PROCEEDINGS

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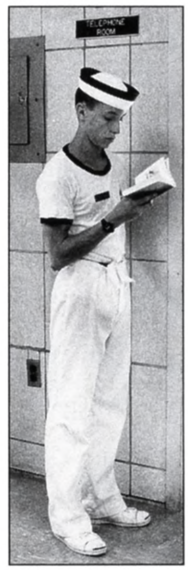

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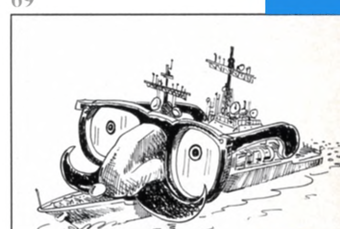

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Cover: Naval Aviation casts its long shadow over the sands of Saudi Arabia today (VF-32 F-14 and VA-75 A-6E attached to Carrier Air Wing Three, embarked on board the USS *Kennedy* [CV-67] by Lieutenant Commander David Parsons, USN), but what's its future? See "Leaner with Marines," pages 34–40. Also, see Special Report on Desert Shield, pages 77–84.

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Don't Give Up On the Ship

By Captain William D. O'Neil, U.S. Naval Reserve (Retired)

Try as it might, the Navy cannot effectively disguise its surface ships from enemy attackers; the wakes of some are visible even from space. But active countermeasures and the unique roles they perform in a wide range of conflicts secure their place in the fleet.

Survival of the ship has never been an end in itself. Keeping it tied up to the quay would accomplish that. The issue is how to survive while accomplishing the mission, and this almost always involves delicate questions of how much mission capability a navy can trade away to gain an increment in survival probability.

At least four aspects of ship survivability relate directly to ship design:

- Evading detection or identification as a target in the first place
- Evading attack once detected
- Preventing or reducing damage from weapons that do hit the ship or detonate in its vicinity
- Mitigating the effects of damage

The ship's sensors, weapons, and control systems, however, may well have more impact on its survival than anything within the orbit of ship design.

The oceans cover approximately 105 million square nautical miles of the earth's surface. Until roughly a century ago, naval forces lost themselves in this vastness, rarely knowing much of enemy movements. Thus, in a strategic sense, warships have long been very stealthy—and stealth has great impact on naval strategy.

But the most recent century has brought profound changes. First, underwater cable networks, then radio, made it possible to glean ship-movement information based on observations relayed by distant friends. Then, as ships came to rely more on radio-frequency electromagnetic emissions and acoustic emissions, the interception and exploitation of these emissions became important and powerful sources of information in their own rights. Aircraft, and lately spacecraft, have vastly expanded the circle of vision. Radio-frequency emissions for radar and acoustic emissions for sonar have added new means of gaining information at distances that grow steadily, as technology advances.

