system or an extra piece of equipment which of course must increase the cost of the ship so it is not the size that demands a higher cost but the extra equipment put into it. If the designer can resist the urge to put more into the extra space we could get cheaper ships. If the designer could say to the operator, no, you can not have this or that. The only way this can be kept under control is for the ship designer to think cost as the most important feature of his design. The designer must cost the ship as he goes. Would the author agree to this.

REPLY TO COMMANDER BERLYN

The reversing thrust of the pumpjet is poor compared to that of a conventional propeller and is due partly to the low reversing speed of the impeller normally associated with the pumpjet. However if the pumpjet looks to be the way ahead as a propulsor because of its limited noise, other devices may have to be provided to assist in the stopping and reversing manoeuvres. Such devices as parachutes, flaps and bow jets have been tried on large merchant ships for the purpose of slowing the ship to an eventual stop. Maybe these devices will have to be used in warships as well as auxilliary reverse thrusters.

REPLY TO CAPTAIN DALRYMPLE

I agree that cost in a warship is a very important factor which must be considered by the designer. The idea of costing each of the warships systems or functions and equating it to effectiveness or proposing merit values is at present being adopted by the U.S.N.

Although recognising the importance of such cost effective studies, I do not have the experience or confidence in the use of such techniques to speak with much authority on the subject. All I can therefore say is that I consider such studies very important to the design of an effective warship and as a ship designer like all other designers in the department of navy we are endeavouring to gain a better understanding of these techniques. Time and experience will therefore tell us how best they can be applied to Australian designed warships.

The subject of warship cost effectivemess studies could therefore be the subject of a future technical paper.

REPLY TO MR. C.C. HERBERT

I must first of all thank Mr. Herbert for his contribution and for giving notice of his comments.

As the title of my paper is "Warship Design in the R.A.N." it was not my intention to discuss warship design in Australia. Although I understand that your firm, Y.A.R.D. (Aust) as well as the Department of Transport have had some experience in the design of warships, I am not in a position to comment upon how warships are designed outside the Department of Navy.

When discussing the conceptual design stage in the first section of the paper I thought I had made it very clear that the warship designer in the Department of Navy is very much involved in the evolution of practical staff requirements and in considering the most feasible and practical means of ship acquisition which takes into account the industrial climate, financial limitations and allother forms of resources. We are however limited in the knowledge of the reasoning processes adopted by politicians.

In these days of specialisation, I believe that it is most unlikely that a designer can hope to be a good industrialist, a good economist and a good politician. However, I believe that a good warship designer must be willing to provide the economist, the industrialist and the politician with good sound accurate information and advice to ensure that the best final decision is reached regarding the operational requirements and warship acquisition.

It is true that Australia is very dependent of foreign equipment and technology for its warships. This problem is not unique to Australia. To a lesser degree we find that the R.C.N. the R.N.N. and even the U.S.N. in some instances fit foreign equipment in their ships. The selection of such equipment being based on its availability, its cost and its effectiveness. With the United Kingdon now forming part of the ECM, I believe we will see more European equipment finding its way into R.N. ships. I agree therefore that foreign content in a warship is a complex problem that needs resolving in the early stages of design.

The potential for developing forward looking concepts in Australia is very limited because of the lack of research facilities. However, this doesnot prevent the Australian warship designer from keeping abreast of overseas developments which allows him to recognise possible applications for these new concepts. Even today in the RAN we can foresee that new concepts may be necessary to meet some of our future needs.

The warships struggle to be built is of course important to all warship designers. Foreign and defence policy matters are not decided by the designer, therefore he has very little control over them. However, once these policies are established and the scenarios or combat situations are decided upon, it is up to the designer to ensure that the operations researchers etc who determine if ships are the best means of combating the proposed threats, are provided with the best available design information with which they can carry out realistic studies. Providing the scenarios or threats do not change during the ship design period, I believe that these studies are the foundation on which the warship's survival is assured.

REPLY TO COMMANDER BEWS

For the purpose of keeping the paper to a reasonable size, those design aspects associated with deeply submerged submarines were not covered. This point was mentioned in the introduction to the paper.

