'PERMOBILITY'

BY

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INTRODUCTION

Warship design is an interesting and highly advanced science, and any good marine library is full of technical literature on the subject. However, a review of this material soon discloses that very little information is available concerning the machinery arrangement aspects of combatant vessel design. For example, an excellent treatise of over two hundred pages relating to basic warship design devotes less than two pages to machinery arrangement problems. Similarly, an authoritative two volume work of over one thousand pages relating to marine engineering allots less than twelve pages (and most of this is pictorial) to the subject. This situation would seem to suggest that naval machinery arrangement is either an extremely simple, or a very unimportant, subject. However, it is difficult to reconcile either of the foregoing conclusions with current machinery arrangement practice.

In the design of major combatant vessels it is customary to detail several dozen alternate machinery arrangements for purposes of comparative evaluation. These design alternatives often reflect only a rearrangement of the same plant components within the confines of the same hull configuration. The very number of such studies is indicative of the degree of importance accorded machinery arrangements. At the same time, the variety of arrangement solutions and the difficulty experienced in evaluating and selecting the optimum design, serve to emphasize a lack of specific machinery arrangement objectives.

It is clear that an arrangement is supposed to confer something special on a design, and that 'something' is considered highly important. What ? That is the question. Perhaps one might be inclined merely to enumerate such conventional yardsticks as minimum weight and space, and maximum simplicity and reliability. Yet, this 'something' is basically none of these features. After all, they apply equally well to the design of non-combatant vessels, and moreover, they are not altogether achieved or sometimes even achievable simply by arrangement artifices in any substantial degree. More often such features are a function of the type of power plant and the inherent characteristics of the components involved. Only one thing is certain, as is well illustrated by the vagaries of modern arrangement design practice, namely there are no universally accepted naval machinery arrangement criteria.

The purpose of this paper, therefore, is to seek to establish just what it is that the combatant vessel machinery arrangement designer can confer on an overall ship design, and to evolve practical guiding principles which will better enable him to fulfill this primary mission.

In the interest of simplicity the scope of the following analysis is limited to a consideration of major combatant vessels. The latter term as used herein connotes vessels having four propulsion shafts, with a minimum of forty thousand horsepower per shaft, and utilizing steam turbine—reduction gear drive. As these limitations may appear overly restrictive, it is perhaps important to emphasize that the ascendency of sea-borne airpower justifies the accent on the larger vessel type, and the turbine-gear plant still reigns supreme in the specified power range.

WARSHIPS EXIST FOR WAR

It is manifest that combat efficiency or military usefulness is the prime requisite of warships. The only return on the tremendous investment that a warship represents is its performance in battle. No competent naval designer would deny the validity of these propositions. Yet, machinery arrangement designers (whether consciously or sub-consciously, and whether voluntarily or by virtue of real or imagined pressures exerted by other participants in overall ship design) apparently incline to a belief that such fundamentals have little or no application within their sphere of responsibility. The uncertainty which pervades arrangement studies and the ultimate evaluation of alternate solutions is ample testimony to the aptness of the foregoing assertion. Yet, it is not merely difficult to evaluate naval machinery arrangements without regard to inherent and varying degrees of battle endurance—it is impossible. An evaluation on any other basis denies or ignores the very purpose of the vessel and is utterly meaningless.

The primary objective of the propulsion plant designer is therefore obvious. He must attempt to provide the plant layout that will assure the maximum degree of continued vessel mobility, by arranging plant components so as to minimize the disrupting effects of battle casualties on machinery, electrical, and piping installations. This fundamental characteristic, unique to combatant ship design, shall be designated by the composite term ‘ permobility ’.

‘ PERMOBILITY ’ A NEW CONCEPT

The word ‘ permobility ’ is intended to denote the characteristic of permanent or enduring vessel mobility as a function of the machinery arrangement in the face of always imminent, if not inevitable, war damage. At the same time, the term is intended to connote the battle endurance characteristics of the electrical power generating unit arrangements, in virtue of their vital relation not only to propulsion auxiliaries, but to the offensive weapons and damage control facilities in a ship. With this understanding of the term, it is easy to justify the contention that permobility should be the essential basis for evaluating alternate machinery arrangements. For example, in the recent World War, two out of every five vessels that were hit suffered propulsion damage, but only one out of every seven vessels suffering such damage, were lost. On the other hand, two out of every three vessels that were immobilized were lost. It is thus obvious that permobility is not some abstract objective, but is fundamental to the continued usefulness and very existence of the ship itself.

