An Introduction to SSDS Concepts and Development

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The goal of Ship Self-Defense Systems (SSDSs) is to provide leak-proof, affordable defense of ownship from cruise missile attack. Like other air defense systems, an SSDS comprises the detect, control, and engage functions that operate logically to defeat attacking aircraft or missiles. The system is a basic building block of air dominance and has the prerequisite effectiveness to protect ships operating "in harm's way."

The Navy's operational concept for the littorals positions ships within the range of Anti-Ship Cruise Missiles (ASCMs) that may be launched from aircraft, submarines, ships, or ground-based launchers. In a hostile region, the ship's sensors must be able to detect raids of small, fast, maneuvering targets flying at low altitude just as they cross the sensors' horizon. Target detection in littorals is made more difficult by anomalous propagation conditions and land background clutter. Simultaneously, the system must react to the threat, relying on automated command and decision processes to select and fire its weapons. Very fast, highly maneuverable, extremely accurate, and lethal short-range homing missiles complete the engagement. For some ship classes, the last-ditch defense is a very high-rate-of-fire gun system. The technical performance of such a modern SSDS is based on a proven APL concept for a distributed systems architecture that integrates existing sensors and weapons using commercial off-the-shelf (COTS) components. The articles in this section of the *Technical Digest* provide insights into the technical development of these new systems.

The littorals have proven to be regions of uncertainty where irrational acts can occur. The following vignette—paraphrased from a concept-of-operations document for anti-air warfare (AAW)–integrated ship defense—is about an Amphibious Ready Group (ARG) operating in a littoral region. Working with the Navy's operating personnel, APL engineers developed and documented the concept of operations as the primary building block of requirements analysis. It illustrates the power and flexibility of modern self-defense systems to protect the ships.

> The night action in the Gulf was over in less than 5 minutes, and now the watch officers in the ARG were collecting after-action reports via the classified Internet. Three ASCMs had been destroyed, along with the lone "rogue"

aircraft that had launched two of them at the ARG and its escorts. Six missile rounds had been expended to kill the ASCMs and the launch aircraft. A fourth target had been tracked and lost, apparently having been seduced by a decoy. The escorting destroyers had also expended five land attack missile rounds, counterattacking the coastal batteries that had launched two of the ASCMs. The secondary explosions ashore continued to light up the predawn sky.

Day in and day out, the three-ship ARG—an LSD, LPD, and LHD— had plied the waters of the Gulf, remaining just offshore and under the layers of air defense provided by Aegis ships and the carrier's air wing. Anti-government mob violence in and around the major ports and airports had decreased since the ARG and its embarked Marines had been seen on international TV news. Months earlier, a few military units had reportedly aligned themselves with anti-government organizations, but it appeared that discipline had returned to the ranks after the recent executions of a few rebel officers.

On this moonlit night, the carrier had secured from flight operations, running downwind with the escorts to join an underway replenishment group. The Carrier Battle Group Commander had assigned an Aegis destroyer and cruiser to remain with the ARG Commander to provide area defense coverage while the carrier was off-station. So as not to spark hostilities in the tense surroundings, the rules of engagement were highly restrictive, effectively collapsing the battlespace. Routinely during the campaign, the ARG Commander had ensured local force-protection readiness by exercising the quick-reaction air defense doctrine in each of the ships. This flexible capability was designed into the SSDSs that form the innermost layer of air defense for these non-Aegis ship classes.

When the rogue aircraft was detected leaving the dense commercial aircraft traffic pattern, the composite identification on this "unknown, assumed friendly" track changed to "unknown, assumed hostile," and immediately changed to "positive hostile" when the ASCMs were detected as separating from it. Earlier in the evening, the Tactical Action Officers (TAOs), using their knowledge of threat and mutual interference along with the ARG Commander's instructions, had entered the local self-defense doctrine for these SSDS Mk 1 and 2 equipped ships. As the aircraft's track changed from unknown to positive hostile, each SSDS alerted the TAOs, allowing them to evaluate the targets, engage them in semi-automatic mode, and finally engage in full automatic mode to make the last kills.