I do however agree that most of the requirements & trends suggested in the paper could be adequately met by the submarine. I therefore believe that the future of the submarine as a naval combat vessel is assured.

REPLY TO MR. D. PICKETT

I believe that research funds, if made available in Australia should be best spent on research that was not being conducted by other countries. This would enable Australia to contribute to the Western World's pool of knowledge and enable a more ready access to this pool of knowledge by becoming a worthwhile contributer. Of course all kinds of ship design, operation etc development work would still need to be conducted in Australia.

It is true that there is almost no information available on sea spectra for Australian waters. This does not prevent us from designing ships. Australian ships were designed long before the theory of superposition and statistical analysis were introducted into ship design. These days, it is of course desirable that such information is available as it enables the designer to use another tool for design. Until such data is available however, it is the practice of the department of navy to use sea spectra which has been developed for the North Atlantic waters.

REPLY TO MR. J. SIMMONS

I agree that the ship designer must always be concious of cost, but he must also be aware of effectivemess. It is my view that one can not be considered without the other.

RESPONSE TO MR. HERBERT BY MR. J. MAYSON

There is a system in being whereby the ship designers, the producers and the financiers can get together and woek out a plan to determine the feasibility of the design from aspects of production and cost etc.

RESPONSE BY MR. R. BYWATER TO MR. HERBERT & CAPTAIN ROURKE

Regarding the comments made by Mr. Herbert on the problems facing the Australian designers, I do not think that this situation is unique to Australia, We have only got to note what has gone on in the world during the last decade or so and we can see the high degree of procrastination that has taken place in the U.S.A. Canada and the U.K. with regard to warship design and production. In Canada, if we go back to the early 1960s we see that early attempts to acquire a destroyer were thwarted, and only just recently they have acquired the DDH 280.

Even back as far as 1964, I can recall reading about the USN DDX programme. The prototype for this class is still two years away from completion. This makes a total of 8 years in all. God knows how long the MOD (N) have been talking about building Through Deck Cruisers.

Sure, we find that the previous Australian Goverment has procrastinated with the DDL, but the present government rather than cancelling destroyers for the R.A.N. have stated that destroyers in some form or other are still required.

Regarding a couple of points raised by Captain Rourke on whether Australia can afford the time and cost to design a ship in Australia. I think the reply made by Mr. Robson concerning government policy regarding its intention to take the seemingly easy way out and to buy from overseas or to look further into the future and to build up expertise in this country is very valid. There is some mention in the press of the government considering the purchase of the USN Patrol Frigate, if this happened, where does it leave Australia in the time of need and in the time of national emergency.

Regarding actual ship cost, I defy anyone here tonight to prove to me that it would take all that much longer or cost all that much more to design and build a warship in Australia compared to having it designed and built overseas. I believe we are an emerging nation in lots of ways and of course we are emerging in the field of warship design and given the chance we can design a ship to meet the needs of the R.A.N.

At the completion of these discussions a vote of thanks was given by Mr. R. Bywater (visitor) to Mr. Robson for his presentation of an most interesting paper.

WRITTEN DISCUSSION BY CAPTAIN W.J. ROURKE RAN (FELLOW)

1. In attempting a paper that covers the whole range of warship design problems, Mr. Robson has taken on a very large task. Given the scope of the paper. and problems of disclousure of classified information, I believe Mr. Robson has covered the subject well.

2. My aim in discussion is to enter a few demurrers on some particular specific points - scattered fairly widely - and to offer a few more connected comments on the place of cost in warship design.

3. Out of the vast scope of the paper let me select a few points for discussion. The author states (p13) for future warships the need for noise suppression will increase. This seems to assume that noise will become increasingly important as a means of detecting warships. I suggest that this is not necessarily so, that aerial surveillance may become more important, and that the importance of noise suppression might decline. The principal objective of noise suppression may well become the improvement of habitability.

4. On page 23 the author refers to shock testing and says 'short of testing the first of class to destruction it is difficult to predict the full environment shock levels!.... There appears to be some inference here that testing to destruction is not practicable. This would not be a correct inference as testing to failure of first of class is a common practice in the US Navy. It does not serve to predict shock levels of course, but does help, for given shock levels, to predict the outcome, and to allow for an empirical modification to design.

