AIRCRAFT CARRIER (IN)VULNERABILITY

What it takes to successfully attack an American Aircraft carrier

Naval STRIKE FORUM

Lexington Institute

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What It Takes To Successfully Attack an American Aircraft Carrier

EXECUTIVE SUMMARY

The Navy's twelve nuclear-powered aircraft carriers are among the most potent expressions of American military power. In recent years, though, there has been growing concern that changing mission requirements and enemy capabilities may make carriers more vulnerable to attack. This study analyzes the steps adversaries would need to take to execute a successful attack. It concludes that carriers are likely to be highly survivable for many years to come (barring major tactical blunders), and that carriers are becoming more resilient over time.

The first step in attacking a carrier is to find it. Most potential adversaries would have difficulty doing this as long as the carrier remains in the open sea, takes prudent evasive actions, and actively counters efforts at detection. If a carrier is actually detected, the next step an enemy must take is to establish a continuous target track. That is necessary because a carrier is likely to be far from the location where it was first detected by the time weapons arrive there.

Few if any nations today possess an assured capacity to track carriers continuously. All of the relevant methods — radar, electronic eavesdropping, electro-optical and acoustic sensors — have major drawbacks such as high cost, vulnerability to preemption, and inability to precisely discriminate. While that may change over time, aggressors will still face a daunting task in penetrating the layered defenses of a carrier battle group.

The most significant threats to carriers are cruise missiles, wake-homing torpedoes, ballistic missiles and mines. But cruise missiles are unlikely to penetrate the battle group's integrated air defenses, and few potential adversaries are capable of employing submarines or torpedoes effectively. Ballistic missiles lack necessary targeting features and mines are easily dealt with using a variety of existing and prospective methods. The intrinsic resilience of large-deck carriers further mitigates the threat posed by adversaries.

This report was prepared by Dr. Loren Thompson of the Lexington Institute staff. All members of the Naval Strike Forum had an opportunity to review and modify the final report.

A Unique Capability

The United States Navy operates twelve large-deck aircraft carriers that are the centerpiece of America's maritime force structure and warfighting strategy. Each carrier hosts a wing of 70 aircraft which if necessary can be launched at the rate of one every 30 seconds. The Navy believes that by the end of the current decade, a typical carrier air wing will be able to precisely target over a thousand separate aimpoints many hundreds of miles from the carrier in a single day.

No other country in the world possesses such a capability. Aircraft carriers are the most visible expression of America's will to shape global politics and discourage aggression. But it is precisely the visibility and capability of these vast warships – which displace 97,000 tons, carry nearly 6,000 personnel, and have flight decks measuring in excess of four acres – that periodically lead to debate about their survivability.

Critics contend that carriers will grow increasingly vulnerable in the early decades of the new century as potential adversaries acquire reconnaissance satellites, long-range cruise missiles, very quiet diesel-electric submarines, and other tools for denying the U.S. Navy access to littoral areas. With so much of its resources and warfighting capacity concentrated in so few vessels, the critics argue, the Navy will be forced to avoid exposing its carriers to danger in places like the Persian Gulf and Formosa Strait.

The question of carrier vulnerability may be the most important issue the current generation of American leaders faces in determining the future composition of military forces. The issue cannot be dismissed with the rote formulations that the Navy has invoked for decades to justify its force posture. If an aircraft carrier were lost in combat, thousands of Americans might die, and the popular will to sustain a war effort could be severely undermined.

The purpose of this study is to assess the severity of threats to U.S. aircraft carriers over the next twenty years. The study reviews the tasks that an adversary would have to accomplish in order to find, target, attack and disable a carrier, and then examines whether potential enemies are in fact acquiring the required capabilities. The study concludes that, barring a major tactical blunder, aircraft carriers are likely to remain highly survivable for many years to come.