Sensor integration in these ships is performed at the measurement level, using both ownship's sensors and those of other ships in the sensor network to compute composite tracks. This capability is shared by the SSDS and the Cooperative Engagement Capability (CEC), and that night it dramatically improved the total sensor coverage of the ARG and carrier battle group. The combination of netted sensors provided the target detections in the available sensor spectrum, overcoming the adverse propagation conditions and the large clutter "foldover" from the land background. Likewise, the correctness and accuracy of air tracks observed in the different ships enabled the real-time evaluation of the aircraft as positive hostile and provided the launch locations of the coastal missile batteries.

The ships had been armed with improved missiles such as the Evolved Seasparrow Missile (ESSM) and the Rolling Airframe Missile (RAM)—which also greatly enhanced their ability to annihilate the raids of attacking aircraft and ASCMs. In this action, two ESSM and three RAM rounds were credited with the ASCM kills, while a single Standard Missile had killed the launch aircraft. Although the LSD in the ARG was not in the tactical data link network, it survived the attack because its SSDS Mk 1 had automatically reacted, launching a RAM and killing the "leaker" ASCM.

The Laboratory continues to make critical contributions in the evolution of self-defense sensors, weapons, and combat systems. An understanding of the operational challenges of littoral operations, a knowledge of the technologies available to perform in this environment, and a characterization of threat trends are essential in helping warfighters to define their requirements. Having gone to sea, measured the littoral environments, and characterized the various effects on sensors and weapons, our engineers have analyzed and defined the technical performance required to protect various ships against projected threats.

Two critical capabilities exist at APL that are necessary to understand the effectiveness of any system to meet the operational concept: (1) the expertise to evaluate technologies that can be applied to the problem and (2) experience in the conduct of critical experiments and demonstrated proofs of concept alongside the warfighters. Insights from the technologies or the critical experiments are not inherently obvious without having this in-depth background and understanding of the operational need and surrounding environments. Authors of the articles that follow this introduction will bear out this assertion.

HISTORICAL BACKGROUND

The performance of modern SSDSs has evolved significantly over the last 30 years, having been stimulated by three major milestone engagements. These events were of great consequence in that they all ended tragically, with great loss of life and either the loss of or severe damage to the ships. Importantly, these events also provide insights into the causes and effects of required performance as well as the rate at which new capabilities were deployed. Figure 1 ties together the pacing systems and threats as they have evolved over time.

