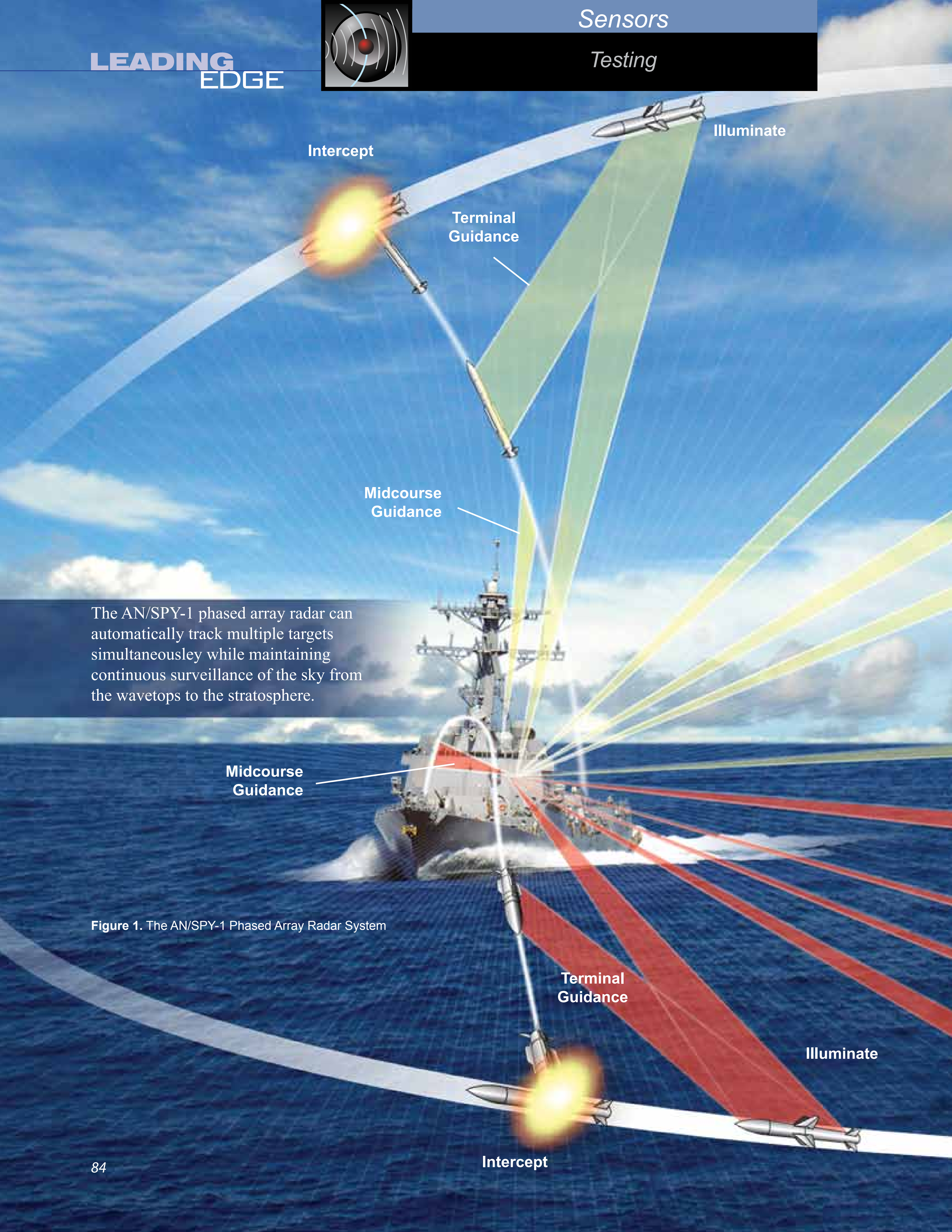
