# WARSHIPS—THE DRIVE FOR AVAILABILITY

BY

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Warships have developed since Trafalgar—Admiral Lord Nelson's ships were wooden walls, powered by sails manipulated by ropes hauled by men. Their Availability on extended missions, lasting years, was assured by large crews and an extensive range of stores; indeed, if they ran out of timber, a local tree was chopped down and the carpenters in his ships' companies were well capable of executing necessary repairs.

Today, warships are among the most complex and costly, if not *the* most complex and costly, items in the Defence Inventory. That the nation—the taxpayers, that includes you in this audience—gets full value from its investment in these complex and costly units needs no elaboration or qualification. In the subject context, a measure of 'value' might be 'the capability and capacity of a warship to perform its roles and missions for as long as may be required in relation to its life-cycle costs'. Life-cycle costs are the sum of all costs attributable to that ship from initial build to disposal: this includes building, maintenance, stores consumed, operating costs, manpower costs, everything. Today it is that part of the value equation which relates to Availability—the capacity to perform for as long as may be required—that I primarily address, taking my definition of 'Availability' as 'the probability that an item will perform its intended function at any instant of time'.

Consider first, very briefly, the 'unit'—the ship—of which we demand Availability. FIG. 1 shows a Type 42 destroyer and a Type 21 frigate, typical of today's destroyers and frigates and for the purpose of this address may be taken as typical warships.

Many of you may be familiar with the motto—*To Float, to Move, to Fight.* True as this is in that order, I will take it in reverse— not just to be difficult, but because the purpose of a warship is to *Fight.*

*To Fight*—visible to you are the 4.5-inch gun and Sea Dart air defence missile launcher and an array of surveillance and control radars. There are also weapon systems not visible to you, again with their detection and associated systems. A total package of systems comprising a wide range of technologies. Some parts of that package—surveillance systems, for instance—are required to be operating almost continuously whilst the ship is at sea or in harbour, whereas some—the missile system, for example—will be required to perform only infrequently, and, hopefully, never in anger. *But,* if and when they are required, they must respond immediately at their full capability or, to use the phrase in the colloquial sense, 'we're sunk'.

*To Move*—this requires a propulsion plant of some tens of thousands of horse power. In this ship, propulsion is by gas turbine—it could be steam (using either a nuclear steam raising plant or a conventional boiler) or diesel engines, or combinations of these prime movers. Whichever plant is fitted, power transmission and ancillary systems—reduction gearing, propellers, air,