The foregoing observations serve only to provide an overall objective. To concede that the paramount concern of the arrangement engineer is permobility actually solves nothing. We are then confronted with the even more perplexing problem of determining the practical attributes of permobility. This problem might best be resolved by resorting to the time-tested process of elimination, considering the nature of the arrangement engineer's contribution to overall ship design. It is manifest that he is essentially concerned with locating given components within the confines of a given hull configuration. Yet, his problems are not fundamentally a question of either the relative locations of components or the conservation of space. New components are orientated in accordance with their function in the plant cycle. Smaller components are simply allotted proportionally less space ; the clearance margin being held more or less constant at the personnel access minimum. In neither case does the arrangement engineer have much design latitude.

The foregoing observations suggest that the arrangement of components within a machinery space is not a factor in permobility. This conclusion is further confirmed by war experience on other grounds. For example, there is not one recorded instance in which a propulsion unit remained operable after a direct hit within the space in which it was located. It is also significant to note that it was a direct machinery space hit which caused disruption of propulsion in seven cases out of ten.

MACHINERY COMPARTMENTATION, THE BASIS OF PERMOBILITY

It would seem that the machinery spaces proper are the major weak spot in the propulsion system, rather than external appendages such as shafting, uptakes, propellers, and combustion air supply systems. It would further appear that the arrangement of propulsion components within a space is of relatively minor significance, since a hit space is a lost space. The inescapable conclusion is that the compartmentation of machinery is far more important than the arrangement of machinery within compartments. Machinery box compartmentation is therefore the fundamental characteristic or attribute of permobility.

The foregoing conclusion brings the arrangement engineer into direct contact (and too often, into conflict) with the naval architect. The latter is, of course, vitally concerned with ship structure and compartmentation as they are factors in strength, stability, and watertight integrity.

The arrangement engineer may take his cue from the hull designer, who all too often regards him as both an unfrocked artist and a fugitive from science. This situation sometimes keeps naval architects happy. Rarely, and only accidentally, does it result in an optimum machinery arrangement from a machinery arrangement point of view. However, the engineer is always able to salvage his professional honour by subscribing to two very valid propositions, namely : all ship design is necessarily founded upon compromise, and all of the alternate machinery arrangements proposed are fundamentally sound and feasible. Nevertheless, one of the collateral objectives in this presentation shall be to indicate and emphasize that the machinery arrangement engineer has an equally vital interest in, and responsibility for, machinery box compartmentation, apart from those aspects of ship subdivision admittedly wholly within the purview of the naval architect.

CRITERIA FOR MACHINERY COMPARTMENTATION

What compartmentation criteria are to be applied by the arrangement engineer in order to achieve an arrangement incorporating maximum permobility ?

It is obvious that each propulsion unit should be self-sufficient and independent of all other propulsion units. It is also fairly evident that each propulsion unit should be accommodated in the minimum practicable fore and aft length. This follows from the fact that length is the only really variable compartment dimension (height and breadth being substantially 'fixed' in a given design), and is accordingly a measure of the individual propulsion unit target expanse. If disruption of propulsion is predominantly the result of a direct hit, then it is highly important that the target expanse of the propulsion unit be minimized. Finally, it is highly desirable that compartments containing propulsion units be separated from each other by less vital auxiliary spaces. Thus, and in the order of their relative importance, the three basic criteria for propulsion units are—keep them isolated, keep them short, and keep them separated one from the other.

These propulsion arrangement criteria all operate to make a combined main machinery space (i.e. a single compartment containing a complete propulsion unit) fundamentally superior to an arrangement in which the boilers and turbines comprising a propulsion unit are located in separate compartments. As regards isolation, there is a compelling temptation to provide certain piping connections in both directions (fore and aft) from a boiler room flanked longitudinally by propulsion turbines. This violation of the principle of isolation is made palatable by noting its ' improved flexibility '. Still, it cannot be stated too emphatically that this type of flexibility is entirely incompatable with isolation, and isolation of propulsion units is a fundamental requisite.

It is the same with propulsion unit compartment lengths. A fire room/engine room arrangement will always require more length per propulsion unit (on the order of twenty feet for the ship type under consideration) than a combined main machinery room type of arrangement. To be sure, the respective lengths of the fire room and engine room will each be less than the length of the combined machinery room, but we are discussing permobility. This means we are considering the overall length of the propulsion unit. Compartmentation only enters into consideration because the combined space results in less propulsion unit length (and therefore presents less expanse of vulnerable target area) than is required for the two comparable separate spaces of the fire room/engine room arrangement.