The defining historical engagements were the sinking of the Israeli destroyer *Elath* during the 1968 Middle East War, the loss of the British frigate HMS *Sheffield* at the Falklands in 1982, and the near loss of the frigate USS *Stark* in the Persian Gulf in 1987. The *Elath* and *Sheffield* engagements stimulated the development and deployment of the Basic Point Defense Missile System (BPDMS), Phalanx Close-In Weapons System (CIWS), and Rolling Airframe Missile (RAM) Guided Missile Weapon System. The BPDMS integrated the air-to-air Sparrow Missile and shipboard launcher with a manually steered X-band tracker/illuminator. The CIWS integrated a new track-while-scan (TWS) radar with the Vulcan gun system, another airborne weapon technology, aimed at detonating the ASCM warhead away from the ship. The 5-in.-dia. RAM integrated the shoulder-launched Stinger Missile's medium-wave IR seeker with a new radio-frequency guidance system designed to home on the ASCM seeker. This combination gave RAM the needed maneuver advantage
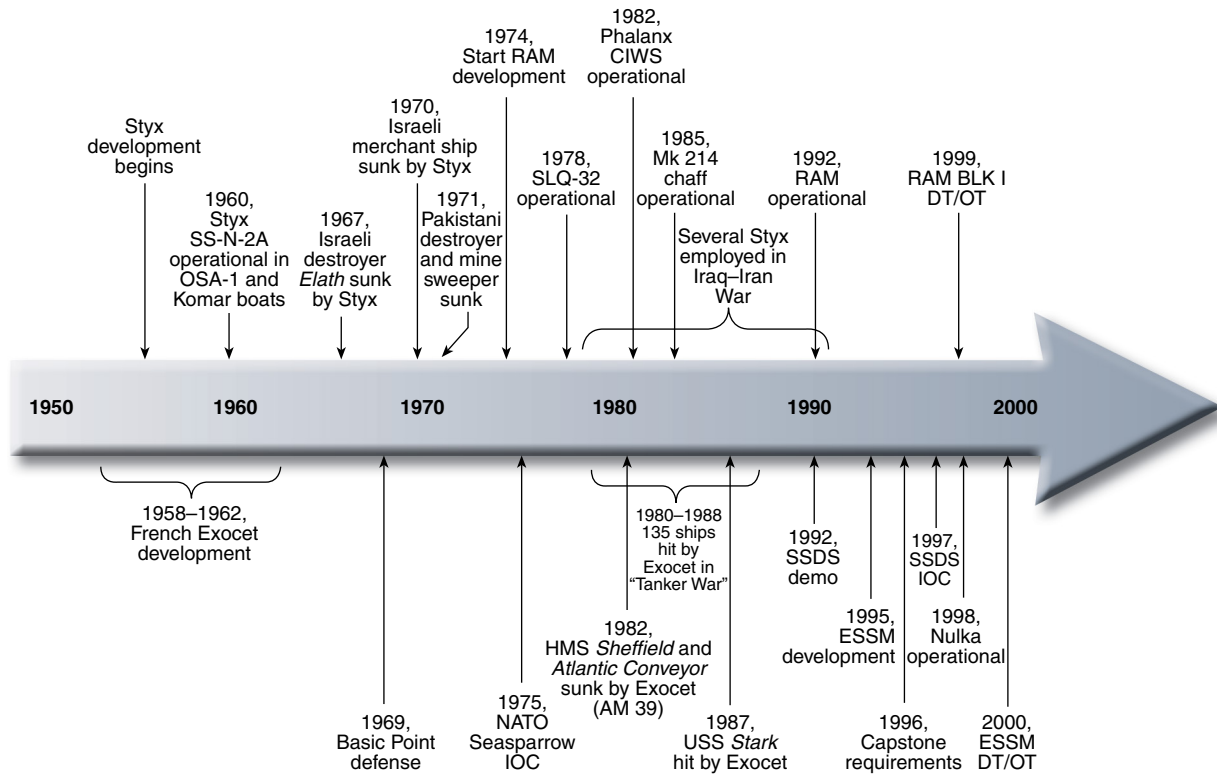

Figure 1. The influence of history on ship self-defense.

over the ASCM and matched accuracy with the lethality of its small warhead.

These systems were based on the need to ensure single-shot kills against the expected ASCM threats. The battle over the Falklands also demonstrated the effectiveness of chaff to decoy the attackers, enabling a measure of "softkill" for protection. The Falklands proved the difficulty of operating in a severe littoral environment, and, importantly, it signaled to all navies the existence of a growing and uncontrolled ASCM market. The *Stark* engagement signaled the need for very quick-reacting end-to-end system solutions for keeping pace with the evolution and proliferation of ASCM threats around the world. The attack on *Stark* showed the need for instant response, even though not at war.

