WEAPONS AND SENSORS

BY

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ABSTRACT

This article examines the evolution of naval weapons and sensors, looking particularly at the manner in which full advantage has been taken of recent advances in technology. The development of digital processing techniques is seen as the greatest influence on current equipment design and has resulted in the integration of discrete weapons and sensors into unified combat systems.

The crucial role of command systems in providing the tactical picture and in coordinating the resources of friendly forces is discussed, and the increasing difficulty of coping with the quantity of information available is highlighted. Ways in which new technology may be applied to solve the latter problem are outlined.

Introduction

The exploitation of emerging technology for offensive and defensive purposes is not a new feature of our civilization. Throughout history, almost every technical innovation has found a military application and in many cases the military requirement has stimulated the initial research. Naval warfare has remained at the forefront of development and a modern warship is equipped with a formidable outfit of weapons and sensors to enable it to perform its function.

Naval supremacy has always rested with the side best able to monitor and control the environment. In modern warfare, sensors provide the means of monitoring the environment whilst weapons give the ability to modify and control it. Improvements in equipment capability have led to an increase in the complexity of the environment, which in turn has stimulated the demand for yet more sophisticated weapons and sensors to counter the perceived threat.

The strategic objectives of maritime powers have remained fundamentally unchanged since Nelson's time but the area over which a single ship is able to exert an influence has increased dramatically, particularly since the Second World War. This is largely due to the improvements in the ability of sensors to monitor the environment and to the increase in the range and destructive power of weapons that allow the environment to be controlled. Enhanced communications have contributed to the effectiveness of individual ships and, most significantly, to the coordination of the resources of a number of platforms.

The main thesis of the article is that, whilst the capability of a warship is determined by the outfit of weapons and sensors, its effectiveness depends on the ability of the command system to support the command team. The command system is the limiting factor in realizing the potential of modern warships and it is argued that further development of weapons and sensors will be of limited benefit unless significant progress is made in command system technology. Ways in which current commercial developments may be exploited to achieve this progress are explored and the paper concludes with a view of the impact that knowledge-based systems may have on combat system design.

The Environment

The environment of interest to a warship is determined by the perceived threat and by the capability of the ship's weapons. Until early this century naval commanders relied solely on human senses to detect the opposition and the limited communications meant that intelligence information was not available in real time. Consequently, naval battles were fought with the protagonists within visual range of each other. Numerical superiority was crucial, as was firepower. The advent of torpedoes, mines and submarines introduced a severe complication to the environment, as swimmers and outlying rocks had previously been the only significant underwater threat. Similarly, the development of aircraft provided the means to exploit the air environment. As these new threats were posed, so it became necessary to counter them by their detection and subsequent elimination.

