THE ROYAL INSTITUTION OF NAVAL ARCHITECTS

AUSTRALIAN BRANCH

TECHNICAL PAPER

TRENDS IN WARSHIP DESIGN

BY K.H.W. THOMAS O.B.E. R.C.N.C. F.R.I.N.A.

PRESENTED BEFORE THE INSTITUTE ON 21 JULY 1971

TRENDS IN WARSHIP DESIGN

BY

K.H.W. THOMAS, OBE, RCNC, FRINA

1. The history of warship development through the ages is a fascinating one encompassing many far reaching and sometimes dramatic changes. The temptation was strong to start with the wooden walls and trace developments through to the present day. This has been resisted for two reasons:

a. The need to restrict the length of this paper.

b. The fact that many eminent authorities have covered much of the ground before and the transactions of the Institution contain many papers on this subject.

1.2 The end of World War II has therefore been taken as the starting point from which trends will be traced through to the present day. An additional reason for selecting this starting point is that World War II led to the development of a new type of Naval warfare based on the use of the aircraft carrier and marked the end, very clearly, of an era in warship design culminating with the phasing out of the battle ship. At the same time it marked equally clearly the beginning of an era of rapid technological development and change which has had a profound effect on warship design.

1.3 The past 25 years have seen the advent of some of the most far reaching developments affecting warship design, more so than at any other time in their history. In the past, there have been dramatic single instances such as the change from the use of wood to steel for hulls, sail to steam for propuslion, armoured ships and turret guns, use of oil instead of coal and the introduction of steam turbines, but these almost all occurred as consecutive steps. In the 25 years I shall be dealing with, we have had the almost simultaneous advent of nuclear power, guided missiles, gas turbines, computers, rapid developments in radars, sonars and electronics generally as well as other less spectacular advances in many branches of technology. Certainly nothing in the past has ever matched this and it is difficult to see that any country will be able to afford to continue with this rate of development in the future.

/2...

1.4 This paper has been kept broad deliberately and not confined to the warships or equipments of any one Navy. One of the main reasons for this is to give greater scope for illustrating the points being made. Furthermore, it deals only with trends in new construction and not with any developments linked to modernisations and conversions which are often borne of the economic necessity of not disposing of perfectly sound hulls and which do not truly reflect general trends. Since information regarding USN, RN and RAN warships is more readily available than for those of other Navies, it follows that discussion, in the main, will relate to USN, RN and RAN warship development.

2. <u>Factors Influencing Warship Design</u>

2.1 It is first necessary to identify broadly those factors influencing warship design and then consider how these have affected developments over the last 25 years. As in all such exercises, the separate factors are not entirely independent and inevitably there is a degree of mutual influence between them.

2.2 The principle factors are as follows:

a. Strategic and tactical.

b. Economic.

c. Sociological.

d. Technological.

These are not in any order of importance and some, as will be appreciated, have a different, if not bigger, effect than others. It is perhaps worth mentioning another factor of the previous era which however, has not applied to the period under review, but has in its time had important effects, namely treaty obligations. Without commenting on the Naval or political aspects of Naval treaties, there are times when those involved in warship design yearn for the discipline which requirements of Naval treaties imposed. Whilst they doubtlessly added considerably to the problems of the warship designer, nonetheless, in their way, they acted as a brake on the proliferation of ideas which never cease during the development of warship designs.

2.3 Finally, politics have not been included as one of the factors, as it is not seen as having any direct effect on warship designs themselves. It is more likely to affect the numbers and types of warship and this would normally be exerted through the medium of the first factor indicated in para 2.2. Strategy, to some extent, is borne of politics.

/3...

3. Influence of Factors

3.1 Strategic and Tactical

These two factors have been linked together for convenience and are to some extent inter-related. By their nature, they have a profound influence on the types of warship developed on the one hand and the development of the associated weapons systems and equipments on the other.

Discussions on the influence of strategic considerations on the development of warship types could occupy a complete paper in itself, but one or two examples must suffice for the purpose of this paper. Since the end of World War II, we have seen a number of new types, or classes, of warship introduced into service as a result of strategic considerations by the nations concerned. This is an inevitable consequence of the development of new strategic concepts which followed in the wake of the conclusion of World War II and the struggle for balance of power.

The USN has provided perhaps the most dramatic example with the introduction of its nuclear propelled ballistic missile firing submarine which incidentally is the nearest approach of any warship design so far to a complete weapons system. At the same time the development of these submarines illustrates the point made earlier of the inter-relationship of the various factors. Without the development of the appropriate technology it would not have been possible to design and produce these submarines with their weapons systems to meet the strategic requirement. To some extent, one would be justified in questioning whether the strategy came first or the technology. Equally, the considerations of global strategy have inevitably lead to similar developments by the USSR and France with indications that China are following suit.

Similarly, but perhaps in a slightly less spectacular way, the USN developed its large nuclear aircraft carriers to meet strategic requirements. On the other hand, in direct contrast, the RN is phasing out its aircraft carriers for strategic and economical reasons. It is probably in the RN that the effects of change of strategic requirements has been most marked over the last 25 years and has involved a complete re-thinking of requirements. In step with the USN and for the same strategic reasons, the RN has introduced and developed nuclear propelled ballistic missile firing submarines.

/4...

Among the other new types of ships introduced by the RN reflecting the change dictated by a strategic requirements are the development of the Landing Ship Docks, INTREPID and FEARLESS which were introduced to enable amphibious forces to be deployed rapidly to deal with localised conflicts. This particular type of ship is not a new concept having been previously introduced by the USN during World War II, but the requirement and the manner of its intended use is new to the RN.

Probably as equally striking as developments in the USN are those in the Soviet Navy, although, of course, information about their developments is very limited. Apart from the nuclear propelled ballistic missile firing submarines, one of their most novel latest types, again obviously dictated by strategic requirements, are their helicopter carriers MOSKVA and LENINGRAD. Here again this is not an entirely new type of ship, bearing some resemblance to the early type of aircraft carriers, but it is certainly a new concept for the USSR. Other Navies have also introduced some form of helicopter carrier either by adapting existing ships as in the case of the RN Tiger Class or by new design as in the case of the USN and the Italian Navy.

3.2 The question of whether Tactical requirements have stimulated technological developments, or vice versa, can lead to an even more chicken and egg type of argument than indicated when discussing strategic considerations. There is no doubt at all that Naval tactics themselves have been developed and changed as a result of technological advances, but in their own way tactical considerations have stimulated the development and use of new equipments and weapons. This particular argument will not be developed further at this stage since many of the relevant points will emerge from the discussion relating to technological developments.

4. <u>Economics</u>

4.1 This is perhaps the most obvious of the factors listed which affects the design of warships, yet, the irony of the matter is that despite the intense economic pressures in nearly all countries, warship costs continue to rise at a remarkable rate. A destroyer escort costs twice as much today as it did in 1950 and will probably cost three times as much in the early 1980's, (Fig 1) and so it no longer appears to be possible to satisfy current naval staff requirements by cheap warships. Some figures published for DEs and DDGs in the US illustrate the trend (Fig 2).

One of the many reasons for this is, of course, the philosophy which must condition a lot of thinking in developing staff requirements, that no price is too high for national security though this has to be tempered with considerations of what a country can afford for defence from its budget. Another reason is the highly sophisticated nature of sensors and weapons systems and their increased complexity to achieve improved offensive potential which adds materially to the costs of building, operation and maintenance. Some aspects of this will be dealt with later in the paper. As a result of cut-backs in Defence spending, efforts have been made over the past 25 years to design and produce relatively cheap warships. This has seldom been successful since warship design is always a matter of compromise. When the cost factor is introduced as a primary parameter, the compromise solution can seldom be a very good one, particularly as regards the effectiveness of the warship. Interesting examples of what results from such exercises are the RN Tribal class frigates, where to keep the size down, the ship was designed with only one shaft and to reduced standards. More recently the RN has commissioned a private firm to design and build a small frigate with the aim of keeping cost down to a minimum mainly by relaxing the stringent Naval requirements and adopting commercial equipments wherever appropriate. The result is the Type 21 frigate currently under construction.

4.2 Inevitably political and economic considerations have made nations far more cost conscious in recent years over their Defence spending and this has led to the introduction of studies of such techniques as through life costing during the development of warship designs to establish the cost effectiveness of variants to satisfy the naval staff requirements. It is interesting to speculate whether such an approach features in the considerations of the USSR Defence spending. The USN however, certainly carry out such studies when developing their warship designs and Mr McNamara, when Secretary for Defence, was largely responsible for their introduction in the USN. Frequently, the application of this analysis often leads to unexpected results which are sometimes difficult to accept by those indoctrinated with traditional approaches. Certainly, it is known that results of some of the studies carried out in the USN were not universally acclaimed. One particular example of the type of ship evolved under this regime has been the KNOX Class of ASW ship. Possibly the most controversial feature has been the fact that it has only one shaft, similar to the RN Tribal Class, but in this case, the ship is 50% bigger. Other than making such a significant change to the propulsion system the only other area where substantial cost savings can be made is in the weapons systems in the ship.