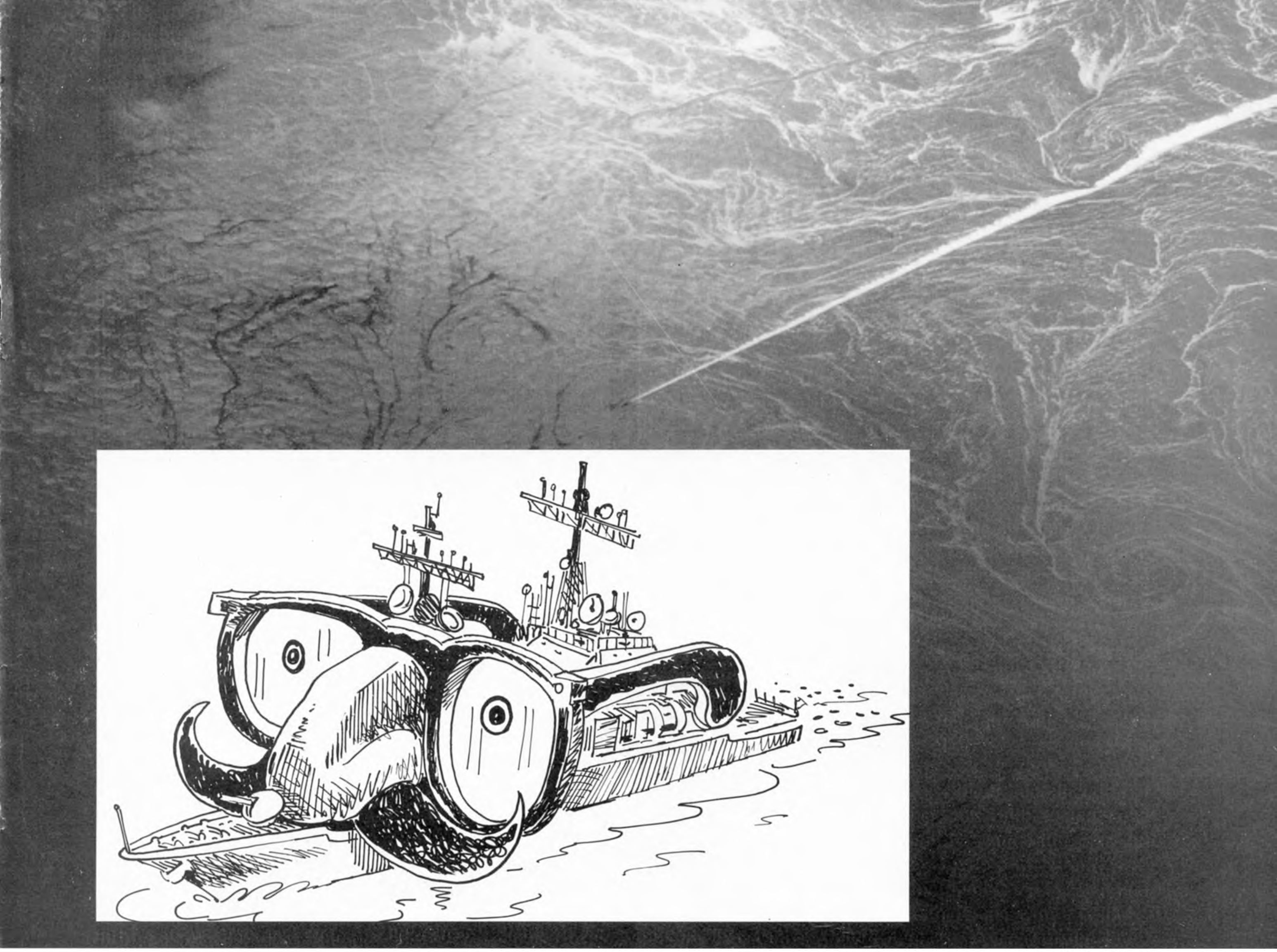
Finally, unintentional energy emissions from ships and reflections of natural energy have increasingly become factors as well. In these ways, the strategic stealth of surface fleets has eroded greatly, at least when opposing a power that has a full range of modern instruments for collecting and assimilating intelligence.

In response, the world's navies created and refined a whole new category of warship, the submarine. In its modern form, a submarine is far more than simply a ship that navigates submerged: designers have done everything possible to make it stealthy, including some modifications that sacrifice mission capability. Submarines are costly, and stealth is their only important military virtue. But that alone makes them the ships of choice for a broadening range of maritime missions.

Of course, modern submarines have carried stealth far beyond that of sailing-ship days. They often can approach within firing range entirely unobserved. Aside from tactical utility, this has been a key to their strategic stealth. It secures them against surprise attack, thus making it reasonably safe to dispense with detectable active radar or sonar sensors in most situations.

Lacking this element of security, surface forces must depend on active systems, such as the powerful SPY-1 radar and SQS-53 sonar—highly effective systems for warning of and fixing threats but also wonderful beacons for opposing forces. Modern naval commanders are keenly aware of this shortcoming in electronic and acoustic emissions and frequently exercise their ships in electronic and acoustic silence. But they see no alternative to using active systems in waters where the risk of surprise would otherwise be high.

Surface forces that silence their electronic and acoustic emissions are most liable to detection by radar, passive acoustic listening, or infrared and visual observation. Radars capable of detecting ships at long ranges operate over a relatively broad portion of the electromagnetic spectrum at frequencies ranging from about 3 megahertz (MHz) (corresponding to a wavelength of 100 meters) to about 10



NASA/INSET: E. SMITH

Gigahertz (GHz) (with a wavelength of 3 centimeters). Clearly, on physical grounds, the mechanisms of target response vary greatly over this range of frequencies, and in general, the radar cross section must also vary.