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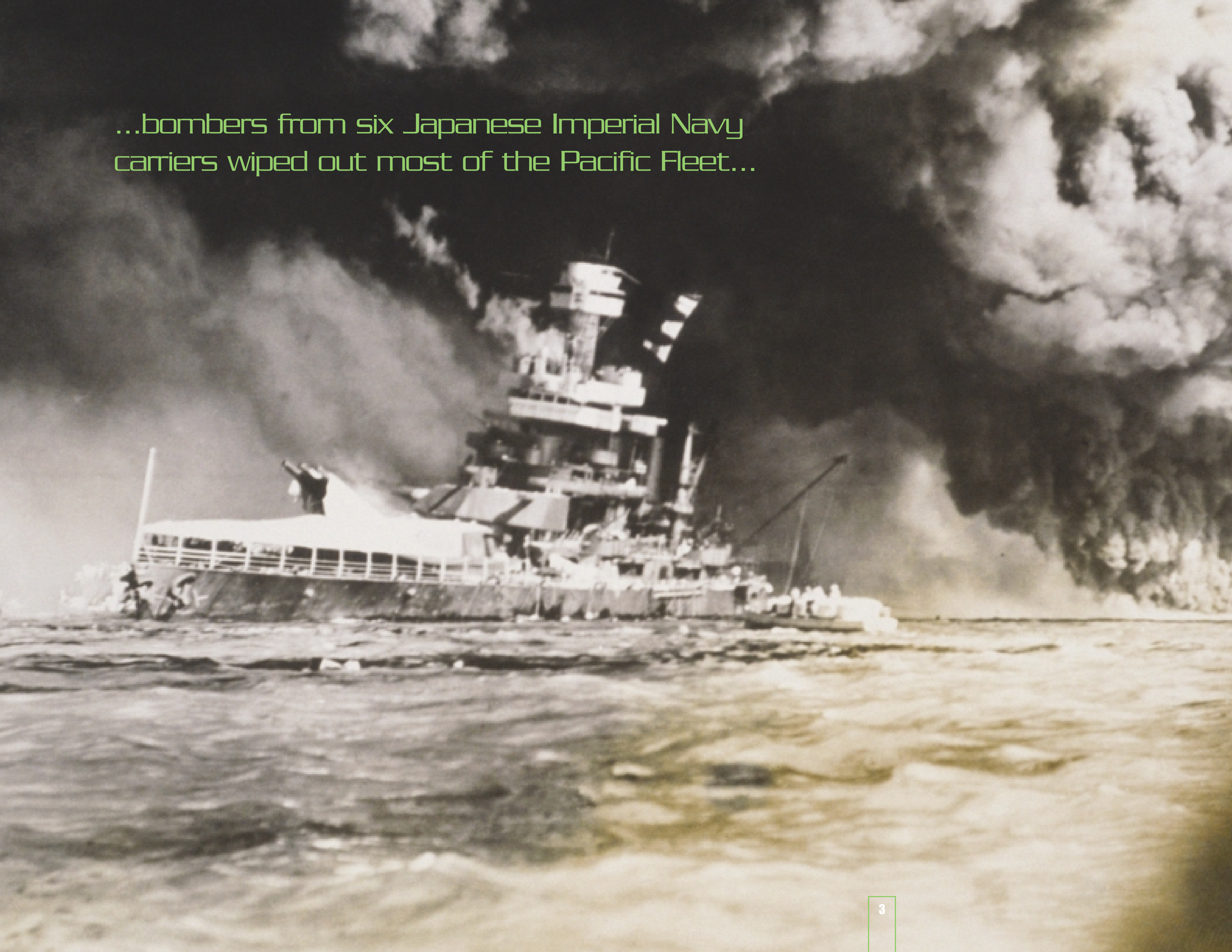


Persistent Concerns

Concerns about aircraft-carrier vulnerability are not new, nor are some of the solutions proposed to remedy it. The Navy learned a devastating lesson about both the strengths and weaknesses of carriers during the first year of World War Two. America's entry into the war was precipitated by an air attack on Pearl Harbor in which bombers from six Japanese Imperial Navy carriers wiped out most of the Pacific Fleet, including all eight battleships. The Pacific Fleet's carriers escaped destruction because they were not in port. Within a year after the attack, though, four of the six Japanese carriers that attacked Pearl Harbor had been sunk, as had most of the U.S. carriers in the Pacific.

As it turned out, the destruction of the USS *Hornet* at Santa Cruz in October of 1942 was to be the last time the Navy ever lost a large carrier. However, the lesson of the war's first year was that even with radar and other defensive innovations, carriers were far from invulnerable. Concern that carriers might be too vulnerable had led the Navy to experiment with smaller carriers during the interwar period. The Navy's first carrier built from the keel up – USS *Ranger*, commissioned in 1934 – was considerably lighter than the Lexington and Saratoga, carriers fashioned from converted battlecruisers that preceded it to sea.

But the disappointing performance of the Ranger convinced Navy leaders that it made more sense to operate a smaller number of big carriers than a larger number of small ones, due to the loss of combat capability and survivability associated with smaller vessels. The service has continued to espouse that view ever since, despite the frequent efforts of civilian leaders to fund smaller, more numerous carriers.

