
E-2D
AND MARITIME SECURITY

EXECUTIVE SUMMARY

The greatest threats to Navy ships in the years ahead come from missile proliferation and submarines, but the best defense starts in the sky with the E-2D Advanced Hawkeye.

"State actors and non-state actors who, in the past, have only posed limited threats in the littoral are expanding their reach beyond their own shores with improved capabilities in blue water submarine operations, advanced anti-ship cruise missiles and ballistic missiles," Vice Admiral Barry McCullough testified to the House Armed Services Committee in 2008.

Monitoring and making sense of the crowded maritime battlespace is job one for the fleet. That's where E-2D Advanced Hawkeye comes in. This carrier-based surveillance plane is best known for the 24-foot rotodome bolted on its fuselage. To the Navy, it's the eyes of the fleet – an essential mix of sensors and computing power with the mission of watching over and directing the air and sea battle.

Older E-2s have been in the fleet for years. They earned the nickname "eyes of the fleet" by doing everything from tracking Soviet bombers and Libyan MiGs in the 1980s to watching Iraq's skies in the 1990s to acting as forward control and communications relays over Afghanistan and Iraq in this decade. The Navy has to buy new carrier aircraft regularly because hard carrier landings and catapult launches wear out the older airframes.

The new E-2D coming off the production line in Florida has more powerful engines, new propellers and flat-screen sensor displays for the crew of five. For the first time, the E-2D fleet will be able to receive fuel in the air, greatly extending mission range and the margin of safety for carrier landings.

But the real magic of the E-2D is in its sensors like the APY-9 radar and cockpit processors that permit highly advanced new techniques in target tracking. What the Navy says publicly is that the E-2D crew can keep track of many more targets at once in an area 300 percent greater than older versions of the plane. Work stations inside have all the links needed to make new Navy fire control architectures even more effective: flat-screen glass displays, satellite communications and the latest secure networking.

Although the whole Naval Integrated Fire Control-Counter Air capability is still maturing, the anti-missile capabilities in E-2D work with systems ready today. Links to the Army's ground-based Patriot air and missile defense batteries are designed in. An F/A-18 can pick up E-2D cues and fire an air-to-air missile at targets. Improved links to surface ships are also on the horizon.

Getting E-2D to the fleet on schedule and in sufficient quantity is vital in a world where the technical prowess of adversaries is on the upswing. The Navy needs to keep the E-2D on track to deliver sophisticated surveillance and better engagement solutions. Missions from presence to sea-based missile defenses may depend on it.

This report was written by Dr. Rebecca Grant for the Lexington Institute.

On the cover: An E-2D flies a test mission in early 2009. Fleet delivery of the E-2D will greatly increase airborne surveillance and cruise missile tracking for Navy and joint forces.

INTRODUCTION

Dusk shrouded the Persian Gulf on the evening of May 18, 1987. At five minutes past nine o'clock, an Iraqi F-1 Mirage launched two Exocet anti-ship cruise missiles at the USS Stark, a U.S. Navy frigate patrolling international waters. The first missile pierced the hull eight feet above the waterline and the second missile detonated across crew quarters and the ship's Combat Information Center. Thirty-seven American sailors died in the attack.

It's been over 20 years since the attack on the USS *Stark*. Since then, the threat in coastal waters and on the open seas has grown to include more sophisticated anti-ship cruise missiles and ballistic missiles. The Israelis had a close call in July 2006 when Hezbollah targeted an Israeli ship with a Chinese-made cruise missile, most likely acquired via Iran. "You have to acknowledge the obvious – we've seen a new capability in striking the naval vessel," said a U.S. government official at the time.[1]

A continent away, stirrings from China indicate that anti-ship missile attacks may be back on the threat agenda for blue-water operations on the high seas, too. China has a big air force, surface-to-air missiles on ships, and now, some reports indicate China may also have modified its older Dong Feng (DF-21) missile into an anti-ship ballistic missile with long range and accurate guidance.

Guarding the U.S. Navy's freedom of action demands airborne surveillance, and specifically, an E-2D Advanced Hawkeye radar plane designed to catch these new threats.

"State actors and non-state actors who, in the past, have only posed limited threats in the littoral are expanding their reach beyond their own shores with improved capabilities in blue water submarine operations, advanced anti-ship cruise missiles and ballistic missiles," Vice Admiral Barry McCullough has testified.[2]

McCullough singled out advanced anti-ship cruise missiles for good reason. At some point, surface ships are limited in their ability to defend themselves because the curvature of the earth blocks radar from seeing some low-flying threats. As the Navy has long recognized, operating in high threat environments calls for airborne surveillance, too.

