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SHIP SELF-DEFENSE AGAINST AIR THREATS

Recent trends in the proliferation of advanced-technology cruise missiles and aircraft and emphasis on multiservice littoral warfare have prompted renewed congressional and U.S. Navy interest in fleet self-defense. This emphasis is focused on ensuring that expeditionary forces can sustain operations to accomplish their mission. The near-land, cluttered, terrain-masked littoral environment places the Navy within enemy striking range and can stress the ship systems' ability to detect, rapidly react to, and engage air threats. Operating in this environment against advanced cruise missiles and aircraft equipped with affordable penetration techniques such as low-altitude, high-speed maneuvers, and deceptive countermeasures can challenge the Navy's most advanced combat systems. Integration and evolution of existing radar, missile, and electronic warfare weapon system elements and the application of new sensor, weapon, and processing technologies can provide the fleet capability necessary to counter these threats in the near term and as they are expected to advance into the next century.

INTRODUCTION: A NEW FLEET EMPHASIS FOR THE LITTORAL ENVIRONMENT

The U.S. Navy has witnessed countless changes throughout its long history, but few as dramatic as the events within the last few years. The demise of the Soviet Union and the rapid worldwide proliferation of advanced-technology weapons to Third World countries have resulted in a rapid shift away from an emphasis on open-ocean global warfare to regional or limited conflicts involving Third World nations in littoral waters. The recent Persian Gulf War is a clear example.

Such conflicts, frequently with geopolitical, religious, or ethnic motivations, are more likely to occur as politically unstable Third World nations are easily able to arm themselves with state-of-the-art weapons. Faced with economic recovery problems, the former Soviet Union has begun to market its most advanced weapons and aircraft, while western nations continue to export technology and weapons. In the recent Moscow[1] (11-16 August 1992) and Farnborough International[2] (6-13 September 1992) air shows, first-line former-Soviet Union weapons and aircraft were for sale along with French, Chinese, Italian, and Swedish advanced-technology weapons. The time lag between development and export is decreasing dramatically at the same time the number of producers is increasing, thus creating a very competitive market for weapons proliferation.[3,4] This technology transfer defines and drives the regional/limited conflict threat. Desert Storm clearly demonstrated the mature and effective networks established in the Third World for procuring technology and weapons. It is expected that not only will these networks strengthen with time, but that nations will develop increasing capabilities to modify imported weapons and tailor them to their specific goals, even further compounding the threat environment. Although fewer threats are expected in any one encounter, they can still represent a high-intensity threat scenario to the defending ship system, owing to advances in coordinating threat arrival times and the limited number of fire control channels available in many frigate, destroyer, and amphibious ships. The advent of patrol boat- and mobile truck-launched cruise missiles (similar to the SCUD ballistic missile Transporter Erector Launchers prevalent in Desert Storm) enables a "shoot and scoot" mode of operation, thereby significantly reducing the effectiveness of air superiority in mitigating the cruise missile threat. The littoral environment, depicted in Figure 1, is also characterized by dense, commercial air traffic and merchant shipping, which present challenges to the combat systems (and their operators) in distinguishing between hostile, neutral, and friendly tracks. The proximity to hostile shores and confined waters decrease the available battlespace and warning time, increase clutter levels, enable the employment of land-based electronic countermeasures, and increase the potential for unexpected attack from land-based missile sites.

To operate effectively in this environment, the required robust and integral self-defense capability must provide both a final antiair warfare (AAW) layer of defense when operating in joint expeditionary operations and an autonomous capability. Although a frigate, destroyer, or aircraft carrier may be "under the umbrella" of an Aegis or New Threat Upgrade Combat Systems' Standard missile envelope, an integral final layer of defense is needed to counter the sea-skimming missile threat. This is especially true when the battle group/threat geometry prevents engagement by the Standard missile ships and opportunities for one ship to defend another against the sea-skimming cruise missile are limited. In addition, the declining force structure as well as the littoral warfare environment results more often in situations where ships operate independently or as small expeditionary forces

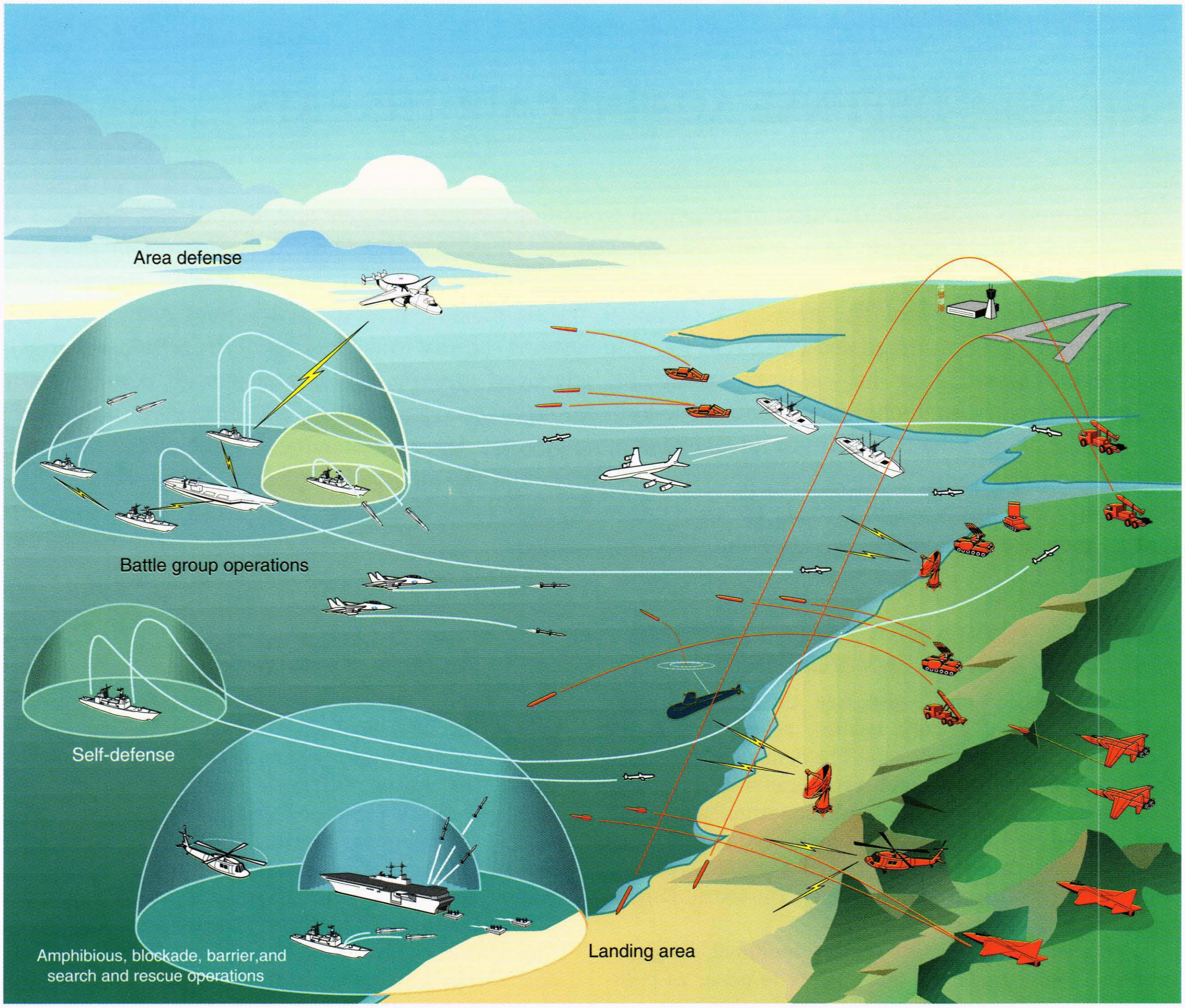


Figure 1. Air defense in the littoral environment includes defense against cruise missiles, ballistic missiles, and aircraft in the diverse, dense-air-traffic, and cluttered near-land setting. A robust integral self-defense capability must provide a final layer of defense in joint expeditionary and traditional battle group operations as well as an autonomous capability for ships operating alone.

