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Stealth Technology in Surface Warships

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Stealth Technology in Surface Warships

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FOLLOWING THE ATTACK upon the USS *Stark* (FFG 31) by Iraqi Exocet missiles in May 1987, the U.S. Navy greatly accelerated its efforts to improve anti-ship missile defenses. Much emphasis was placed on improvements to point-defense missile and close-in weapon systems that could destroy the anti-ship missiles themselves ("hard kill"), on improvements to the performance of the Standard surface-to-air missile warhead and fuse against sea-skimming cruise missiles (another "hard kill" system), and on improvements to the integration of electronic warfare detection and other "soft kill" systems aboard ship and in embarked helicopters. Another area of research that has received increased attention is the improvement of the "soft kill" performance of expendable chaff decoy systems by significantly reducing the warship's radar cross section (RCS). Employing low-observable or "stealth" technology, designers have attempted to reduce a ship's RCS to less than that of a deployed chaff cloud. Theoretically, the chaff cloud would then become a more attractive target for the missile's seeker and more effectively "seduce" the missile toward itself and away from the ship.

Since many airborne and surface-search radars also operate in the same I (8 to 10 gigahertz) and J (10 to 20 gigahertz) frequency bands, as do terminal radar seekers of many anti-ship cruise missiles (or ASCMs), stealth also makes a ship more difficult for many ship and aircraft search sensors to detect. Decreased detectability offers additional advantages (and also some disadvantages) in the stealth warship's capability to perform various naval missions.

The application of modern stealth technology to surface warships differs from its use in military aviation, where the goal is, to the maximum extent possible, to make the aircraft "disappear." By reducing the visual, radar, infrared, acoustic, and electronic signatures, "all-aspect" (or 360-degree) stealth strongly enhances a strike aircraft's ability to survive in a high-threat area. In the cases of the B-2

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and F-117 aircraft, 360-degree stealth features dominated the entire design and manufacturing processes, resulting in very expensive aircraft. Due to the laws of physics, however, we cannot make a large surface combatant "disappear," even if we radically alter its design. To attempt such a change is neither cost-effective nor desirable; sometimes, in fact, we want the surface ship to be *very* visible—for instance, for navigation in busy traffic-separation schemes, in "forward presence" visits overseas, and in Freedom of Navigation operations. The primary purpose of stealth technology in a surface warship is to make the ship appear, to the active-radar, terminal-guidance seeker of an ASCM, smaller than a chaff decoy—that is, to make the ship a less conspicuous missile target and improve thereby the warship's defensive "soft kill" capability.

Using unclassified and open-source material exclusively, this article evaluates the ASCM threat to surface warships today and explores how stealth technology can improve ship survivability in the face of this threat. It then examines potential roles for a "more survivable, less detectable" warship in the execution of the National Military Strategy.

The Anti-Ship Cruise Missile Threat

The proliferation of high-technology anti-ship cruise missiles to more than seventy countries poses a most formidable threat to surface warships today. Rear Admiral Edward Sheafer, USN, Director of Naval Intelligence, recently testified, "Widely deployed, anti-ship cruise missiles give coastal navies a potential lethality far out of proportion to their size."[1] Many of the small navies of lesser-developed countries, in an effort to exercise local sea control with only a modest expenditure, have purchased sophisticated, modern ASCMs as "Great Equalizers."[2] Accurate, lethal, "shoot-and-forget" weapons such as the French-built Exocet are widely exported for profit. As of January 1992, the reported worldwide inventory of Exocets included almost 5,000 missiles exported to twenty-nine countries, including Libya and Iraq.[3] Additionally, the Soviets and Chinese have exported more than 10,000 Styx and Silkworm missiles to about twenty-two countries. Also, as seen at a recent Moscow air show, many of the newer and more sophisticated Russian ASCMs are now for sale.[4] Even the United States has exported a missile—the Harpoon, a very accurate and potent sea-skimming weapon—to about twenty countries.[5] Such missiles can easily be adapted for launch from a variety of platforms, including surface ships, small patrol boats, helicopters, various tactical and maritime patrol aircraft, submerged submarines, fixed shore sites, and even trucks. ASCMs vary in range, warhead size, and flight profile; many, however, are sea-skimmers (that is, they approach their target at such low altitude as to be undetectable to most surveillance radars), and most employ an I or J-band active radar seeker for terminal homing.

