NAVAL SHIP TECHNOLOGY

IN THE 80s AND 90s

by

William D. O'Neil
Director of Naval Warfare
Office of the Under Secretary of
Defense for Research and Engineering
Department of Defense

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By William D. O'Neil
Director of Naval Warfare
OUSDR&E

In this age of "high technology," it can be very frustrating to be a ship person. The shipbuilding industry is often taken to epitomize "low technology" conservatism, lack of innovation, slowness to change. Yet when the marine community does produce something new and different - surface effect ships, hydrofoils SWATH - the excitement usually seems to die out rather sharply as the time comes to get into production.

One response to this frustration is to approach the question of what innovations are to be adopted by the Navy as a purely political one, to be settled on the basis of the political strength of those involved. It would be fatuous to deny that this can be effective - each of us can name ships that would not have been built and systems that would not have seen service but for the intervention of the political process. Yet to cast this purely, or even largely as a political question, beyond disinterested analysis and debate, is to debase it to a war of everyone against everyone, in which victory must go to the most cynical and ruthless. Those who do not aspire to excellence in cynicism and ruthlessness had best give some thought to the rational purposes ships may serve.

We have to guide our thoughts on this, some 150 years of history of rapid technological development in naval ships. (If the pace of technological development has not been as rapid as some might wish, it nevertheless has been extraordinarily rapid by any historical standard.) During this period a great many innovations, great and small, have been adopted in naval ships. At the same time, many proposed innovations have failed of adoption. Why was there more innovation in this era than in previous epochs? And why did some innovations succeed where others failed?

The opportunity for innovation clearly reflected larger trends in Western society which we need not belabor here. The reasons why innovations were taken up were, in some cases, wholly or partly economic. Thus, for instance, a series of engineering improvements and a few basic cycle changes have brought steady progress in ship propulsion energy density and power density. Since these permitted ships to be made smaller for any given mission they were economically attractive and were widely adopted. (Reductions in fuel cost were also desirable but until recently were generally of less economic significance for naval ships than ship size reductions.)

Of course there are a great many features which were once important but which have now become historical curiousities, overtaken by other innovations which offered still greater economic advantages — scotch boilers, triple expansion engines, paddle wheels, and scores more. And many other features, seriously proposed and perhaps even tried on small scales, fell victim to the same fate before ever seeing widespread application in naval ships.

Actually, one might exercise some considerable caution in discussing systems which have become economically obsolete, or have not achieved economic attractiveness. Conditions and technologies can change. Twenty years ago, for instance, most people would have said that electric drive was an idea which had never really made it, doomed by excessive weight and losses, so that it simply could not compete with gearing in either energy density or power density. It had seen widespread use only when wartime demand had outstripped gear manufacturing capacity, and then only in secondary types of warships; most people would have bet that it would only be under such conditions that it would ever see any but specialized uses again. But the general shift to gas turbines (with their relatively poor part-load efficiency and difficulties in providing auxiliary power drives and shaft reversing) as warship prime movers, significant advances in electrical machinery and controls technology, and great jumps in fuel costs (thus increasing the value of even relatively small improvements in thermal efficiency) have combined to make it appear that electric drive will soon re-emerge as an attractive option for warships.

In making economic tradeoffs in warship design it is frequently found that there are two or more quite different systems which are very close, economically, and that small changes in the assumptions or the basis for comparison can alter the choice. Sometimes this results in one system always losing out by just a hair, so that it never comes into wide use even though it is nearly as good. Often it results in one system winning out in this application and another in that, in a seemingly random pattern which can bemuse those unable or unwilling to probe deeply. Or it may give prominence to unquantified factors.

The example of the gas turbine's adoption is thought-provoking. By the late 1950s it had become clear that the gas turbine was a practical prime mover which offered substantial potential for improved power densities. By the mid 1960s a number of gas turbine propelled warships were in service with several foreign navies. (Most used gas turbines for high speed boost only: the Soviet "Kashin" class destroyers were the first major class of all GT warships.) The first major U.S. warships with gas turbine propulsion did not appear until the mid 1970s, and the U.S. Navy endured a good deal of criticism and no little ridicule for its slowness to adopt this "advanced" form of propulsion, usually attributed to excessive conservatism and timidity on the part of BuShips/NavShips.