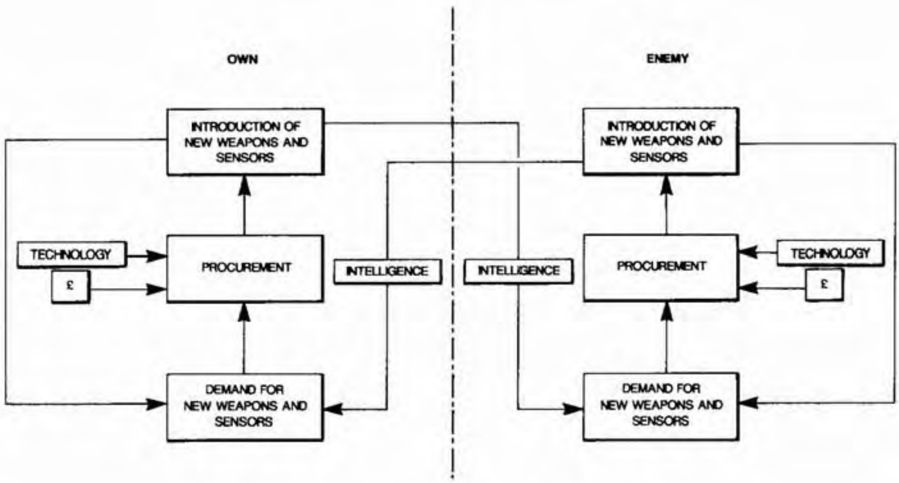

FIG. 1—PROCUREMENT MODEL FOR OPPOSING NAVIES

The struggle for naval supremacy can be represented by the simple but highly unstable model shown in FIG. 1. The only effective controls on the evolutionary process are the availability of the necessary technology and funding. The time constants are determined by the procurement time and the efficiency of the intelligence gathering. Even without the complication of the intelligence input, the development of new weapons and sensors by one side stimulates the demand for new equipment; enhanced sensor coverage requires weaponry to exploit the additional information and the introduction of better weapons needs to be supported by new sensors to provide the targeting information. The shift that has occurred recently is that technology is now an accelerator rather than a damper on the development process. Instead of development being limited by the available technology, the only real constraints on the system are the procurement lead time and the available funding.

Sensors

Sensors fall into two categories; active and passive. Active sensors rely on emitted radiation being reflected by a target, passive sensors detect emissions originating from the target. Submarines tend to rely exclusively on passive sensors so as to remain undetected themselves whilst surface ships, being rather more difficult to hide for any length of time, are more prepared to use a combination of active and passive sensors as the tactical situation demands. Passive sensors are used principally for initial detection and classification whereas active sensors are particularly useful for target localization and tracking.

Radar is a primary sensor in surface ships and is used for both surveillance and target tracking. The design of a particular system is determined by its role, surveillance radars being characterized by high power, low frequency transmitters, and large aerials with slow rotation rates giving all round coverage at long ranges. Tracking radars use high frequencies, very directional aerials and complex control systems to maintain lock on the target. A feature of modern trackers is the combination of several radar and optical systems on the same mounting to provide a capability under adverse conditions. All radars use highly sophisticated radio frequency (RF) techniques to optimize performance and to achieve resilience against hostile jammers. Whilst the last 50 years has seen a steady development in RF capability, the major advance recently has been in the increased application of digital processing techniques to radar signals. These not only enable significant improvements to be made in the quality of the displayed radar picture through stochastic filtering, but also allow the information derived from radar systems to be integrated with that from other sensors. A further benefit of digital processing is the improvements in aerial design that can be achieved by using modern phase comparison techniques. These result both in improved aerial efficiency and in smaller, lighter antennas with reduced topweight and windage.

Sonar is the principal underwater sensor for both surface ships and submarines and is also deployed from helicopters and fixed wing aircraft, the latter using air-dropped sonar buoys. Whilst the principles have remained unchanged since the original asdic sets, once again the availability of digital processors has led to a fundamental change in the operational capability on tactical use of sonar systems. The limitation of passive sonars used to be their poor directional accuracy and their inability to measure target range. These shortcomings have been overcome by the application of improved signal processing which now allows the highly accurate estimation of target position from passive sonar alone. The towed array sonars now used extensively in surface ships and submarines not only achieve accurate results at long ranges but are also less susceptible to own ship noise than are their hull-mounted counterparts.

Whilst radar and sonar continue to be the primary sensors in a warship, a wide range of other sensors are fitted to enable a complete picture of the environment to be deduced. Electronic support measures (ESM) play an increasingly important part in modern warfare, providing the means to monitor the RF spectrum. ESM is a development of the Radio Direction Finding (RDF) equipments that were introduced as soon as wireless and radar began to be used widely. The feature that characterizes modern systems is their ability to determine automatically the parameters of a received signal and to compare them with a library of known emitters held in a computer data base. This enables rapid and accurate classification of signal and hence target identification. Identification Friend or Foe (IFF) is also used to interrogate and identify specific contacts.

The increasing complexity of the RF environment and the susceptibility of RF sensors to jamming and interference has stimulated the demand for sensors that use other frequencies for target detection. Optical sensors are widely fitted, with a rapid growth in the use of lasers for target illumination and range finding. Sensors are available that can detect a ship's infra-red or magnetic signature and chemical sensors that exploit exhaust emissions are a logical development.