The radar cross sections of most ships are so large that detection ranges will normally be limited only by the altitude of the radar. Since the distance to the radar horizon (in nautical miles) is about 1.2 times the square root of the radar's height in feet, a radar of moderate power in an airplane flying at 30,000 feet should be able to detect ships at ranges in excess of 200 nautical miles, if employed conscientiously to scan the horizon. If the airplane is flying at a speed of Mach 0.8 (470 knots) and has a 0.8 probability of detecting any ship crossing its horizon, it will sweep out some 75,000 square nautical miles per hour.

This is not sufficient for economical search of vast ocean areas (and places the searching aircraft in danger if interceptors guard the ships), but it is enough to put ships at excessive risk of detection when operating in narrow waters subject to air search.

Radar probably poses the greatest threat of non-cooperative detection in most circumstances, but visual, infrared, and passive acoustic detection can be significant means of detection as well. The accounts of astronauts and the photos they have brought back indicate that the wakes of large ships can be seen with the naked eye from several hundred miles, at least under certain lighting conditions. Calculations indicate that high-altitude infrared detectors of sufficient sensitivity and resolution should also be able to detect large ships at great ranges. In practice, both means of detection are at the mercy of the weather, and naval commanders have often made deliberate use of this fact. But the potential for long-range visual and infrared detection cannot be overlooked if forces must operate in all weather and locales. In addition, sensitive listening arrays can hear and localize propeller and machinery noises of heavy ships at ranges of 100 miles or more.

The following factors contribute to the large radar cross sections of surface ships:

- Numerous dihedrals and trihedrals with included angles near 90°
- Numerous flat plates set normal to prevalent radar sight lines
- Numerous stanchions, kingposts, antennas, and other dipole elements

Correction of these problems can dramatically reduce ship radar cross sections, and applications of coatings or screens of radar absorbent materials can help where such direct measures are not feasible.

One published study outlines how the maximum radar cross section of a typical cruiser might be reduced from 1,400,000 square meters to 320,000. This is a very impressive reduction, but it likely will not significantly affect detection range in most circumstances, since a third of a million square meters is still a large radar target.[1] Much deeper reductions would be necessary for effective protection against radar detection. The engineering problems in achieving this would be substantial, and solving them could significantly compromise ship operability.

Warships are already painted in schemes calculated to reduce their visibility. And, indeed, it is unusual for a ship to be observed directly at ranges greater than about 30 miles, even from the air. The wake is another matter, however, and would have to be suppressed or attenuated for security against visual detection.

The short-wave infrared radiation emitted by a ship's engine exhaust plume is attenuated significantly by the water present in the lower reaches of the marine atmosphere, and it thus is useless for long-range detection of ships.[2] Longer waves emitted by surfaces warmed by the sun or internal energy sources penetrate the marine atmosphere better. But they are still undetectable in most cases more than a few miles away, as long as the sensor is at or near the surface. The problem in infrared detection comes primarily from sensors looking down at the ship from space or high-flying aircraft. Insulation, active cooling, and control of emissivity all have some potential for reduction of infrared detectability.

Measures that have been so successful in controlling radiated acoustic noise in submarines can also be applied to surface ships. In surface ships the propeller's proximity to the surface and immersion in a disturbed wake complicate efforts to control signatures emanating from it. The surface ship can compensate to some extent with its ready access to large volumes of air, which may be used to create bubble screens to attenuate noise.

Because radar is the most effective of these non-cooperative sensors, undertaking expensive efforts to reduce other signatures may be pointless, unless the radar cross section is reduced significantly. Reducing any or all of these signatures will have no effect on strategic stealth, except in cases where the ship can dispense with emissions for sensing and communications or make these emissions undetectable.

At a tactical level, both submarines and hypothetical stealthy surface ships face real limitations on their stealth. Torpedoes can easily compromise the stealth of the firing ship. The same is true of cruise missiles, whose water exit plume can provide an all-too-clear bullseye directly over the launching submarine. And even if these problems were to be overcome, the sudden and otherwise unexplained disappearance of a ship at sea, especially if accompanied by a bright flash and loud noise, is bound to raise suspicions of submarine activity.

Airplanes rely strongly on their speed and relatively unconstrained maneuver to evade attack. Anyone involved in the design of antiair weapon systems can attest to the difficulties these factors introduce. At one time, fast and maneuverable ships could also avoid attack when they chose or could control the terms of action. But the value of speed and maneuverability in this respect has diminished, as hunting ships has become more and more a function of aircraft and missiles that are faster than their prey.