Using the MM-40 Exocet surface-to-surface missile as an example, with capabilities listed in open-source literature, the threat could develop like this. Aboard a small patrol boat about twenty-five miles from your ship, targeting data has been programmed into a storage container that also functions as the missile launch tube. A sixteen-foot-long, 1,875-pound Exocet with a 360-pound high-explosive, fragmentation warhead is launched; your ship is the intended target.[6] Using its inertial guidance system and radar altimeter, the missile flies near the sea surface at about six hundred miles per hour. Total time of flight is about 150 seconds. At a range of about twelve miles, when the Exocet enters your radar horizon, the missile's active radar seeker turns on in accordance with its prelaunch targeting instructions. The missile acquires your ship and descends to its second cruise altitude, less than ten feet above the water. Now on its final approach, the missile is less than seventy-five seconds from impact. Fortunately, you are operating at a high alert condition, and the Exocet's seeker is detected by your passive electronic sensors. You have about one minute to shoot down or decoy this missile. The stealth technology and radar-absorbing materials also used by many weapons' manufacturers to diminish the RCS of their ASCMs likely make it very difficult for your "hard-kill" systems to acquire, track, and destroy this one.[7] Accordingly, your fire control radars must look for a missile with an RCS similar to that of a large bird. If you do not successfully counter the missile, the resulting damage will be similar to what the *Stark* suffered in the Persian Gulf or HMS *Sheffield* during the war in the Falklands.

This is *why* stealth technology is being introduced into our surface warships. What follows is *how* it is employed to counter the enemy missile's seeker.

How Does "Stealth" Work in a Surface Warship?

Stealth is not new to naval warfare. For centuries, man has used the vastness of the oceans to hide from the enemy. Submariners have long relied on stealth to avoid detection and to position themselves for a submerged torpedo or, today, cruise missile attack on enemy surface shipping.

"Observable" Signatures. Today's typical surface combatant has five distinct emission signatures that make the ship vulnerable to detection and enemy attack. All of these signatures must be minimized.

- *Acoustic*—caused by machinery noise radiating from the hull into the surrounding water. Extensive efforts have been made to shock-mount equipment and otherwise mask this signature.
- *Electronic*—generated by active electronic emitters radiating into the atmosphere. It can be silenced by turning off the emitters; however, the ship then loses its radar detection and radio communication capabilities.

- *Visual*—simply the fact that a ship is visible to the human eye during daylight hours. A ship's wake is visually detectable from the air and from space, and it has a surprisingly long persistence. Beyond improving mottled paint schemes, which lessen the contrast detected by electro-optical sensors, little can be done to alter a ship's visual signature in daylight.
- *Infrared (IR)*—caused by thermal radiation in the electromagnetic spectrum, particularly in the wavelengths corresponding to a region known as the Middle IR, or MIR. "Hot sources [such as exhaust uptakes and exhaust gases] radiate strongly in the MIR region. . . . Indeed, such is the level of IR radiation in these areas that what amounts to two percent of the ship's [total surface] area can produce 99 percent of the total MIR signature. . . . It is the MIR 'window' and these concentrated IR sources [that attract ASCMs having IR or dual-mode (IR-and-radar) seekers]. . . ."[8]
- *Radar Cross Section (RCS)*—that is, radar energy reflected by the ship. The strength of this signature is "influenced by the size of the ship, its angular orientation, the absorption coefficient of the materials from which it is constructed, and by the frequency of the illuminating radar."[9] Since most ASCMs employ active-radar terminal seekers, the RCS signature is the most important. Accordingly, we will hereafter focus primarily on the surface warship's RCS signature and how it can be minimized.

Radar Cross Section. The RCS of an object is defined as "a measure of the power reflected in a specific direction and is normally expressed in square meters or logarithmically in decibels per square meter (dBsm)."[10] While an entire ship as a whole (that is, in its macrogeometry) reflects radar energy, individual parts of its superstructure and also small objects such as gun mounts, radar antennas, lifeline stanchions, and deck lockers (that is, microgeometry) also reflect energy separately, each object according to its shape, size, and orientation with respect to the incoming radar energy. Because many of these smaller reflecting objects are approximately the same size as the wavelength of the illuminating radar, they are called "prime (or 'resonant') scatterers."[11] All of these reflections, from macro- and microgeometry, combine to influence the total RCS.