As ships and submarines become better able to conceal themselves by reducing their own signatures and minimizing the use of active sensors, so the demand for even more sensitive and accurate sensors will continue. The key to effective use of the outfit of sensors fitted in a ship lies in the ability to collate information from a variety of sources and so derive more complete knowledge about specific targets. The exchange of information via tactical data links between friendly units is essential in achieving a composite picture, and significant progress has been made in automating this function.

Weapons

The development of the performance and scope of sensors in monitoring the environment has been matched by the development of weapons to control it. Guns are no longer the primary offensive naval weapon, although they still have an important role to play. The problem of predicting accurately a fast moving air target's manoeuvre during the time of flight of a ballistic shell has meant that the conventional large calibre gun is no longer an effective anti-aircraft weapon. It is, however, still highly effective in surface-to-surface engagements and shore bombardment. Smaller calibre, rapid-fire guns are used extensively for self or point defence and a significant recent development in these weapons has been the application of closed loop spotting techniques. The stream of bullets is tracked by radar and gun pointing is then corrected so as to bring the stream on to the radar target. This removes the need for target prediction and greatly increases the kill probability, particularly against closing targets with low crossing rates.

Guns also play an important part in providing a layered offensive capability. A warship may be called upon to perform a variety of peace-keeping and patrolling duties, frequently against a less capable opposition. Firing half a ton of guided missile across the bows of a recalcitrant fishing boat hardly comes within the strict definition of the use of minimum force and in these circumstances a gun is a much cheaper and equally effective means of achieving the same objective.

The development of guided shells is progressing and may allow large calibre guns to be considered as viable anti-aircraft weapons. A control system is fitted to allow the shell to be redirected in flight and, subject to adequate kinetic energy remaining, guided onto the target. The relatively low cost of these projectiles makes them highly cost-effective and their size allows a large number to be carried in a ship. The principal limitations are the short effective range and the susceptibility of the guidance link to jamming. The short-term difficulty is the development of a sufficiently robust guidance system that does not slow the shell excessively.

The principal weapon in the armoury of a warship is now the guided missile and a ship will be fitted with a number of systems to provide both surface-to-surface and surface-to-air capability. Tactical, as opposed to strategic, missile systems are now also being fitted increasingly in submarines and pose a potent threat.

The technology embodied in missile airframes and propulsion systems was developed in the aerospace industry, the tracking and guidance systems and warhead being more specific to the naval application. Guidance systems now allow the missile to do more 'thinking' for itself, reducing its reliance on the launch platform and providing greater resilience against jamming and seduction. Warhead design concentrates on achieving an optimal balance between lethality and weight with sophisticated fusing systems being used to ensure detonation as close as possible to the target.

The remote targeting capability provided by data links allows a missile to be fired against a target beyond the range of the launch platform's sensors and a missile can be well into flight before the guidance system is given the selected target. Apart from the cost of guided weapons, which can exceed £1M per missile, the major limitations on their use are the relatively small outfits of missiles carried in a ship, the difficulty of resupply at sea and the low number of simultaneous engagements that can be carried out. A single ship relying on missiles alone has a very short survival time against a stream or saturation air attack and even a group of ships operating together cannot put up an impenetrable screen of missiles.

Survivability depends on the use of a combination of hard kill weapons, such as guns and missiles, and soft kill weapons. Examples of the latter are electronic jammers and laser damage or dazzle weapons, the common feature being that no projectile is required. Jammers can be used both against the sensors of enemy units and also against incoming weapons. Early jammers relied mostly on radiated RF power alone to interfere with enemy radar but these were succeeded by more subtle systems, designed to confuse and seduce rather than just swamp. This resulted in greater effective jammer ranges and reduced RF power outputs and obviated the need for the jamming ship to stand out like a homing beacon. Considerable research is now being done on highly directional 'electric' guns, designed to damage the electronics of enemy sensors and weapons by firing bursts of focussed RF energy. This, together with laser damage weapons, is being actively addressed in the American Strategic Defence Initiative programme and there will undoubtedly be a spin-off of the technology into naval weapons.