(e.g., in amphibious landing operations, blockade or barrier operations, or search and rescue operations). As a consequence of these trends, every surface ship will be threatened by advanced sea-skimming cruise missiles in the regional/limited conflict environment. A robust, autonomous ship self-defense capability is essential for these ships to be able to sustain operations and accomplish their missions.

This situation has produced a sharply focused emphasis on fleet self-defense within Congress and the Navy. In response, the Navy created a Program Executive Office for Ship Defense (PEO-SD) (recently expanded and rechartered as the Program Executive Office for Theater Air Defense) to coordinate efforts to improve self-defense capabilities across the fleet. The regional/limited conflict setting and advanced-cruise missile threats introduce several new warfighting challenges that necessitate combat system advances. Improvements in each of the three major weapon system elements—detect, control, engage—are required to operate effectively in this environment and counter the air threat. The near-land, high-clutter environment, coupled with sea-skimming missiles, can overburden many of our existing sensors. Radar improvements in effective radiated power, aperture, waveform flexibility, and signal processing are required to achieve adequate detection ranges. Improved integration and the increased automation of sensors, weapons, and fire control systems are essential to shorten reaction time and coordinate weapon response. In addition, advanced command and control features are needed to enable command personnel to direct and monitor the overall operation of the combat system in this environment with complex rules of engagement and identification requirements. Finally, advanced defensive missiles with increased kinematics, fast flyout, multimode seekers (e.g., semi-active homing and IR terminal), improved autopilots and agility, and improved low-altitude ordnance fuzing are essential to countering the advanced-cruise missile threat.

The Applied Physics Laboratory has assisted the Navy in creating a ship self-defense roadmap that identifies a technical approach for achieving the capability required to pace the threat through the incremental improvement of existing elements, the development of critical new elements, and their integration into the combat system. This roadmap reflects, in part, the results of several analytical, developmental, and evaluative programs conducted over the past several years, including the Short-Range AAW Defense Systems Study (Kuesters Study, 1985), the Short-Range AAW Program (1986), and the NATO AAW Weapon System Program (1987–90). The overall technical approach has been endorsed by the Office of the Chief of Naval Operations (OPNAV), Naval Sea Systems Command, and PEO-SD sponsors. Although not all elements of the roadmap have been programmed and funded, numerous specific recommendations have formed the basis for current design and development activities.

THREAT TRENDS

History has demonstrated that weapons developers recognize the vulnerabilities of our defensive systems and develop or evolve weapons to exploit the weaknesses. Numerous examples can be found of this "responsive" or "reactive" threat. Even as new developments have increased our capabilities, the weapons developers have continued their efforts to identify and exploit the limitations of our systems in an attempt to defeat them. Classic examples, shown in Figure 2, are the increasing cruise altitude of the high-cruise-dive missile threat and the very low-flying sea-skimming threat that attempt to penetrate defensive systems by flying above and below sensor and weapon envelopes. As the threat becomes more sophisticated, additional penetration aids will be increasingly

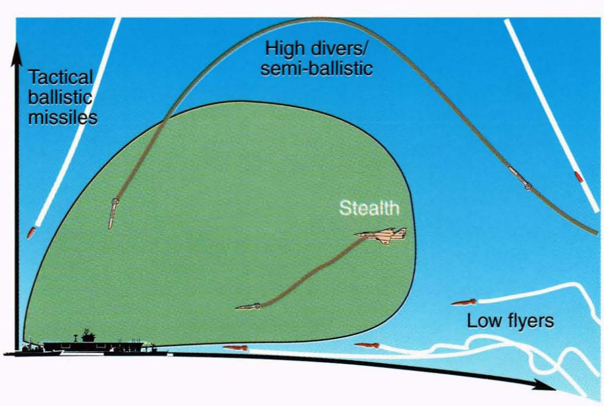


Figure 2. The reactive threat attempts to penetrate the weapons envelope and exploit system vulnerabilities with advanced penetration techniques such as low-altitude, semi-ballistic, and ballistic profiles, stealth, electronic countermeasures, and high-acceleration maneuvers. Worldwide cruise missile proliferation and technology transfer define and drive the threat environment.

commonplace. Trends in the cruise missile threat include the following:

1. Smaller signatures and lower/higher altitudes.
2. Higher speeds and high-acceleration maneuvers.
3. Radiation control and multimode guidance.
4. Advanced electronic countermeasures.
5. Hardening and relocation of vulnerable components.
6. Coordinated arrival times.

These features are prominently promoted by several weapons producers, including French, Italian, and Swedish manufacturers.[5-7] Supersonic, maneuvering, sea-skimming missiles in development such as the French Aerospatiale Anti-Naivre Supersonique (ANS)[8] cruise missile exemplify the current trends. Reduced radar cross sections and low/high-altitude flight profiles will be employed to reduce the available battlespace by limiting the detection range and thus the time to react to and engage the target. The high-speed and high-acceleration (high g) terminal maneuvers can challenge the weapon system performance by stressing the defensive missile's kinematics and agility. In addition, multimode seekers (combinations of RF active, antiradiation homing, or IR homing), as well as strict emissions control aimed at minimizing detection opportunities and the effectiveness of deceptive electronic countermeasures and decoys, can create further challenges for defensive electronic warfare systems. As promoted by the French and Italian weapons producers, digital RF memory and repeater jammers will make deceptive countermeasures very affordable penetration techniques that can delay detection and challenge defensive weapon performance. Relocation and hardening of vulnerable components can further stress defensive missile performance by reducing the ability of ordnance to disable key cruise missile components. Additionally, the French and Swedish weapons producers, Aerospatiale and Saab Missiles, respectively, describe their ability to ensure near-simultaneous arrival by controlling the thrust profile or through the use of trajectory waypoints with the ANS, Exocet Block II,[9] and RBS 15[10] antiship missiles, further stressing the combat system in terms of available firepower (number of fire control channels) and the ability to ensure the engagement of all targets in the raid (missile-to-target "pairing" efficiency).

COMBAT SYSTEM CHALLENGES

The littoral environment and projected advanced threat developments will challenge the combat system in terms of detection range, reaction time, and defensive missile performance against the advanced threats (Fig. 3). The near-land, high-clutter environment and low-altitude, small radar-cross-section cruise missiles will restrict the sensor detection range, thereby limiting the battlespace in which the defensive systems must react. Relatively long reaction times will delay missile launch against the threat and further reduce the battlespace and time to engage the target. In this situation, slow average-speed defensive missiles will result in very short-range intercepts, risking debris impact and ownship damage. Defensive missile performance will also be stressed against

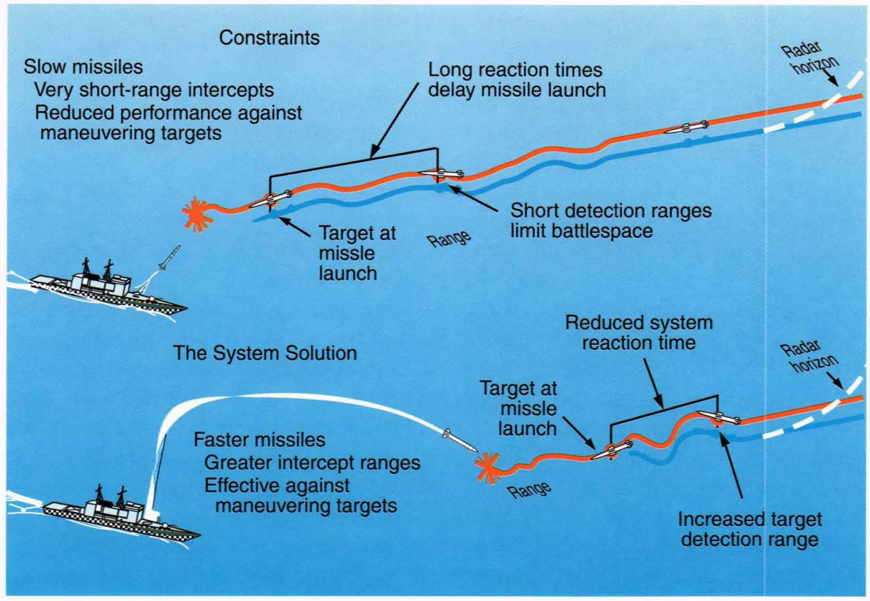


Figure 3. Projected combat system challenges in engaging advanced supersonic sea-skimming cruise missiles include short detection ranges, long reaction times, and defensive missiles with reduced performance against advanced, highly maneuvering threats. Effective defense requires detection, command and control, hardkill and softkill system enhancements, and increased system automation and integration.

advanced maneuvering targets because of limited kinematic capabilities and relatively long guidance and airframe response time constants.