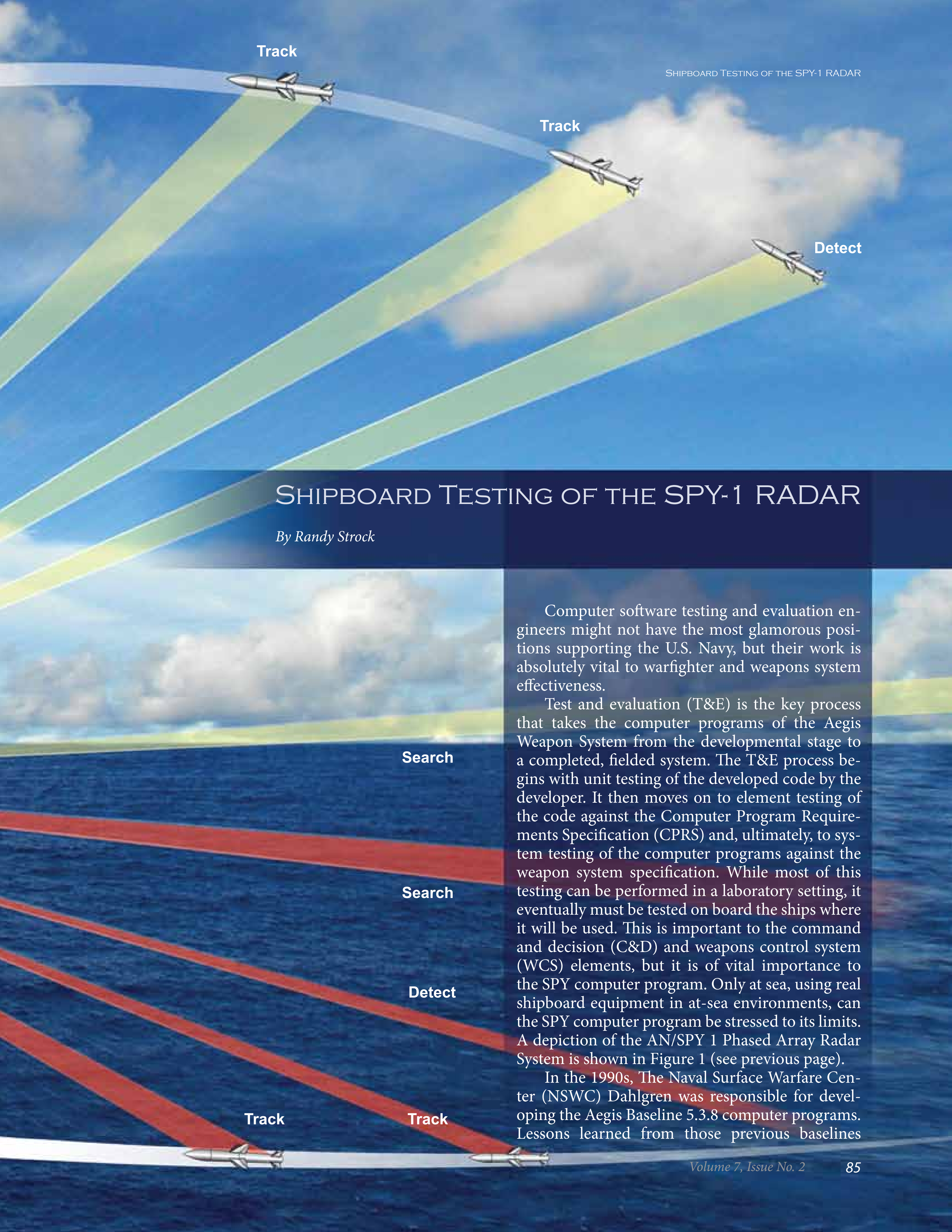