Cold-War Threats

The Navy has traditionally viewed airborne threats -- manned aircraft and cruise missiles -- as the principal danger to its carriers. During the early years, carriers could outrun most surface combatants and submarines. They could not outrun aircraft originating from land bases or other carriers though, leading to an emphasis on air defense.

That emphasis persisted even after the Soviet Union began deploying large numbers of nuclear-powered submarines in the 1960's. Because the U.S. enjoyed a substantial advantage in undersea warfare – conferred in equal parts by favorable geography, superior technology, and rigorous training – the main thrust of defensive investments for carriers throughout the Cold War was to address air-breathing threats. Network-centric warfare is the latest manifestation of this multi-generational effort.

It was concern about Soviet cruise missiles that led the Ford Administration to mount the last major effort to build smaller, conventionally-powered carriers rather than nuclear-powered ships. In 1976 defense secretary Donald Rumsfeld proposed foregoing another Nimitz-class nuclear carrier and instead buying two fossil-fuel driven carriers that could host vertical-takeoff and landing aircraft. Rumsfeld argued that the Navy needed to begin dispersing its sea-based tactical aircraft in response to the growing anti-ship cruise-missile threat.

That proposal was rebuffed by Congress after the Navy argued large-deck, nuclear-powered carriers were intrinsically more survivable against most threats. In addition to the larger ship's capacity to absorb damage, it could also accommodate more robust defenses such as F-14 interceptors and E-2C early-warning aircraft. Moreover, nuclear propulsion enabled a carrier to operate at maximum speed (about 30 knots) indefinitely. Nuclear carriers were thus harder to attack, had less need for logistical support, and more room for defensive stores (munitions and aircraft fuel). Due to these considerations, the Nimitz class has remained the Navy's reigning carrier design for three decades.

For most of that time, the Navy had no ongoing carrier research program. Each of the carriers built since the original *Nimitz* was commissioned in 1975 -- including the USS *Ronald Reagan* (CVN-76), scheduled to replace the conventionally-powered USS *Constellation* in 2003 -- has been a "modified repeat" of the baseline design. That will begin to change with CVN-77, the tenth and last Nimitz-class carrier, which is destined to replace the conventionally-powered USS *Kitty Hawk* in 2008. CVN-77 is the bridge to a new class of carriers, and will incorporate important changes such as a new combat system and more capable radars.

Future Threats

But because they have a fifty-year service life, carriers under construction today may still be in the active fleet in 2050. That longevity, combined with the uncertainty about future threats in a period of rapid technological change, makes the issue of carrier vulnerability hard to ignore. While it is impractical to predict what technological breakthroughs might occur three or four decades from now, it is possible to develop credible estimates of threats over the next twenty years by observing trends already under way.

The priority mission of U.S. aircraft carriers during the next twenty years will be to enforce access to Eurasia – the center of global population and commerce, and the historic source of all major external threats to American democracy. Future adversaries seeking to deny the U.S. such access will probably employ four types of weapons against the carriers: long-range cruise missiles launched from aircraft, ships or land bases; ballistic missiles launched from ships or land bases; diesel-electric submarines employing wake-homing and other advanced torpedoes; and drifting or tethered mines.

Because of the breakdown in Cold-War barriers to trade and the related globalization of economies, there has been a gradual proliferation of all four categories of weapons among prospective adversaries of U.S. power. Dozens of nations possess cruise and ballistic missiles; countries such as China, Iran and Pakistan have recently been acquiring modern diesel-electric submarines from foreign sources; and virtually every littoral power now has the ability to lay mines. Moreover, the spread of information technologies in global commerce has made it easier to provide such weapons with sophisticated guidance, countermeasures, and other hallmarks of digital warfare.

So long as the carrier remains in the open sea, the capacity of most adversaries to find it will be limited.

However, the mere possession of modern munitions does not readily translate into effective anti-access capabilities. In the case of aircraft carriers, potential aggressors must first find the carrier, then establish a continuous target track, penetrate multiple layers of defense, and accomplish significant damage. An assessment of the capabilities adversaries are likely to have – and the steps U.S. forces plan to counter emergent threats – indicates that successfully attacking a carrier will remain one of the most challenging military missions imaginable.

Finding the Carrier

The first step in attempting to attack an aircraft carrier is to find it. Given the carrier's size – longer than three football fields, as tall as a twenty-story building – that might seem like a simple task. It is not, especially in wartime. The Navy's plan when confronting major littoral adversaries is initially to operate the carriers at least 200 nm from shore, using submarines, unmanned vehicles and various joint assets to collect information about potential threats.