A balanced, integrated combat system solution is essential to defeating the air threat in this environment. Improvement in any one element alone is inadequate. Increased target detection ranges, decreased system reaction times, advanced command and control features, and improved hardkill and electronic warfare weapons can be developed, integrated, and coordinated to provide an effective defense. The improvement trends that can be realized with these upgrades are shown in Figure 4. The probability of escaping a significant hit (probability of successfully defending against all targets in the raid) is shown as a function of the target detection range (which is influenced by the target radar cross section, altitude, speed, and the environment) for both a baseline and an advanced combat system. The threat raid consists of multiple advanced low-altitude, supersonic, maneuvering cruise missiles; the critical combat system characteristics include system reaction time, defensive missile launch rate, flight time to intercept, endgame effectiveness, and the number of available illumination channels.

SELF-DEFENSE REQUIREMENTS

The littoral environment and threat trends described previously influence the mission and system-level requirements. In establishing mission requirements, OPNAV grouped the U.S. ship classes into high, medium, and low risk categories on the basis of their expected employment and anticipated targeting by hostile forces. The requirements took the form of specified probabilities of escaping a significant hit for a specific raid density (number of targets and arrival rate) with threat parameter bounds such as speed, altitude, radar cross section, IR signature, and terminal maneuver. The requirements varied among the ship class/threat categories. The allocation of the mission requirements, as suggested in Figure 5, to the detect, control, and engage elements of the combat system emphasizes the interrelationships of the elements and the extent of the modifications required to counter the advancing threat effectively. Requirements were established in two time frames—1998 and beyond 2004—such

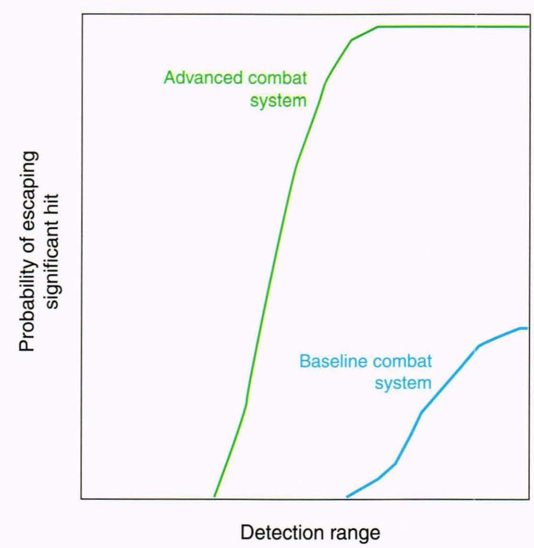


Figure 4. The projected combat system performance against multiple advanced low-altitude, supersonic, maneuvering cruise missiles depends on the detection range as well as the system reaction time, defensive missile launch rate, flight time to intercept, endgame effectiveness, and number of available illumination channels. Adequate performance can be achieved with detection, command and control, defensive missile, and electronic warfare upgrades associated with the advanced combat system.

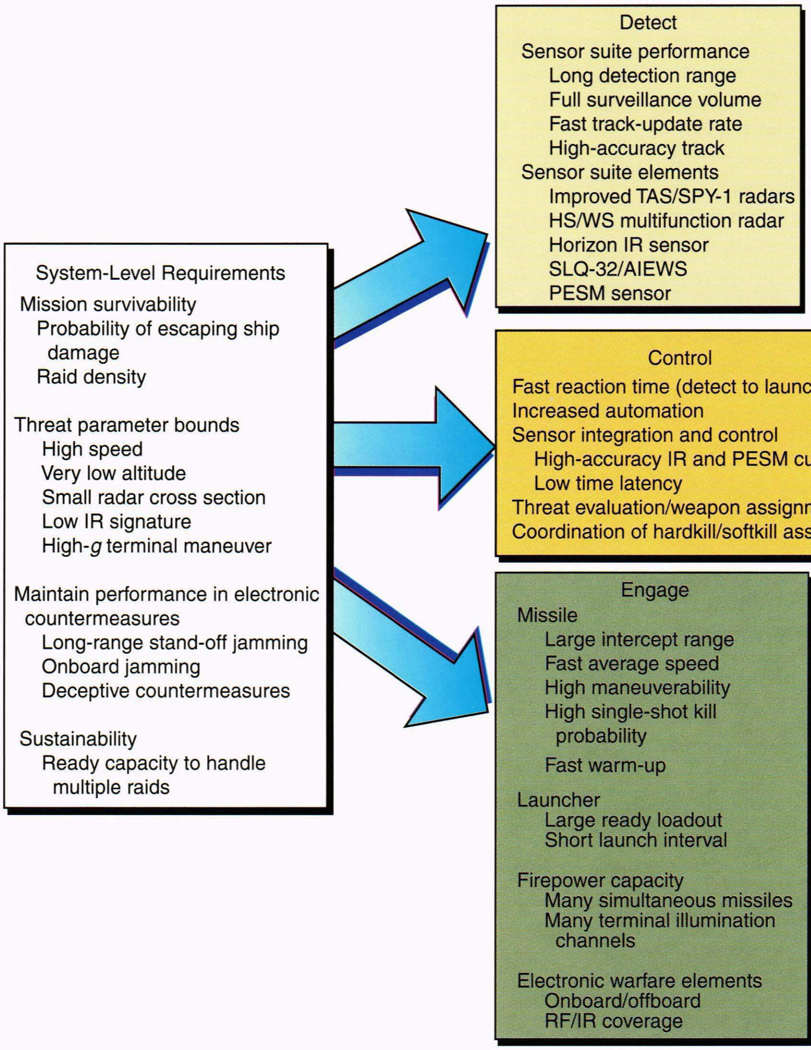


Figure 5. The overall combat system mission-survivability requirements can be allocated to the major elements (detect, control, engage) of the weapon system. The individual element requirements and threat parameter bounds determine the necessary technology and the extent of the modifications required. TAS = Target Acquisition System, HS/WS = Horizon Search/Weapon Support, AIEWS = Advanced Integrated Electronic Warfare System, PESM = Precision Electronic Support Measures.

that the resultant systems will pace the threat as it advances. The 1998 requirements were established from both a top-down threat and mission survivability perspective as well as a bottom-up viewpoint of the technological and design changes achievable in that time frame. The 2004+ requirements, on the other hand, require the introduction of advanced radar and missile guidance and seeker technology to counter the projected threat.

Sensor system requirements are specified in terms of detection range, countermeasures resistance, track accuracy, and timeliness. The command and control requirements include reaction time (i.e., time from detection to missile launch), data latency, data fusion, and cueing accuracy. Engagement system requirements are partitioned into hardkill (e.g., missile or gun) and softkill (i.e., electronic warfare) requirements and address the missile's average speed, maneuverability, agility, single-shot probability of kill, number of fire control channels, decoy response time, accuracy of electronic support measures, and frequency coverage. These balanced and integrated requirements, when combined at the combat system level, achieve the mission survivability goals.