The AN/SPY-1 phased array radar can automatically track multiple targets simultaneousley while maintaining continuous surveillance of the sky from the wavetops to the stratosphere.

Figure 1. The AN/SPY-1 Phased Array Radar System



Shipboard Testing of the SPY-1 RADAR

By Randy Strock

Computer software testing and evaluation engineers might not have the most glamorous positions supporting the U.S. Navy, but their work is absolutely vital to warfighter and weapons system effectiveness.

Test and evaluation (T&E) is the key process that takes the computer programs of the Aegis Weapon System from the developmental stage to a completed, fielded system. The T&E process begins with unit testing of the developed code by the developer. It then moves on to element testing of the code against the Computer Program Requirements Specification (CPRS) and, ultimately, to system testing of the computer programs against the weapon system specification. While most of this testing can be performed in a laboratory setting, it eventually must be tested on board the ships where it will be used. This is important to the command and decision (C&D) and weapons control system (WCS) elements, but it is of vital importance to the SPY computer program. Only at sea, using real shipboard equipment in at-sea environments, can the SPY computer program be stressed to its limits. A depiction of the AN/SPY 1 Phased Array Radar System is shown in Figure 1 (see previous page).

In the 1990s, The Naval Surface Warfare Center (NSWC) Dahlgren was responsible for developing the Aegis Baseline 5.3.8 computer programs. Lessons learned from those previous baselines proved to software engineers that at-sea testing was critically important. Before then, after baseline development and testing was thought to be complete, the computer programs would go to sea. Once exposed to that environment, however, many more problems were found. Some problems were easily fixed, while others pointed to more deeply rooted design issues. Subsequently, with the Baseline 5.3.8 program, the Aegis philosophy of "build a little, test a little" was taken seriously and adopted by the SPY development team. From the beginning, during early development, the computer program was taken to sea as much as possible to wring out problems with the computer program code and transition data to support decisions on the next phase of development. NSWC Dahlgren was, and continues to be, in a unique position for this kind of work due to its close association with both the operational Navy and the developmental side of the Navy. The result of this at-sea testing approach yielded very successful computer programs that are currently fielded on 37 Aegis cruisers and destroyers.

In the early 2000s, Aegis Baseline 7 Phase I was under development by Lockheed Martin for the DDG 91 and follow ships. On these ships, the SPY-1D(V) radar was introduced. This third-generation SPY-1 signal processor brought several significant changes to the radar, including a large suite of clutter-canceling, moving-target indicator (MTI) waveforms. Designed and developed in the 1990s, this new radar suite had been extensively tested at land sites, including developmental testing (DT) and operational testing (OT) at the Combat System Engineering Development Site (CSEDS) in Moorestown, New Jersey, where Lockheed Martin is located. But it wasn't until 2003 that a ship was built with the radar installed.

NSWC Dahlgren engineers had been involved in virtually every phase of development and testing of the SPY-1D(V) radar system for the Navy. With the advent of the new radar signal processor and new computer programs to support it, it was strongly believed that at-sea testing was needed as soon as possible to ensure that the radar was giving the Navy the product that it required. NSWC Dahlgren engineers led the effort to go aboard USS *Pinckney* (DDG 91) while it was still in the Pascagoula Mississippi, shipyard in the summer and fall of 2003. They had prepared for at-sea testing as soon as the ship was put to sea. This effort led to the Navy executing an extended Alpha Trial, which contained over 34 hours of testing specifically for the SPY-1D(V) radar to test functions that were either impossible to test at land-based sites, or where the land-based data was insufficient. NSWC Dahlgren engineers were part of the team that developed the test procedures, performed the testing on the ship, and analyzed the data afterward. The results of this effort were very successful, in that many problems were found with the computer program that had been overlooked during land-based testing. These problems were then corrected in later builds of the computer program. Figure 2 shows the guided missile destroyer USS *Pinckney* (DDG 91).

Figure 2. The Guided-Missile Destroyer USS *Pinckney* (DDG 91)

The at-sea testing approach aboard USS *Pinckney* continued through the remainder of its shipbuilder trials and through its transit from Pascagoula to its home port in San Diego, California, in 2004. Many hours of specific testing were completed by the test team, as well as collecting and analyzing data from day-to-day operations. Problems continued to be found during this period and were fed back to Lockheed Martin to correct in later builds. By the summer of 2004, the team began to feel that the radar was going to be ready for its formal DT/OT testing in September.

As the developmental and operational test date approached, it became clear that the date was going to slip into 2005. USS *Halsey* (DDG 97) was targeted for testing in September of 2005, but budgets were tightening, and DT became one of the victims. Consequently, instead of a separate test event with its own test aircraft and missiles, DT was ordered to piggyback on the existing Combined Combat Systems Ship's Qualification Trials (CSSQTs) for the DDG 91 through DDG 95. NSWC Dahlgren was instrumental to the team that produced the development test plan and influenced the CSSQT testing to collect the data that was needed to test all the SPY-1D(V) functions called for in the Test and Evaluation Master Plan (TEMP). Over the next year, as testing progressed through the CSSQTs of the five ships, as before, more problems were found and fixed in the Baseline 7.1 computer program. By the time that USS *Halsey* completed the OT, the SPY-1 radar was ready. For the first time in the history of Aegis, the SPY radar was deemed "operationally effective." The guided-missile destroyer USS Halsey is shown in Figure 3.

During early- to mid-year 2000s, SPY computer program development shifted to an open architecture (OA) approach. This involved a complete rewrite of the computer program. Some design elements were brought forward from the preceding baselines, including 5.3.8 and 7.1, but the underlying structure of the program was rebuilt from the ground

Figure 3. The Guided-Missile Destroyer USS *Halsey* (DDG 97)

up. Testing at this time changed completely from the 1990s' approach. On the military UYK computers, the code was developed and compiled on a VAX computer and then had to be loaded onto the UYK computer in a special laboratory to be tested. The process was tedious and time-consuming, and laboratory time was limited. With the OA computer program, personal computers (PCs) had come along far enough that the SPY computer program could be written, compiled, and tested on a single desktop PC. Thus, the same computer program that was compiled and run on tactical computers on board ship could also be compiled and run on a PC. Using a PC, the program interfaced with the Testable Computing Environment (TCE) developed by Technology Services Corporation (TSC). This capability enabled developers to code and test computer programs 24 hours a day at their desks. This capability dramatically increased productivity and turnaround time, and decreased overall computer program error rates. However, desktop testing could never substitute for testing performed in the at-sea environment.