SEPARATION, A FUNCTION OF BOX LENGTH

Finally, there is the question of separation. Separation can be discussed intelligently only in connection with overall machinery box lengths. We shall arbitrarily assume the overall length of the separate fire room/engine room arrangement as the standard of comparison. The reason for this choice is that for a given machinery plant, a combined space arrangement can always be developed that will require less overall length than the separate fire room engine room arrangement of the same plant. This follows from the fact that the combined space design permits a more compact arrangement of the propulsion unit itself, and entails such incidental but cumulative savings in space as result from shorter piping leads ; less piping ; fewer valves (as occasioned by the absence of bulkhead penetrations and associated bulkhead cut-out valves in major piping systems) ; the adequacy of four in lieu of eight propulsion control centres ; less necessity for duplicating instruments, controls, and communications equipment ; better utilization of space permitted by locating boilers face-to-face with a common tube-pulling area ; fewer bulkheads, and resulting less personnel clearance requirements between equipment and bulkheads ; and less space sacrified to compartment access provisions.

Now, as we previously implied in the discussion of length, the overall length of four combined machinery rooms will be on the order of a total of eighty feet less than the overall length of the eight compartments required for the comparable separate fire room/engine room arrangement. For the latter arrangement we shall further assume that all compartments are of equal length, and that this length is increased as necessary to accommodate all the required propulsion and auxiliary machinery. Thus, if we assume the same overall box length when we come to considering combined machinery room arrangements, we note that each pair of propulsion units may be separated by a non-vital auxiliary machinery room, each of which will be on the order of twenty-seven feet long. The eminent superiority of the combined space arrangement on the basis of inherent permobility (in addition to the space-saving advantages previously noted) is then obvious. The degree of propulsion unit isolation is identical for the two arrangements, but the combined space arrangement offers the dual advantages of less propulsion unit length, and considerable propulsion unit separation.

Of course, it we provided comparable separation in the fire room/engine room arrangement, then its overall vulnerable machinery box length would increase proportionately. Still, for equivalent machinery box lengths, the fire room/engine room arrangement provides no separation of propulsion units. It is perhaps unnecessary to note that equivalent overall machinery box length is the only valid basis for a comparison of alternative machinery arrangements. After all, machinery box length reflects the pre-empted ship volume allotted to the machinery plant, and we certainly desire the optimum machinery arrangement (permobility-wise) for any given penalty in ship volume surrendered for accommodating the machinery plant.

COMBINED SPACE ARRANGEMENT ALTERNATIVES

Thus far we have endeavoured to indicate that for a given overall machinery box length a combined space arrangement has superior permobility when compared with a fire room/engine room arrangement. The next logical question concerns means by which we may comparatively evaluate the merits of alternative combined space arrangements. This problem, in turn, resolves into a consideration of the number, location, and machinery content of auxiliary machinery rooms. We shall therefore consider auxiliary machinery rooms in two ways : their relation to propulsion space integrity, and their relation to ship service generator integrity. It will be remembered that the vital character of a ship's electrical power generators has already been emphasized incident to defining permobility.

First we shall consider the relation of auxiliary machinery rooms to the permobility aspects of propulsion unit spaces. Thus, on the basis of separation of propulsion spaces, the ideal number of auxiliary spaces would be three, such that an auxiliary space is interposed between each pair of propulsion spaces. Obviously, four auxiliary spaces would be illogical, since one auxiliary space would not be a separating space. At the same time, applying the concept of separation to the auxiliary machinery itself, logic compels the conclusion that a minimum of two auxiliary spaces is required, so that we won't have ' all our eggs in one basket '.

The concept of isolation as applied to auxiliary spaces ideally entails four spaces, such that each propulsion space has its corresponding auxiliary space. By the same token, three spaces would be better than two, in that only two main spaces would share a common auxiliary space, rather than there being two common auxiliary spaces each of which would serve two propulsion spaces.

The criteria of shortness militates against the adoption of four machinery spaces, particularly since separation is ideally effected by only three spaces.

We therefore conclude that the number of auxiliary spaces should be not less than two nor more than three. Three spaces are best on the basis of both isolation and separation. Two spaces are best on the basis of shortness ; it being manifest that cumulative floor area savings are realized as the number of compartments (and therefore separating bulkheads) is reduced. The inescapable conclusion is that superior propulsion unit permobility accrues to the arrangement utilizing three auxiliary spaces.