/6...

Whatever one feels about the validity of the results of the application of cost analysis techniques to warship design, it is perhaps a necessary discipline following World War II during which, for obvious reasons, cost was seldom a factor to be considered as a restraint on the design of warships. In particular, the technique has highlighted the need to consider the running costs and refit cost of warships in addition to the initial capital costs. Thus the warship designer is subjected to pressures to produce ships which are easier to maintain and to operate and thus are more cost effective in that a higher operational availability is achieved than hitherto with less time spent tied up alongside the dockyard wall for repairs or refit. The modern warship should therefore be designed to facilitate accessibility or removal of all principal components which are likely to require maintenance or replacement and at the same time equipments or components fitted should have a high degree of reliability. The penalty for this, however, is greater space and weight leading to increased size of ships. On the other hand, ship size can be reduced by installing higher performance and more sophisticated systems with the penalty of reduced reliability and greater training problems. Thus in some USN warships, boiler pressure as high as 1200 psi have been adopted leading to smaller boiler rooms and smaller ships, but with higher crew pay due to higher level of competence required and costs of special training, together with a system more prone to failure. Here again the warship designer must strike a compromise. Wherever possible, to cut down refit time, and costs, the policy of refit by replacement is now being adopted for many major items. To achieve maximum benefit from this provision for ready removal and the replacement of the items involved has to be made during the design. Many of the equipments now coming into service lend themselves particularly to the adoption of such a policy, examples of this are gas turbines and the use of solid state circuits.

5. <u>Sociological</u>

5.1 Perhaps at first sight this is a surprising factor to include, but nonetheless it is a very important one. Its importance can best be summed up by recalling that World War II marked the end of an era when men ran away from home to go to sea. This now no longer happens to any significant extent and the Navies of the free world are being forced to provide conditions of service not only to attract the recruits they require, but to encourage them to remain in the service against the competing attractions of life ashore, as well as avoiding the loss of men who in many cases have been given extensive and expensive training. The traditional 'join the Navy and see the world' approach no longer has the attraction it had. Higher standards of living, more ready cash and modern transport facilities provide means and opportunities to see the world without the commitments of service life.

/7...

5.2 Pay, conditions of service, job satisfaction and status are all factors which have to be kept continuously under review to ensure that service life will continue to attract and retain the men required. The main impact of these on warship design has been in the area of habitability. To some extent many of the improvements which have been and are being introduced follow the lead given in merchant ship design where no dissimilar problems of recruitment are being experienced.

5.3 Generally, up to World War II, sailors slept in hammocks on their mess decks where they also ate. Their recreation was taken either on mess decks or wherever they could find space. Officers generally were better off, but the majority of them had to share multi-berth cabins. Officers and crew could be excused for thinking that the complement was regarded by the ship designer as a necessary evil.

At the end of the last war, the first moves were made to introduce bunk sleeping and with it a better standard of accommodation as far as space allocation for the crew was concerned. Not surprisingly, it was found that the penalty for these improvements was that more space was required than previously. From these beginnings, the current thinking of habitability was evolved. It is, of course, difficult to generalise, but there is much in common with the trends in nearly all Navies. Generally, the policy is to give sailors more privacy together with a high standard of fitting out of accommodation spaces and more stowage space provided for kit. One of the reasons for the latter is that the size of the kit carried has grown due to the need for making provision for sailors civilian clothes for wearing ashore - a facility not afforded to ship's companies prior to World War II.

To make the most effective use of space with bunk sleeping the trend is now to provide sleeping areas separate from living and recreation areas - this also meets the need of ensuring that watchkeepers can get their sleep without fear of being disturbed by others off duty. Meals are taken in separate dining halls with junior ratings or sailors eating in a different dining hall from senior ranks.

The era of the large mess deck with its rather communal life is now passed and modern ships are designed with smaller numbers in mess decks. In the latest warships, Petty Officers are provided with small dormitories and Chief Petty Officers in multi-berth cabins. Separate recreation facilities are provided. Just as at home the television set tends to dominate the recreation area, so too has provision to be made for TV viewing in dining halls or mess decks. Apart from entertainment, TV has the additional benefit of being available for instructional purposes when used with a ships close circuit system.

/8...

5.4 However, improvements to habitability have not stopped there. Over the years more effective and extensive air conditioning has been introduced until modern warships are now fully air conditioned to a high standard in all accommodation spaces and offices. To meet these cooling loads as well as those of operational compartments with their complex electronic equipment, there has been a substantial increase in the number and capacity of air conditioning plants - a further price to pay for improved habitability (Fig 3). Air conditioning can be, however, something of a mixed blessing in a warship. It is more complex than the earlier ventilation systems, but as it is based on the principle of re-circulating the bulk of the air in the compartments served, it lends itself more readily to the requirement for rapid closing down of the ship should it be subject to chemical or biological attack. On the other hand, as has been found on occassions, it can rapidly result in large areas of the ship becoming uninhabitable if fire occurs in an air conditioned compartment accompanied by acrid or toxic smoke which is then re-circulated through other compartments. A balance has therefore to be struck between small numbers of extensive systems which simplify control or large numbers of small systems.

5.5 Increasing attention is being paid to the decor in accommodation spaces and more and more use is being made of plastic and other lining materials for deck heads and ship sides for hiding pipes and cable runs - generally creating a pleasant surroundings in which the crew can live, work and relax. Again, the benefits from this have to be weighed against the problems of damage control when quick access to areas of damage are necessary to ensure the ship can be kept afloat to fulfil its primary function. Equally, many plastics in current use give off dangerous and sometimes toxic fumes in a fire which, as previously explained, can often affect large areas of the ship.

5.6 Thus the improvements to habitability require more and more space and some additional weight. The former poses serious problems in a modern warship and is one of the main reasons for the efforts which continue to be made to reduce the complement. A further factor contributing to the demands for additional space for accommodation is that with more and more complex and sophisticated machinery being built into modern warships, the complement contains a greater proportion of more highly qualified ratings who in turn require more space. Although the trends to improve habitability have led to increased space requirements they have not been a significant factor in increasing the size of warships. The rate of increase in size of warships has outstripped that for accommodation so that over the period under review, the percentage of total ship area necessary for accommodation has decreased (Fig 4).

/9...

5.7 One final factor under this Section. With the growing campaign throughout the world to preserve environment and to fight pollution, Navies have been forced to consider the problems of dispensing of waste of all kinds. The traditional gash chutes and general ditching over the side are becoming things of the past as they are replaced by garbage grinders, can crushers and similar devices. In addition, all modern warships are being designed with sewage plants to dispose of the normal domestic waste. In common with all other improvements they extract a price by way of requirements for additional space and weight. On the other hand, the introduction of sewage plants has some benefit in providing more flexibility to the ship designer for grouping and positioning heads, WC's and bathrooms in the ship.

6. Technological

6.1 The effects of technological developments of warship design over the last 25 years have been so great and cover so many fields that no single paper could possibly do them justice. Of necessity therefore, this review must be very broad and can only cover the major elements.

6.2 Weapons

For obvious security reasons, it is not possible to give very much detail of developments in these fields. As previously discussed, the end of World War II marked the beginning of the transition from guns to guided missiles as the principal armament of warships. This transition has been slow and it has only been over the last half of the period under review that this trend has fully manifested itself. Initially the concept was to use guided missiles as a defence against high-flying, high speed aircraft. With the possibility of aircraft carrying guided missiles, or even nuclear weapons, it was necessary to find a means of attacking an enemy aircraft at greater ranges and with a greater hit probability than the anti-aircraft gun - hence the use of the guided missile. Guns were still retained in warships for anti-ship and bombardment purposes. This stage of development is well illustrated by the USN DDG's and the UK County class. At this stage the development of rocket motors and electronic control systems were such that the payload of the missiles was relatively small. Subsequent developments, particularly with fuels and solid state circuitry have enabled a higher proportion of the weight to be given to explosive charges with greater destructive power and this, in turn, has facilitated the development of anti-ship missiles. The first demonstration of anti-ship missiles was the use of the Russian Styx Missile against the Israeli Ship ELIATH. This incident also served to illustrate in a dramatic manner that craft of patrol boat size can have a substantial fire power - as great as a World War II cruiser - and the FPB is now having a new lease of life as a guided missile carrier.

A number of nations are building this type of craft and relatively small Navies can now have a substantial offensive capability.

As far as the warship designer is concerned the advent of the guided missile introduces many new problems. As far as any comparison can be made, a guided missile system tends to be much lighter than the gun system for the same role, but with the associated guidance and control systems more spaces are occupied in the ship both as regards compartments and the layout of top sides (Fig 5).