The earliest version of the SPY OA computer program that reached the stage where it could be tested on shipboard equipment was a version intended to be used with the SPY-1D(V) radar. NSWC Dahlgren was instrumental in getting this computer program to sea. Support included:

- Working with the ships to find test opportunities
- Developing the test equipment that went aboard the ships to interface with the shipboard computers
- Developing test procedures
- Participating in the onboard test events
- Analyzing the data during and after the events

As usual, the at-sea testing proved critical in the development of the SPY OA computer program. Many problems were found and corrected in the computer program thanks to the at-sea testing that was performed. Unfortunately, the SPY-1D(V) version of the SPY OA computer program was not put into service. However, since it was architected to be a superset computer program for all SPY-1 variants, it was taken as the basis for the Advanced Capability Build 2008 (ACB08) Cruiser Guided Modernization (CGM) computer program aboard Baseline 2 SPY-1A radar-equipped ships.

The ACB08 computer program was first made available to USS *Bunker Hill* (CG 52) in the fall of 2008. Once again, the SPY-1 engineering community took the initiative to get aboard the ship as soon as possible and collect data with the new computer program. Early testing in November and December 2008 focused on the simple basics of radar operation: search and track of targets of opportunity. Beginning in February 2009 and continuing through March 2009, more structured testing was accomplished. NSWC Dahlgren engineers were involved in the test planning for these events and supported the testing aboard the CG 52 for a total of 5 weeks during this period. Recorded data was received at Dahlgren after each test event and was analyzed in the weeks afterward. As learned many times before, at-sea data proved invaluable in providing an environment that simply cannot be replicated in a laboratory setting. Many additional computer program problems were discovered and corrected in later builds of the program as a result of this testing and analysis. USS *Bunker Hill* (CG 52) is shown in Figure 4.

Going into CSSQT of USS *Bunker Hill* (CG 52) and USS *Stockdale* (DDG 106) in June of 2009, at-sea testing of the SPY-1 radar continued. The CG 52 has the latest ACB08 computer program build, and the DDG 106 will be running with the Baseline 7.1R computer program. While weapon system problems are never desired, it is always better to discover them beforehand than to have ships deploy and go to war with them. Shipboard testing and evaluation of computer programs, therefore, really is vital to warfighter and weapons system effectiveness.

Figure 4. USS *Bunker Hill* (CG 52)

Integrated Electronic Warfare Test Facility

By Mark W. Karrick and Ronald D. Wood

The Integrated Electronic Warfare Test Facility opened in 2003 to enhance the Combat System Integration effort at the Naval Surface Warfare Center (NSWC) Dahlgren. The facility was built around the existing AN/SLQ-32(V) Electronic Warfare Reprogrammable Libraries (EWRL) mission, which provides mission updates to fleet electronic warfare databases and oversees the cyclic threat-database update process. The facility is used to lead the Navy's effort to upgrade aging shipboard electronic warfare systems and ensure that this critical warfighting data is integrated into the combat system while continuing to support the core EWRL mission. The Naval Surface Warfare Center, Dahlgren Division (NSWCDD) partnered with the Electronic Warfare Systems Project Office (PEO IWS-2E) and industry to meet the Navy's electronic warfare objectives through the Surface Electronic Warfare Improvement Program (SEWIP). SEWIP provides upgrades and new capabilities to the current AN/SLQ-32(V) electronic countermeasures system. A number of Integrated Electronic Warfare Test Facility projects are discussed as follows.

The Integrated Electronic Warfare Test Facility

The EWRL is involved in the development of electronic surveillance (ES) and electronic attack (EA) threat databases and active responses. The facility has a robust radar simulation capability in the Combat Electromagnetic Environment (CEESIM) and VARIgen simulators, which provide both live radio frequency (RF) and digital radar simulation inject (see Figures 1 and 2). Precise radar simulation is vital for accurate ES system identification and EA system response. The facility offers a unique site and equipment configuration. The core AN/SLQ-32(V) is divided in half, with the port side of the system inside the laboratory and the starboard side on an external tower. This allows for isolated testing on the port side and for detection of emitters of opportunity and live overwater and overland ES/EA testing from the starboard-side equipment.