Operating far out to sea would not greatly constrain the use of the carrier's strike aircraft, since both its F/A-18 E/F Super Hornets and next-generation Joint Strike Fighters are expected to have unrefueled combat ranges of about 600 nm. During the early stages of conflict, both the aircraft and cruise missiles from other warships in the carrier's battle group would be used to destroy enemy sensors, weapons and communications (including satellite downlinks) posing an immediate threat to the battle group. As those threats are gradually eliminated, the carrier can move closer to land without fear of detection, expanding the coverage of strike aircraft over enemy territory.

So long as the carrier remains in the open sea, the capacity of most adversaries to find it will be limited. In addition to the battle group's efforts to suppress enemy sensors and communications, the carrier will be moving constantly, and much of that movement will be designed to avoid areas of potential vulnerability. The fact that all of the Navy's carriers but one will be nuclear-powered by the end of the current decade is important in eluding detection, because nuclear propulsion enables the ship to maneuver at maximum speed for weeks without having to accommodate the complex logistics of frequent refuelings at sea.

The most basic protection the carrier has against being detected, though, is distance. The areas in which carriers typically operate are so vast that adversaries would be hard-pressed to find them even in the absence of active countermeasures by the battle group. Consider, for example, the South China Sea, where China recently held hostage a Navy EP-3 electronic-intelligence aircraft and its crew on Hainan Island. Even though it comprises less than five percent of the Western Pacific, the sea measures over a million square miles.

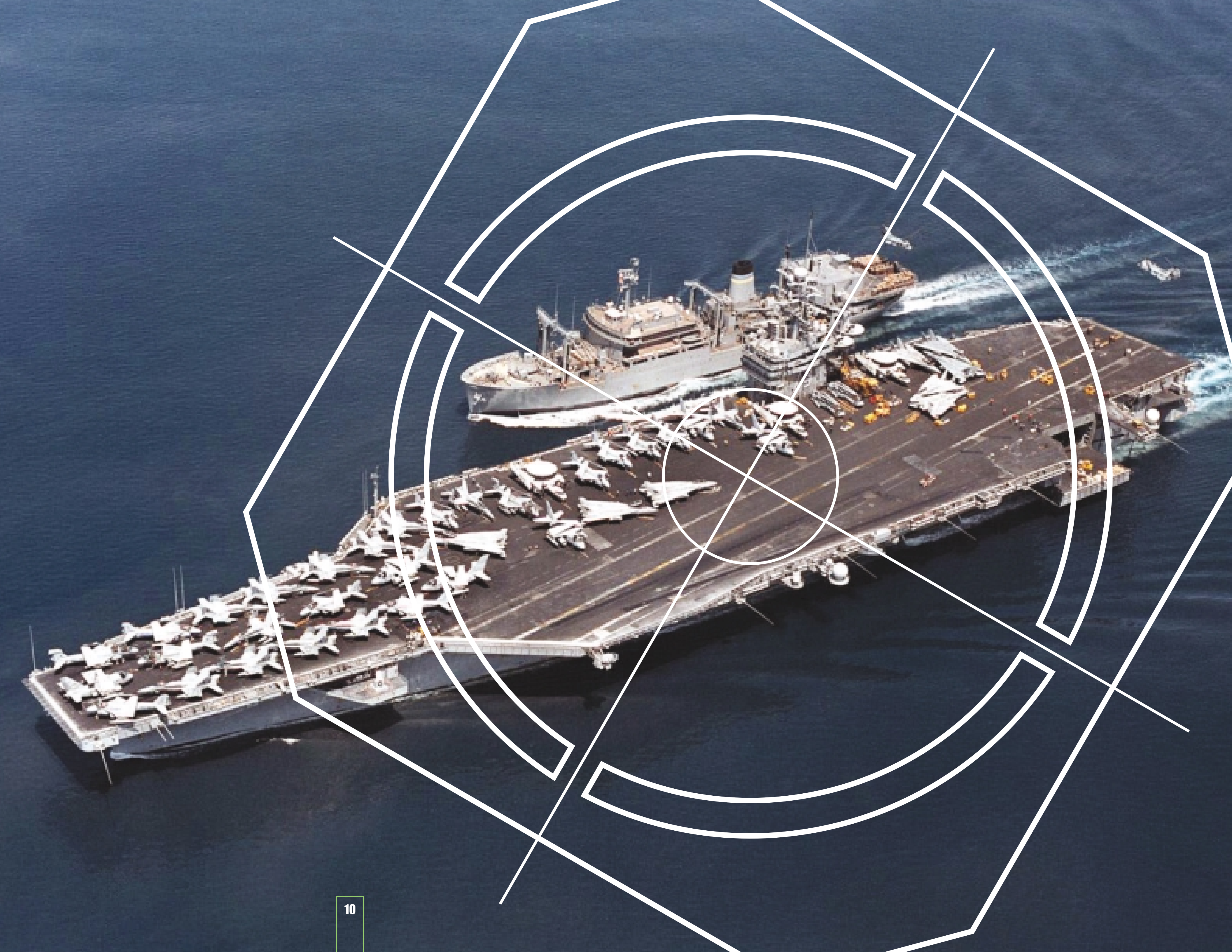
The most practical way to conduct surveillance over such expanses is with satellites, which have a much wider field of vision than sensors operating inside the atmosphere. However, China does not presently possess military reconnaissance satellites capable of finding a carrier, and the commercial satellites to which it might turn take days or weeks to task and deliver imagery -- making them useless for finding a continuously moving vessel.