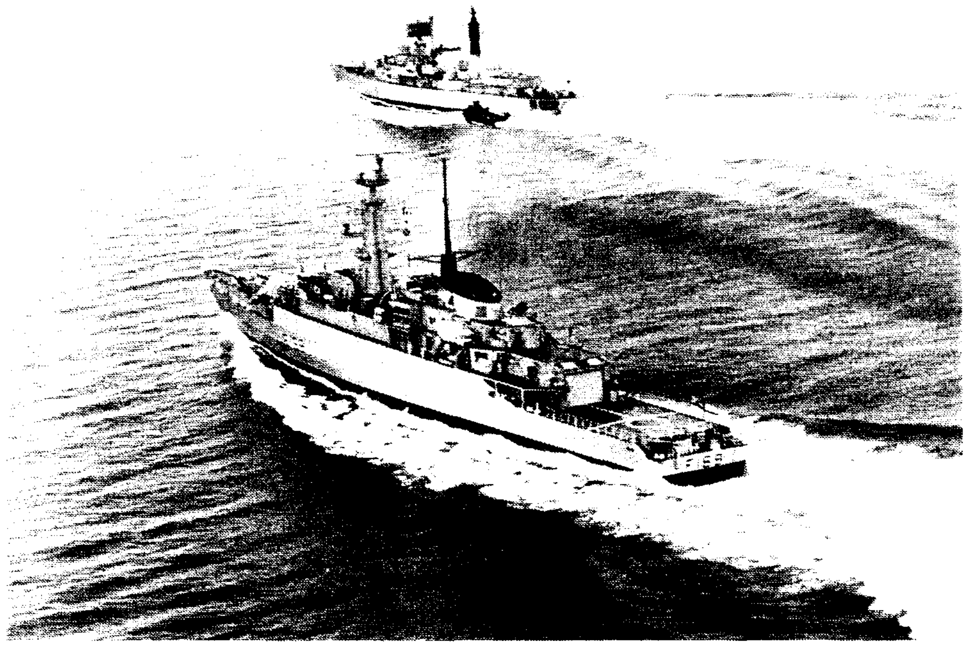

FIG. 1—A TYPE 42 DESTROYER AND A TYPE 21 FRIGATE

fuel, water, lubricating oil systems—are necessary. To enable the ship to go in the desired direction, navigational systems and steering gear are required. The ship needs communication systems so that it can 'talk' with other ships and authorities. To support the propulsion plant and weapon systems requires a very wide and varied range of systems and equipments; systems and equipments are also necessary to provide for the creature comforts of men over extended periods. So there is need for an electrical power generation and distribution network, air-conditioning and ventilation systems, hydraulic systems for deck and other machinery providing for refrigerated stores, the stowage of ammunition, galleys, laundries, etc. and the list could go on.

A great array of systems (ranging many technologies) that, whilst the ship is at sea, must work as a cohesive whole either operating continuously or be ready, with a high level of confidence, to operate at very short notice—that is minutes and seconds, not hours.

*To Float*—the whole of the systems and equipments I have outlined, along with a crew of about 200, must be accommodated within a hull which will float under all conditions of sea, wind, and icing likely to be met, which contains self-defence systems against nuclear, biological, chemical, missile, and other attack, and which has the capability to remain afloat having sustained a good measure of damage. Ladies and gentlemen, that is a brief description of the unit—the ship—which we have to make Available.

Concerning operating cycles, a usual mission time, for design purposes, is thirty days at sea. There may be a number of such missions within a four to six month period away from base maintenance and support. Maintenance and support periods, which also provide for crew leave and relaxation, are usually of three weeks duration. So not only do we have a complex unit, but also the mission times in relation to much other equipment in the defence inventory are long—and this audience will recognize the impact of mission length in the availability equation.

Are we entirely satisfied with the availability of ships of the Fleet? Do we achieve the necessary levels of Availability at sensible costs? The answer to these, and similar questions, is that we are not entirely satisfied. How could we ever be? However, in a practical sense, we are not satisfied that in all areas we are achieving the necessary levels of Availability in the most cost-effective manner. The importance attached to achieving and maintaining the required level of Availability is contained within a recent Admiralty Board Directive that 'within cost constraints, equal attention is to be paid to achieving the Functional Performance and Availability requirements set down in Naval Staff Requirements for ships, systems, and equipments'. Put another way—the achievement of Availability and Functional performance each cost money. With money available being a predominant constraint, there has to be realistic trade-off between the Availability and functional performance targets. Whilst this could not be said to be a new requirement, for it has always been implicit or understood, the Directive has raised it to the level of a Command from on high—and such Commands require response and action. At this juncture I am tempted to say, 'And then comes the Naval Discipline Act—disregard the Command at your peril!' But powerful though that Act is in some fields, it is most unlikely to bring success in my subject field—it leaves too much to chance, if only because many, if not most, involved in meeting the aim are without the force of the Act. Achievement and maintenance of levels of Availability that are commensurate with ships of an effective fighting force cannot be left to chance. Palpably it requires engineering expertise, harnessed to disciplined procedures and drive, spanning both the Ministry and Industry.