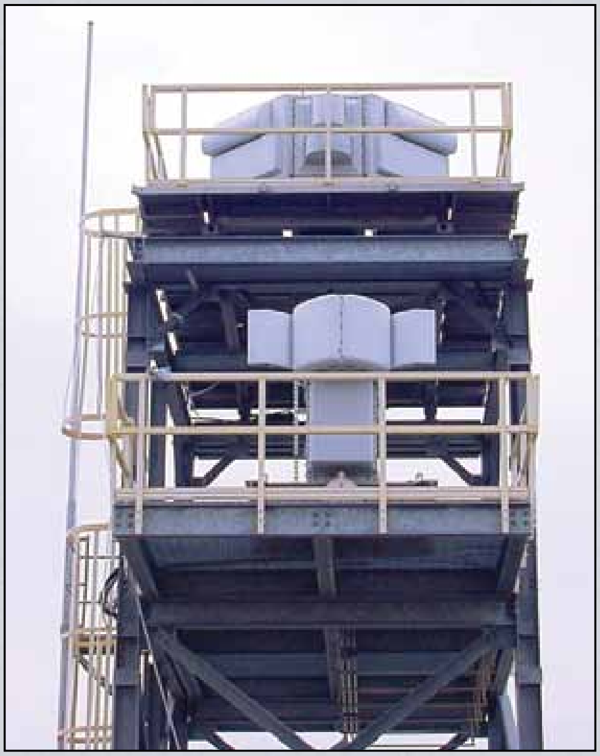


Figure 1. Integrated Electronic Warfare Test Facility AN/SLQ-32(V)5 Electronic Surveillance and Electronic Attack Antenna Tower

Figure 2. Radar Simulation and Generation Van

Surface Electronic Warfare Improvement Program (SEWIP)

SEWIP is a spiral development program for upgrading and providing new capabilities to the current AN/SLQ-32(V) electronic countermeasures system (see Figure 3). To date, the program has provided an upgraded open-architecture processor, a display console, and the addition of a specific emitter identification (SEI) capability. Future enhancements will involve adding a high-gain/high-sense receiver that will significantly improve the sensitivity of the SEWIP system. NSWCDD is the lead for threat database software testing for the SEWIP Program. The facility has the only shore-based connection between the SEWIP system and SIPRnet; NSWCDD used this unique singular link to development the U.S. Navy's AN/SLQ-32(V) Mission Planning website.

Common Display System/Common Processor System (CDS/CPS)

The CDS/CPS is the replacement for the fleet-standard Q70 display console. NSWCDD is researching the migration of the SEWIP Q70 software to the CDS/CPS platform for PEO IWS-2E as part of the Aegis Modernization Program. A prototype is shown in Figure 4.

Future considerations for this facility include connectivity to the Ship Self-Defense System (SSDS) at Wallops Island, Virginia. This would facilitate direct SSDS and AN/SLQ-32(V) threat database testing. Additional combat system integration with the Sea Air Integrated Laboratory (SAIL) at Patuxent Naval Air Station, Maryland, will provide integration with the AN/ALQ-142(V) and AN/ALQ-210(V) systems aboard the Light Airborne Multipurpose System (LAMPS) helicopter (see Figure 5). Integrating with SAIL will allow threat database analysts to upload ES system libraries to LAMPS platforms in real time. SSDS and SAIL integration will provide a more realistic and combat-system-representative testing environment to help keep the U.S. Navy on the forefront of electronic warfare and combat system integration.