Tracking the Carrier

Simply finding an aircraft carrier at a particular moment in time won't satisfy an attacker's targeting requirements. Once the carrier is spotted, the attacker must make a series of command decisions leading to the launch of weapons, and then the weapons must transit the space between their point of origin and the carrier. While all this is occurring, the carrier is moving. During a 30-minute period, it may have maneuvered anywhere within a circle measuring 700 square miles. Over 90 minutes, the area grows to 6000 square miles. In a day – if it is cruising in a straight line at high speed – it can move over 700 nm from where it was first sighted.

In order to keep up with the carrier's movements, an attacker must establish a continuous track of the vessel using some combination of land-based, sea-based, space-based and airborne sensors. Moreover, the track must be sufficiently precise so that it can provide targeting coordinates to weapons when they arrive in the carrier's vicinity. As of today, even the United States has difficulty accomplishing such a feat, and no other nation is close to having the requisite capabilities.

There are four basic types of sensors suitable for tracking vessels at sea: radar, acoustic, electro-optical and electronic-intelligence. Radar typically is used in line-of-sight applications (such as from aircraft or satellites), but in the case of tracking carriers it could also involve "over-the-horizon" systems that deflect their energy off the ionosphere. Acoustic sensors intercept distinctive noises



generated by the target to determine its location. Electro-optical sensors such as photo-reconnaissance satellites seek out the target's visible or infrared "signature." And electronic-intelligence sensors collect telltale transmissions from the target's on-board equipment.

Each sensor type has advantages and disadvantages. Space-based or airborne radar with the capacity to track moving ground targets (such as the Joint Surveillance and Target Attack Radar System, or JSTARS) has the greatest potential for providing reliable targeting information, because it combines precision with a capacity to operate day or night in all kinds of weather. However, few prospective adversaries are likely to have such systems before the end of the next decade. The U.S. has deferred plans to develop a constellation of space-based radars, and no other nation is actively considering such a project. Airborne radars like JSTARS or the Global Hawk unmanned aerial vehicle are a more viable option in the near term, but these have limited fields of view, can be intercepted, and currently are beyond the technical competence of prospective adversaries.

Ground-based over-the-horizon radars could provide countries like China with a near-term capacity to detect carriers, but they have two critical drawbacks in providing targeting data. First, the resolution of the data they collect is poor. A carrier might be impossible to distinguish from a tanker. Second, the radars employ large, fixed arrays for transmitting and receiving signals that are vulnerable to attack in wartime. Such installations are unlikely to survive the early hours of a war.

Cost and Complexity

Networks of passive acoustic sensors deployed on the ocean floor might be able to track aircraft carriers by monitoring the sounds they emit. However, the resolution and reliability of such networks is directly related to their density, and the cost of deploying dense grids across millions of square miles of ocean would be prohibitive for most adversaries. In wartime, the operation of the grids could be impeded through acoustic interference, active deception (using decoys), or outright destruction. So while underwater acoustic arrays are likely to be a useful antiaccess tool in key chokepoints such as the Strait of Hormuz, their utility in places like the Western Pacific is less clear.

The value of another passive tracking approach, electronic intelligence gathering (or electronic eavesdropping), is also unclear. Aircraft carriers generate numerous electronic emissions from their sensors, communications equipment, and other onboard systems which at least in theory might be exploited to establish a target track. However, the Navy has developed methods for managing its electronic emissions in wartime, and passive sensors are subject to a variety of countermeasures such as jamming and deception. Like acoustic monitoring, electronic intelligence gathering is a sub-optimal way of tracking surface vessels.