Most ship superstructures, and hull forms as well, have extensive flat, vertical surfaces and also many shapes formed by two or three planes that intersect at ninety degrees. Topside configurations also include numerous vertical cylindrical forms, such as kingposts, stanchions, and masts. These shapes—vertical surfaces, planes joining at ninety degrees, and vertical cylinders—intensify an already large RCS.[12]

The two principal ways of reducing a warship's RCS are the application of radar-absorbent material (RAM) to the most reflective parts of the ship and the use of computer-aided design (CAD) to optimize the shape of the hull and superstructure. CAD modeling helps engineers estimate, and then minimize by reshaping, the radar reflection from the three-dimensional forms that make up the ship. The goal of shaping is to eliminate sharp corners and vertical surfaces, and otherwise cause the radar energy to be scattered away from the enemy and not reflected back in the specific direction of the enemy radar receiver. With regard to RAM, the goal is to absorb radar energy, to trap it in a medium that will dissipate its microwave energy as heat and thereby eliminate most of the reflection. Obviously, for ships already constructed the incorporation of stealth technology is largely restricted to the installation of RAM. In that connection, emerging stealth technology is producing today a variety of new and increasingly effective radar-absorbent materials, including "structural RAM" and RAM with IR-suppression characteristics.

Recent Warship Applications. Stealth technology is already being incorporated in warship design by a number of navies. For example, in its description of the USS *Arleigh Burke* (DDG 51), *Jane's Fighting Ships 1991–1992* notes that its "stealth technology includes angled surfaces and rounded edges to reduce radar signature. . . ."[13] Also, the new French *La Fayette*–class frigate is apparently being built with stealth features. The shape of its hull and superstructure avoids any vertical surfaces. Most of its superstructure is enclosed, and RAM may be used to reduce RCS further.[14] Likewise, the Israeli Navy is incorporating a defense system with extensive stealth features (involving both shaping and RAM) in the design of the new Sa'ar V corvette being built by the Ingalls Shipbuilding yard at Pascagoula, Mississippi.[15]

The British, for their part, are experimenting with "multi-spectral" materials—RAM that includes IR-reflective materials and thereby simultaneously reduces both the ship's RCS and IR signatures.[16] An advertising leaflet describes the complexity of this material: ". . . ADRAM (Advanced Dielectric RAM), which covers the range 6–35 [gigahertz . . . and] employs a honeycomb with a radar-transparent outer skin of Kevlar, a Nomex core containing an absorber, and a reflective carbon fibre inner skin."[17]

The Swedish navy has built a prototype ship for stealth optimization. *Smyge*, as it is named, is an experimental surface effect ship which incorporates extensive stealth features, including retractable masts and antennas, an angled superstructure and hull form, and stealth coverings for the gun mount, missile launcher, and most deck fittings.[18] During testing, the Swedes hope to gain extensive knowledge on all aspects of stealth to demonstrate the offensive and defensive usefulness of stealth properties and to validate their predictions that the prototype can evade ASCM seeker lock-on.[19]

Finally, the author toured the *Udaloy*-class destroyer *Admiral Vinogradov* during the visit of Soviet warships to San Diego in 1990 and observed numerous rounded edges on the superstructure that appeared to be covered with RAM.

When asked, Soviet officers confirmed that the purpose of the covering was to "absorb radar."

As previously noted, the actual performance of the stealth treatment in various ships is carefully guarded. No unclassified figures are available that show actual RCS measurements or actual test results specifying the effectiveness of stealth against various missile seekers. However, Table 1, which has been adapted from a published study, illustrates the general concept of RCS measurements.