Providing a single integrated air picture arching over the entire maritime battlespace is the job of the E-2 Hawkeye, a propeller-driven, carrier-based radar plane. With this single integrated air picture, Navy aircraft and ships can instantly be on alert for threats like anti-ship cruise missiles, unmanned air vehicles, military jets or anything moving through the air. That's why they call the E-2 the "eyes of the fleet."

An older E-2C takes off from the carrier deck. E-2s earned their nickname "Eyes of the Fleet" by providing surveillance and a common air picture for the air and sea battle.

EYES OF THE FLEET

The E-2 first earned its nickname "eyes of the fleet" back in the 1960s. E-2 squadrons go to sea with the aircraft carrier's air wings. Their mission is to provide airborne early warning and battle management day and night, in all weather – hence the nickname.

This unique plane looks like nothing else on the carrier deck. A 24-foot rotodome is bolted onto the fuselage of the aircraft. Inside is a powerful airborne search radar. A crew of pilots and sensor operators does everything from scanning for hostile aircraft near the strike group, to assisting strike fighters on missions to support ground forces.

E-2s have always been busy. They coordinated strikes during the Libya crises of the 1980s. E-2s were central to the operations of six carriers during Operation Desert Storm in 1991. After that, they deployed regularly as Navy fighters patrolled no-fly zones over Iraq for 12 years. The latest version, the E-2C, orchestrated forward control and communications relays for Navy strike fighters operating over Afghanistan when Operation Enduring Freedom began in 2001, and have continued to be a part of operations there and in Iraq. E-2s also fly counter-drug missions in the Western hemisphere. Now the Navy is ready to modernize and upgrade the force with an all-new aircraft known as E-2D Advanced Hawkeye.

Just what is so urgent about bringing the E-2D into the fleet? Part of the reason is that it's time for new aircraft. Navy aircraft – and Marine Corps aircraft embarked on carriers and amphibious ships – face a punishing environment of convulsive catapult launches, arrested landings and corrosive salt air. For this reason, the Navy has always maintained a firm schedule for replacing its fighting aircraft.

But with E-2D, there's more. A new radar, greater time in flight, and many other technology advances are greatly changing the E-2D's mission. These design features will enable the E-2D to expand the battlespace surveillance over water and land, and make targeting against anything hostile much more lethal and flexible.

BIG IMPROVEMENTS

Seventy new E-2Ds will take over as the core airborne surveillance force according to Navy plans. The E-2D will have more powerful engines, and the structure on this completely new airframe has been strengthened to account for a heavier airplane taking the stress of arrested landings on the carrier deck.

The crew of five including pilot, co-pilot and three system operators will have more tactical flexibility in the E-2D. The tactical displays go beyond the glass cockpit which replaced dials and gauges years ago. What E-2D crews will have are 20-inch flat screen monitors to call up multiple types of sensor information. Screens in the E-2D can easily show the crew both aircraft mission systems and tactical displays. Either the pilot or co-pilot can summon the tactical picture and act as a fourth sensor operator as required.

The E-2D Advanced Hawkeye in final assembly in St. Augustine, Florida. Production is increasing at a steady pace to deliver full fleet capability in 2015.

The E-2D will also be able to receive fuel in the air. Amazingly, E-2 crews have worked in hostile environments and around the ship for decades without being able to take fuel from airborne tankers, like the carrier-based fighters and attack planes routinely do. The E-2D is a heavier aircraft than its predecessors, making the refueling option even more critical. Not being able to take on fuel in the air subtracts mission time on station. It's also less than safe. Carriers almost always have one refueling aircraft airborne for what they call recovery tanking – topping off a homeward-bound aircraft that's low on fuel, damaged or otherwise having trouble getting aboard the ship. Even the U.S. Air Force's mammoth Airborne Warning and Control System (AWACS) can head to the tanker to extend a mission, although the refueling link-up can be a rough ride. In the carrier air wing, every other fighting aircraft could top off from a recovery tanker near the ship and make another pass or divert; but not the E-2. The new E-2D will remedy that for future Hawkeye fliers.[3]

TARGET RICH ENVIRONMENT

The real magic of E-2D is in its sensors and processors – and the way the airframe is designed to get the most out of them. The whole fleet is counting on it to form a key link in detecting threats and managing data for a network of ships and aircraft.

Remember the rotodome, the E-2's most eye-catching feature? Think of the body of the E-2D as being built around the new APY-9 radar inside the rotodome. This electronically scanned radar is a major scientific advance over all previous E-2s. It combines two important radar functions, scanning and dwelling, in a way that lets the E-2D crew select the mode they need at any given moment.