The same cannot be said of space-based or airborne electro-optical sensors, which are the method of tracking carriers most frequently discussed in open literature. The United States and several other countries already operate constellations of photographic reconnaissance satellites that could one day evolve into tracking systems. However, it is important to recognize how costly and complex such systems would need to be in order to continuously track a carrier.

In the case of the South China Sea, three bands of 46 satellites each (138 spacecraft in all) operating in 40-degree inclined polar orbits would be required to provide constant monitoring. The size of the satellite constellation is driven by the need for continuous coverage and high resolution. High resolution dictates low-earth orbits. Low-earth orbits in turn dictate how many satellites must be in each band to avoid gaps in coverage, and also how many bands there must be to cover the whole sea given a 300 nm field of view per band. Continuous coverage could be achieved from higher altitudes using fewer satellites, but resolution would deteriorate to a point where it was no longer suitable for use as targeting data.

There is very little likelihood that any country, including the United States, will deploy such a constellation of reconnaissance satellites over the next twenty years. If it did, it would still be able to cover only a portion of the Western Pacific. And if it were an enemy of the United States, both its spacecraft and its links to them would be subject to attack in wartime. As noted earlier, commercial satellites are unlikely any time soon to offer the resolution, coverage or immediacy necessary to track a carrier.

One day, unmanned aerial vehicles may offer an alternative to orbital platforms for the deployment of electro-optical sensors that can monitor carriers. However, their greater vulnerability to preemption combined with their more limited field of vision makes this a less-than-ideal solution. In any event, no country other than the U.S. today has the technology to make such a solution work, and that is likely to remain true for many years to come.

Penetrating Air Defenses

No potential adversary today has the assured capacity to track and target a U.S. aircraft carrier. However, it is a reasonable assumption that adversaries will eventually devise targeting techniques, especially in the littoral areas adjacent to their homelands. At that point, they can consider the next step in successfully attacking a carrier: penetrating its defenses. There are four types of weapons that pose a danger to carriers: cruise missiles launched from aircraft, ships or land bases; ballistic missiles launched from ships or land bases; torpedoes launched from submarines; and drifting or tethered mines. The carrier battle group has defenses for coping with each.

In the case of cruise missiles, attackers would face the densest, most sophisticated air defenses ever developed. It is much easier to defend carriers than land bases against air attack, because they are mobile, hardened targets surrounded by flat oceans that afford maximum sensor visibility. Land bases are bigger, more vulnerable targets that don't move, and often are located near geographical obstacles that impede the ability to detect threats. The layered air defenses of a carrier battle group exploit these advantages to maximum effect.

The outermost defensive perimeter of the battle group – hundreds of miles from the carrier – is provided by the carrier's E-2C Hawkeye airborne surveillance radar and Aegis radars on surface combatants. As attackers penetrate further, they come within range of various other sensors, including those on the carrier itself. As part of its transition to "network-centric" warfare, the Navy is integrating all of the air-defense sensors in the battle group into a Cooperative Engagement Capability that enables every participant to see what all do. The system quickly merges, filters and disseminates information from dozens of airborne and surface radars to provide a composite picture of the surrounding airspace.

The ability of defenders to share a common picture of the battlespace, and to view any particular threat from multiple aspects, greatly enhances the survivability of the carrier battle group. Even stealthy, sea-skimming cruise missiles are unlikely to escape detection, and defensive weapons can be employed with maximum efficiency. At the outermost perimeter, those weapons would consist of the carrier's interceptor aircraft, armed with air-to-air missiles. Closer in, the interceptors would be supplemented with surface-to-air missiles carried on Aegis destroyers and cruisers. The final layer of defensive weapons consists of the carrier's own missiles, the Phalanx Close-In Weapon System (a 20 mm Gatling gun that shoots over 4,000 rounds per minute), decoys and electronic countermeasures.

In a major conflict, the carrier battle group would seek to disable enemy sensors, communications and weapons long before a launch decision could be made. Even if that effort failed, it is unlikely that cruise missiles could penetrate the diverse defenses of the battle group. The range of Navy investments in new defensive systems such as the Cooperative Engagement Capability and the Radar Modernization Program for the E-2C is so extensive that carriers are actually becoming less vulnerable over time, despite the increasing sophistication of air-breathing threats.