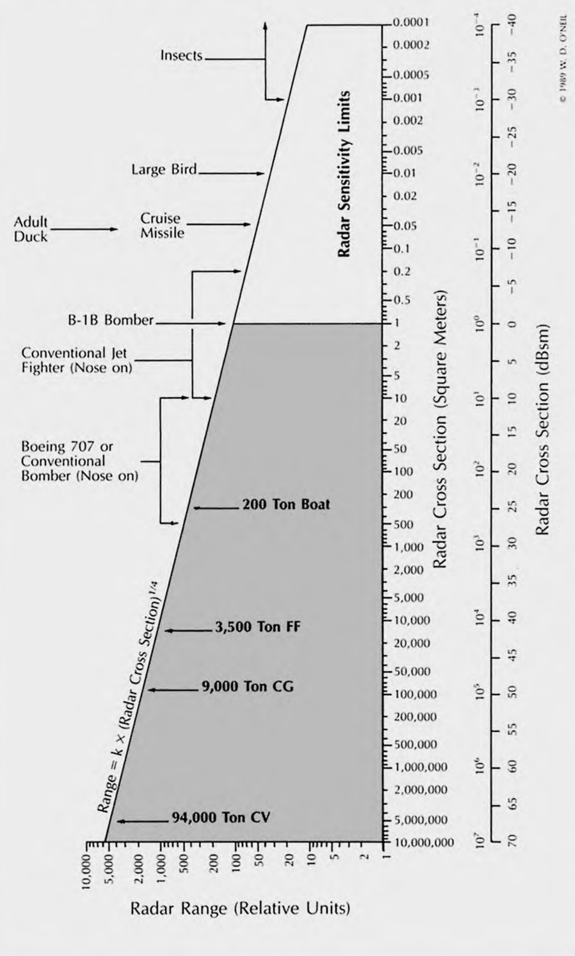
Speed remains important in evading attacks by ships or submarines armed with short-range weapons (by comparison with detection ranges). The old seaman's rule of thumb that requires a speed advantage of at least 50% to be sure of engaging an evading target is a good general guide.

Speed also remains significant in avoiding attack by torpedoes, which have limited speed and range. Submarines can further complicate torpedo attack by diving deep, thus increasing the volume that the torpedo's sonar must search and possibly exceeding the depth limits imposed on the torpedo by its structure or propulsion system.

As a general rule, however, the ship's hunters can more easily outfit themselves with faster, longer-ranged, and

W. O'NEIL (ADAPTED BY WILLIAM J. CLIPSON)

Figure 1 ***Radar Cross Section and Radar Range***



Note: Radar cross section figures should be regarded as approximate since (1) they have been taken from published sources which may not be accurate and (2) radar cross section varies greatly with aspect, radar frequency, and other factors.

more capable weapons than shipbuilders can increase the speed or depth capabilities of their units. Thus, attack evasion will probably continue to be largely a matter for active countermeasures, perhaps supported by ship signature reductions or other measures tailored to improve countermeasures effectiveness. Aircraft speed and maneuver requirements are not usually determined by attack evasion needs, either, and aircraft rely increasingly on active countermeasures, as well.

The rate at which observables increase with speed may be more significant than absolute top speed. Unless its pursuers have no access to the services of aircraft or long-range weapons, a submarine will want to balance the benefits of evading more quickly against the greater ease with which its pursuers can track it, as its noise output increases. Similar considerations may enter in the case of stealthy surface ships.

For centuries, naval architects have sought designs that resist enemy weapons. The proliferation of weapon types, each with its own damage mechanisms, has made the task increasingly difficult.