Yet a closer examination reveals a more complicated and interesting story. The conditions which the U.S. Navy faced were by no means the same as those which influenced others to go to gas turbine propulsion in the early 1960s. Because our Navy's bases lay so far from its area of operation, the Navy demanded long cruising ranges at 20-knot speeds, creating total energy requirements substantially in excess of those for most foreign warships of comparable size and type. At the same time, the U.S. Navy was willing to accept slightly lower speeds than some foreign navies, substantially reducing power requirements. Thus energy density was relatively more heavily weighted, and power density relatively less heavily weighted, in U.S. Navy tradeoffs than in those of the navies which had moved quickly into gas turbine propulsion.

The situation differed on the technology "supply side" as well: while the U.S. had a strong gas turbine industry, the U.S. Navy had led in the development of steam plants operating at higher steam conditions and had reaped significant advantages in both energy density and power density over the steam plants available to other navies. The net effect was that the gas turbine's advantage in power density over steam was relatively less in this country than in others, as well as being of lesser significance, while its disadvantages in energy density were both greater and of greater consequence.

By the late 1960s much had changed. GE had produced a gas turbine whose efficiency at full power rivaled that of the best steam plants, and was reasonably competitive even at part power, while also offering unexcelled power density. Moreover, the Navy had come to believe that it would become increasingly difficult and expensive to meet the operating and maintenance needs of steam plants, while the LM2500 promised to be easy and economical to operate and maintain. There were also some subsidiary benefits, such as rapid starting and response.

Even so, the choice was not so clear-cut as some have since made out. Babcock and Wilcox and GE (another division) counterattacked with a very innovative and attractive steam plant. If it could not quite match the gas turbine alternative in terms of total weight of machinery plus fuel it offered attractions in avoiding the need for separate systems for reversing and electrical power generation. Moreover, there was at that time a distinct differential in the prices of the residual fuels then used by steam plants and the middle distilates demanded by gas turbines. Thus the decision for gas turbines in the case of the DD 963 class was something of a judgement call. Subsequent events seem, in general, to have confirmed the wisdom of the choice and there seems little likelihood of a widespread revival of steam for warship propulsion. But it is difficult to see in the selection of gas turbines the inevitable and divinely inspired triumph of progress and light over the forces of blind conservatism that some paint.

Indeed, it is difficult to point to many innovations whose virtues have been so manifest as to secure their acceptance on general principles. In the great majority of cases innovations win acceptance only when they appear in the form of carefully-engineered systems of demonstrable practicality and economy. This, of course, raises a very vexing question: Who will be willing to pay for the necessary engineering, prototyping, and testing to turn an innovative idea into a competitive system? Or, to put it in the form often heard by those in my position, "Why don't you idiots have enough sense to support development of my wonderful idea?"

The classical theoretical judgement on the development of innovations is that it is economically desirable just in those cases were the effective rate of return on the money so invested is greater than the returns available on alternative investments. This is a perfectly sound principle, but unfortunately there are usually wide differences between the highest and lowest estimates of the returns to be gained from the development of any given proposed system. There is inevitably a great deal of judgement involved, particularly at the early stages. Thus the would-be developer finds himself condemned to a weary round of efforts to convince others of the merits of his ideas--many of them people who are ill-prepared to understand his technical arguments and ill-disposed to listen. Failure thus to secure sufficient resources for development can doom an otherwise meritorious idea. Fortunately, it is usually easier to convince others of the merits of ideas whose benefits are specially great

Thus far, the discussion has been confined to the economic aspects of technology innovation for naval ships. This of course does not exhaust the topic of naval ship technology, and indeed does not even touch upon the aspects of naval ship technology which first occur to most people: technology for greater military effectiveness.

Unfortunately, the military virtues of a proposed innovation are generally a good deal more problematical than the economic benefits. In general, the military impact of any significant innovation can be adequately evaluated only after thorough consideration of the innovation's interaction with and impact upon all cooperating forces, <u>and</u> the probable enemy reactions. To do this often requires access to knowledge which is very closely held, or is at any rate rather recondite by ordinary standards. This can make it difficult to conduct truly meaningful discussions of military technology issues, as it is precisely the innovations which have the most far-reaching implications which are most hidden from public view. It has been my observation that there are in fact very, very few real experts on the broader aspects of military technology: those who have adequate time for reflection generally lack a great deal of crucial knowledge, and those who possess adequate knowledge (a very small group) for the most part have no time whatever for reflection.