Ballistic Missiles

Air-breathing threats – manned aircraft and cruise missiles – are not the only danger carriers may face from above. Three dozen countries outside the Atlantic Alliance possess tactical and theater-range ballistic missiles, including China, Iran, Iraq, Libya and North Korea. Ballistic missiles reach their intended targets much faster than cruise missiles, and thus may diminish the defensive advantage conferred by aircraft-carrier mobility.

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The U.S. Navy expects to deploy effective defenses against all classes of tactical and theater ballistic missiles by the end of the current decade, largely through the upgrade of existing sensors and weapons. For example, upgrading software for the Aegis combat system and equipping Hawkeye early-warning aircraft with an infrared search-and-track sensor would greatly reduce the challenge of tracking hostile ballistic missiles – particularly when networked with other joint assets already in place or under development.

Moreover, the threat posed to carriers by ballistic missiles over the next 20 years appears relatively minor. The ballistic warheads of potential adversaries lack the terminal guidance or maneuvering capability that would enable them to home in on carriers during the final moments of flight. Such warhead/seekers are very difficult to build due to the high temperatures and speeds associated with atmospheric reentry. But without those features, attackers would have to use thousands of warheads in barrages in order to have some hope of harming a moving aircraft carrier – unless nuclear warheads were used, a step few enemies are likely to be able or willing to take.

No prospective adversary has the resources required to expend thousands of ballistic-missile warheads in attacking a single aircraft carrier. Even if one did, it would be a poor tactic, possibly costing more to execute than the price of the carrier itself. Until the very challenging task of developing a terminal guidance and maneuver capability for ballistic missiles is solved by some rival, this is probably the least important threat carriers face. Unfortunately, the same cannot be said concerning the danger posed to land bases by ballistic missiles, owing to the larger size and greater vulnerability of such bases.

Penetrating Sea Defenses

Faced with the daunting challenge posed by integrated air defenses and the operational limitations of available aerospace munitions, adversaries might seek to attack a carrier from the sea using mines or torpedoes launched by submarines. The U.S. Navy has developed a layered defensive system to deal with these threats too, and its warfighting advantages in the undersea environment are at least as pronounced as the edge it holds in aerial combat.

The most ubiquitous seaborne threat to aircraft carriers is drifting or tethered mines. Virtually every littoral power has some capacity to employ mines, and over a dozen countries export them. Mines are cheaper to buy and easier to use than other munitions, but under the right circumstances can do comparable damage. And although they tend to be fairly simple mechanisms, the performance of newer mines benefits from the same digital technologies enhancing other categories of weapons.

However, mines suffer from several intrinsic limitations. Bottom mines are ineffective in water deeper than 600 feet – the depth typically found more than 100 miles from shore – and floating mines tethered to the bottom are relatively easy to detect in water of that depth. Moreover, tens or hundreds of thousands of mines are required to effectively "seed" a carrier operating area in the open sea. Once released, the mines pose at least as great a threat to an adversary's vessels as they do to the warships in a U.S. carrier battle group.

Mines present a greater threat in shallow water where they are harder to detect, and in chokepoints like the Straits of Hormuz. The Navy plans to operate its carriers in such areas only when they have been cleared of mines, and has made extensive investments in various mine detection and neutralization systems. By the end of the current decade, every carrier battle group will include helicopters equipped with the Airborne Laser Mine Detection System (ALMDS), the Organic Airborne and Surface Influence Sweep (OASIS), the Airborne Mine Neutralization System (AMNS), the Rapid Airborne Mine Clearance System (RAMICS), and the Towed Mine Detection System. Battle groups will also deploy unmanned underwater vehicles capable of autonomously finding and destroying mines.

With so many mine-countermeasure systems organic to battle groups, there is little chance a mine will actually strike a carrier. Even if it did, the likelihood of serious damage is minimal. Nimitz-class carriers have thousands of separate compartments and heavy side armor that would deflect or contain the explosive force of mines. Larger ships are generally able to absorb more damage without being disabled, and nuclear-powered aircraft carriers are the biggest warships ever built. So while the proliferation of mines among potentially hostile littoral powers is a real problem, it poses less danger to aircraft carriers than to other types of warships.

Submarines and Torpedoes

A more serious undersea threat to aircraft carriers is presented by submarines equipped with advanced munitions, especially wake-homing torpedoes. Although the nuclear-powered submarine threat of Cold War years has been greatly diminished by the decline of the Russian Navy, countries such as China and Iran are acquiring very quiet diesel-electric submarines and modern torpedoes in international markets. Tracking and neutralizing such submarines in the shallow waters adjacent to these countries' coastlines is a complex challenge.