Command Systems

The increasing complexity of the environment and the wide choice of weapons available place great demands on the command team. The process of collating and interpreting data from the sensors presents severe problems of coordination and display whilst the efficient deployment of weapons calls for a complete awareness of the tactical situation and equipment status. The ship can no longer be considered as having an outfit of independent weapon and sensor equipments but must be regarded as a platform for a unified combat system. The combat system comprises all those assets that the command has at its disposal for fighting the ship, the command system being a key element, within the combat system, that provides the command team with the facilities necessary to manage its resources.

Computerized command systems were first introduced in the Royal Navy in the early 1960s and were used exclusively for picture compilation and aircraft control. Subsequent developments in processor and data storage technology enabled the role of the command system to be expanded to include the provision of target tracking and weapon control facilities. The processing power of the large computers fitted in the command system was used to automate many of the functions associated with the weapon and sensor equipments and the centralized architecture evolved as shown in Fig.2. Each peripheral equipment is interfaced directly with the command system and data communication between equipments can only be achieved via the command system. The reliability and performance of the command system becomes a critical factor in determining the effectiveness of the overall combat system and achieving the required standards has proved difficult, particularly

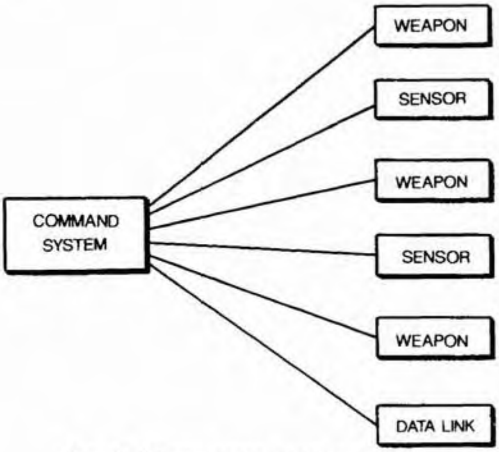

FIG. 2—CENTRALIZED COMBAT SYSTEM ARCHITECTURE

in the design and implementation of the command system interfaces. The principal limitation of this architecture, however, is the size and complexity of the command system software necessary to support the displays and interfaces. This results in high development and support costs, long procurement lead times and a lack of flexibility to adapt to weapon and sensor updates or changes in tactical doctrine. Large amounts of data pass through the command system unnecessarily, often causing bottle-necks, and system response times can become unacceptably slow.

The current wide use of computers within weapons and sensors means that it is no longer necessary for the command system to carry out data processing on their behalf and equipments are now capable of communicating directly with each other. The trend is to carry out processing where the need for it arises, thus reducing the need for data communication, and weapons and sensors are linked via a data highway. The architecture of this type of distributed system is shown in FIG.3 and the Type 23 frigates are the first R.N. ships to adopt this approach. The highway itself is a twisted pair of wires, duplicated along several parallel paths to provide resilience under action damage conditions. Member systems are joined to the highway by highway connection units built to a common design, thereby ensuring electrical compatibility between interfaced systems, and data message protocols are established to provide software compatibility. Further details were given in this *Journal* by Anstee[1].

The command system is treated as a member system on the Combat System Highway. Command system messages are handled in the same way as any other messages on the highway and sensors and weapons can continue to communicate with each other even if the command system fails.