Figure 3. AN/SLQ-32(V)5 Legacy and SEWIP Configuration

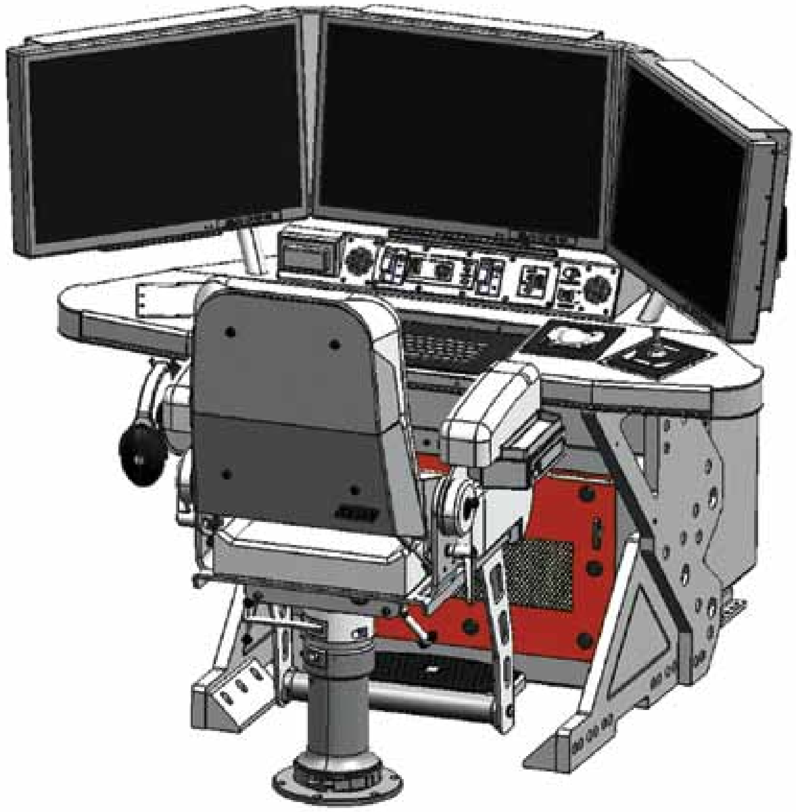


Figure 4. Prototype of the CDS/CPS Console

Figure 5. SH-60 LAMPS MK III Seahawk

Dual-Band Radar Program: Government and Industry Teamwork Wins the Day

By Brian Hill and David Scalia

Extraordinary events occur in the realm of test and evaluation. Sometimes the success of these efforts extends beyond tangible results and provides a glimpse of successful Naval Sea Systems Command (NAVSEA) Warfare Center government-contractor partnerships. The successful integration of the AN/SPY-3 Multifunction Radar (MFR) and the Volume Search Radar (VSR) Engineering Development models at the Naval Surface Warfare Center, Port Hueneme Division (NSWC PHD), while only one part of the overall test program for these radars, exemplifies how government and industry can partner together to achieve success despite seemingly insurmountable challenges.

The MFR and VSR constitute the Dual-Band Radar Program, a system of the DDG 1000 Program that operates in a full-service contract environment. It is within this environment that government and industry have nurtured a significant cultural change to combine, manage, and execute tasking. This effort led to a partnership among the Navy, prime contractors, and various support contractors that further led to increased responsiveness and adaptability to meet program executive office (PEO) requirements and contractual obligations. The end results have been a series of events successfully conducted and completed on schedule and within budget.

The government competitively awarded Raytheon Integrated Defense Systems a contract to produce the MFR Engineering Development Model in 1999, which underwent land-based testing at the Surface Combat Systems Center, Wallops Island, Virginia, through the end of 2005. The program of record was to conduct at-sea testing on a yet-to-be-determined platform. Northrop Grumman Ship Systems (NGSS), as lead integrator, selected the 563-ft, 9,200 ton, Self-Defense Test Ship (SDTS), ex-USS *Paul F. Foster* (DD 964) to serve as the at-sea platform. What followed was a 9-month, close-working partnership among Raytheon, NGSS, and NSWC PHD (our national team) to design the MFR installation for the SDTS (see Figure 1). Northrop Grumman utilized the local industrial base and NSWC PHD personnel via a Work For Private Parties agreement to make efficient use of the allocated budget.

Figure 1. AN/SPY-3 Multifunction Radar (MFR) Installed on SDTS

The SDTS, being a decommissioned Navy destroyer, was designed for operating complex Navy combat systems. The MFR, designed for use aboard DDG 1000, made various engineering challenges immediately apparent in order to adapt the system for the SDTS. For example:

- The SDTS had no physical location to hold the 25,500-lb array enclosure at the proper height, so a tower was designed and constructed pierside (see Figures 2 through 4). This necessitated other studies to be performed, including weight and moment analyses.
- The SDTS had sufficient power for the MFR installation; however, distribution became an issue. The load had to be balanced from multiple load centers while accounting for the ramp rate and other power factors.
- The SDTS chilled water system had to be modified and augmented to allow sufficient cooling of the MFR.

Figure 2. MFR Tower Being Installed on SDTS

Other challenges included various security requirements, resource sharing with other systems installed aboard the SDTS, and corrosion concerns related to operating a temporary installation in a corrosive saltwater environment.