First, does the Navy know what levels of Availability are required of new ships and their weapon systems to make them worthwhile additions to the Fleet? I believe that the Operational Research and Analysis methods which have been evolved over the years have the facility to provide, in gross terms, for the ship and weapon system fit, well-reasoned and realistic answers to this question. Important though this first step is, the most crucial follows: namely, apportioning the levels of Availability required of the various systems such that, when brought together, the required Availability of the whole is achieved. Many, if not most, in this audience will have at least a feel for the nature of this exercise—one of trade-off of potential engineering realities in the form of possible system concepts and potential reliability of equipments and components involving probable costs of the various engineering options, the means of achieving Availability through various but related levels of Reliability, Maintainability and Support, and the relationship between Functional Performance and Availability. Conceptually, not too difficult an exercise but, as you will appreciate from my earlier brief description of the array of systems and equipments which go to make up a warship, it is one of no mean proportions. Despite its magnitude, it is one that cannot be ducked; it must be followed through to well-reasoned conclusions for, very importantly, the levels of Availability which are arrived at from this particular exercise are the levels which will be required of system and equipment designers and manufacturers dispersed through the length and breadth of the United Kingdom and, maybe, the odd one or two overseas—weapon system companies in the Home Counties, gas turbine manufacturers in Coventry, pump manufacturers in Glasgow. Thus the exercise is not only a most important one, but also one of a real and vital interface of the Ministry with Industry and which therefore requires the involvement—data provision and engineering judgment—of both parties. For me to suggest that as of today we have arrived at an elegant, crisp, well-proven means of executing this crucial step would be folly. What I can say, however, is that, being fully appreciative of the importance of the ship, we have been working and continue to work hard at it and we see light at the end of the tunnel. Here, it is worth noting that in driving through the tunnel we have not been hampered by any shortage of fundamental 'tools of the trade'; the problem has been one of developing the available tools to handle the particular problem and to cope with its size and variability and of acquiring and marshalling of the data necessary to give a proper degree of validity.

The very purpose and nature of weapon systems makes this second step a particularly crucial and demanding exercise for the Director General Weapons. Recognizing this, Director General Weapons has recently reorganized his headquarters and in doing so has charged one of his Directors with responsibility for the complete weapons system design in a ship, to ensure the mutual compatibility of the individual weapon systems in terms of performance, manpower, and Availability. This is in recognition of the fact that a ship is no longer a platform on which a number of weapons are placed, but has become a complete weapon system in itself as is the modern fighting aircraft.

At the ship concept stage, the Director concerned will agree with the Naval Staff the ship's fighting capability and the required Availability of weapon systems during a mission. Target Availabilities will then be allocated to individual weapon systems to satisfy the overall requirement. This process will be an intramurally-led exercise using specially developed computer models so that the proper trade-offs between Availability, costs, performance, and manpower can be made. Because many weapon equipments need to be developed before the ship requirements are known, action is in hand to improve the specification of the Availability requirements of equipment to ensure mutual compatibility when they are brought together as a total Weapon package. In particular, mission profiles will need to be specified in greater detail than hitherto.

A similar exercise is carried out for the ship systems and equipment, acknowledging the interdependence of those systems.

Importantly, these exercises tell us in gross terms where to deploy our resources, both human and money, in order to achieve the maximum benefit to, and a proper balance between, the required ship and weapon capabilities.

Turning to system and equipment design and development, Project Managers are charged with the pursuit of Availability in proper balance with other major design parameters, i.e. functional performance and cost. They are required to develop, in association with contractors, Availability Programmes embracing a systematic discipline and carefully constructed plan into which is integrated the use of Availability Design Techniques, models, and procedures, such as failure mode effect analysis and fault tree analysis. Suitably trained project staff will be charged with responsibility for ensuring that Availability requirements are met. To advise and assist them and their contractors in all aspects of Availability Design, cells of specialist ARM expertise have been established in the Weapons Department and in the Ship Department. These cells work closely together and their joint Bible, *Availability, Reliability, and Maintainability in the Naval Service,* will be issued shortly as a major Book of Reference (BR 2552).