The other main problem with guided missiles is that of its interception. Most modern missiles of this type fly at supersonic speeds and even if detected at the extreme horizon range by a ship's sensor system there is less than 2 minutes to deal with the missile itself or possibly the ship from which it is fired (Fig 6). For this reason the tendency is for both offensive and defensive weapon systems to be developed for long range action. A further development adding to the problem of defence of ships is the sea skimming guided missile which can travel at high speeds a few feet above the surface of the sea, making it very difficult to detect and to intercept. Apart from anti-aircraft (or missile) an anti-ship weapons developments have also taken place in the field of anti-submarine weapons. The RAN for example has developed the Ikara (Fig 20) which is a guided rocket propelled missile carrying an anti-submarine weapon which can be dropped in the proximity of a submarine whose position has been established by the ships sonar. The weapon subsequently, homes on the submarine. The USN counterpart of this type of weapon is ASROC. Both of these weapons enable submarines to be attacked at considerably longer ranges than hitherto, a necessary requirement with the development of high speed submarines.

6.3 Sensors

At the beginning of World War II, the primary means of detection of an enemy target was visual with the control of guns by range finders. Ships could also be detected by their radio transmissions, but this could be readily avoided by preserving radio silence when necessary. Subsequently, the detection of a ship by its magnetic and/or pressure signatures was used to operate mines, whilst the noise emission, particularly from propellors, could be used for the detection of surface ships by submarines. Sonar equipment enabled submarines to be located by surface ships though at very limited ranges. The advance of technology particularly in the field of electronics brought with it radar. This rapidly replaced visual detection as more reliable, particularly under adverse weather conditions, though radar suffers the disadvantage that it depends on the transmission of radio waves which enables the transmitting ship to be located by suitable equipment.

/11...

One of the main problems for the warship designer is to find the space necessary for the many radar aerials now required, e.g. navigation, long range warning, weapon control and missile guidance together with aerials and equipment for detection of enemy radar transmissions, and for jamming these and enemy missile guidance beams, all of which are required, ideally to have all round coverage. As technology continues to develop, these radars have become more and more sophisticated, operate at greater powers, aerials are bigger, cooling loads increase and generally they require more space and are heavier.

In addition to the radars, space must also be found for the large numbers of aerials required for communications. Nowadays these cover practically all wave bands both for transmission and reception. This proliferation of communication requirements results from a variety of needs arising from the manner in which warships now operate, the transmission of data between ships, communication with aircraft and possible long distance communication by satellite (Fig 7).

The problems of siting all these aerials is further complicated by the necessity of avoiding interference between the various systems when they are transmitting or receiving. Thus in many warships the situation has been reached where the length of the ship, and to some extent the configuration of the top sides, is determined by the need to achieve optimum location and siting of the forest of aerials. The achievement of an acceptable solution to this problem fully taxes the ingenuity of the warship designer. One form of Upper Deck configuration which has been developed to cater for this aerial forest is the 'MACK' or combined mast and stock favoured by the USN and latterly by the USSR and Germany in their new missile ships.

Taken to the extreme, and as the USN have found, to meet so many conflicting requirements it may be necessary to have a separate ship operating with the fleet, equipped for communication purposes only.

6.4 It is probably true to say that with the developments in microminiaturisation and electronics generally, practically any phenomena or disturbance from the natural state caused by a ship can be detected, amplified and discriminated against normal background level to provide some response to suitable sensors carried by ships, aircraft, (possibly satellites) or sited at shore stations. Not all of these are yet practicable, but noise of all kinds, heat emission, radio and radar transmissions, pressure patterns, magnetic signatures are now utilised for detection of ships, guidance and homing of missiles or for triggering weapons.

/12...

The warship designer therefore has a big part to play in trying to reduce these 'distrubances' as much as possible. As with so many things in life, the law of diminishing return applies and the point is soon reached where the cost and practicability of implementing suitable remedial measures become important and possibly prime considerations.

Equally, the weapons engineer, himself, has a similar role in developing appropriate countermeasures, decoys and jammers which will be effective against enemy weapons systems while at the same time developing suitable weapons which will not be affected by enemy countermeasures - the shell v armour competition which exercised the skill and ingenuity of the technical experts prior to World War II has now been replaced by a far more sophisticated technological battle of wits as weapons systems are developed to outwit enemy countermeasures which are constantly being developed against weapons systems.

6.5 The heart of the complex of sensor systems in a warship is the Action Information Organisation centered around the Operations Room. Here all the information from the ships sensors is collected and processed for presentation to the Command. From this the decisions are made concerning appropriate offensive or countermeasure action. With so many and increasingly effective sensors the Command can soon be saturated by the amount of data with which it is presented and the human mind is unable to deal with it all in a rational manner (Fig 8). Moreover, as has been shown already, the reaction time necessary for effective action or counteraction is likely to be seldom more than one or two minutes. Assimilation of all relevant data and decision making cannot be achieved within this time scale with a normal Operations Room where the raw data is processed on manual plots by a staff of officers and ratings. It is here that the computer comes into its own. By the use of computers the data from all sensors can be analysed, targets identified and the appropriate countermeasures solution established and advised to the command in a matter of seconds. If necessary, the computer can be programmed to operate the appropriate Weapons System so that an enemy plane or missile can be detected and engaged almost before men can be roused from their bunks! In addition, the computer can be programmed not only to work out the most effective counteraction, taking account of all the Weapons Systems, their state of readiness and availability of ammunition, but can also advise the command of alternative actions in order of effectiveness. This all sounds rather like the science fiction of not so long ago, but there have been warships operating with such systems for some time, e.g. in the RN the aircraft carrier EAGLE was fitted with ADA (Action Data Automation) when modernised in 1964.

With the advances now being made in computer design and solid state circuitry, the potentialities of these automated systems cannot yet be fully realised because of the lag in the developments with sensor systems. Thus modern computers could handle much higher data rates than can at present be achieved by modern radars.

6.6 Propulsion Machinery

There have been two major developments in the field of propulsion machinery for warships during the past 25 years.

a. Nuclear Power

b. Gas Turbines.

There has also, of course, been developments with conventional boilers and steam turbines as well as with diesel engines and fuels but these have not had such a marked effect in the field of warship design as the introduction of nuclear power or gas turbines.

6.7 Nuclear Power

Nuclear Power has found its main applications in warships in the field of submarines where its prime advantage is the ability it affords the designer to develop submarines with high underwater speeds and long submerged endurance. The use of nuclear power plants has limited the need for a submarine to surface other than for replenishment of stores and weapons and to change crews - a significant operational advantage. Its introduction inevitably brought with it the need to develop other technological aspects of submarine design to ensure that the benefits of nuclear propulsion were fully realised.

The use of nuclear power in surface ships has been rather more limited and at present the only surface warships with such propulsion systems are some of the USN aircraft carriers and the USS BAINBRIDGE - a guided missile ship. The main reasons for this is that the benefits to be gained from nuclear propulsion systems are normally not sufficiently great in surface warships to offset the penalties in weight and space which arise from nuclear reactors. The containment vessel housing the reactor, in particular, is very heavy and involves significant additional hull structure and stiffening.

6.8 Gas Turbines

Although gas turbines have been under development throughout the past 25 years for use in aircraft, their application to ship propulsion has been much slower and it is only within recent years that they have been adopted as a means of propulsion for warships.

/14...

The main reason for this timelag compared with the aircraft application are the problems of corrosion in the marine environment, the relatively high fuel consumption compared with either steam turbines or diesel engines and the fact that the gas turbines were non-reversible. Their advantages of compactness and high power/weight ratio only offset these disadvantages in the application to high speed fast patrol boats and it was in this type of craft that much of the early work was done to develop marinised forms of gas turbines. Not all the problems have been fully solved and corrosion arising from the ingress of salt spray still causes some difficulty. However, fuel consumption of the larger gas turbines is now sufficiently competitive with other forms of propulsion machinery to enable the advantages of gas turbines to be fully realised. As a result we are now on the threshhold of an era of warships fitted with all gas turbine main machinery, examples of which are the Canadian DDH 280, the USN DX 963, the RN Type 42 and the RAN DDL Design.

6.9 There are a number of features of gas turbine warships which are worth summarising.

a. The normal operating pattern of a warship comprises long periods at medium cruising speed with a need for relatively short periods at high speeds. To meet these quite different requirements and achieve reasonable fuel consumption rates for each speed the normal solution is to fit two gas turbines per shaft, one for cruising and one for boosting to high speeds.

b. The more or less instant starting capability of a gas turbine provides it with a substantial advantage over steam turbines where a ship has to be held at a certain notice for steam in harbour - it brings with it, in turn, the problem of instant recall of a ships crew from bars and other places of pleasure if the advantage is to be fully realised!

c. The use of gas turbines eliminates the need for boilers and attendant auxiliaries, but in so doing, brings with it the problem of providing auxiliary power for electric power generation, domestic services, etc. Thus either some form of auxiliary boiler has to be provided for steam turbo-generators or the ship made all electric with power generation by diesels or gas turbines - the latter has not yet been developed to the point where it has a decided advantage over diesel engines for electric power generation.

d. Having been developed from aircraft engines, gas turbines are at present non-reversible. It is therefore necessary to provide either a reversing gear box or, as is more normal, to fit a controllable pitch propellor. To some extent this is a disadvantage because of the additional mechanical complexity with the possibility of break down and is more vulnerable to action damage.