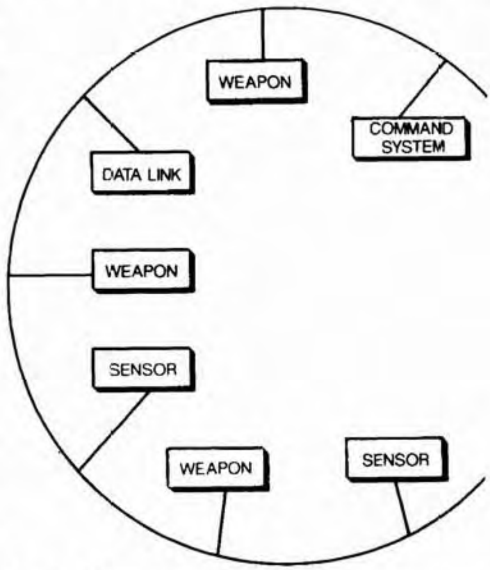

FIG. 3—DISTRIBUTED COMBAT SYSTEM ARCHITECTURE

The design of command systems is also moving towards a distributed architecture, offering more efficient use of processing power, improved reliability, and software that is more easily managed and better structured. User workstations are capable of largely autonomous operation but are connected to a network that allows access to common data areas and which enables information to be exchanged between operators and their systems. Commercial equipment and techniques are used increasingly in the design of command systems, both in the hardware and in the software operating systems. This is helping to control the acquisition costs but the application software continues to require highly specialized, expensive and time-consuming development. It is in the applications area, however, that still more effort and resource need to be concentrated if the full potential of modern warships is to be realized and if incidents such as the shooting down of an Iranian airliner by the U.S.S. *Vincennes* in July 1988 are to be avoided.

The volume of information provided by sensors far exceeds the assimilation and retention capacity of the command team and filtering of the raw data by the command system is necessary. The information provided by different sensors will usually be corroborative and will contribute towards the compilation of an accurate representation of the environment, but often the information will be incomplete or inconsistent. The command system may either resolve conflicts using programmed rules or may refer them to an operator for a decision. In the former case there is a risk that the algorithms may be inadequate to deal with the situation; in the latter, the risk is that the operator may make an error of judgement due to stress or lack of ability, training or information. Either way, the result can be a wrongly classified friendly or neutral contact which is subsequently engaged and destroyed. Even if the initial classification is correct and the contact is hostile, a weapon may be assigned to the wrong track or two units may each believe that the other is engaging the track, the outcome being that the enemy is not prosecuted. The density and complexity of the threat is rising and so too is the pressure to reduce the size of manpower complements and required skill levels. The computer-assisted fog of modern naval warfare can only be dispersed by a radical improvement in the capability of command systems.

Sensor and weapon system evolution has taken account, in some cases not necessarily deliberately, of the fact that warfare is essentially probabilistic rather than deterministic in its nature. For example, target detection algorithms examine noise to establish whether it is more likely than not that a pattern corresponding to a contact is emerging, while weapon warhead design relies on an assessment being made of the probable distance from the target at which it will detonate. Current command system philosophy does not show the same realism and seeks to provide determinate solutions from incomplete information. The principal reason for this shortcoming is the immense difficulty of specifying what is required of the command system. The tendency, because it is easier, is to analyse what the command team is doing and then attempt to automate it rather than to establish why the team takes the actions it does and then to model the process.

The command systems that result from this approach are able to perform mechanical tasks, such as track labelling, satisfactorily but cannot provide real assistance in decision-making where it is so urgently required. Current practice tends to be carried forward from system to system and the design stagnates. A further factor is the reluctance of users to delegate important decision-making to the command system. The system will normally be required to prove itself significantly better than the individual, rather than just his equal, before being allowed to make decisions. The illogicality that emerges is that whilst it is accepted that humans may occasionally make fatal mistakes, command systems are allowed no such latitude, despite making few mistakes. There is no place for such inconsistency in a conflict whose outcome will be determined by the balance of probabilities.

The Way Ahead

The development of weapons and sensors has outstripped that of the command system to the extent that much of their medium and long range capability cannot be used effectively. Point defence is achieved using systems that are largely independent of the command system and which apply their own draconian criteria for determining whether to engage an incoming target. A small risk of destroying non-hostile tracks is accepted as being preferable to being sunk and it is this principle that should now be extended into command system philosophy. Intelligent knowledge-based systems already exist that allow complex decision-making problems to be expressed in terms of probabilities and this approach is ideally suited to warship command systems. The implementation of such a system, however, is unlikely to be achieved for at least another ten years. In the meantime, the integration of existing equipment into properly engineered combat systems is likely to be the most cost-effective way to improve both survivability and offensive capability.

Reference

1. Anstee, R.J.: Combat system highway engineering in the Type 23; *Journal of Naval Engineering*, vol. 30, no. 1, Dec. 1986, pp. 85–105.