SELF-DEFENSE ENHANCEMENT ROADMAP

To satisfy self-defense requirements, existing system elements must be upgraded and new critical developments must be initiated. The emphasis within the detection system is no longer limited to radar frequency bands, but rather is multispectral in nature. Particular emphasis is placed on an active-element, phased-array, horizon-emphasis multifunction radar, a horizon-scanning IR system, and a precision electronic support measures sensor to achieve the required detection ranges against small radar-cross-section threats at sea-skimming altitudes in the cluttered land background of the littoral environment. Increased automation and multispectral data integration are essential to coping with the reduced battlespace and short-range target detection. Complex rules of engagement and target identification in the Third World/regional conflict environment require advanced command and control concepts to permit the system operators to manage and tailor the weapon system to the threat and operational tactics with preestablished doctrine rather than attempt to react to the threat in real time. Advanced missiles with increased average speed (shorter missile flight times), with adequate maneuverability margin, and with increased agility are essential to countering advanced highly maneuverable threats. Electronic warfare system upgrades are required to provide effective onboard countermeasures and offboard decoys to contribute to defense against the anticipated threat-raid densities. Integration of electronic warfare necessitates advanced hardkill/softkill weapon coordination mechanisms not only to avoid mutual interference that degrades performance, but also to enhance the total combat system effectiveness through cooperation. Softkill techniques can be employed, for example, to increase the target's vulnerability to hardkill engagement.

The roadmap or technical approach to achieving self-defense goals is shown in Figure 6. Three time frames and capabilities are addressed: an immediate capability enhancement for the 1995 time frame, a near-term capability in 1998, and a far-term capability beyond 2004. The development path achieves the far-term capability while at the same time enables near-term improvements. The upgraded capabilities have been designated the Ship Self-Defense System (SSDS) Mk I, Mk II, and Mk III. Each capability is designed to provide effective defense against the threat anticipated for that time frame and, thereby, pace the threat as it advances through incremental improvement in combat system performance. Also shown in Figure 6 are candidate ship classes for each weapon system upgrade based on the intended mission and requirements established by OPNAV for each ship class. The specific upgrades for each SSDS configuration depend on the existing combat system configuration (specific radars, missiles, guns, electronic warfare, decoys, and command and control elements) and the ease of integration of new elements. The specific configurations will, therefore, vary among ship classes. The Program Manager for Ship Self-Defense has established a Ship Self-Defense Master Plan Analysis Working Group that is continuing to assess the most advantageous upgrades for each ship class on the basis of warfighting benefit and cost considerations. The analysis group includes participants from the Naval Surface Warfare Center, the Naval Research Laboratory, and APL. Existing hardkill and electronic warfare weapon system performance models have been upgraded, and

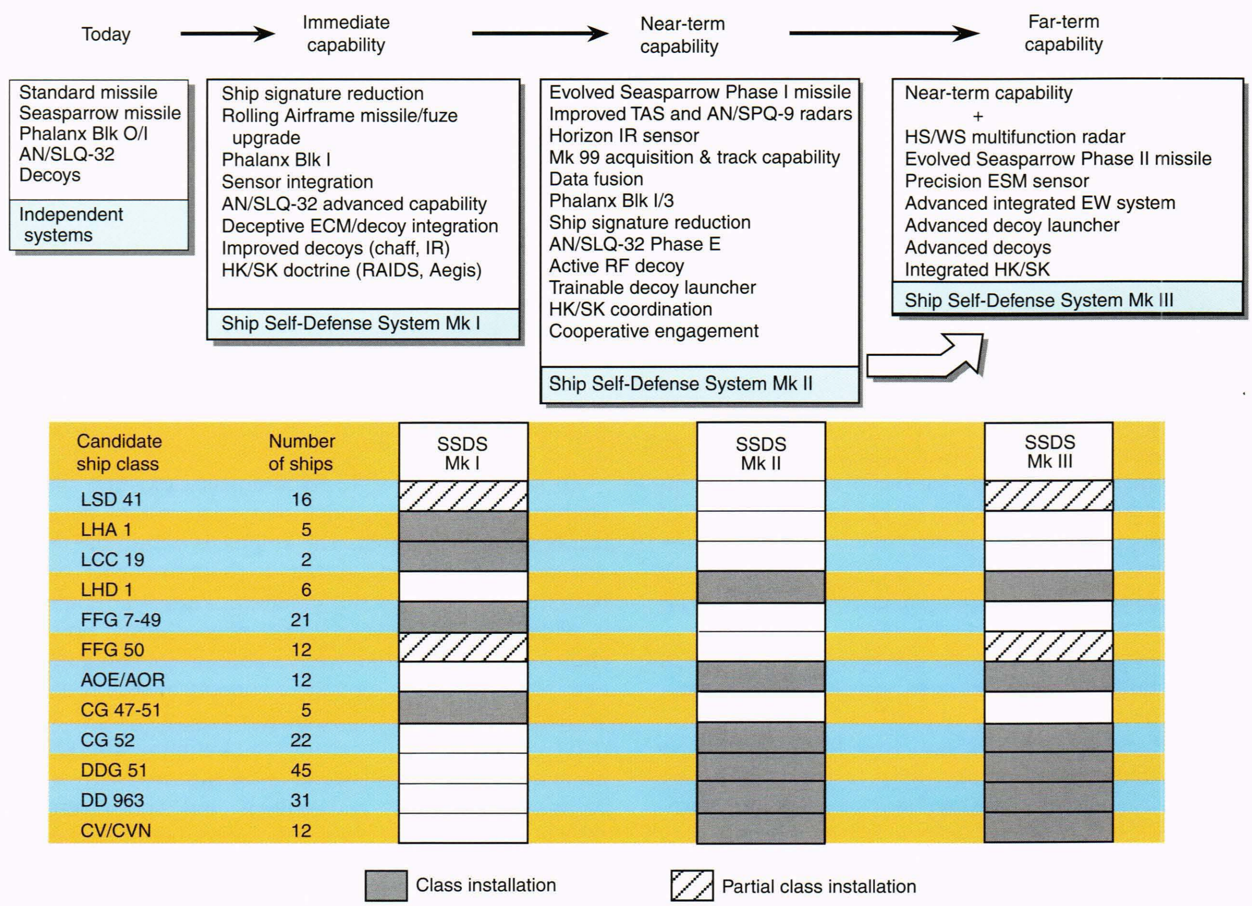


Figure 6. The self-defense enhancement roadmap is summarized, showing the time-phased introduction of the Ship Self-Defense Systems Mk I, II, and III. These capability enhancements include hardkill and softkill upgrades, their integration, and increased automation. Potential ship class installations and the number of systems required are identified; specific configurations vary among ship classes. Ship class descriptions can be found in Ref. 11. ECM = electronic countermeasures, HK/SK = hardkill/softkill, TAS = Target Acquisition System, HS/WS = Horizon Search/Weapon Support, ESM = electronic support measures, EW = electronic warfare, SSDS = Ship Self-Defense System, RAIDS = Rapid Antiship Missile Integrated Defense System.

hardkill/softkill integration techniques are being developed to permit detailed combat-system-level performance assessment, configuration alternative analysis, and configuration definition.

SHIP SELF-DEFENSE SYSTEM Mk I

The immediate goal is the rapid deployment of an enhanced self-defense capability on those ship classes currently without a short-range missile system. Driven by the 1995 time frame, the upgrades necessarily include off-the-shelf capabilities and the integration of existing combat system elements. The upgrades include the addition of the Rolling Airframe missile (RAM) with its dual-mode seeker (antiradiation and IR homing) and a fuze upgrade for improved performance against the near-term sea-skimming threat. In addition, the Close-in Weapon Gun System (Phalanx) will be upgraded to the Block I configuration to increase the elevation coverage, search sensitivity, magazine size, and gun firing rate. The Phalanx search radar, AN/SPS-49 search radar, and AN/SLQ-32 electronic warfare system will be integrated through an architecture based on a local area network such that all sensors can contribute to both RAM missile and Phalanx gun engagements. An SSDS Mk I demonstration capability was installed on *USS Whidbey Island* (LSD 41) during the Spring of 1993; it demonstrated significantly improved combat system performance against multiple target raids.