These challenges were in addition to the normal approvals that surround installing and operating a system, such as frequency approvals, site approvals, adherence to National Environmental Protection Act requirements, and for this particular effort, coordination with the California Coastal Commission. The national team was able to complete the entire installation without mishap within the time and budget allocated. The result was the successful completion of the MFR at-sea test (DTB2-410) in the scheduled four underway periods via a collaborative Raytheon and government test team. At the conclusion of the at-sea testing, the MFR was scheduled for installation in a newly constructed building, the Wallops Island Engineering Test Center (WIETC), where it would be integrated with the VSR. Construction delays moved the building completion date, which required the MFR to remain installed on the SDTS. This allowed the MFR test team to continue testing, leveraging off of other programs and their test events.

Figure 3. MFR Antenna Shelter Being Mounted on Tower Onboard SDTS

Figure 4. MFR Signal-Processing Enclosure Being Installed on SDTS

An engineering challenge arose when the leverage test events required the SDTS be operated without personnel on board. The SDTS has been modified to allow full remote control of the entire ship, including all permanently installed combat systems; so for the primary systems, this requirement was already met. The MFR, however, was never intended to be remotely controlled. Once again a partnership between Raytheon and NSWC PHD engineered a solution, modifying portions of the hardware and software to allow the MFR to be remotely controlled while meeting all safety and security requirements. Challenges again arose with respect to ensuring that interference from the MFR would not cause unintended consequences for the primary system undergoing test. Raytheon and the MFR test team had to work closely with the subject matter experts for each of the various systems to test and validate that there were no issues. Ultimately, MFR participated in an additional 2 years of testing aboard the SDTS. This feat was possible only due to national team collaboration across government and industry.

Volume Search Radar (VSR)

The VSR's path to NSWC PHD brought a new set of engineering challenges for the government and industry team. Raytheon was awarded a contract to develop and build the VSR array with Lockheed Martin Maritime Systems and Sensors. The plan of record was that after completion of the VSR array near-field testing at the Lockheed Martin facility in Moorestown, New Jersey—which was scheduled for completion at the end of May 2007—the VSR was to be installed in the newly constructed WIETC. Once installed, the VSR would undergo initial high-power testing and technical performance measurement (TPM) verifications prior to the start of integration with MFR. These initial tests were required by NAVSEA Program Executive Office Ships (PMS 500) and Program Executive Office Integrated Warfare Systems (PEO IWS 2.0) (responsible for ship construction and radars, respectively) to make a decision on whether or not to proceed with VSR production. However, the delays that prevented the removal of the MFR from the SDTS also affected the VSR, and it became apparent to both program offices that this testing was in jeopardy of not meeting the schedule. To maintain the program-of-record schedule, a study was commissioned in August 2006 to determine the feasibility of performing the initial testing at an alternate test site until WIETC construction was completed.

The Radar Suite Acquisition Team subsequently determined that the Surface Warfare Engineering Facility (SWEF)—a five-story, 50,000-sq ft, oceanfront, land-based test site, located at NSWC PHD—met the criteria for performing the initial testing. Faced with exacting time, funding, and resource constraints, the government and industry team convened to boldly orchestrate an unparalleled set of actions that accomplished the installation goal within a 4-month time frame. The effort enabled the VSR to conduct 5 months of extensive far-field integration and TPM verification that included high-power radio frequency (RF), system alignment, antenna patterns, and accuracy measurements.

As with the MFR installation and test effort, the government and industry team partnership included NAVSEA and Raytheon, with the addition of Lockheed Martin, as well as local southern California industrial support. Concerning the major challenges for this project, some efforts remained in the government's purview—namely, environmental and site approvals (working with the California Coastal Commission), along with a concentrated contracting authority effort to modify various contract vehicles to enable what was an essentially unplanned event.