"The E-2D radar is a multi-generational leap in performance over the existing APS-145 system and will be transformational in detection and accuracy with significantly improved overland, jamming and EMI *[electro-magnetic interference]* capability," said the admiral who was in charge of air warfare requirements as the E-2D prepared for flight tests. "The single integrated air picture provided by the E-2D in littoral and overland operations will vastly expand our battlespace surveillance and flexible targeting capability," he added.[4]

Why is this a major advance? It turns out that continuous scanning across the full 360 degrees limits power applied in any one direction. To keep the scan revisit rate relevant, the radar can only spend a brief instant on each degree of arc before sweeping around again. That is usually more than enough to pick up a target and establish its track. But what if the target is especially hard to see – i.e., stealthy? Or what if it is flying low in ground clutter? In that case, what's needed is a focused beam that dwells longer, sending more energy in a specific direction. Increased energy transmitted out produces more energy received back and a sharper radar return.

The E-2D for the first time combines both modes in a naval platform. Electronic scanning enables the radar to function both as a rotating beam generating 360-degree coverage, and as a staring beam that can pour radar energy into tracking even the smallest, stealthiest targets. As a result, the E-2D radar is so flexible that its crew can rapidly switch between three main modes of operation. First is the classic rotating beam, ensuring the strike group has no blind spot. Second is a mode which continues the rotation but carves out a 45-degree slice, for example, where power is enhanced. The crew can focus the beam at the direction of a known or cued threat and boost the power while the beam is pointing that direction. It's the equivalent of scanning the horizon but pausing briefly to stare especially hard at the area of interest. Finally, the E-2D can temporarily turn off the rotating function and funnel all its considerable radar energy at a target.

The special construction of the aircraft allows it to keep the beam fixed on an object like an inland airfield or a ship at sea to give an unblinking eye on the problem. Note the unusual vertical stabilizers on the E-2D's tail. Most aircraft turn by banking, which means slightly tilting their wings to alter pressure and steer right or left. However, the E-2D has the multi-sectioned tail so it can turn without banking and thereby keep the radar in beam mode fixed completely on its target. (In a banking turn, the E-2D fuselage would blind its own radar at certain points.)

The E-2D's radar operates in the ultra high frequency (UHF) bands where wavelengths are optimized for detecting smaller objects. Flying at a notional 25,000 feet, the E-2D can "see" 200 miles or more before curvature limits range. Compare that to a warship on the surface where the horizon dips at roughly 20 miles. The powerful Aegis ship-board radar has no problem with targets like aircraft and ballistic missiles coming in from above. But a maneuvering cruise missile flying 15 feet above the waves can sneak up much faster under the cover of geometry. Having the E-2D airborne protects the strike group.

Added range and power gives the E-2D radar the ability to sort out targets over land, too. Many rogue states and regional actors might organize cruise missile launch facilities so that the first part of the missile's flight begins over land. A big problem with detecting low-flying targets over land has always been ground clutter. Canyons, buildings, and terrain features generate radar returns that in the past created a stew of reflected energy.

A white delta symbol on its nose distinguishes the E-2D from earlier models for carrier landings.

E-2D solves this with a combination of the new APY-9 radar and its on-board processing power. The E-2D incorporates a signal processing technique called Space Time Adaptive Processing or STAP. Space Time Adaptive Processing combines the hardware of the radar antennae array with software solutions to orchestrate the radar gain in ways that reduce random signals. Multiple receivers in the E-2D's electronically scanned radar make use of the STAP technique possible. The other key ingredient for STAP is computing power. In years past, it would have taken an on-board supercomputer to run the filtering. However, the E-2D's cockpit technology advances make it possible to perform the functions airborne for the first time in a carrier-based surveillance aircraft. The same systems can keep track of numerous individual targets in the air picture. The net result is a big step forward in factoring out clutter and crystallizing the moving image – namely, the inbound cruise missile.

Of course, even a superior radar platform needs datalinks to pass along the information. E-2D's tactical datalinks will form the hand-off to the Navy's Cooperative Engagement Capability and new architectures.

WORKING TOGETHER TO ENGAGE TARGETS

From the moment it reaches the fleet, E-2D will take up a central role in the network of Navy ships and aircraft called Cooperative Engagement Capability, or CEC. Cooperative Engagement Capability was first tested in the 1990s. It fused sensor data to build a network link among aircraft and ships. The special advantage of CEC was that a ship or aircraft could use the link to transmit higher-quality targeting data.