/15...

e. Whilst the gas turbine itself is a more compact system than the boiler cum steam turbine system, this is partly offset by the very much greater space requirement for intakes and uptakes for the gas turbines which require very large quantities of air for their operation. This can be further aggravated if silencers have to be fitted for the reduction of noise in addition to the large spray filters which have to be fitted to intakes. The cross section areas of the intakes and uptakes bring in their wake structural design problems for the Naval Architect with very large openings necessary through strength decks.

f. The compactness of the gas turbine unit lends itself to being treated as a module and this facilitates the repair and maintenance of gas turbines because of the ease with which they can be removed from the ship.

6.10 Hull

The developments relating to hull design associated with the technological advances made over the past 25 years can be considered under two main headings.

6.11 Materials

There has been a continuous development of steels for application to warships with particular attention being paid to high tensile, low alloy, steels, notch toughness as a safeguard against brittle fracture and weldability. The use of the high tensile, low alloy, steels has enabled hull weight to be reduced and this has become an important factor with the increased size of warships although this has not been achieved without increased costs. Other weight savings have been achieved in warship design by the use of aluminium for superstructures though this is now considered less favourably because of the increased hazard from fire in the event of action damage. The use of more suitably designed steel sections for the transverse framing and longitudinal members has enabled more economical use to be made of material in the design of the hull for welded construction leading to further weight savings.

With the reduction in machinery weight and weapons weight the hull weight is becoming a greater proportion of the total ship weight so that any weight savings which can be achieved by the foregoing are likely to be of significance in reducing the total displacement (Fig 9).

6.12 The most recent significant developments in the field of materials have been in the field of application of plastics. Just as their use has grown in normal everyday life, so has their application to many features in warship design.

/So far

So far their primary use has been for the multitude of fittings and furnishings with some use for low pressure pipe and ducting systems, though here again the use has been limited because of the possibility of destruction of the pipes or ducts by damage and the production of toxic fumes in the event of fire. As far as their use in warships is concerned, we are only at the beginning of the plastic age and without doubt with the continued development of the many types of plastics, there will be increasing use made of them.

The use of Glass Reinforced Plastic for ship's hulls has steadily grown from the early applications to ships boats and sections of submarine casings to the stage where a complete mine sweeper hull nearly 160 ft long is being built. There are still many problems to be overcome with the use of such materials for warship hulls, not the least being the relatively long and costly process of laying up the hull, layer by layer, under controlled conditions. This involves expensive moulds and fully enclosed building facilities so that the process is only economical if there is a large ship construction programme. To some extent, the high initial capital costs involved are offset by lower maintenance costs throughout the life of the hull. There is also still a great deal of research to be done to study the behaviour of such hulls under shock loading conditions and whilst the possibility of larger GRP hulls cannot be discounted, it is likely to be a long slow process of development.

6.13 Hull Forms

This has always been a 'happy hunting ground' for inventors and innovators. It is therefore not surprising that a number of hull forms or types introduced for the first time many years prior to World War II have been resurrected. This has occurred because of the developments with more suitable propulsion systems and materials which were often the main factors making the earlier craft uneconomical or impracticable. Of particular interest has been the re-introduction of hydrofoil craft in a variety of forms for small, fast warships. It is likely that for some applications the hydrofoil craft will prove to be of advantage particularly where very high speeds are required. As against this the problem of damage to the foils continues to prove a disadvantage. In the field of warships as opposed to commercial usage, the limited application that hydrofoil craft are likely to have can be seen from the fact that the Germans had developed a number of experimental hydrofoil craft during World War II and so far, despite a continuous development programme, there has been very little application for warships beyond the prototype stages.

/17...

Air Cushion Vehicles are somewhat akin to hydrofoil craft as far as their development and use by Navies. Here again the principal developments have been in the commercial field, but the mobility of ACV's over both land and water commend them to application to amphibious operations and logistic support. It is in this field that the greatest attention is being paid by Naval authorities, though here again very few have progressed beyond the prototype stage.

6.14 It is perhaps worth commenting on the changed appearance of warships since World War II. At that time, the normal warship appeared to be bristling with guns of all sizes, depending on the role of the ship, and consciously or sub-consciously a warship was judged to be a powerful unit or otherwise, depending on the armament it could be seen to carry. The modern warship, particularly in the destroyer or frigate class, presents a quite different appearance and on the basis of the earlier criteria would hardly appear to carry any significant armament - indeed the appearance tends to be more of a cruise ship rather than a powerful warship, particularly with the cleaning up of the top sides and superstructure which has been necessary to facilitate pre-wetting and washing down when steaming through nuclear fall-out and reduction of the number of re-entrant corners which would otherwise enhance the radar target. Such appearances are, however, quite misleading since the guided missiles capability is far greater both in accuracy and destructive power than the combined gun armament of any warship of World War II.

6.15 <u>Electrical Engineering</u>

The developments in this field have been mainly related to the ever increasing generating capacity which has now to be provided in a Warship (Fig 10). These increases have been due to the demands of new weapons systems and sensors, as has been explained previously, together with the requirements associated with improved habitability and domestic services. As indicated in the discussions on gas turbine ships, warships of the future may well be all electric other than for propulsion. This accounts for the very significant increase in electrical generating capacity in warship design within recent years. One result of this development and a necessary step to keep the increased weight of electrical cables within economical limits is the adoption of higher voltages for the main distribution systems, though the extent to which these can be adopted has to be weighed against the increased hazards particularly in the event of action damage. Plastics too have played their part in weight saving with their use for a substantial number of electrical components.

/18...

They have also made a significant contribution with the replacement of lead sheathed cables by polychloroprene sheathed cables and more recently by silicone rubber sheathed cables.

The possibility of new methods of electrical power generation by super conducting machines opens up new fields of development with possible weight and space savings resulting from their greater power to size ratio compared with conventional motors or generators. These machines are in the early stages of development and as far as is known no prototypes are yet running in warships at sea.

6.16 Ship Design

As stated from the outset it is impossible to do justice in a single paper to the tremendous changes and developments which have taken place in warship design since World War II. The aim of the paper has been to highlight some of the more important developments against the prime factors influencing trends. Whilst not strictly relevant to the main purpose of this paper, it is of interest to consider briefly the corresponding developments in the warship design task itself - many of the problems concerning the modern warship designer have been hinted at in various sections. Those who are familiar with the use of the 'weight equation' for dealing with design changes and developments will perhaps not be surprised to learn that with the demise of the all-gun armament and armour protection, the modern warship is now space or volume critical and not weight critical. In other words, the volumetric requirements of weapons, sensors, crew, etc, determine the ships size so that generally space savings now assume the importance that weight savings once held.

The advent of the computer has had a profound effect in the field of ship design as it has had in many other areas. Their use has steadily grown in the application of computer programmes to many of the calculations and investigations previously carried out by Naval Architects and Engineers as is apparent from the increasing number of papers on these applications appearing in the Transactions of the INA. In addition their use on board the ship has already been indicated in discussions under the Action Information Organisation. Further uses aboard ships are likely to be found with their application to data logging and monitoring systems where, by the use of appropriate detectors or sensors, the performance and behaviour of any system or machine can be monitored and timely warnings of failure given thus obviating the need for watchkeepers in many areas. This can lead to some reduction in complement with corresponding savings in space.

/19...

As far as the ship design process is concerned, programmes are already in use which enable preliminary ship design studies to be carried out speedily. In the more detailed design phases, the design and strength calculations of many of a warships complex structural arrangements can now be carried out by the use of the Finite Element Analysis Technique, fairing of ships lines is now feasible and the consequent assessment of speed and power required, the normal range of stability calculations can be carried out very quickly, and in addition the effects of variations of the ships characteristics can be established rapidly. Computer aided pipe system and electrical installation design are all fields currently under development and likely to simplify the design process. Inevitably this will affect the whole approach to warship design and provide the opportunity for speedy investigations in greater depth of the effects of the many variables involved which if properly applied can result in a more balanced and cost effective design than the older traditional approaches. In fact, it becomes more of a problem of designing weapons systems rather than a ship on to which a number of weapons can be fitted.

7. Conclusion

Inevitably in a paper of this kind there are many omissions. Generally these are of the less spectacular developments, but this is not to say they are not important nor have not taxed technology as much as those described in this paper. The aim has been to try to present a balanced picture of developments in the many fields of engineering which have contributed to the evolution of warship designs over the past 25 years and which are steadily bringing the art of warship design closer to being a science.

Acknowledgement

The author wishes to thank the staff of the Forward Design Branch, Navy Office, for their assistance with the preparation of this paper and for undertaking the necessary research.