Another published study clearly shows, with the following example, how a stealth warship's survivability increases. "A typical frigate or destroyer might have an RCS of 25,000 square meters [44 dBsm]. This can be reduced to 12,500 square meters by a 3 dBsm reduction (achievable with some low-performance radar absorbing paints) and to as little as 6,300 square meters [38 dBsm], with other RAM materials. . . . On a platform equipped with modern chaff launchers, where RCS is reduced [with shaping and the application of RAM] by as much as 16 dBsm, the overall radar cross section is *less* than the echoing area of the protective chaff bloom."[20] In other words, if a warship with an RCS of 44 dBsm is "treated" to achieve a minus-16 dBsm reduction, it will theoretically have an RCS measuring 28 dBsm—less than 1,000 square meters. This is slightly larger than that of a two-hundred-ton boat and well below the RCS of a "two-round" chaff cloud (i.e., a radar-reflective cloud formed by firing two countermeasure projectiles). Figure 1, adapted from that study, illustrates how stealth works in theory.

Other Advantages of "Low Observability." As previously mentioned, the application to a warship's superstructure of RAM "tuned" to be most effective against I and J-band radar seekers affects the performance of search sensors operating in the same frequency range. The stealth destroyer noted in the example above would present to the surface-search radars carried on many ships and aircraft a smaller radar target than before, one detectable only at a closer range.

Treating large areas of the superstructure with RAM is also likely to reduce electromagnetic interference (EMI) between the ship's own sensors. Many metallic lifeline arrangements, topside lockers, deck fittings, and mast structures that reflect the ship's own radar and communications emissions, causing interference, are now covered with a material that absorbs electromagnetic radiation. This reduces extraneous electromagnetic energy in the vicinity of topside antennas and improves the performance of radar and communications receivers on board.

For ships equipped with active electronic countermeasures (ECM), a reduced RCS is of particular benefit. For an incoming missile "jammed" by active ECM, a "burn-through" range exists where the actual radar energy reflected back to

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the missile by the ship overcomes the jammer's power output; at this point, the ship's active ECM is no longer effective, and the missile will "see" the ship and attempt to maneuver to hit it. With stealth, less radar energy is reflected, and the shipboard jammer, without increasing its power, becomes more effective. "Burn-through" occurs closer to the ship, where the missile has less time and space to maneuver.

Though not an operational advantage, the appearance of topside areas is improved by stealth technology, which requires removal of all unnecessary lockers and "stuff" that tend to clutter the weather decks. Conversely, and very importantly, the operational performance of the stealth treatment is significantly degraded if topside areas are not kept free of unnecessary reflective clutter. Something as seemingly inconsequential as a trash can or a swab bucket could significantly increase a ship's RCS.

Disadvantages. As noted, reduced detectability on radar can be a safety hazard when maneuvering in fog or reduced visibility, particularly in areas of high shipping density. This disadvantage can be overcome either mechanically (by using portable radar reflectors) or electronically (with an electronic repeater or "blip enhancer" to give a larger RCS). Stealth warships might choose to operate in peacetime with portable radar reflectors rigged in order to conceal the ship's actual "stealthy" RCS until it is tactically needed.

Treatment with RAM adds several tons of weight high above a warship's previous center of gravity, adversely affecting the ship's stability and seakeeping ability. For older ships already having a topside weight problem, this could be a serious concern. As new ships are designed incorporating this technology, initial weight and moment calculations (related to stability) can allow for stealth additions. For new construction, stealth design involves proportionally more superstructure-shaping and less RAM application, and therefore less topside weight.

Finally, stealth technology in a surface warship is associated with a defensive "soft kill" capability that lacks credibility in the minds of some naval officers. The natural instinct is to act aggressively and attempt to shoot down an incoming missile with a "hard kill" system rather than launch a chaff decoy and wait to see if it works. Many ships, lacking an integrated electronic warfare suite, find it difficult to tell if the deployed chaff decoy is being effective. Even if the combination of chaff and stealth appears to be working, many would still question: "Will the chaff continue to be effective as the missile nears the ship?" "Are we *one hundred percent certain* that stealth will be effective against this particular ASCM seeker?" "Are we presenting the ship's 'stealthiest' aspect to the seeker?"