These events also stimulated improvements for shipboard sensors that increased the volume of the battlespace. Evolutionary changes to the three-dimensional S-band AN/SPS-48 radar and the L-band AN/SPS-49 radar have improved high-altitude, long-range volume surveillance coverage. Electronic warfare systems have evolved to better support both detection and jamming of threat missiles, as well as deployment of countermeasures such as chaff and decoys. The CIWS TWS radar, with its high rotation speed, provided the needed detection, tracking, and data rates for closed-loop spotting and pointing of its very high-rate-of-fire gun. Its Ku-band radar proved to be highly effective in propagation conditions that degraded the performance of radars in other frequency bands. And commercial computer technologies, displays, and modern program designs have enabled sensors and weapons to be integrated, combining all their attributes to meet the demands of littoral operations and counter the projected threats.

CHALLENGES IN SHIP SELF-DEFENSE

Today's challenges in ship self-defense are still about tomorrow's threats and the projected operating environments of the Fleet. The problem is complex because many of the missions are peacekeeping in nature, being carried out under highly restrictive rules of engagement and often in concert with other friendly or coalition forces. The advantage goes to an attacker, who can conceal himself in the indigenous air activity much in the way a terrorist operates. More than 70 nations (Fig. 2) have obtained an air-, sea- or land-launched ASCM capability, having gained potential for denying access or transit in the littoral.

Figure 2. More than 70 nations have an ASCM capability.

The intelligence community has reported on over 100 existing and projected varieties of these missiles that can have speeds from subsonic to supersonic, ranges from high-altitude divers to seaskimmers, and fuel ranges of over 100 nmi. Of particular interest are the trends in maneuver, multimissile attacks, and countermeasures as penetration aids (Fig. 3).

Two significant studies conducted in the late 1980s provided supporting technical rationale for investment decisions for developing current SSDSs. The so-called "Kuesters' Study" provided a roadmap for system improvements and development investments. The NATO AAW System (NAAWS) Study, completed in 1991, was conducted by engineers from the United States and a NATO consortium; it provided many of the technical concepts found in modern SSDSs. APL engineers conducted technical analyses and contributed significantly to both of these studies and led the overall technical direction for the NAAWS Study.

CONCEPT AND DEVELOPMENT

The requirements for today's SSDS were driven by the operational necessities described above. Figure 4 illustrates the raid annihilation problem solved by the SSDS. The ship's operators enter appropriate semi-automatic and automatic engagement doctrine parameters for the system. The ship's sensors search the volume and detect supersonic, low-flying, maneuvering ASCMs as they cross the horizon. Target tracks are established within the system, and composite tracks are computed by associating the measurements from all the sensors. Custom filters optimize the track and measurement data for threat evaluation, weapon assignment, and fire control computations. Operators monitor the sensor and weapon control doctrine and their dynamically changing status while the system continues to compute the weapon laying and engagement solution. The system
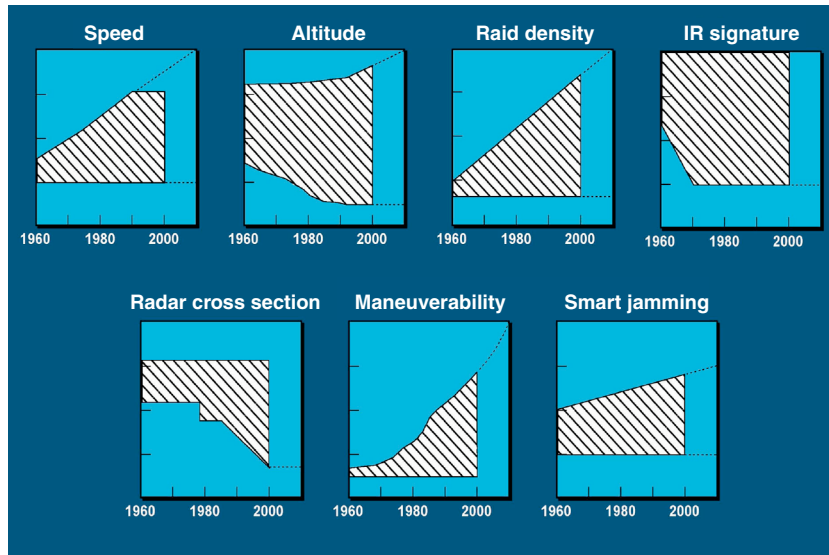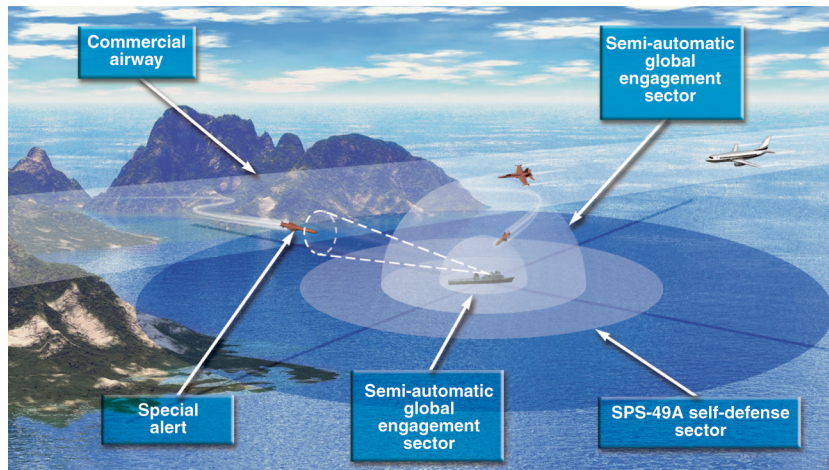
Figure 3. Threat trends of ASCMs.