5. There are a few other minor matters that I would like to give a different emphasis to:

a. The author refers to the possible effects of biological warfare on ship design (p26). It is suggested that a ship is an inferior target for biological warfare compared to say a city, and that ship designers can therefore ignore the problem.

b. On page 41 the author talks of placing ru. .ers in the propeller race. There is a potential pitfall here as if controllable pitch propellers are used, and set to zero pitch, the rudders will be effectively screened from any flow. In ships with CP props the rudders should be set out of the line of the propellers.

c. On page 42 the author notes that he is actively engaged in the definition of acceleration and displacement limits for weapons, sensors, and crew fatigue. While not wishing to decry the importance of such matters, it is felt that their specification by the RAN is duly esoteric, as it is doubted whether we are in a position to design to limits such as these. They tend to be derived factors other than controlling factors.

d. On page 43 a limiting probability of deck immersion is stated. This presumably must require some postulated sea state and ship speed; these seem to be omitted from the paper.

e. On page 44 the author commends magazines below the waterline, as this enables rapid flooding. I suggest this advantage is illusory and that wherever the magazine is, the use of firemain pressure will normally be the quickest means of flooding. Firemains these days have a pressure of 100 psi or more; the draft of a destroyer provides only about 8-10psi by flooding. Magazines low down are of course less susceptible to damage.

f. I am puzzled at the helicopter that can land in a breadth equal to the rotor diameter (p46). I a preciate that this is probably a matter of termology - but perhaps a significant one. It is not the space the wheels come to rest on that matters, but the clear space in which to fly.

g. The final section of the paper deals with warships of the future. It deals with many interesting concepts including the modular approach that is so appealing to one faced with the very long lead time of warship procurement. However some of the failure possibilities are not new. Mr. Robson refers to the semi-submarine, or near surface submersible, illustrated in Figure 22. Back in the eighteen eighties sime-submarines were built in the Great Lakes, as grain carriers, with the specific purpose of profiting from the lack of wave making resistence. These 'whale backs' as they were known ran commercially for many years but were abandoned because of operating difficulties.

6. Having delivered myself of a number of disconnected comments I would now like to discuss the matter of cost in design - and design to cost. My current posting is that of Project Director, New Destroyers and I am very conscious indeed of the signifiance of cost in warship design. I was glad to see Mr. Robson emphasize its improtance, but I don't think he emphasized it quite enough. Let me state some basic precepts.

- defence is only one of many aims of public spending, and must compete for scarce dollars.
- it is necessary for designers to show they can offer a least cost solution for a particular defence objective.
- it is necessary to ensure that the estimated cost of a proposal will not be exceeded.

7. There will be a tendency to say that this is stating the obvious; but it is suggested the actual practice is still some way short of the ideal. Let me try and demonstrate this by a few rhetorical questions.

- how do we attain a least cost solution? Specifically what is the rate of exchange between crew numbers and capital cost?
- alternatively, what premium should we place on an added 5% availability?

These questions bear on our ability to offer a least cost solution and we need to be able to answer them. Let us go on to the matter of holding to the estimated cost. Here I would like to ask:-

- How do we ensure that the system specified can be purchased within the budgeted cost?
- If the actual cost proves higher than the budgeted cost, who would be responsible for the error?

I suggest that we currently cannot answer these questions too well.

8. Let me refer to a partciular comment on costs by Mr. Robson. He says (p43) 'Due to the increasing acquisition and running costs of warhips and the ever diminishing funds, warships of the future will no doubt be smaller in size than those presently in service'. May I transpose the comment to refer to other types of ships. 'Due to increasing acquisition and running costs - and ever diminishing funds - tankers of the future will no doubt have to be larger still'. What I am trying to illiminate is that the test of cost-effectiveness, or value for money, or profitability, does not necessarily mean that the ship must get smaller. In the case of the tanker it is the reverse, and we need to go more deeply into the matter before we can determine just how the optimum warship is likely to vary from its predecessor.