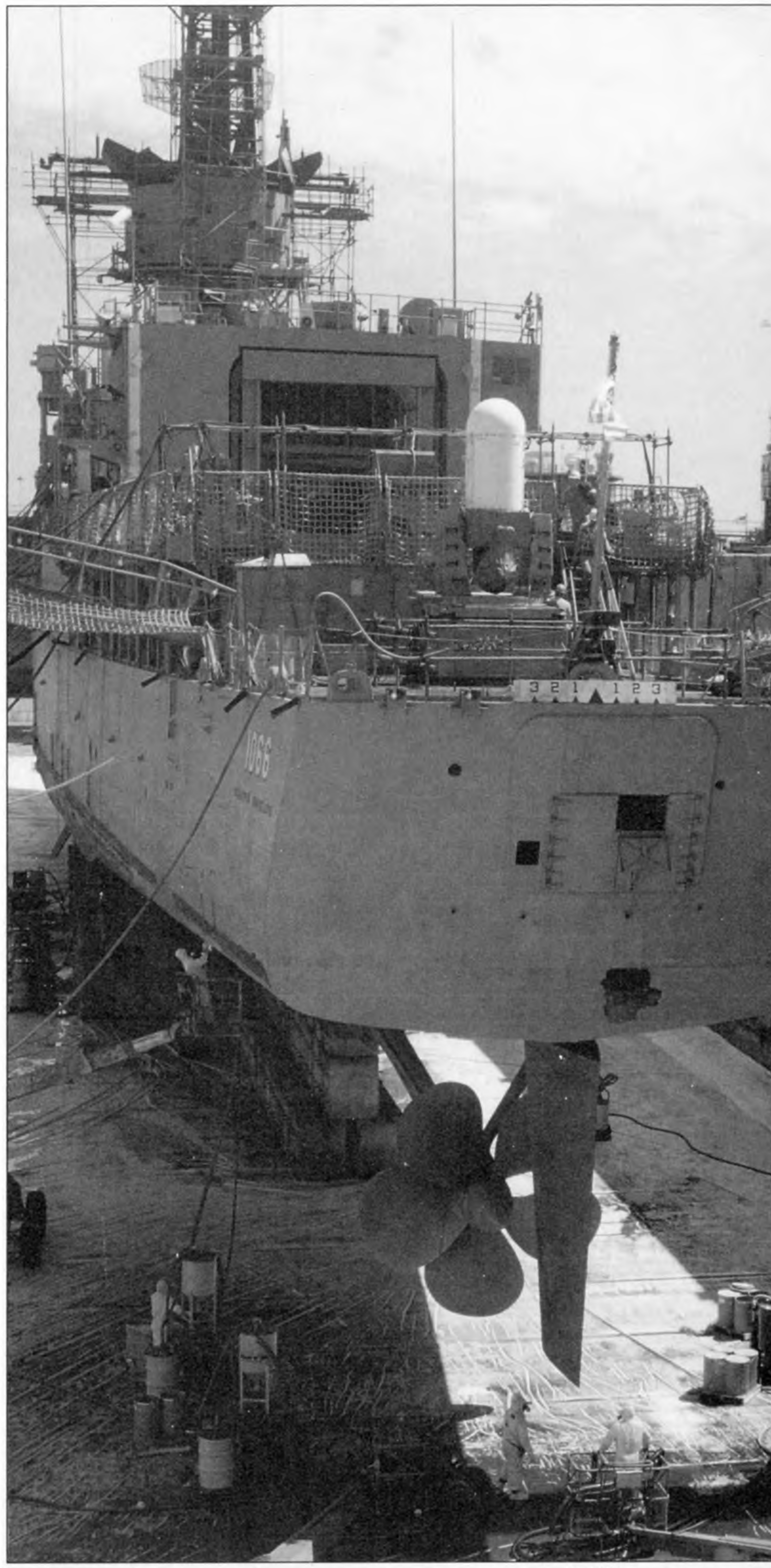
Nuclear weapons, for example, are so powerful that the possibility of ships being designed to survive a nuclear near miss is extremely remote. But since the weapons will most likely be used either against whole formations or in cases where the users seek to use power to make up for uncertain accuracy, variations in the ability to withstand distant nuclear bursts could be worthwhile.

Water's incompressibility permits submerged nuclear blasts to generate high overpressures—more than 1,000 pounds per square inch at a range of 10,000 yards from a 10 megaton deep burst, in theory, and 100 pounds even at 45,000 yards away. But in practice, pressure release at the surface strongly affects the overpressure experienced by targets much closer to the surface than to the nuclear burst. Deeply submerged submarines are most at risk from deep nuclear bursts and more so, if they are near their limiting depths. Pressure waves from underwater nuclear blasts are affected by the same refractive and reflective influences as underwater sound, and this can lead to freakish damage at long ranges.

Short of nuclear weapons, the most immediate threats to ship survival come from underwater detonation of conventional chemical explosive charges. Large ships, such as aircraft carriers, can be protected against torpedo warheads exploding in contact with the hull by dissipating the energy of the explosion within the hull. But smaller ships lack the space to accomplish this.

The most dangerous forms of underwater explosions, of course, are those that occur under the ship. Gasses emitted at high pressure from the explosion (which quickly vent to the atmosphere in the case of side-hitting weapons) expend much of their energy in damaging the ship through a number of mechanisms. Several nations have sought under-the-keel detonation systems for their torpedoes since as early as World War I. We must assume that they have by now succeeded. Some kinds of active countermeasures may work against these weapons, although they could involve difficult engineering problems.