By combining radar, sensor and tracking data from multiple platforms, CEC created a common picture of threats and their locations. "CEC extracts data from sensors aboard surface ships and aircraft throughout the battle group operating region and displays fire control quality data, within microseconds, to every asset in the battle group," explained analyst William O'Neil.[5]

Today, CEC data is good enough so that one ship can shoot a missile at an incoming target based on tracks developed by other ships or aircraft. In simple terms, CEC hands off the actual radar dwell information, meaning that the ship or aircraft receiving the data can pass it straight to the missile or other weapon to shoot down the target.

A ship patrolling miles away from another can pick up the data, and use decision logic to let the second ship fire. Alternately, a ship or aircraft can just receive the CEC data and target a weapon. Cooperative Engagement Capability thereby expands both the coverage area and the number of potential defenders in the game.

"The dominant command and control provided by the *Hawkeye* will only continue to expand as the E-2 grows in missions, communications, capabilities and sensors in a network-centric environment," noted the admiral in charge of air warfare requirements.[6] In time, the E-2D may feature low probability of intercept links designed for operations with stealthy aircraft like the F-35C and the experimental Navy Unmanned Combat Air System. The open architecture of the E-2D will allow it to add new communications links and other features in the future.

The Navy also plans a new system to link tactical data from the E-2D to aircraft and ships, too. Officially it's named the Naval Integrated Fire Control-Counter Air, or NIFC-CA.

E-2D is especially important here. Unlike ships, it will be able to use its airborne perch to scan and sort targets over land, and feed them rapidly into the architecture. As soon as the E-2D enters the fleet it will be able to transmit firing data to an F/A-18E/F, for example. The size and reach of the radar on the E-2D far exceed what strike fighters provide. The E-2D also has new computer systems optimized to store and prioritize the information it sweeps up. In short, E-2D's battle management role will go far beyond being the "eyes of the fleet." E-2D will be a big share of the brainpower, too.

Later, E-2D will hand off to a new missile now in development called the SM-6 which combines the larger, standard missile body with the seeker of the smaller, highly maneuverable air-to-air missile, the AIM-120. Cued by E-2D data, this new missile should be agile enough to chase down missile or aircraft targets jinking, diving and banking toward ships.

That's why rapidly fielding the E-2D is so vital. Any other ship or aircraft can get the E-2D data – merged as part of the common operating picture – via CEC. Basically every ship in the fleet can benefit from E-2D right away. "The only limitation is that the common tactical picture extends only as far as the sensor reach of the units participating in the CEC network," noted O'Neil. E-2D ups the value substantially.

DETERRING THE THREAT

One of the main drivers behind E-2D is the rise of cruise missiles in the maritime environment.

Anti-ship cruise missiles have been around a long time. The Soviet Union debuted the SS-N-2 Styx in 1960. Best-known of the class is still France's Exocet, seen first in 1975. China developed its Silkworms in the 1960s. Typical anti-ship cruise missiles like Exocet employ active radar as the targeting device and can be fired from 40 to 50 miles away from the target. Unfortunately, there are even nastier threats. Russia's Krypton anti-ship cruise missile is reported to have a range of 120 miles with active and passive radar.

Much more disturbing are the speed and maneuver of these modern anti-ship cruise missiles. Don't imagine these missiles are flying in straight and level toward their targets. "The Russian Club, *Moskit, Yakhont*, and Russian/Indian *BrahMos* Anti-Ship Cruise Missiles (ASCMs) use supersonic climb-and-dive attack tactics (and the latter three use ramjets to achieve speeds over three times the speed of sound) making them extremely difficult to defend against," noted a recent report from the Marshall Institute.[7]

In 2003, the beginning of the Iraq war pointed out why cruise missiles can be especially challenging. While U.S. and Kuwaiti Patriot theater missile defense batteries intercepted and destroyed all nine Iraqi ballistic missiles launched against the Coalition, they "failed to detect or intercept the five HY-2/CSSC-3 Seersucker cruise missiles launched against Kuwait," concluded the Congressional Research Service.[8]

Those are the kinds of threats the Navy of today and tomorrow will face. "Cruise missiles are easy to hide, adaptable, highly capable and relatively cheap," experts have noted. "In short, they are an instrument for deterring or increasing the costs of U.S. military operations," concluded the Marshall Institute authors.[9]

Iran provides a good example of how the cruise missile threat has continued to evolve and why the role of the E-2D is so important. During the "tanker wars" of the 1980s, Iran dotted its coastline with anti-ship missile batteries. These were older variants with a limited range. More important, U.S. Navy ships knew that the threat would come from a specific direction.