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Table 1

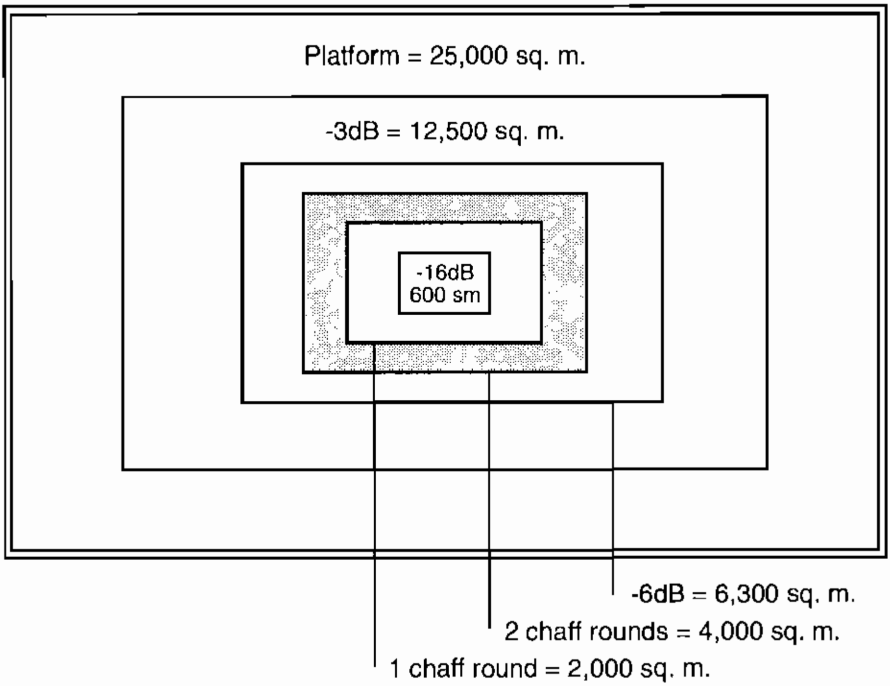
Radar Cross Section	(Square Meters)	(dBsm)
	0.0001	−40
Insects ——>	0.0003	−35
	0.001	−30
	0.003	−25
Large Bird ——>	0.01	−20
	0.03	−15
Adult Duck ——>Cruise Missile ——>		
	0.1	−10
	0.3	−5
B-1B Bomber ——>	1	0
Conventional Jet Fighter (Nose-on) ——>		
	3	5
	10	10
	30	15
Boeing 707 or Conventional Bomber (Nose-on) ——>	100	20
200-ton Boat ——>	300	25
	1,000	30
	3,000	35
	10,000	40
3,500-ton Frigate ——>		
	30,000	45
9,000-ton Cruiser ——>	100,000	50
	300,000	55
	1,000,000	60
	3,000,000	65
94,000-ton Aircraft Carrier ——>		
	10,000,000	70

Radar cross section figures shown should be regarded as approximate: they have been taken from sources that may not be accurate, and RCS varies greatly with aspect, radar frequency and polarization, roll of the ship, and other factors.

Source: Adapted from William D. O'Neil, "Don't Give Up on the Ship," U.S. Naval Institute *Proceedings*, January 1991, p. 48.

Figure 1

Improved Survivability of a "Typical" Frigate or Destroyer



-44 dBsm	=	25,000 sq.m.=	untreated ship
-3 dBsm	=	12,500 sq.m.=	achievable with low-performance radar-absorbing paints.
-6 dBsm	=	6,300 sq.m.=	with other RAM installed
As much as -16 dBsm	=	600 sq.m.=	modern warship design with shaping and RAM.

Source: David Foxwell, "Stealth: The Essence of Modern Frigate Design", *International Defense Review*, no. 9, 1990, pp. 988–90.

Potential Roles for Stealth Warships

In the words of the new maritime White Paper, "As Naval Forces shift from a Cold War, open ocean, blue water naval strategy to a regional, littoral and expeditionary focus, *Naval organizations will change*. Responding to crisis in the future will require great flexibility and new ways to employ our forces."[21] In responding to a crisis situation, naval expeditionary forces have long been seen as the flexible military instruments of first choice; this will not change. Such forces are rapidly deployable, can remain in a region indefinitely, and can be quietly withdrawn if policy makers reach a diplomatic solution or choose not to intervene. As we exercise "gunboat diplomacy" in a crisis situation and threaten the use of force to support U.S. foreign policy objectives, we are likely to be doing so in a tense near-land or littoral environment made especially dangerous today by the proliferation of high-technology anti-ship weapons.