9. Whatever the product of the design optimisation turns out to be I believe the principle will hold that cost is a most important parameter, and that designers will be required to design to a cost. I would like to emphasize that this does not in any way imply a sacrifice of military objectives. Good design should mazimise the attainment of military objectives for a given expenditure. What the process should involve is a conceptual match of what is needed, and what resources can be assigned, that results in accaptance by designers of a contract to meet the need within the agreed cost.

10. Finally I would again like to commend Mr. Robson for undertaking a task of such magnitude as the preparation of this paper, and for presenting it so ably.

November 73. <u>W.J. ROURKE</u>

<u>REPLY TO WRITTEN DISCUSSION BY CAPTAIN W. ROURKE RAN.</u>

Due to the great number of isolated points raised by Captain Rourke, my reply will therefore be made covering these points in the order in which they were raised.

On the subject of noise suppression and its importance in the future, I still believe that it will remain a dominating factor in submarine hunting. In particular as a means of the submarine detecting the surface warship. Aerial surveillance will be of some benefit to the surface warship while detecting a submarine, but it can not help the submarine for its surveillance. Even considering the importance in reducing the detection and acquisition range for homing torpedoes and acoustic mines against surface warships, this aspect alone could make it highly desirable to have quieter ships in the future. I therefore must disagree with Captain Rourke's suggestion that the importance of noise suppression might decline in the future.

On shock testing, I am very suprised to learn from Captain Rourke that it is the current practice of the USN to shock test the first of its ship class to destruction. They must be the only Western Navy that does this. I just can not imagine the USN being willing to test to destructinn say the first of the Spruence class or a CVA

Captain Rourke may be getting confused with shock hardening trials normally conducted on USN and RN ships. These trails only serve to indicate nuisance problems associated with ships minor equipments. The trials only consist of setting off a rather minor charge under ship which in no way represents the full environmental levels referred to in my paper.

I can not say that I inferred that the ship designer should ignore the problem of biological warfare. What I did say however is that if the biological threat increases "Surface warships as we know them today may have to undergo considerable change".

The idea of keeping the rudders out of the C.P. propeller race because of screening effects when the propeller is at zero pitch is difficult to accept. It is difficult to accept when one considers that the c.p. propeller will only operate at zero pitch for a very short period of time when the blades are in the transient mode. If for reasons required for a crash stop the propeller blades will be quickly changed from ahead to an astern pitch and even in this astern condition, the rudders if placed in the race of the propeller will be more effective when stopping and going astern.

The seakeeping studies referred to in the paper are being developed with the idea of giving the naval staff and the ship designers their first idea of just how fast and up to what seastates certain classes of ships can be driven without having any detremental effect on their operational performance. It is to ensure that one does not try to place a magnificent piece of weaponry on a ship that is too small to enable the crew to operate it to its full potential because of adverse ship motions.

The postulated seastates and speeds are specified by the operators or naval staff in their requirements. It is therefore up to the ship designersto ensure that unacceptable deck accelerations or deck wetness does not occur at seastates and speeds below the specified levels.

I do not believe that the advantage of having the magazine below the waterline is illusionary. It is agreed that the pressure available in the firemain will be higher than that of the static head of the water for free flooding. However with the firemain, the quantity of water that can be supplied is dependant on the size of the available pumps and their other demands. Quick free flooding can be provided in a warship by having at least four large 12" dia flooding valves. It is considered that this arrangement will be superior to the spray system run off the firemain. It also leaves the firemain available for a more important task of fighting fires and cooling electronic equipment.

The minimum requirement of one rotor dia for the landing area on a ship for a helecopter is to ensure a uniform lift over the entire rotor udring the very sensitive process of landing on the ship.

Regarding the aspects of ship cost and effectiveness, these are important factors to the designer and my comments to Captain Dalrymple apply to Captain Rourke's discussion. I must emphasis however that expertise in these matters as well as all other design aspects only comes with experience and practice. If the Australian designer is to become or is expected to become experts in such fields it is up to the government to state its policy on ship design and building in Australia. If it is decided that a viable shipbuilding industry is desirable for Australia it must be willing to support the industry until such expertise is acquired and the industry can stand on its own two feet.