The recommended SSDS Mk I capability also includes electronic warfare upgrades such as a reduced ship radar cross section achieved by the application of radar-absorbing material, advanced deceptive electronic countermeasures in the AN/SLQ-32, integration of deceptive countermeasures with offboard decoys to facilitate threat seeker transfer from the ship to the decoy, and deployment of available improved decoys such as the NATO Sea Gnat Mks 214 and 216 seduction and distraction chaff and Torch IR decoys. These electronic warfare weapons are coordinated with hardkill weapons using relatively simple doctrine to prevent interference. Although intended for the SSDS Mk I configurations, the electronic warfare upgrades can be implemented in other ship classes as well, providing some enhanced capability before receiving the SSDS Mk II capability upgrades described later.

The SSDS Mk I is recommended for integration in ship classes that currently have no short-range missile system such as the LSD 41, LHA 1, LCC 19, CG 47-51, and FFG 7 ship classes (Fig. 6). (Ship class descriptions can be found in Ref. 11.) The addition of the RAM missile significantly improves their combat capability. Future upgrades to the SSDS Mk I ships include electronic warfare upgrades but not the Mk II or Mk III configurations.

SHIP SELF-DEFENSE SYSTEM Mk II

The SSDS Mk II enhancement incorporates both upgraded and new weapon system elements, including the first phase of the Evolved Seasparrow missile with increased kinematics and agility to counter a highly maneuvering target. The recommended SSDS Mk II capability includes an improved Target Acquisition System Mk 23 radar, an improved AN/SPQ-9 radar, and a horizon-emphasis IR sensor to aid in the detection of the supersonic threat at adequate ranges to enable engagement. The recommended near-term configuration also includes the introduction of a continuous-wave acquisition and track system in the Aegis Mk 99 illuminators. This system provides for horizon search by exploiting the low-elevation propagation advantage inherent at X-band. The horizon IR sensor provides an opportunity for multispectral data fusion and precision cueing of the AN/SPY-1 phased-array radar and the Mk 95 or Mk 99 fire control radars. Increased integration also enables data fusion at the weapons level, combining radar range with precision IR angle data to support missile initialization, midcourse guidance, or terminal illumination. The SSDS Mk II also incorporates the Phalanx Block I Baseline 3 upgrade, which includes a surface target engagement mode, a forward-looking IR sensor, a new digital signal processor, and a search-through-track antenna capability.

Additional electronic warfare upgrades and new elements are identified in SSDS Mk II, including AN/SLQ-32 electronic support measures sensitivity improvement, an offboard active RF decoy such as Nulka, and a trainable decoy launcher. One of the constraints of offboard decoys is the geometrical restrictions relative to the threat axis, ship's heading, wind, and fixed azimuth/elevation launch tubes. A trainable decoy launcher will ameliorate these constraints, thereby providing improved performance. Concurrent with these upgrades is the next layer of sophistication in hardkill/softkill coordination of deceptive electronic countermeasures with missile engagements to increase the vulnerability of the target to hardkill engagement.

The SSDS Mk II capability includes the Evolved Seasparrow missile and is, therefore, recommended for integration into the NATO Seasparrow Surface Missile System fleet, including the LHD 1, AOE, AOR, DD 963, and CV/CVN ship classes. The proposed Mk II configuration for the DD 963, for example, is shown in Figure 7. It incorporates both new and upgraded combat system elements and their integration. The SSDS Mk II capability is also recommended for introduction in the Aegis CG 52 and DDG 51 ship classes to provide an essential additional layer of defense against the advanced supersonic sea-skimming missile. These ship classes will be upgraded to the Mk III configuration in the far term as described in the next section.

SHIP SELF-DEFENSE SYSTEM Mk III

The far-term capability shown in Figure 6 incorporates advanced technology elements and consequently is projected beyond 2004. This capability has been designated SSDS Mk III and is an upgrade of the Mk II capability. The Mk III concept incorporates an advanced wideband, active-element, phased-array multifunction radar that performs horizon search as well as midcourse uplink and terminal illumination for engagement support. The solid-state, multifunction radar will enable near-horizon detection ranges against the reduced-cross-section sea-skimming threat and provide multiple channels for pulsed

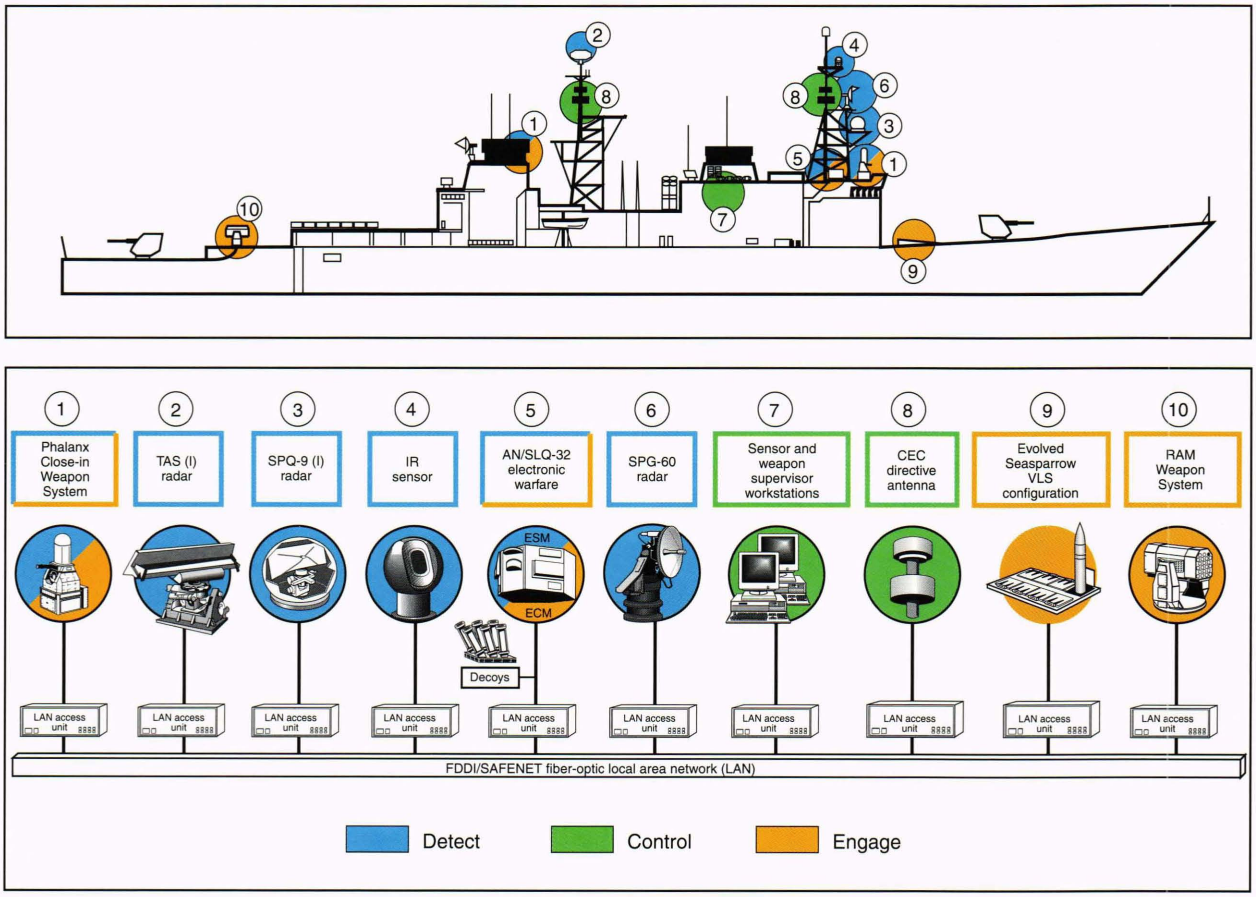


Figure 7. As an example of the Ship Self-Defense System Mk II configuration, the proposed DD 963 upgrade includes both new and modified combat system elements. Multiple sensors and weapons are automated and extensively integrated through an architecture based on local area network technology to achieve the required capability. TAS = Target Acquisition System, CEC = Cooperative Engagement Capability, VLS = vertical launching system, RAM = Rolling Airframe missile, ESM = electronic support measures, ECM = electronic countermeasures, LAN = local area network, FDDI = fiber distributed data interface.