References

1. Owen H. Oakley "Size Determinants in Destroyer Design" Marine Technology 1968

2. Sir Alfred Sims "The Contribution of Warship Design to Industrial Technology" Trans R.I.N.A. 1969

3. Type 42 Guided Missile Destroyer. Navy Supplement

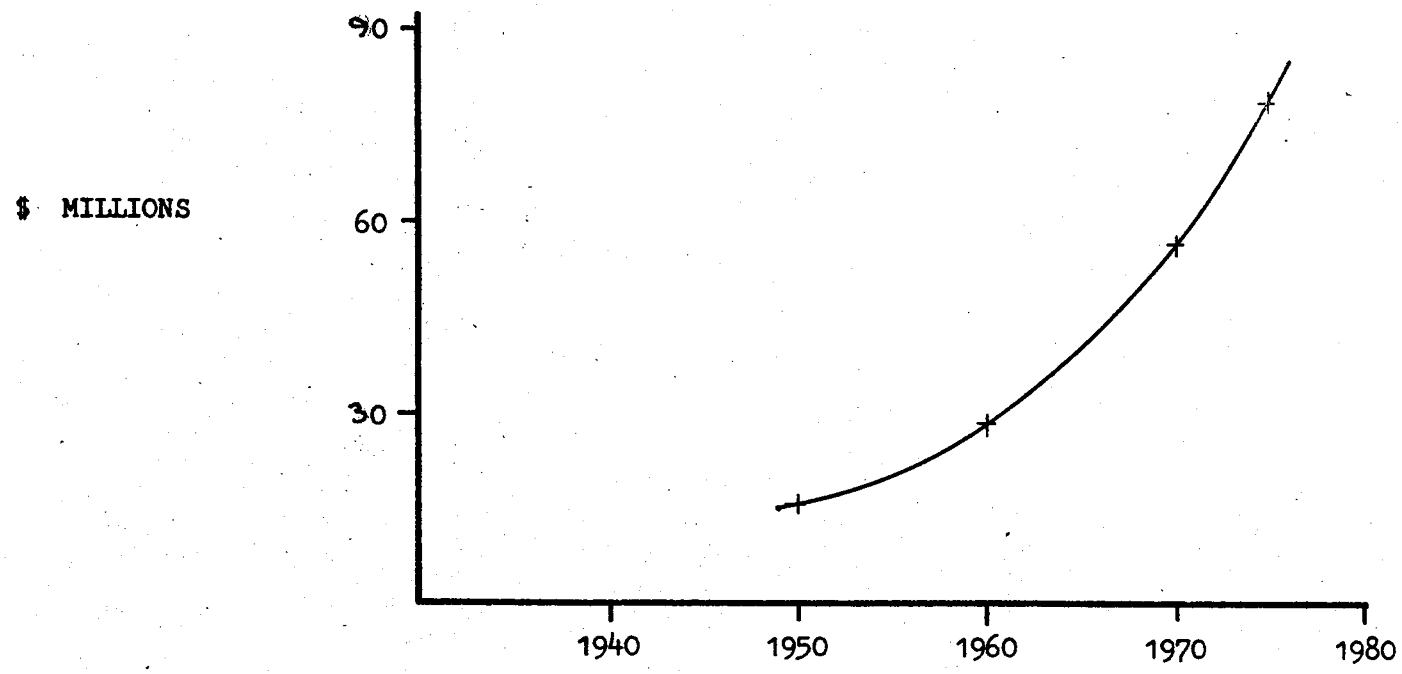


FIG. I TOTAL SHIP COST (DE's)