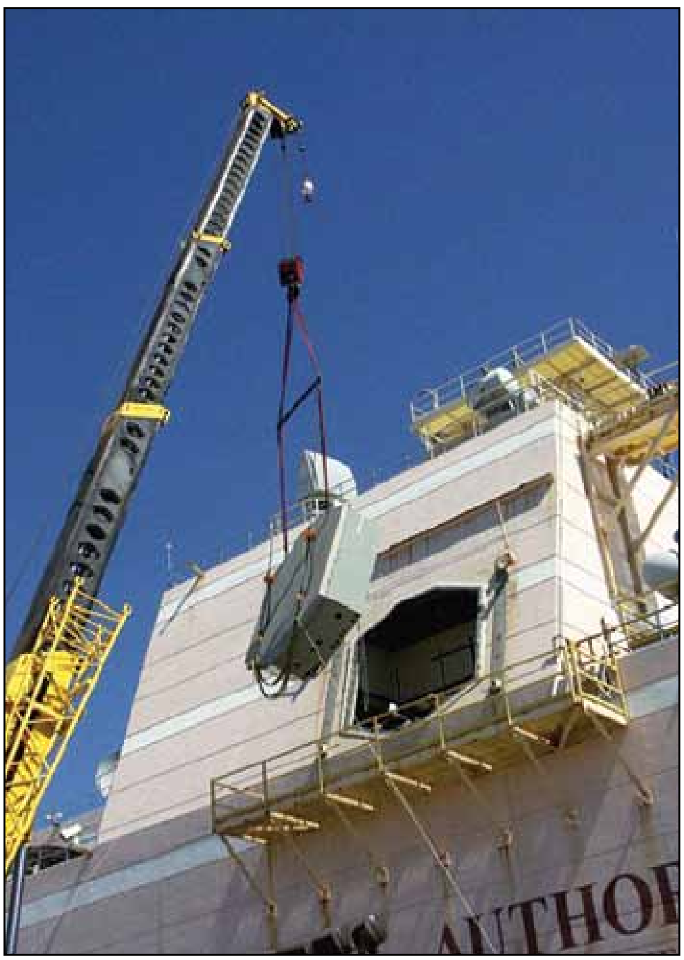


Figure 5. SPY-1A Array Being Uninstalled from the SWEF

The engineering challenge involved removing an existing AN/SPY-1A radar suite and reconfiguring the building infrastructure to support the VSR (see Figures 5 through 8). Since all existing installation drawings were designed for a WIETC installation, considerable effort was required concerning design and technical specifications before installation drawings could be produced. Additionally, due to the intended temporary nature of the project, a concentrated effort was made to keep cost as low as possible by utilizing equipment and plans already on hand and by holding infrastructure changes to the SWEF to a minimum.

The overall endeavor had several unique challenges that were overcome or mitigated by exemplary engineering practices. One recurring challenge was that many of the contributing events had never been attempted before with the VSR. These challenges included:

- The VSR's installation specifications had to be adjusted because they were derived from the final ship design, where the radar needed to be installed into a composite superstructure with the array and load-bearing structure, unlike the SWEF installation.
- The VSR system had never been installed and connected end-to-end, let alone lifted and placed into a full mounting surface or attached to the exterior of a building.
- Installation required lifting the array with a nonexistent lift fixture that would support 14 tons and allow the array to be tilted back to a 20-deg angle.

There was an exact requirement for the flatness of the array face after installation across the 16-ft array face. The plan was to use adjustable shims for each mounting hole. This provided the capacity to alleviate some of the flatness margin to counter what turned out to be an out-of-tolerance foundation due mostly to lesser criteria when the building was constructed and the SPY-1A array installed. A series of machined aluminum leveling plates were designed that allowed the foundation to maintain the flatness required.

VSR had the same requirements for environmental and site approval as the MFR; however, due to the location of the SWEF—within 100 yards of a public beach—and due to the compressed schedule, a more concerted effort was required. Community leaders were engaged and briefed, as were key representatives from all affiliated groups to ensure that all community concerns were addressed up-front.

Figure 6. The Original Octagonal SPY-IA Opening Was Made Rectangular to Accommodate the VSR

Figure 7. VSR Being Installed at the SWEF

The most difficult challenge to overcome was one that provided the most important lesson—that even a tight schedule should not trump best engineering practices. The initial design of the secondary cooling loop consisted of stainless-steel piping of various diameters and specified using flange joints in the construction to reduce the complexity and construction timeline. This proved to be an error in the design. Excessive flexing of the cooling system due to the high rate of flow and pressure required to cool all of the equipment led to continual leaks at all flange mating surfaces despite various efforts to correct this defect. Faced with this issue, the team's engineering decision sacrificed 3 weeks of the project schedule by replacing all flanges with butt welds. Schedule impact was ultimately mitigated by resequencing other start-up test events (i.e., lighting off and testing the IBM mainframe computers). Consequently, the team was able to alleviate the impact to the overall schedule, and as a result of the partnership, Raytheon was able to conduct over 5 months of high-power testing and confirm that key performance parameters were being met.

Win-Win-Win Situation

The culmination of an incredible amount of coordination across the government and industry is a testament to the dedicated professionalism of all those involved. The success of the Dual-Band Radar Engineering Development Models Project at NSWC PHD demonstrated the team's ability to put cultural differences aside and focus on the common goal of advancing the programs along their acquisition paths in support of the DDG 1000 Program. The result—government and industry teamwork wins the day, and Navy warfighters gain enhanced radar capabilities.

Acknowledgments

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Figure 8. SWEF with the VSR Installed