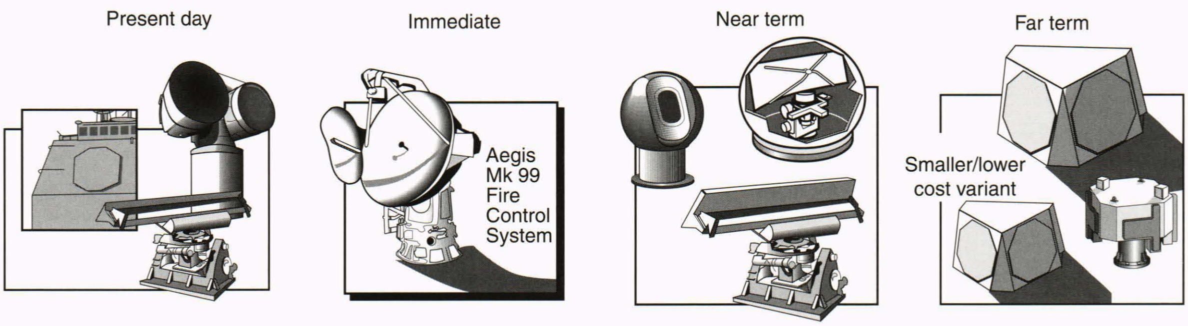
continuous-wave illumination for sample-data terminal homing.

The SSDS Mk III concept also includes the second phase of the Evolved Seasparrow missile with its improved sensitivity RF and imaging IR multimode seeker, improved ordnance, and a boosted variant for increased kinematic performance and range in vertical launching system applications. The phase-two missile seeker and radome will be matched to the broadband illumination capabilities of the shipboard active radar to achieve enhanced performance in low-altitude, multipath, and clutter-rich engagement environments.

The Advanced Integrated Electronic Warfare System will be fully integrated into SSDS Mk III, including an advanced precision electronic support measures system using phase interferometer technology and improved sensitivity to generate very precise azimuth and elevation track data for precision cueing of the phased array, data fusion, and weapons employment. The precision electronic support measures data can be correlated with IR and radar data for enhanced target identification, improved tactical situation awareness, and weapon-level data integration to support target engagement with either hardkill or softkill weapons. Advanced offboard decoys, millimeter-wave countermeasures, and IR countermeasures are also included in the SSDS Mk III capability.

HORIZON-EMPHASIS SENSORS AND NEW TECHNOLOGY

The horizon-emphasis sensors necessary to pace the advancing threat include both upgrades to existing radars and new developments in radar, IR, and electronic support measures sensors, as identified in Figure 8. Among the potential radar upgrades is the addition of a continuous-wave acquisition and track capability for the Aegis fire control system. The upgrade concept is based on the existing Terrier and Tartar fire control radars and adds an X-band receiver to the Aegis illuminator to provide an adjunct search, detection, and track sensor. The fire control radar can then be used in horizon search to detect sea-skimming threats using the inherent Doppler-based sub-clutter visibility (due to Doppler filter processing) and X-band low-altitude propagation advantage (16–27 dB im-



Candidate ship class	Number of ships	Fire Control System upgrade	Horizon IR sensor Improved TAS radar Improved AN/SPQ-9 radar	Precision ESM sensor Horizon Search/ Weapon Support radar
LSD 41	16		Class installation	Partial class installation
LHA 1	5			
LCC 19	2			
LHD 1	6		Class installation	Class installation
FFG 7-49	21			
FFG 50	12		Class installation	Partial class installation
AOE/AOR	12		Class installation	Class installation
CG 47-51	5	Class installation	Class installation	
CG 52	22	Partial class installation	Class installation	Partial class installation
DDG 51	45	Partial class installation	Class installation	Partial class installation
DD 963	31		Class installation	Class installation
CV/CVN	12		Class installation	Class installation

Class installation ▪ Partial class installation

Figure 8. The horizon-emphasis sensors necessary to provide adequate detection ranges and weapon support against the advanced threat in the cluttered, electronic countermeasures environment include radar, horizon IR, and precision electronic support measures sensor upgrades and new technology application (Figs. 10–12). The integration of these sensors in each ship class is determined by the performance requirements of the Ship Self-Defense System Mk I, II, and III capabilities. Ship class descriptions can be found in Ref. 11. TAS = Target Acquisition System, ESM = electronic support measures.

provement over typical search radar frequencies [S- and L-band] at 10 nmi, depending on radar height and target height—see Fig. 9). The X-band receiver also provides a noncooperative target recognition capability for track identification based on radar signal modulation techniques. This feature provides an additional means for the combat system and its operators to identify targets in the cluttered littoral environment where it is difficult to discriminate hostile threats from neutral and friendly air traffic.

To ensure adequate target detection ranges against the advanced threat on other ship classes (Fig. 8), upgrades of the Target Acquisition System Mk 23 and AN/SPQ-9 radars are required. The upgrades include advanced digital signal processing for increased sensitivity and subclutter visibility, increased average power, and increased aperture. Both radar upgrade concepts employ a scan-back feature providing single-scan detection by forming an additional beam offset in azimuth following initial track detection. Given this nearly simultaneous track dwell and coherent digital signal processing, Whitfield

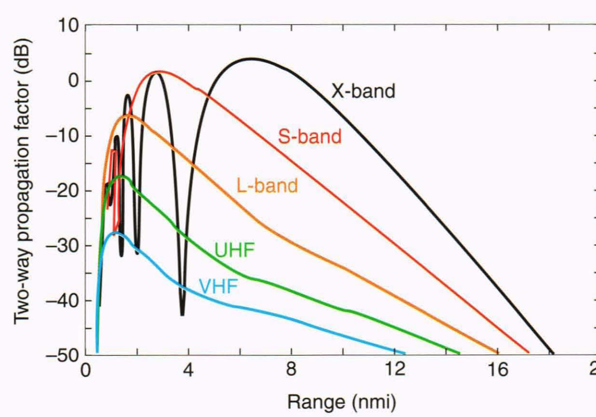


Figure 9. The low-elevation two-way propagation factor is shown for several frequencies at a radar antenna height of 100 ft for a sea-skimming cruise missile at a 12-ft altitude. The X-band advantage over S- or L-band at a detection range of 10 nmi is as great as 16 or 27 dB, respectively.

confirmation techniques[12] can be used to enhance track detection and achieve a 6–10 dB improvement, depending on radar frequency and target speed. These features decrease the track formation time from several seconds to less than one second. The improved Target Acquisition System radar also includes a larger antenna to provide increased gain, better performance in electronic countermeasures environments, and coarse elevation in addition to range and azimuth information.