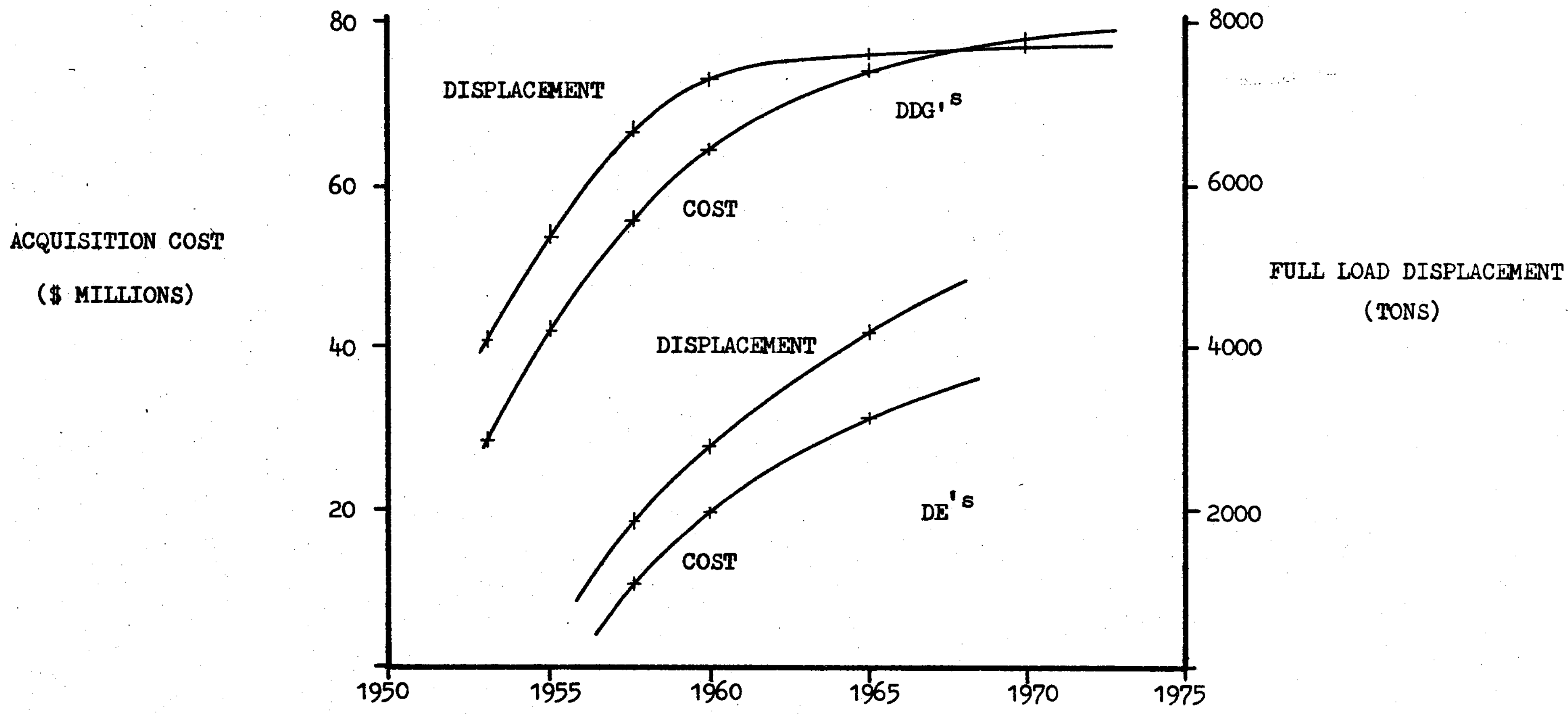


FIG. 2. SHIP DISPLACEMENT/COST

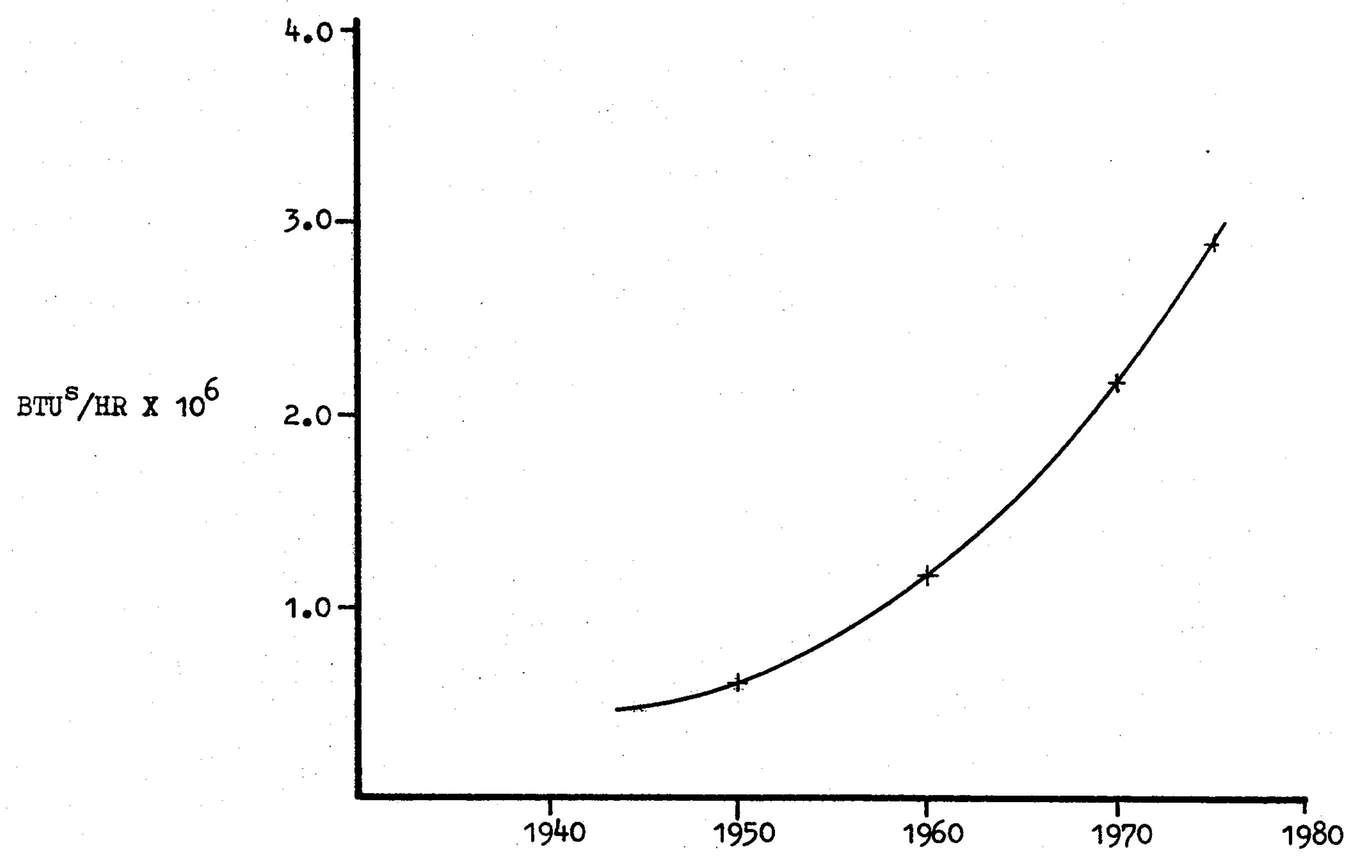


FIG.3. INSTALLED AIR CONDITIONING CAPACITY

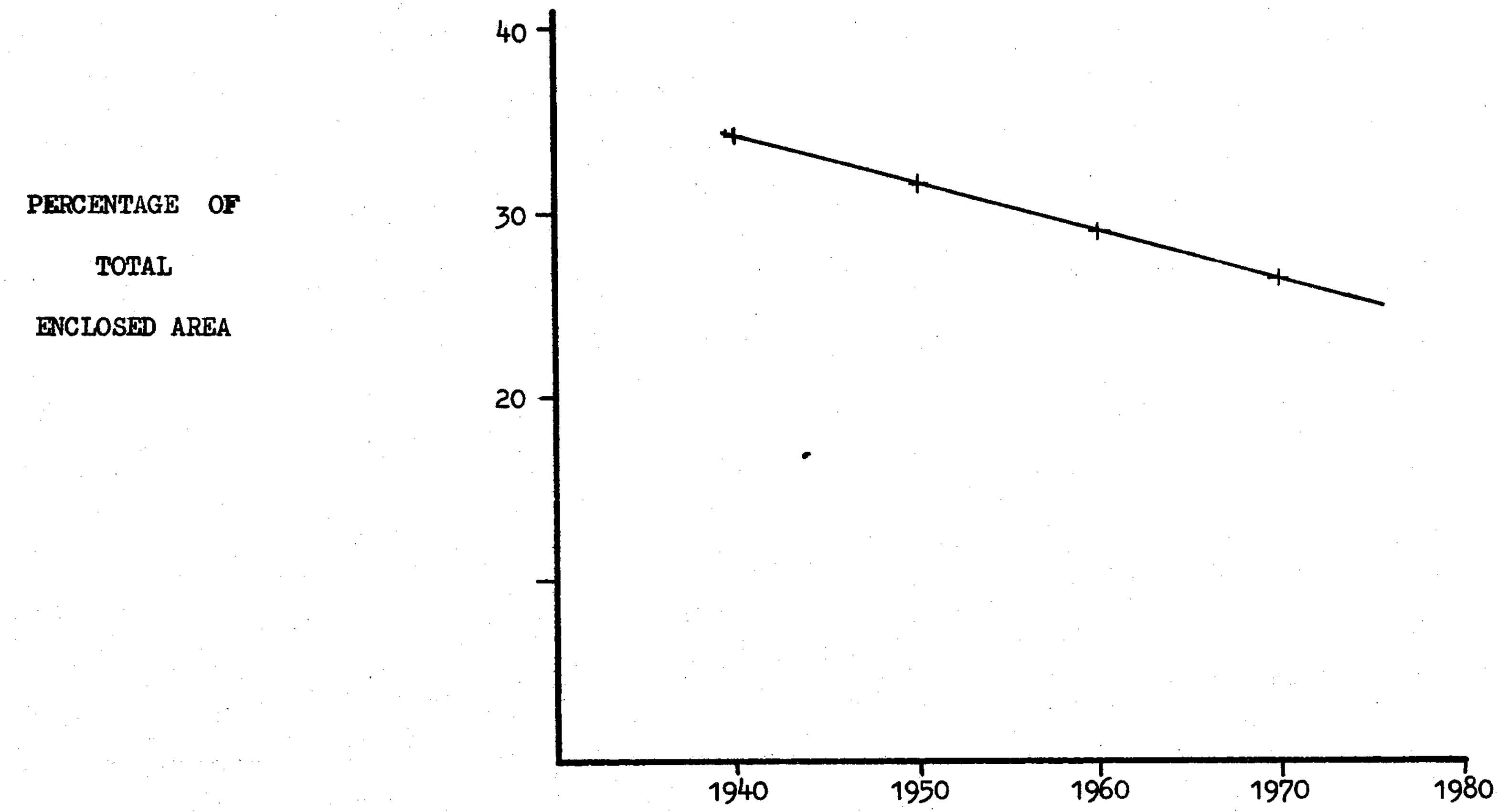


FIG.4. AREAS - ACCOMMODATION