It remains possible, however, to obtain some useful <u>partial</u> insights into military technology for naval ships. First it is necessary to observe that most innovation issues will involve both military and economic considerations. For instance, consider the question of increasing density. One of the characteristic features of technological progress in all areas is that it tends to offer increases in density -- output power per unit of constraining input. As noted above in connection with propulsion systems, this raises the purely economic issue of whether the reduction in ship size will (in conjunction with any other economic benefits) be great enough to pay for the cost of development. In addition to this, in many cases, comes a military issue of how much of that class of output may be required on any given ship.

This can perhaps best be appreciated through consideration of a concrete but simplified and purely hypothetical example. Let us suppose that we have a ship whose missions include jamming a certain enemy radar whenever the airplane which carries it approaches within the range at which it can launch a weapon at our ships. At present the enemy's weapon range is 100 nautical miles, his radar is restricted to a 10 MHz band, a jamming level of 100 W/MHz into the radar's sidelobes will deny it any detection or tracking capability at a range of 100 n.m. Thus the present jamming output of 2 KW is quite sufficient.

But the threat is not standing still. Intelligence estimates that the enemy is developing a new aircraft which will carry a more powerful and sophisticated radar and longer-ranged weapons. To counter this threat will require a jammer with 1 MW of power, weighing 100 tons. It may turn out that such a thing is simply inconsistent with the other aspects of the ship's missions. Or perhaps it it found that it is more economical, in the altered situation, to counter that threat in some other manner — say with an airborne jammer which can be carried much closer to the threat radar.

In any event, the new 0.2 ton, 2 kW jammer does not get taken up. And since the intelligence projections of the new threat, and our own plans to deal with it, are naturally very sensitive, the naval authorities are quite vague about the reasons for rejecting the new jammer. Moreover, the new ship might end up fitted with another jammer of lesser capability in order to meet other needs. All of this may well leave the would-be manufacturer of the new jammer wondering if he had somehow been done in by a nefarious scheme, or bureaucratic incompetence.

It is of interest to apply this sort of thinking in the matter of ship speed, since it is speed upon which many contemporary innovations focus. The search for speed at sea has a long and fascinating history. The introduction of the automobile torpedo about a century ago gave it new impetus, since torpedo craft needed a considerable margin of superiority in speed to have any chance of gaining a favorable firing position against an alerted opponent. Given the limitations of contemporary gun mounts and fire control systems, it quickly became apparent that aspiring destroyers of torpedo boats had also better be fast. What was wanted was dash speed; a torpedo attach on an alerted battle line would all be over, one way or another, in the space of half an hour.

All of this led to some very remarkable ships. But between about 1910 and 1950, improvements in gunnery gradually changed the "overt" torpedo attack against a prepared enemy from a feasible, if always risky, operation of war to a matter of plain suicide. It no longer depended on the relative speeds of torpedo craft and defender; by 1950 it was becoming suicidal to deliver torpedoes even with airplanes.

At this point the Soviets were the only major power with much incentive to think about attacking naval battle forces. They correctly perceived that it was the advent of real standoff weapons -- weapons able to hit accurately at ranges approaching detection range -- which had (together with the extension of detection range brought by radar) rendered surface torpedo craft obsolete. They then decided, with impeccable logic, that the battle force's standoff weapons could be countered in either of two ways: arm the attacking force with weapons having still greater standoff range, or nullify the battle force's standoff range advantage by preventing it from detecting the attacker. The first line of thinking led to the antiship cruise missile, the second, to the submarine. (Both already existed, of course; the Soviets simply refined the designs and built up large forces.)