A critical element of the SSDS Mk III advanced capability is the Horizon Search/Weapon Support radar, which performs wideband horizon search and precision track, uplink and terminal illumination support for the Evolved Seasparrow missile, and terminal illumination for the Standard missile (in ships configured with both missiles). The multifunction radar concept combines key features of several older technologies (Fig. 10) with solid-state active-element radar technology to achieve low-loss, ultrastable, wideband operation. Advanced beam-forming, pulse-Doppler, and other flexible waveforms, in addition to a high effective-radiated-power level, will result in near-horizon detection ranges against even the most stressing sea-skimming threats, especially when cued. Wideband operation provides additional advantages in detecting targets in multipath environments and essentially eliminates the multipath-induced signal fades that otherwise degrade missile semi-active terminal homing. Advanced digital signal processing provides significant electronic countermeasures immunity with adaptive null beam-forming for jammer suppression and deceptive illumination. Pulsed continuous-wave illumination provides the equivalent of multiple fire control channels. This feature permits time multiplexed illumination of several tracks during the same terminal homing interval for multiple concurrent engagements. The solid-state phased-array radar will be developed in two configurations that differ in aperture size and number of transmit/receive modules. The large-array radar is matched to the Aegis Combat System with its requirement to support the long-range Standard missile as well as the Evolved Seasparrow missile. The smaller array is adequate for those combat systems that employ only the Evolved Seasparrow missile. This use will result in a lower cost system for ships such as Spruance class destroyers (DD 963) or newly constructed amphibious ships.

Multispectral target detection and data fusion are also required to provide adequate detection ranges and, therefore, adequate battlespace for weapon response

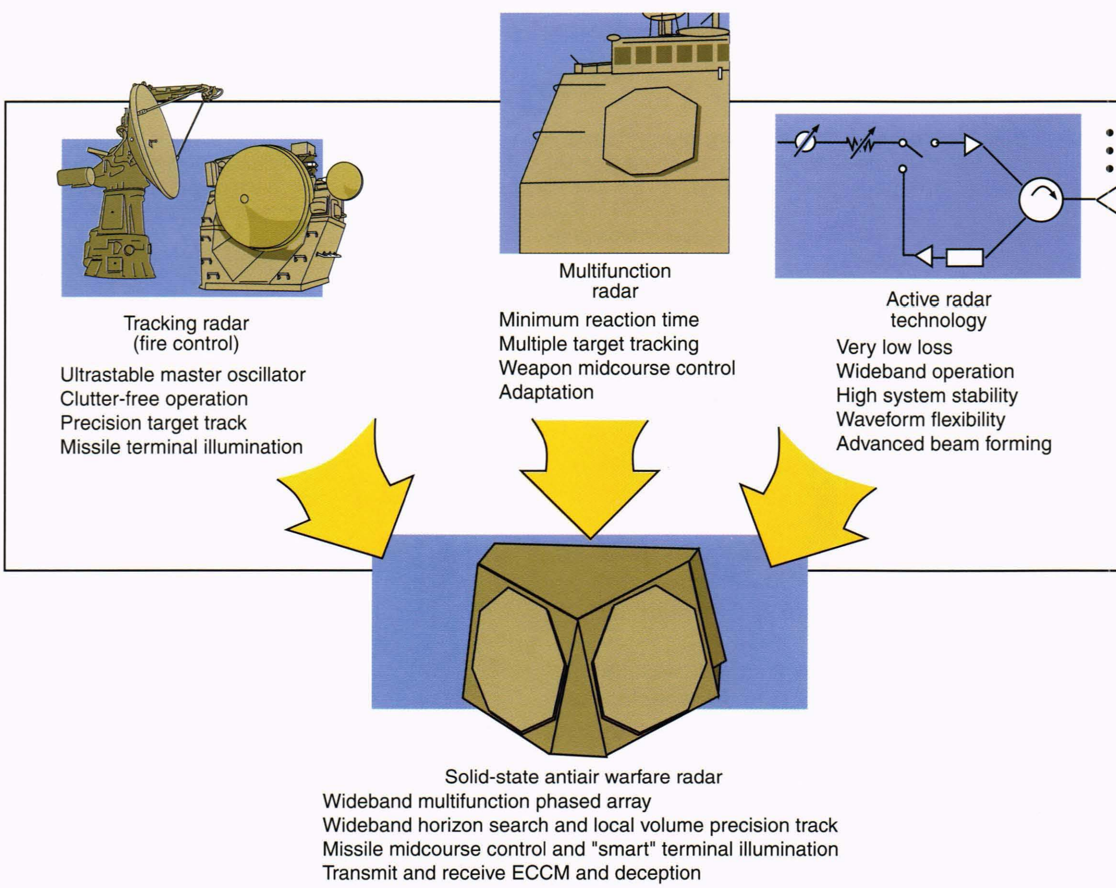


Figure 10. The Horizon Search/Weapon Support multifunction radar is a mix of old and new technologies. The application of solid-state, active-element radar technology significantly enhances performance in terms of low loss, high stability, wideband operation, waveform flexibility, and electronic countermeasures resistance. ECCM = electronic counter countermeasures.

against the stressing, reduced-cross-section sea-skimming threats. A horizon IR sensor is, therefore, essential to the enhanced ship self-defense capability. It is also a combination of old and new technology, as shown in Figure 11, with 360° azimuth coverage, up to 3° or 4° of elevation coverage, and a 1-Hz scanning rate. Concentration on the horizon to provide added detection capability against the sea-skimming threat allows the optics to be lightweight in comparison with the AN/SAR-8 IR search and track set (which attempted to cover high elevation as well) and, therefore, to be mounted high on the mast, further extending the horizon. Focal-plane-array technology with a large number of detectors provides increased sensitivity (10-12 dB improvement) and two bands provide detections on the basis of rocket motor plume and aerodynamic heating. Fast scan rates compatible with today's high-speed digital signal processors will be used. With its milliradian angular accuracy, the horizon IR sensor will provide precision cues to mechanically steered or phased-array radars, enabling them to use tailored waveforms and thus increase their performance by 8-10 dB. This precision azimuth and elevation track data can also be used for missile guidance and illuminator pointing. Against the supersonic, reduced-cross-section threat, the horizon IR sensor in some environments will provide declaration ranges nearly double those of today's surveillance radars. This improvement enables engagements to occur in situations that may have otherwise been denied because of short-range detections of small-cross-section, high-speed threats.

A precision electronic support measures sensor is the third element of the SSDS sensor triad. Like the horizon IR sensor, it is a mix of old and new technology (Fig. 12). Unlike the existing AN/SLQ-32, it is pitch and roll stabilized and provides azimuth and elevation data of milliradian accuracy and improved sensitivity using phase interferometry techniques. The sensor also provides instantaneous frequency measurements using advanced microprocessors and transputers to achieve high-speed parallel processing of large amounts of data. When combined with a Precision Passive Detection and Tracking System,[13] precise angle and angular rate data are generated and can be used for automatic radar-to-electronic support measures track correlation. Various discriminants such as frequency, pulse repetition interval and type, scan rate, and pulse width are also processed and used for enhanced target identification. As with the precision IR data, electronic support measures data provide precision cues that result in improved performance and can be used for weapons employment.