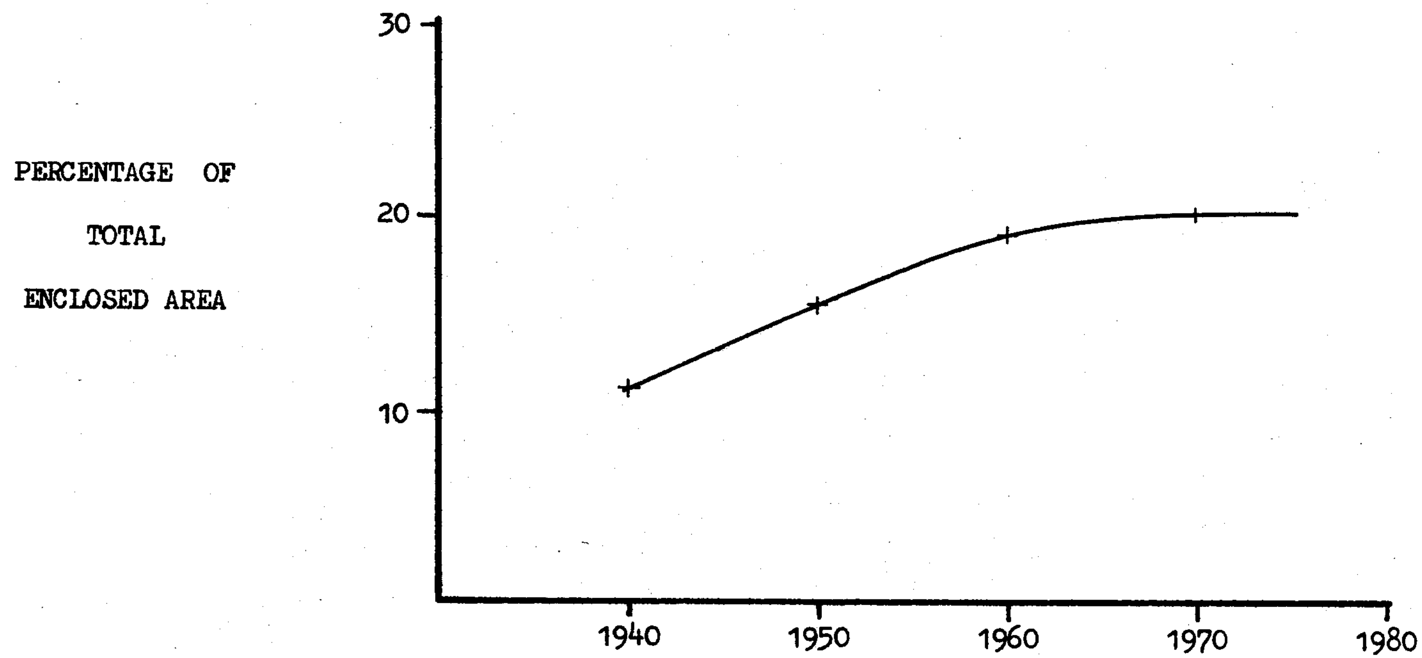


FIG.5. AREAS - WEAPON

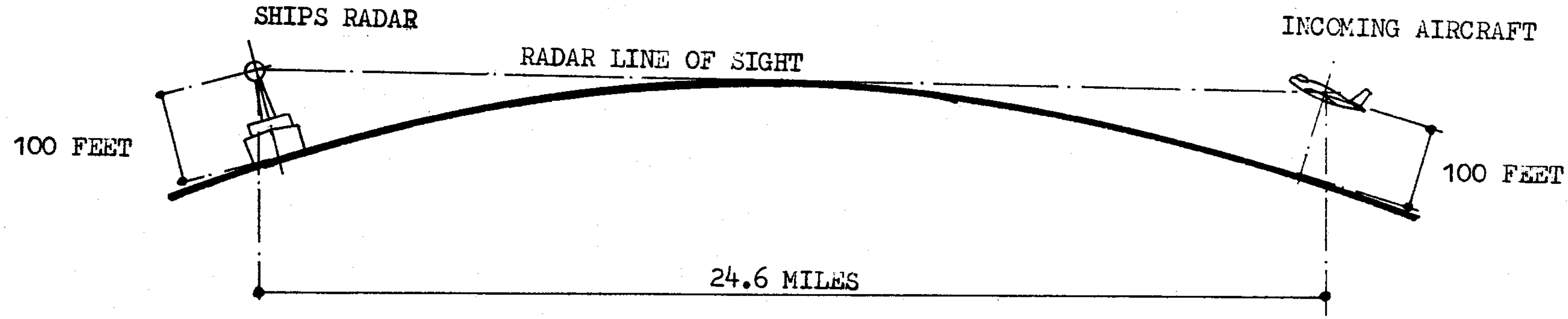
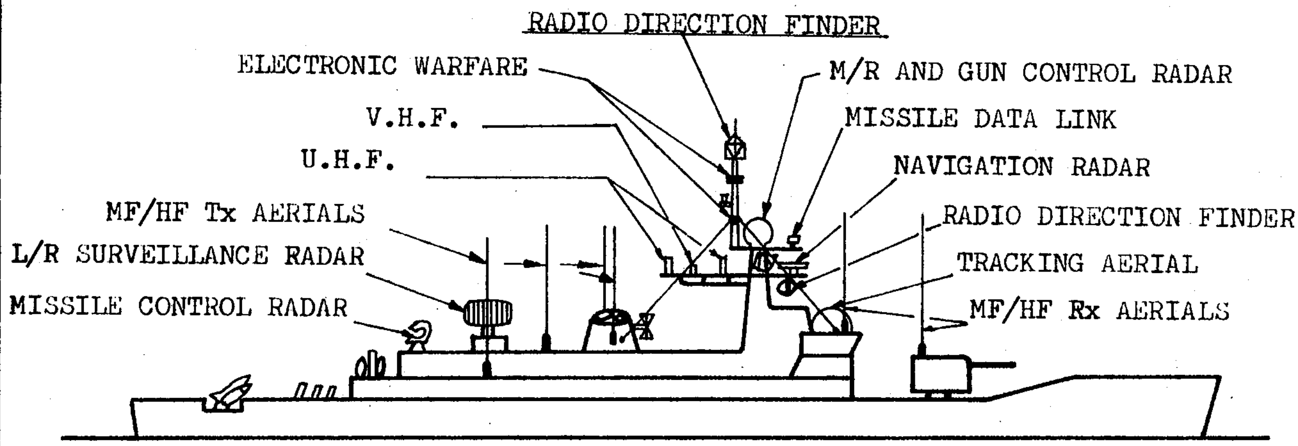
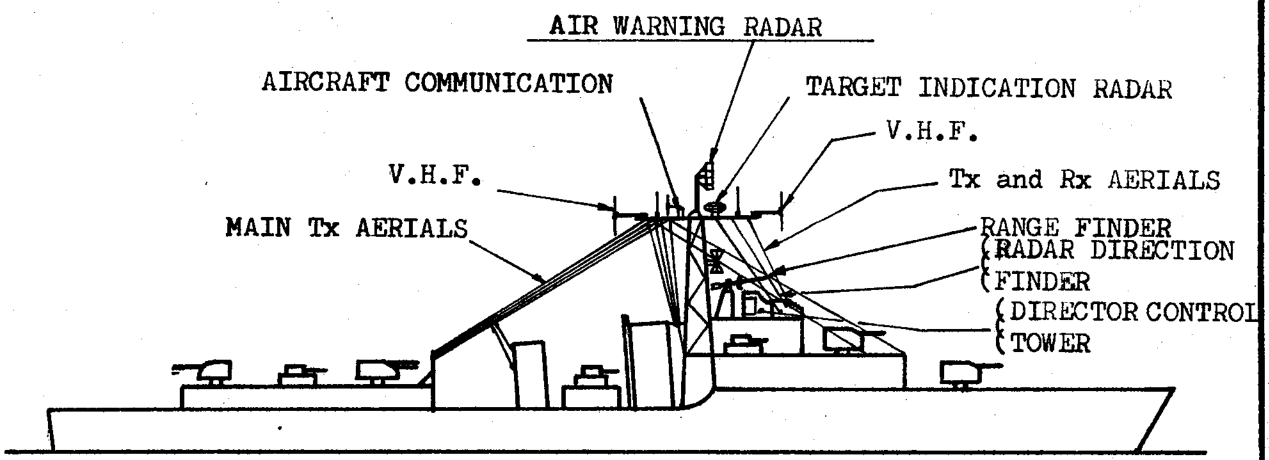


FIG. 6. RADAR HORIZON LIMITS



a) MODERN D.E.