Figure 4. SSDS engagement doctrine is controlled by ships' operators.

continues to manage the engagements and ensures weapons support through missile intercept.

The engineering concept for the SSDS was demonstrated aboard USS *Whidbey Island* (LSD 41) in 1993. This proof-of-concept demonstration of the Quick Reaction Combat Capability (QRCC) was engineered and made ready for at-sea demonstration in just 20 months by APL engineers in collaboration with a team of engineers from the Naval Surface Warfare Center, Dahlgren Division, and Hughes Aircraft Corporation. The system infrastructure comprised distributed system components, physically integrated with a local area network (LAN) sharing a common middleware computer program. The use of COTS equipment and computer programs, similar to those in the CEC development system, facilitated development of the demonstration system and at the same time provided an opportunity to evaluate the development of LAN technologies. Employing the same principle of CEC for sensor integration at the measurement level, the system computed composite tracks from the AN/SPS-49, the IR Search and Track System AN/SLR-8, and the CIWS TWS radar measurements, presenting them in a much enhanced surveillance display to the operators. A local command and

decision capability provided the TAO with a means of selecting and controlling the engagement doctrine needed for the reaction time and supporting the weapon assignments for RAM and CIWS. The success of this demonstration resulted in the formal program initiation for an operational system, now known as the SSDS and its variants.

THE ARTICLES

Raid annihilation is the fundamental performance attribute for SSDS. Each ship class is assigned a probability of raid annihilation P_{RA} against a range of potential threats. The Chief of Naval Operations (CNO) established operational requirements for ship self-defense for the different ship classes. These requirements are derived based on the ship's mission, the ship's expected operational environment, and the ability of area defenders to reduce the raid size. The article by Prengaman et al. describes the process by which P_{RA} is used to quantify the performance of the SSDS. This performance allocation, in turn, drives the technical performance requirements for composite tracking, system reaction time and automatic doctrine, and the custom weapon–threat response to defeat the most sophisticated threats. The authors then describe the methodology for testing the SSDS to meet its P_{RA} requirement.

The demonstration QRCC system and SSDS Mk 1 are innovations in combat system architecture. Norcutt describes the use of COTS computer programs and components comprising real-time, high-volume, low-latency computer processes distributed via LANs. The article also details the information-oriented concepts and features of the SSDS Mk 1 system architecture, along with the advantages of the approach, and discusses the physical architecture of the system network, including its suitability for real-time weapons system support.