In many respects, the problem presented by the submarine in 1950 was like that of the torpedo boat in 1900. In 1950, surface antisubmarine warfare (ASW) ships could detect submarines and engage them only at very short ranges. It followed that the ASW ship needed a speed advantage over the submarine. This created few problems against diesel-electric submarines, even the most advanced of which never had burst speeds much in excess of 20 knots. The advent of 30-plus knot nuclear submarines might have been expected to create a need for very fast ASW ships, however. But the U.S. Navy elected instead to pursue a standoff capability against submarines. This has in fact been achieved to an extent which effectively nullifies ASW ship speed as a tactical factor. The typical engagement of a submarine by an ASW ship now would involve a sonar detection at a range of many miles, followed by dispatch of a helicopter or a rocket to deliver a torpedo. War games and simulations show that high dash speed would only rarely be of any value to the ASW ship, regardless of the submarine's speeds.

Interest continues to attach to high transit speeds for ships, independent of dash speed. First of all, just as in commerce, high transit speeds can bring economies through increased utilization of expensive capital resources. Beyond that, however, there is the military consideration of strategic mobility; the ability to transfer forces rapidly from one theater to the next. It is, fundamentally, this consideration which has led the Soviet navy to stress long range aircraft as carriers of antiship cruise missiles.

As noted before, the U.S. Navy has placed more emphasis on sustained high transit speeds for its ships than any other major naval power. Even so, its hydrocarbon-fuelled ships have deficiencies in strategic mobility which are sometimes serious, and naval leaders have stated that they would prefer to build only nuclear ships, if it were feasible. Thus any innovation which brought increased transit speeds would be welcome just in case it brought improvements in specific resistence or energy density sufficient to permit ranges at least as great as those achieved by today's ships at their lower transit speeds. Moreover, the innovation would clearly have to be more affordable than, say, nuclear power.

All of this is not to say that speed lacks value; it is for their speed that we buy most airplanes. If airplanes did not exist we should undoubtedly be more interested in faster ships.

All in all, it is difficult to envision dramatic developments in those aspects of naval ships which have traditionally been the principal focus of interest for naval architects and marine engineers. Yet there will certainly be changes, and I will venture a few personal observations and predictions:

— The dominance of the gas turbine as the power source for warships will continue and, if anything, grow. Medium and slow speed diesels will be seen with increasing frequency on naval auxiliaries and even certain combatants, because of the operating economies involved with their low fuel consumption. New generations of gas turbines will continue to be derived from aircraft engines, but will come slowly due to the very high development costs (typically about $1 billion for a major new aircraft engine).

— The search for energy density, and fuel cost savings, will lead to increasing integration of shipboard energy systems.

— Nuclear propulsion systems with increased power density and reduced cost would be very attractive, but the costs and risks involved will probably continue to stymie serious development efforts.

— There will be significant use of fiber composite materials — particularly high-modulus materials — in highly weight-sensitive applications. Except for this, there seems to be relatively little prospect of substantial change in ship structural materials.

— A variety of "advanced vehicles" -- (including hydrofoils, surface effect ships, air cushion vehicles, and small water-area twin hull ships — will be built for naval missions in which one aspect or another of their features will be of special value. Most of these craft will be relatively small, however, and there will be no wholesale move toward unconventional vehicles for most missions.

— Modularity, in one form or another, will come to be of increasing interest in naval ship design. There will be great reluctance, however, to pursue modularity past the point where ship size or acquisition cost is significantly affected, regardless of projected long-run savings.

There will be increasing interest in improving approaches to passive protection of warships against a wide variety of weapons. But again, the interest will stop short of anything which will increase ship cost by more than a few percent, except in a few special cases.

— Ships will be host to ever-growing numbers of increasingly complex digital electronic devices, linked by serial data buses.

— Flexible, adaptable robots will increasingly take over the more routinized of shipyard tasks, and may start to take their place in ship "crews."

Development of improved shipboard combat systems will, of course, continue. Announced Navy programs in this area concentrate, for the most part, on systems which are superior to those they will replace but not fundamentally different in principle.

Many people believe strongly that VTOL (vertical takeoff and landing) aircraft will become common on warships of all types over the next two decades. I am not among them for reasons which would make a lengthy paper in themselves.

In general, I believe that naval war will come more and more to be dominated by surveillance: he who can best detect and track his opponents half an ocean away will enjoy great military advantages. Conversely, he who can deny the enemy the ability to find and follow his ships (and other units) will reap similar rewards. In the contest of surveillance and counter-surveillance, operational and technological surprise will be of compelling importance, and so I must leave you, in this area, to speculate for yourselves.

THE END