b) POST WORLD WAR II DESTROYER

FIG. 7. **AERIAL RIGS**

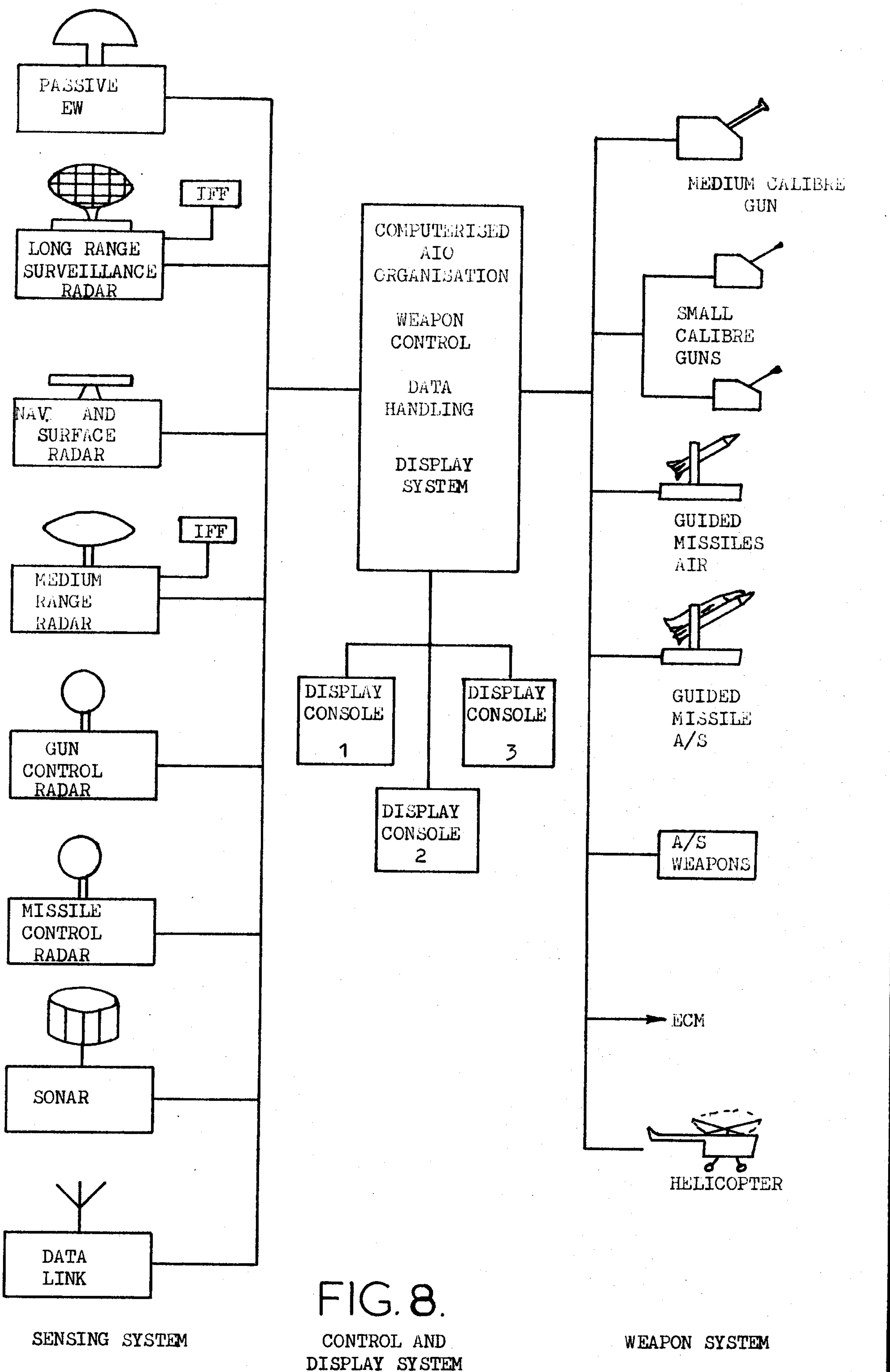

PASSIVE EW
IFF
LONG RANGE SURVEILLANCE RADAR
NAV. AND SURFACE RADAR
IFF
MEDIUM RANGE RADAR
GUN CONTROL RADAR
MISSILE CONTROL RADAR
SONAR
DATA LINK
COMPUTERISED AIO ORGANISATION
WEAPON CONTROL
DATA HANDLING
DISPLAY SYSTEM
DISPLAY CONSOLE 1
DISPLAY CONSOLE 3
DISPLAY CONSOLE 2
MEDIUM CALIBRE GUN
SMALL CALIBRE GUNS
GUIDED MISSILES AIR
GUIDED MISSILE A/S
A/S WEAPONS
ECM
HELICOPTER
SENSING SYSTEM
CONTROL AND DISPLAY SYSTEM
WEAPON SYSTEM

FIG. 8.

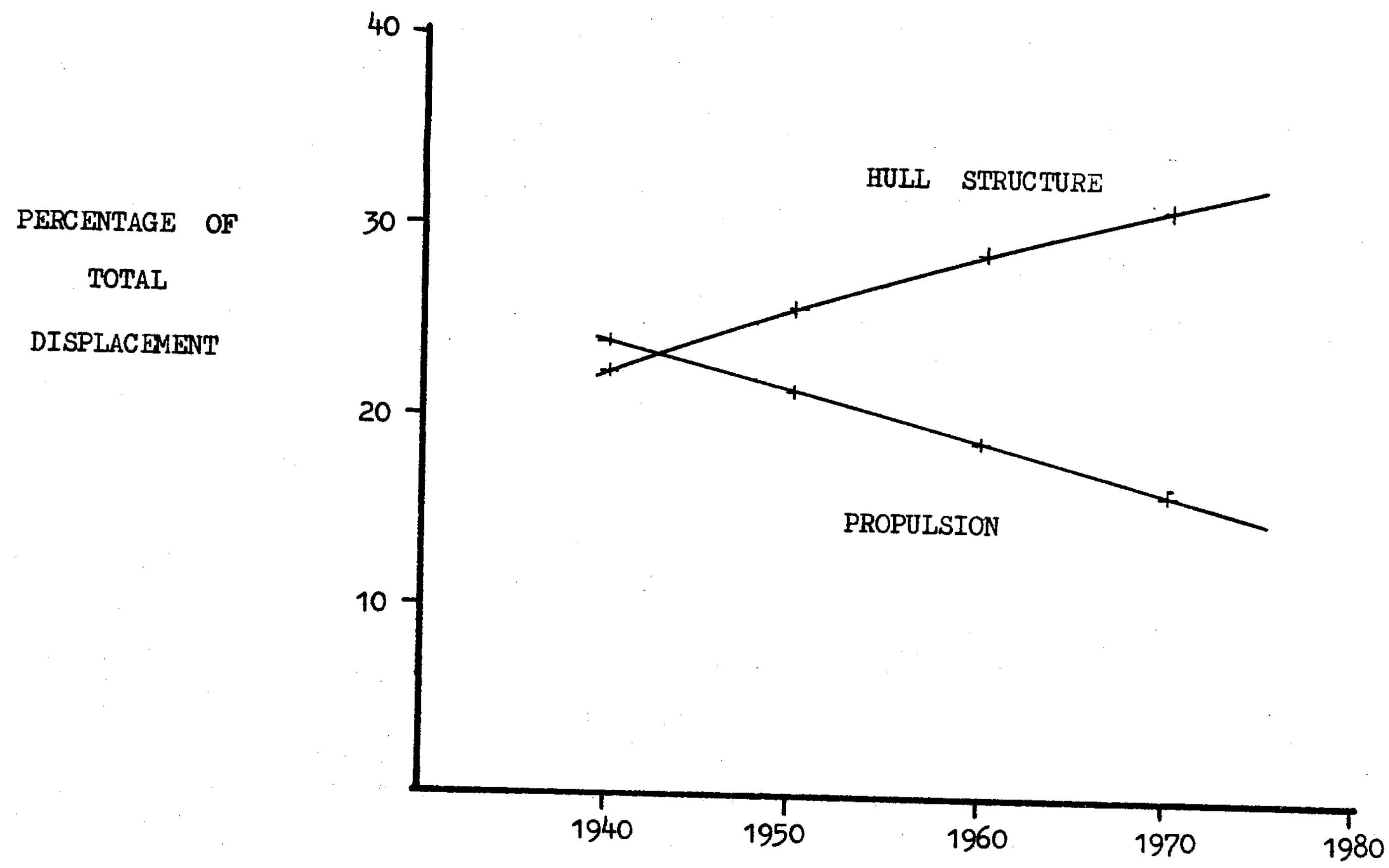


FIG.9. WEIGHTS - HULL STRUCTURE AND PROPULSION

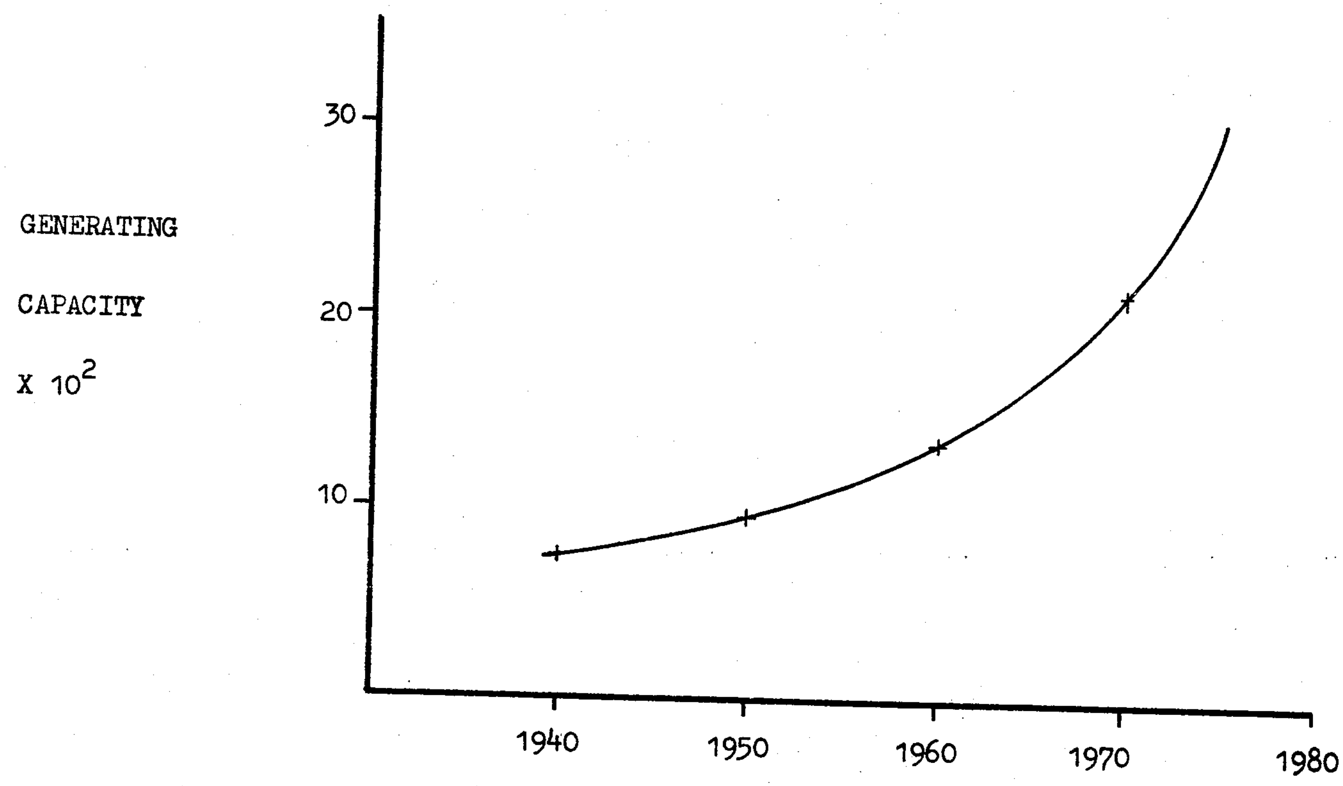


FIG.10. INSTALLED GENERATING CAPACITY