An explosion at or near the outer surface of a deeply-



A. P. SOTO

Most U.S. Navy surface ships, including the *Marvin Shields* (FF-1066) here in drydock, are simply not stealthy. Their stanchions and kingposts cut too wide a swathe on radar, and their propellers can be heard 100 miles away.

submerged submarine's pressure hull will deliver much of its total energy toward deformation of the hull plating. Even a relatively small mass of explosive can rupture the strongest hull under these conditions. Soviet submarines employ double-hull construction, with the standoff in some cases reaching several meters. Obviously, this reduces the portion of the warhead's energy that is available for deforming the distant pressure hull. Double-hull construction comes with a number of disadvantages, however. Western submarine designers generally conclude that this reduction in vulnerability does not outweigh the potential drawbacks.

Reports indicate that some types of antisubmarine weapons now come fitted with shaped charge warheads (also known as directed-energy warheads). These use explosive energy to form a jet of metal particles at a velocity of approximately 30,000 feet per second. Since the dynamic pressure of the jet substantially exceeds the yield strengths of ship structural materials, they flow plastically before it. The holes made by shaped charges are characteristically small in diameter—generally no more than 10% of the diameter of the warhead—but even a small hole is serious to a submarine in combat. Shaped-charge warheads were first developed to defeat heavily armored land vehicles and in this application the standard countermeasures are:

- "Compound armor," deep deflector systems external to the hull, intended to divert and defocus the metal jet
- "Active armor," in which explosive sections outside the hull detonate to disrupt the jet

Another land warfare warhead type that submarines may face is the long-rod penetrator. In land applications, this is typically a rod of depleted uranium, tungsten, or other especially dense material carried in a high-velocity rocket or launched by a sabot from a gun tube. Reaching velocities as great as 10,000 feet per second, it also may exert dynamic pressure sufficient to cause plastic flow. In an ASW application, a coaxial gun within a torpedo could launch such a rod that would be triggered by impact with the outer hull. Armored vehicle designers generally regard protection against long-rod penetrators as a very difficult problem.

Shaped-charge and long-rod warheads can also be employed against surface ships, with generally similar protection considerations. Ships without significant ballistic protection (which includes the vast majority of modern surface warships) can be penetrated by semi-armor-piercing bombs or missile warheads. Homogeneous metal armor or systems combining a very hard facing material (generally a ceramic) with a very tough backing layer can provide protection. Advanced composite and metallic armors can provide ballistic protection with areal densities lower than that of traditional homogeneous steel armor. But high cost has discouraged widespread applications. In any event, as warships have come to have more and more critical volume potentially in need of more protection, even advanced armor is too heavy for any but the most selective of applications. Protection of critical and unduplicated electronic components is worthy of consideration.

Ships have so far avoided attack by contaminant weapons—radioactive materials, disease organisms, or chemical agents—but this immunity will not likely hold forever. Water-wash systems, together with a sealed and pressurized citadel concept, seem to be the only means to avoid contamination. But cost and lack of demonstrated threat has retarded acceptance of citadels. Adequate warning systems are essential in any case, because no full-time passive protection system seems likely.

Many ships that might otherwise have been saved have been lost to fire and progressive flooding. Shock itself rarely sinks ships, but it can disable them and contribute significantly to subsequent loss. A more insidious problem, and one that may grow more serious in the future, is the spreading of contaminants through a ship. This type of damage control involves a complex branch of naval architecture that can only be touched upon here.

Fire is a likely consequence of most damage, and it is one of the most serious problems a ship can face. Money spent on well-designed systems to combat or prevent fires has usually proved a good investment.

For some reason, many people have recently seized on aluminum as a serious fire hazard on board a ship, and they seem to believe that aluminum structures will burn. The combustible properties of beer cans or aluminum pots left to boil dry on the stove should provide sufficient evidence to put this to rest. But they never seem to. The conditions under which aluminum will support free combustion are only slightly more likely to arise in shipboard fires than those under which steel will. Obviously, steel (with a melting point in excess of 2,500°F) is a better material for structures expected to be exposed to fire than aluminum (which in most alloys will melt below 1,000°F). But the differences in fire hazard between the two metals are marginal in most cases and reasons for preferring aluminum in some applications are valid.