Two events changed the status quo. First, in February 1996, U.S. observers spotted Iranian vessels with the C-802 cruise missiles made in China aboard. "What that means is that you now have a 360-degree threat," said a senior Department of Defense spokesman at the time. "That makes the surveillance effort – keeping track of the ships – much more important."

Just over a year later, Iran added another dimension to the threat. On June 6, 1997, the Iranians launched a C-801K with a demonstration warhead from an F-4 against a target barge in the Persian Gulf.[10] A 360-degree threat with a much shorter time line added to the complexity of the environment. From the Navy's point of view, "your readiness always has to be up, and that [the threat] can come in a lot quicker," said the official. The U.S. lodged a formal complaint with China and sales to Iran were thought to have diminished.

Therein lies a tale of the resilience of asymmetric threats. Once technologies make it to the world market, they can turn up anywhere. Ten years later, those missiles were in the hands of Hezbollah.

There's no telling what the fleet and the E-2D may face in years to come. China, for one, is steadily asserting its naval power. "We see a continued emphasis on building capacity for sea- and land-based anti-access and area denial operations," a Defense Department official said in a briefing on the release of the Pentagon's annual report on China's military power.[11]

In January 2009, Dr. Ashton Carter of Harvard University wrote of the five challenges to U.S. security that must be balanced in the defense strategy. Third of five was "hedging against an unlikely but possible downturn in relations with China" and the fifth was "to continue to overmatch potential adversaries on the conventional battlefield."[12]

China may already be capable of presenting the Navy with some big challenges. According to the U.S. Naval Institute, China said in March 2009 that it has developed a guided anti-ship ballistic missile with a range of 2000 kilometers. The missile may be based on its older DF-21 series and purportedly has a low signature and is maneuverable. All this is well within the realm of the possible from a technology perspective. Hitting a moving target like a carrier would be no easy feat. But at some point, commanders in the Pacific will have to weigh the risks.

A threat like this underscores the need for E-2D in its original, blue-water mission. No carrier can operate without advanced warning and tactics for a potential threat like the DF-21. Whether China develops this capability in 2010 or 2015 or 2020 scarcely matters. The technology drive and the desire to deter U.S. action is there.

KEEPING E-2D ON TRACK

As with all things in Washington, there's a lingering danger that program cuts could slow delivery of the E-2D to the fleet. Vacillation by Congress in 2008 and 2009 gave a sense of the potential problems. Congressional staff zeroed out money for one of the three E-2Ds funded in the 2009 spending bill. The result was slower progress in E-2D testing.

For the next few years, steady program funding will be essential as tests continue and the Navy prepares to deliver E-2D to the fleet. The E-2D is in what's called a "ramp up" to full production. Engineers, production line specialists, managers, accountants, and the team needed to run an advanced aircraft program are getting into place. The factory floor has to be readied to accommodate full production. Then there are the suppliers. While Northrop Grumman is the prime manufacturer, a big program like Advanced Hawkeye relies on scores of other companies to supply parts from fasteners to major subsystems and software. Some of the suppliers are big names (like Lockheed Martin, manufacturer of the APY-9 radar) while other suppliers are known only within the industry. All together, they represent thousands of additional workers. Contracts with suppliers are negotiated well in advance and cuts mean going back to

Inside the disc-like rotodome, the APY-9 radar can operate in circular sweep mode or focus its beam to dwell on a wedge of the battlespace. E-2D is designed specifically to watch for threats like anti-ship or land-attack cruise missiles. Production E-2Ds will be capable of air refueling.

ask for new terms and prices. It's hard to manage a program well on terms favorable to the government when the program whiplashes around.

The E-2D capabilities are special enough that they will be in very high demand from all deploying strike groups. If there aren't enough E-2Ds to go around, then those that are available will be swapped between squadrons and kept almost constantly on deployment.

Of course, that's happened before. "I remember coming back from 7-9 month deployments and spending the post-cruise period frantically stripping boxes, engines, even outer wing panels to help a sister squadron get ready for deployment," wrote one former E-2C aviator of the days when the E-2Cs were new and in short supply. [13]

Navies have dealt with equipment shortages before, of course, but the E-2D problem is different. Cold War threats depended on the state of the superpower balance and might be low one year, higher the next. Asymmetric threats never go away. They just wait and their presence in critical areas is a constant. Insufficient E-2Ds directly increase the risk of an adversary using the relatively low-tech cruise missile to complicate or lock out maritime maneuver. Ultimately, that poses risks to missions from presence to sea-based missile defense. In a world of threats ranging from pirates to peers, that's a risk the U.S. Navy can't afford.

END NOTES

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Available at www.lexingtoninstitute.org

Printed in the United States of America
May 2009

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