The SSDS Mk 2 design is the product of an in-depth analysis of technical performance requirements conducted by APL engineers. The CEC is being installed in battle groups to provide a shared display of the networked long-range surveillance and volume search radars, and SSDS uses its track database to meet its AAW mission requirements. The details of how this analysis was conducted and how the custom filter technology led to a fundamental allocation of performance requirements is detailed by Thomas et al. For the most advanced threats, the critical driver in ship self-defense is reaction time. The key element of meeting the engagement timeline is the accuracy and timeliness of establishing the target track. An innovation of APL's custom filter technology is the system track promotion concept for multisensor track promotion. Custom filter technology has also been applied to certain weapon integration functions for RAM and ESSM. Thomas et al. also discuss other important elements of combat system integration such as automatic engagement control doctrine and display and the engagement systems.

ESSM has been developed to keep pace with evolving ASCM threats. Its capabilities are essential to the layered air defenses in our Navy. The article by Frazer et al. traces the various aspects of development under the NATO consortium and discusses how the missile meets the needs of the member nations. Underpinning this successful program are the missile systems engineering contributions made by APL engineers.

RAM is a critical weapon for ship self-defense because it can hit maneuvering targets at close range. Laboratory engineers have a long history in the technical development of RAM guidance technologies, as well as IR sensor technologies employed in the RAM program. The RAM is a "fire-and-forget" weapon, relying on the accuracy of the ship's designation system and its own robust guidance. RAM Block I incorporates an autonomous IR (AIR) homing mode, and the latest missile upgrade to keep pace with the ASCM threat. The Block I variant successfully completed operational test and evaluation in late 1999, and additional modifications to the guidance computer program are being designed to enable the missile to defend the ship against attacking low-speed aircraft, helicopters, and surface craft. The article "Rolling Airframe Missile Development, Test, Evaluation, and Integration" by Elko et al. provides technical background for the development decisions in RAM Block I, along with the methodology for the predictive analysis prior to testing. The RAM program is a cooperative missile development program with Germany; Denmark also contributed funding to the Block I development.

Integration of the existing electronic support measures (ESM) system AN/SLQ-32A(V) with SSDS Mk1 is essential to support RAM engagements. It also provides kill assessment for emitting threats, and it augments local situational awareness. The article by Kochanski and Bredland covers the development and technical basis for this integration.

The very nature of development and operational testing of self-defense systems and weapon components against modern threat-representative targets dictates remote control test operations. Although a great deal of simulation and predictive analysis is conducted to support confidence in system performance, live-fire tests are required to support the acquisition milestone decisions for the weapons. In 1987, the Navy designated the decommissioned USS *Decatur* (DDG 31) as the Self-Defense Test Ship (SDTS) to support live-fire testing. Various ship self-defense configurations have been installed in the SDTS, and APL engineers integrated the remote control operations. The article by York and Bateman describes the integrated remote control system used to support weapon system tests. Most recently, CIWS Block IB and RAM Block I operational tests and ESSM developmental tests have been conducted from the SDTS.

CONCLUSION

Historically, advances in ship self-defense systems have been stimulated by ASCM attacks that resulted in the tragic losses of ships and personnel. These losses have common themes that underscore the need for quick-reacting systems that are highly capable of engaging difficult targets in the harsh operating environments of the littorals. Notwithstanding the potential for adversaries to obtain improved ASCMs, the advantages of networked sensors, distributed systems architectures, embedded doctrine, and quick-reaction weapons in combat systems can outperform these threats. This new generation of combat systems is essential to the Navy's operational concepts for access in the littoral. They are also fundamental to emerging concepts for hard kill and soft kill integration, reduced crew manning, and network-centric warfare. APL's technical contributions to these combat systems will add to the confidence of warfighters to defend themselves in the close operating quarters of the world's littorals.

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