A common problem in many ship damage-control systems is that the crew will fail to maintain them or will actively subvert their operation. This is in part a matter of better education of ship crews. The ship designer must also have a realistic appreciation for what he can reasonably expect from a crew with limited skill levels and great demands on its time.

Of the 60 ships of the line involved in the 1805 Battle of Trafalgar, only one was sunk in the course of the battle, and only three eventually foundered from the damage they sustained. (The battle was followed by an unusually severe storm that resulted in the loss of a number of other ships, some of which probably would have survived but for damage sustained in battle.)

By 1916, every aspect of naval warfare had changed. But at the Battle of Jutland that year, only five capital ships were sunk out of 64 engaged. Moreover, all of the sunken ships were the least-protected types and three of them probably could have been saved if ammunition handling arrangements in their designs had been refined in a relatively minor way.

Twenty-five years later, both ships and weapons had improved greatly. Ships still were able to survive reasonably well in ship-to-ship actions, but a number of other engagements resulted in catastrophic losses. In the 1942

B. ALBERT

Fire at sea is a captain's worst nightmare. Better-trained crews and more realistic expectations of shipboard fire-fighters by ship designers can help prevent fires—here, on the *Guadalcanal* (LPH-7)—or minimize the damage they cause.

Battle of Midway, for instance, five out of seven aircraft carriers engaged were lost, three of them in the space of five minutes. In general, ships proved unable to survive in the face of air attack unless protected by strong air forces of their own.[3]

In the four decades since the close of World War II, the survivability of ships has progressed only modestly, mostly through refinement of detail. The battleships of the *Iowa* (BB-61) class built in that earlier era are still regarded as among the most survivable units of the fleet. But in light of improved weapons and delivery systems, the net survivability of ships has been substantially eroded. This does not suggest that ships cannot survive in modern war, but the burden of survival must fall more and more on the ability to destroy enemy antiship forces before they can deliver their attacks. One must feel uneasy about the fate of surface ships in a major conflict, at least in areas that are relatively open to enemy air and subsurface forces.

In contrast, submarines, which devote most of their attention to hiding (as ballistic missile submarines do) are virtually undetectable and hence invulnerable. Attack submarines are compelled to lift their stealth at some points in order to accomplish their missions. But they are, nevertheless, expected to enjoy reasonable longevity. Submarines hunting other submarines are perhaps in the most enviable position—submarine detection is becoming so difficult that it will likely be a long time between perilous encounters. Many submariners expect that mines will pose the greatest threat.

It is hard to see how surface ships can expect to survive in high-threat areas during a general war except by following the same stealthy strategy. The questions are:

- Can large surface ships be made stealthy enough by any practical means?
- How much will that stealth cost?
- How much will they need to give up in mission capability to stay stealthy?
- Beyond the costs and reductions in mission performance, will stealthy surface ships be desirable in comparison with submarines?

Another point of view on surface-ship stealth bears consideration: suppose we simply accepted that surface ships (at least those that are not stealthy) are unsuitable for high-threat areas in a general war. Do we really buy aircraft carriers, cruisers, amphibious ships, and all the others primarily to fight a general war—or to help prevent one? Indeed, it is difficult, in this era of swift, deadly, and long-range land-based systems, to define general-war tasks for which surface ships are uniquely suited. But they demonstrate their unique value in limited conflict situations all too frequently. Perhaps the most sensible thing is to acknowledge that we really need our surface fleet to keep the peace.

Adopting this philosophy would by no means make the issue of surface-ship survivability moot, but it would put it in quite a different context. The military technology available to the nations outside the East-West power structure is becoming more and more sophisticated, but limited conflicts do not seem to pass beyond a certain scale of violence. At the same time, however, such conflicts make mission demands that can severely tax many features of survivability, and rules of engagement dictated by their fundamental political purposes can limit the effectiveness of active defenses. Thus, perhaps the real test of surface ship design for survivability is not whether the ships can be made to survive on the front line of a general conventional war, but whether they can be made to survive in limited wars—and still fulfill their unique roles in such conflicts.

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[1]Such reductions may be worthwhile for other purposes, however, regardless of their lack of direct effect on detection range. In particular, they may make electronic countermeasures significantly more effective.
[2]Efforts to control the plume are normally motivated by concern about missiles that may use it as a homing signature.
[3]John Keegan, *The Price of Admiralty* (New York: Viking, 1989).

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