INTEGRITY OF THE GENERATING PLANT

Finally, we must consider the influence of auxiliary spaces on electrical generator unit integrity. At this point we are fairly well committed to an arrangement comprising four propulsion spaces with three separating auxiliary spaces, or a total of seven machinery spaces. We have yet to establish the detailed allocation of generators among these spaces. In the interest of brevity we shall arbitrarily assume that a four shaft ship of the type under consideration has eight boilers, and we shall then assume eight generators, one corresponding to each boiler.

Now eight generators may be logically disposed among seven machinery spaces in only three ways. First of all, we may locate two generators in each of the four propulsion spaces. Such a solution is not desirable since it would tend to jeopardize the shortness of the propulsion space, which we wish to maintain at the minimum necessary to accommodate the propulsion unit. The second alternative would be to locate one generator in each space except the central auxiliary space, which latter would be allotted two generators. This arrangement offers good flexibility as regards sources of steam for generators located in the auxiliary spaces, and minimizes the concentration of generators since only one space has two generators. However, it introduces the twin problems of load unbalance and non-uniformity of arrangement, and inherently is repugnant to the basic concept of isolation. The final alternative consists in locating one generator in each of the propulsion spaces, and two generators each in the foremost and aftermost auxiliary spaces. In this arrangement the central auxiliary space would not contain a generator. This arrangement appears to offer an optimum compromise of flexibility and isolation, and the forward and after plants could be identical in all respects. It is therefore the recommended arrangement.

We are now left with the problem of effectively using the central auxiliary space. First of all, we shall assume four distilling plants in accordance with the concept of isolating which implies four complete and independent machinery plants. Two of these distilling units would be allotted to the central auxiliary space, and one each to the other auxiliary spaces. Such an arrangement is not contrary to the concept of isolation as would be the case if we were considering generators, since it is assumed that such non-vital auxiliaries as distilling units would be secured under battle conditions. Finally, it should be noted that the upper level of the central auxiliary space would be ideally disposed for accommodating the Central Control Station.

AN OPTIMUM DESIGN

We have thus arrived at what appears to be an ideal machinery arrangement on the basis of permobility. It is realized that difficulty in following some of the reasoning may have been invited by failure to resort to basic sketches. However sketches were intentionally avoided in order to arrive at a conclusion independent of particular cases. Should anyone feel inclined to disavow the conclusions of the foregoing analysis we can suggest a simple test. First of all, set down your favoured arrangement beside the one proposed herein. Secondly, review the two arrangements in turn, assuming consecutively one, two, and three, etc. contiguous spaces are disabled, and noting the corresponding number of propulsion units disabled in each case. Thirdly, assuming the generators in an auxiliary space can be supplied from boilers immediately forward and aft of that space, once again assume consecutively one, two, three, etc., contiguous spaces are disabled, and note the corresponding number of generators disabled in each case. If your arrangement survives this test better than the arrangement proposed herein, and does not entail an increase in overall box length, well—maybe you really have something permobility-wise. And that's the whole point of this treatise, to encourage arrangement analysis on the basis of permobility.

Of course, marine engineers must eventually make their peace with the naval architects. Thus, the most profound and compelling arguments in favour of a combined space arrangement may be completely nullified by the naval architect's contention that the length of the combined propulsion space is simply prohibitive. It is well, though, to remember that making such a statement doesn't make it so. Substantiating proof should be demanded. After all, the length of the machinery box is usually just slightly more than twenty-five per cent of the length of the ship. In other words, compartmentation and subdivision do not have to be wholly accomplished within the confines of the machinery box. War experience has furthermore confirmed that the flotation capacity of ships already exceeds their permobility. As a matter of fact, during the recent war several immobilized ships were sunk by our own forces only with great difficulty, to prevent their falling to the enemy. It seems the permobility aspects of ship design have not received their just due.

CONCLUSION

The foregoing is hardly proposed as the last word on a subject which is so manifestly complex. It represents only the opinion of one who has tried to analyze the problem objectively. It should be emphasized that the author is not so much concerned with being right as with promoting a discussion by more qualified and competent naval architects and engineers. Such discussion could, through a process of synthesis, ultimately result in a right solution. It is therefore earnestly hoped that this article will not only serve merely as a point of departure, but will moreover constitute a challenge calculated to stimulate constructive thinking, such that naval machinery arrangement designs will not only reflect an optimum design, but may be achieved in the future with a considerably improved economy of time, effort, and money.