From this common foundation of aims, policies, and practices, there will, by the very nature of the systems and equipments for which they are responsible, be differences in detailed approach and emphasis between the Weapon and Ship Departments. The main reason is that, in the weapon system field, the design and development of systems is almost solely for naval use, whereas equipment for ship systems wherever possible use commercially-available equipments or equipments developed therefrom to meet naval requirements. The development times for ship equipments are, in general, somewhat shorter than those for weapons systems. Indeed, for a large proportion of ship equipments, development and procurement would be possible during the gestation period of ship design and construction.

However, this could, and probably would, lead to a massive inventory of small quantities of equipment, of which few had been subjected to proper test and evaluation. So there is a policy of using standard ranges of equipments which have been subjected to rigorous selection, test, and evaluation. The virtues of this policy are self evident particularly in the fields of maintainability and in-service support.

For maintainability we have a well-developed step-by-step approach. Maintainability aspects of equipments are routinely examined from the earliest design stages and, later, the prototype equipment is subjected to a full maintenance evaluation by naval personnel, who are experienced in onboard maintenance. They see the equipment not as free standing in the contractor's works, but as they might find it in a ship installation—in which, of course, they have a vested interest. In their next ship they themselves could be the maintainer and would not wish that lack of maintainability should consume those precious hours when they might be with their families or on a run ashore in some sunny clime. Maintainability demonstration techniques are also being developed.

In developing ship installations, extensive use is made of models and full-scale mock-ups. In early stage models, the arrangement is juggled until an inherently acceptable layout is achieved. In later models and mock-ups, maintainability is demonstrated by exercise. If an upkeep-by-exchange policy is adopted for an equipment, all removal routes, slinging arrangements, and so on are proved. These exercises form the basis of the ERRP—that is not a rude noise, but the abbreviation for Equipment Removal and Repair Plan—which is then used in subsequent maintenance, planning, and execution. We could spend up to £1M pounds on models and mock-ups during a ship design; that may seem big money, but, I assure you, we reap the benefits multifold.

Test and evaluation programmes are no longer of the nature 'Run for a 1000 hours or so and check it over'. We are becoming more objective: the schedules are constructed not only against the running profiles (time and load) that the system or equipment will meet at sea, but also they specifically address the critical areas of reliability identified in the earlier design reviews. Also we now consider the potential for growth in realiability during development testing: that is, not only do we demonstrate that the system or equipment meets the stipulated target level but also we ascertain what increase in reliability is inherent in the design and to what degree it might be cost effective to pursue.

So far I have barely referred to arrangements for in-service support and I do not intend to develop this field except to say that it is now firm policy to develop in-service support packages, both hardware and software, in parallel with system and equipment design and development.

You will recall that at the beginning I said that achievement of the specified levels of Availability could not be left to chance. So, recently, Director General Weapons and Director General Ships have extended their review procedures into the Availability field. For weapons, the long-standing Weapon Acceptance Authority has been reinforced by additional expertise so as to be able to concentrate on the Availability aspects of design. Their approach will be one of continuous assessment during development of the project, rather than a 'once-and-for-all' acceptance at the end of development—the latter being far too late to ensure Availability. The Ship Department have initiated a Material Availability Board—a Board chaired by a rear-admiral supported by a commodore and captains, or their civilian equivalents, and charged with ensuring that Projects Managers are taking suitable measures to ensure the achievement of proper levels of Availability of ships and ship systems and equipments. This is a high-priced Board by any measure and that is a visible indication of the importance that the Director General Ships places on achieving Availability. The Board not only investigates intramural activities, but also goes out into Industry and carries out detailed reviews of projects. Where it is not satisfied it goes back again and again so long as necessary. In the audience there are gentlemen from one or two of the companies that that Board has already visited—and, with no names, one of them twice. I look forward to meeting more of you at these reviews.

So much for what the Royal Navy is doing in its drive for enhanced Availability of ships and weapons systems. What lessons have we learnt to date and how do I see the way ahead?

First, and very importantly, to reap real benefits, Availability must be addressed at the earliest conceptual stage and pursued in a disciplined manner through all stages of design, development, test, and evaluation to the in-service stage. The potential rewards of picking up the point at subsequent stages diminish very rapidly. The Weapons Acceptance Authority and Ship Department Material Availability Board are ensuring that this is so for their respective projects.