However, the U.S. Navy has invested extensively in shallow-water antisubmarine systems that can be employed from aircraft, surface combatants, and its own undersea warships. Among the most promising new systems are unmanned underwater vehicles (UUV's) and the Advanced Deployable System, a portable hydrophone array that detects even the quietest subs. When these systems are combined with the formidable undersea-warfare capabilities of the latest U.S. nuclear attack submarines and the extensive antisubmarine capabilities of the surface fleet, it is not hard to see why the Navy expects to retain underwater supremacy through 2020.

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The Navy's overwhelming advantage in undersea acoustic domains derives partly from heavy investment in advanced technology, and partly from the service's unsurpassed rigor in training. No prospective aggressor has demonstrated a comparable level of discipline or sophistication. The threat posed by wake-homing torpedoes, for example, is largely hypothetical since no potentially hostile submarine force has actually employed them over long ranges. That may change in the future, but the likelihood adversaries will ever match the U.S. investment in undersea warfare is remote.

Even with its layered and redundant undersea defenses, though, the possibility of a chance encounter between a U.S. carrier and a hostile submarine cannot be completely discounted. With that in mind, carrier designs incorporate a Torpedo Side Protection System that the Navy believes can effectively defeat any small or side-attacking torpedo. As in the case of mines, the vast scale, heavy armor and complex compartmenting of an aircraft carrier would localize the consequences of a torpedo attack, minimizing the danger of disabling damage.

A final mitigating factor bearing upon the foreign submarine threat to carriers is the challenge any nation faces in establishing and sustaining a tactically-effective submarine force. The mere acquisition of modern submarines does not automatically confer undersea-warfare capability on potential adversaries. That demands many years of training, competent crews, professional leadership and other qualities. Few potential adversaries have demonstrated a capacity to assemble all the qualities needed for a truly effective submarine force.

Aircraft Carrier (In)Vulnerability

Aircraft carriers – even large-deck, nuclear-powered ones – are not invulnerable. But when the full range of challenges a potential aggressor faces in mounting a successful attack are reviewed, it becomes clear there are few military systems more survivable. The vessels are hard to find and harder to track. Their multiple layers of sophisticated air and sea defenses are difficult to penetrate. And even if an attacker manages to target and hit a carrier, the intrinsic resilience of the ship makes serious damage improbable.

That is not just a theoretical point. In 1969, the USS *Enterprise* – a nuclear-powered carrier still in the active fleet today – suffered a catastrophic accident during which nine of its 500-pound bombs detonated. The amount of explosive power released was roughly equal to that of half a dozen Russian cruise missiles. Although 27 sailors were killed and over 300 injured, the *Enterprise* could have resumed strike operations within hours. Carrier designs were subsequently made even more resilient, while safety and damage-control procedures were tightened.

The evolution to a new carrier design that commenced in January of 2001 with the award of a contract to build the last Nimitz-class carrier will result in additional survivability enhancements. A new combat system will be developed, the ship structure will be strengthened, its internal layout will be further rationalized, electromagnetic signatures will be muted, and many functions (including damage control) will be automated. The resulting CVNX class of carriers will be more efficient, more capable, and markedly more survivable.

In the final analysis, the question of aircraft-carrier vulnerability really needs to be posed in terms of what the alternatives are. In the sixty years since the last large U.S. carrier was sunk, the nation has become heavily dependent on carriers to cope with overseas threats and crises. The carrier air wings of today are already much more adept at strike missions than those in Operation Desert Storm, and by the end of the current decade they will be able to precisely attack over a thousand aimpoints deep in an enemy's interior in a single day.

The ability to conduct such operations without the political constraints or military risks associated with land bases is a competency only the United States enjoys. Even if carriers were far more vulnerable than they actually are, policymakers would have to ask what the alternatives are to accomplish those missions. Twenty years into the future, unmanned or transatmospheric vehicles may offer an alternative to carrier-based aircraft in the full spectrum of strike missions. Today, however, unmanned systems lack the capacity to reliably strike mobile targets and most non-naval aircraft are dependent on vulnerable, potentially unavailable land bases.

So any discussion of aircraft-carrier vulnerability must be informed by recognition of how important those ships are to current strategy, and how few real alternatives to them exist in the near term. Fortunately, carriers are highly survivable and likely to become more so in the present decade. The day may come when carriers join dreadnoughts and cavalry in the history books, but for the time being they are an indispensable bridge to that beckoning future.

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