Forward Presence and Crisis Response. Stealth adds to our capability to conduct the forward presence mission by allowing U.S. warships, visible evidence of our commitment to our allies and to maintaining peace and stability, to operate with relative safety in sensitive parts of the world. As the U.S. Navy becomes smaller, we must be able to execute the overseas forward presence mission with only one or two surface combatants, perhaps with amphibious forces, and often without the support of an aircraft carrier battle group (CVBG). For them to be effective, it must be clear to potential adversaries that these smaller forces are capable of actually carrying out the threat they represent: to that end, Tomahawk, Harpoon, and Standard missiles provide a cruiser or destroyer with an impressive combat capability. Equally important, these ships must be able, without the protection of CVBG aircraft, to defend against a significant ASCM threat. Stealth should give these ships a defensive edge in countering such an attack.

The U.S. Navy is already testing different deployment concepts, such as Maritime Action Groups consisting of different combinations of cruisers, destroyers, amphibious ships, submarines, and maritime patrol aircraft but *no* aircraft carriers.[22] The superior capabilities of newer Aegis-equipped surface combatants, as well as the demise of the Soviet naval threat, will probably allow a reduction of the number of ships in CVBGs themselves to six ships from the current nine-to-eleven.[23] (It should be noted, however, that while stealth technology provides a defensive edge for the "treated" combatant, it does nothing to protect sealift vessels or large amphibious ships that might be under escort as part of a forward presence or crisis response operation. Incorporating stealth into large, "boxy" ships would be prohibitively expensive and impractical in general, especially for leased, commercial sealift vessels.)

Crisis response might well involve enforcing economic sanctions—more precisely, a naval blockade. This mission, frequently executed by a few surface combatants operating independently, aims at frustrating a state's efforts to import or export. These blockading ships would be ideal candidates for stealth treatment, especially if the sanctions were causing such pain that our local sea control might be challenged by ASCM attack.

Power Projection. After their impressive performance in Operation Desert Storm, Tomahawk-capable ships might well be targeted in a future enemy's first strike. Stealth technology offers them a greater degree of protection from enemy ASCMs and could allow them to project power from confined areas near land where an aircraft carrier might not be able to operate safely. Stealth could allow combatants to provide naval gunfire support, or transport special operations forces, near to the shore.

It is questionable, however, whether stealth treatment is physically or economically feasible for larger ships that project power ashore, such as aircraft carriers or some amphibious ships. A Naval Studies Board review of future aircraft carrier technologies, entitled "Carrier-21: Future Aircraft Carrier Technology," concluded that "attempting to reduce the radar signature of aircraft carriers would be prohibitively costly."[24]

Stealth warships, operating at night with their own electronic emissions suppressed, obtaining targeting data by a receive-only data link, and employing "stealthy" missile-equipped attack helicopters, could represent a force with an impressive ability to seek out and destroy the enemy.

Skeptics might ask, "Is it worth the effort to try to protect our surface ships? Why do we need to establish local sea control?" In reply, as one author stresses, "The day of the surface warship has not passed. . . . [Recent] events in the Gulf have shown that sea transportation is still essential for the passage of raw materials and heavy military equipment. Surface ships will continue to be needed until peaceful nations stop using the sea for economic survival and until military nations no longer perceive a need to project power beyond their own borders. The debate must therefore be about ways of ensuring the survival of ships."[25]

Stealth is not magic! It is not the ultimate protection against every sort of anti-ship attack. Due to the laws of physics and the limitations of finance, we cannot install stealth technology into our largest warships and our sealift ships. It is unlikely that stealth will defeat every radar-homing ASCM, every time. Stealth might not be effective against a far-advanced ASCM that uses a new type of seeker for terminal homing or that can discriminate better than is now possible between a chaff decoy and a warship. But today, stealth offers an increased degree of protection for a large number of our present and prospective surface combatants, at a modest cost. This system, when used with properly deployed chaff decoys, has the potential to defend against the present generation of widely available radar-homing ASCMs.

The question is not one of either "hard kill" *or* "soft kill," as some would contend. We must take advantage of every tool available—both "hard kill" *and* "soft kill, *enhanced by stealth*"—to give us the greatest chance of survival against the ASCM.

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One DD captain told this observer that in his opinion the most important difference between peacetime training and operating in war was that now he had to think for himself.

Joseph H. Wellings,
writing as a U.S. Navy observer
with the Royal Navy, November 1940