In enforcing the requirement to start at the concept stage, there will, from most being immersed for the first time, be cries of 'We are short on data—MTBFs, MTTRs, detailed costs, and so on'. There is never an abundance of data and, I suggest, by the very nature of the game, there never will be enough to satisfy all. But what we have learnt is that, sparse though the data is in some fields, what *is* available, if used intelligently and with a proper level of professional judgement, holds worthwhile potential value. It is surprising how often clear indicators can be obtained from relatively scanty and crude data provided, I reiterate, it is used intelligently and with sound professional engineering judgement. Used without that judgement, the issue is fraught with danger. What I have said should not be construed to mean that we can be complacent with our level of data accuracy and collection; it is clearly not as satisfactory as it needs to be and steps are being taken initially in the weapons field to develop means of automatic data capture and ADP systems to store and analyse the data ashore.

In so far as costs are concerned, there is increasing evidence that the most cost-effective means of achieving proper levels of Availability of naval material is, in general terms, through enhanced reliability and this is where the Royal Navy is placing emphasis and resources. Is what we are achieving cost effective? Sufficient time has not yet elapsed to provide real evidence. I could, however, give you many illustrations of the cost of not taking disciplined steps. To give two: in some ships, the main propulsion machinery control systems have a failure mode in which the controllable-pitch propeller blades can move in an uncontrolled manner from ahead to astern pitch. A post-design FMEA revealed this deficiency, but, by this time, examination revealed that removal of the offending failure mode required a degree of change that could not be realized through lack of space. Had FMEAs been carried out at proper stages in the design process, it could have been obviated without penalty. Now, we are spending some £350K in these ships replacing elements of the system with more reliable components so that this deficiency will arise less frequently—but note, it is still there. On a somewhat different tack, if we can raise the MTBF of a particular diesel engine to be fitted in a new ship design, of which 12 ships are projected, from 600 hours to 1000 hours, then potential savings over the life of the ships are very conservatively estimated at £9M—no small incentive for reliability growth well inherent in the engine.

We do have gaps in our technical armoury. In addition to that of data collection referred to already, the increasing use of software is highlighting our need for techniques to improve software reliability so as to avoid protracted software proving times. It is significant that software reliability and data collection both warrant separate sections in this symposium, and I look forward to learning something from the experts. Failure Mode Effect Analysis and Fault Tree Analysis have been found powerful tools. These analyses have variations and many are well established but, as we have found to our cost, they are not sufficiently widely understood and used. As already mentioned, the Royal Navy is spending significant sums of money to correct or reduce the impact of failures in systems which were not methodically subjected to FMEA or Fault Tree Analysis in the design stages. From this experience, it is now routinely required that systems and equipments be subjected to Fault Analysis as an integral part of design.

The drive for Availability brought growing recognition of the education problem. As I said earlier, there is no dearth of basic techniques necessary to carry out the analyses and processes required in ship system and equipment design. The fact is, however, they are not yet sufficiently widely understood and methodically used by those who can influence the design; that is, sufficient designers are not using them as an integral part of the design process. The Ship and Weapons Departments are jointly tackling this education problem and have developed a programme of courses for those involved in the design task. These courses are not academically orientated but are feet-on-the-ground courses aimed at design staff. We have had contractors' staff attend these courses and the demand is for more places. I am also encouraged by the number of contractors who are now sending their staff on alternative courses.

Ladies and gentlemen, the Royal Navy is driving for improved Availability of naval material and I hope that from what I have said this morning you will judge that we are driving in a determined and disciplined manner. We have the bit between our teeth and, with concerted joint Ministry-Industry effort, believe that the levels of Availability which the Royal Navy seek are well within our grasp. The prime need is for methodical and disciplined use of the technology and techniques by those engineers who can have a direct impact on design and development in a truly professional manner.

Thank you for inviting me here today.