ARCHITECTURAL TECHNOLOGY INSERTION

To meet mission requirements, achieve improved integration, and provide advanced command and control features, significant processor and console upgrades are

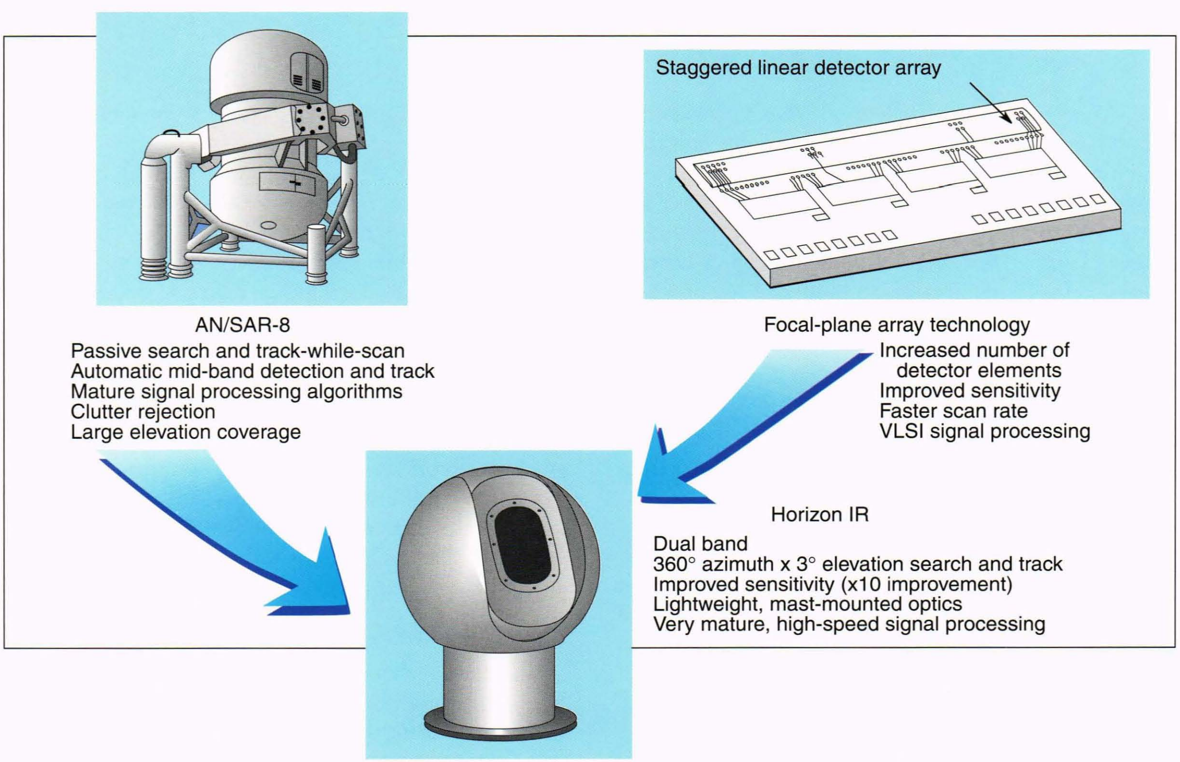


Figure 11. Engagement battlespace lost owing to the high-speed, low-altitude, and small radar-cross-section supersonic cruise missile can be regained through multispectral data fusion and radar cueing using focal-plane-array IR sensor technology with improved sensitivity and a faster scan rate. Lightweight optics permit high mast mounting, which further extends the horizon and detection range against the high-speed (thus "hot" IR signature) threat. VLSI = very large scale integrated circuit.

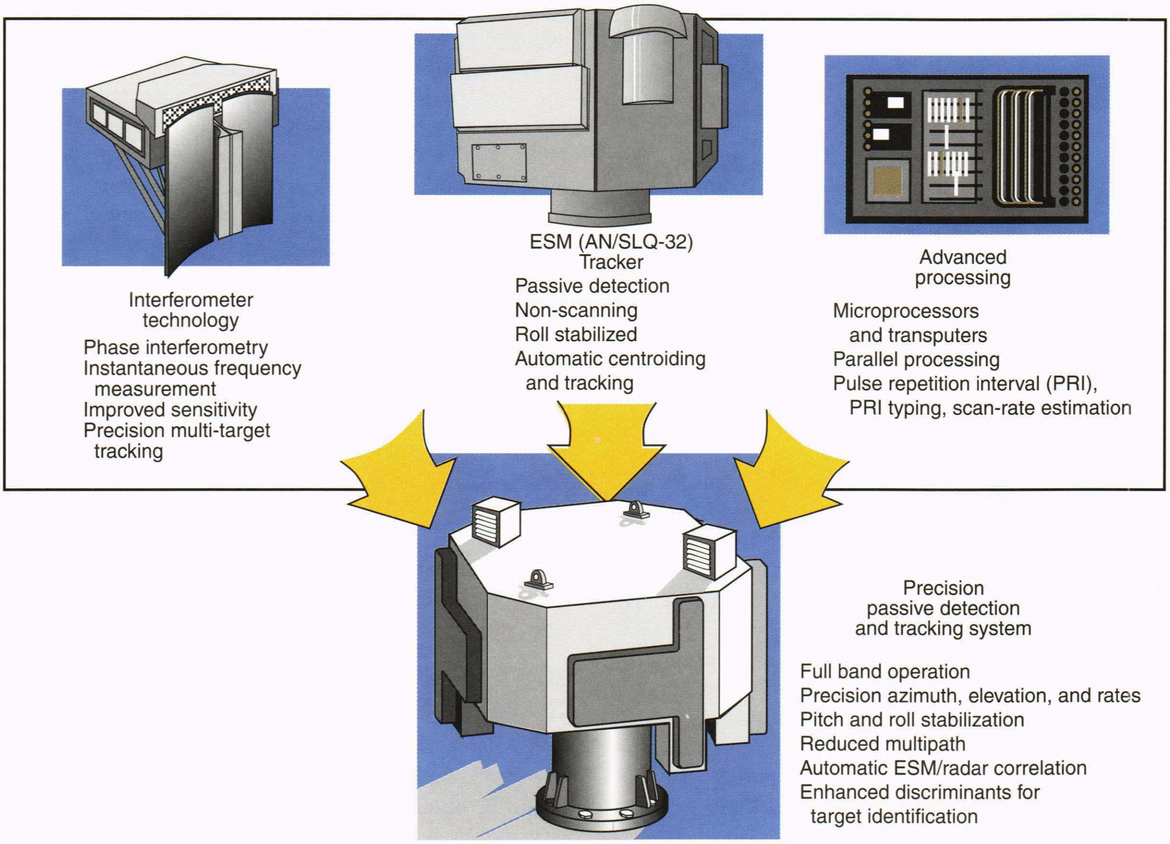


Figure 12. As with the horizon IR sensor (Fig. 11), precision electronic support measures data can extend detection ranges and enhance defense against cruise missiles through data fusion and cueing. Interferometer technology enables improved sensitivity; precision azimuth, elevation, and rate tracking; and enhanced discriminants for target identification. ESM = electronic support measures.

essential. Many of today's systems, however, have limited growth potential as a consequence of the point-to-point architectures, limited input/output channels, and centralized processors. The required architecture must satisfy the low-latency requirements driven by the threat, be capable of growth, and take full advantage of current technology in the fields of computer and display processing (Fig. 13).

The SSDS Mk I incorporates fiber-optic local area networks to support the required redundancy, casualty recovery, and higher data throughput to handle the increased shipboard information to be processed, disseminated, and integrated. It uses both Fiber Distributed Data Interface and Ethernet-based local area networks to interconnect command workstations and the weapon system elements via local area network access units. Distributed microprocessors enable increased automation and integration, and Sun-based workstations present the operators with advanced, multiwindow color displays of map, symbology, status, and doctrine data. These features enable the combat system operators to manage the automated systems effectively using fast-response, screen-oriented controls. The architecture also permits distributed sensor integration that enables multiple radar, IR, and electronic support measures sensor contact data to be fused into a single track and used in weapons scheduling, guidance, control, and engagement kill assessment.

The SSDS Mk II and III systems will employ fully distributed microprocessors grouped in clusters, connected through a combination of backplane buses and networks. This architecture achieves the reaction time (50% reduction from today's most advanced systems) and low data latency required to provide adequate performance against the specified raid densities and to enable multispectral weapon-level data integration. The open architecture thus created ensures adequate reserves in time and core capacity and permits the use of enhanced man-machine interfaces through the addition of advanced workstations. It also enables the relatively easy introduction of new elements, allowing the combat system to keep pace with new technology and its application to countering the advancing threat.

EVOLVED SEASPARROW MISSILE

The Evolved Seasparrow missile, depicted in Figure 14, is critical to countering the advanced sea-skimming and maneuvering cruise missile threat. A two-phase development provides a near-term missile capable of countering the advanced maneuvering threat and a Phase II missile upgrade to defeat the far-term threat and match the capabilities of the broadband multifunction radar. The

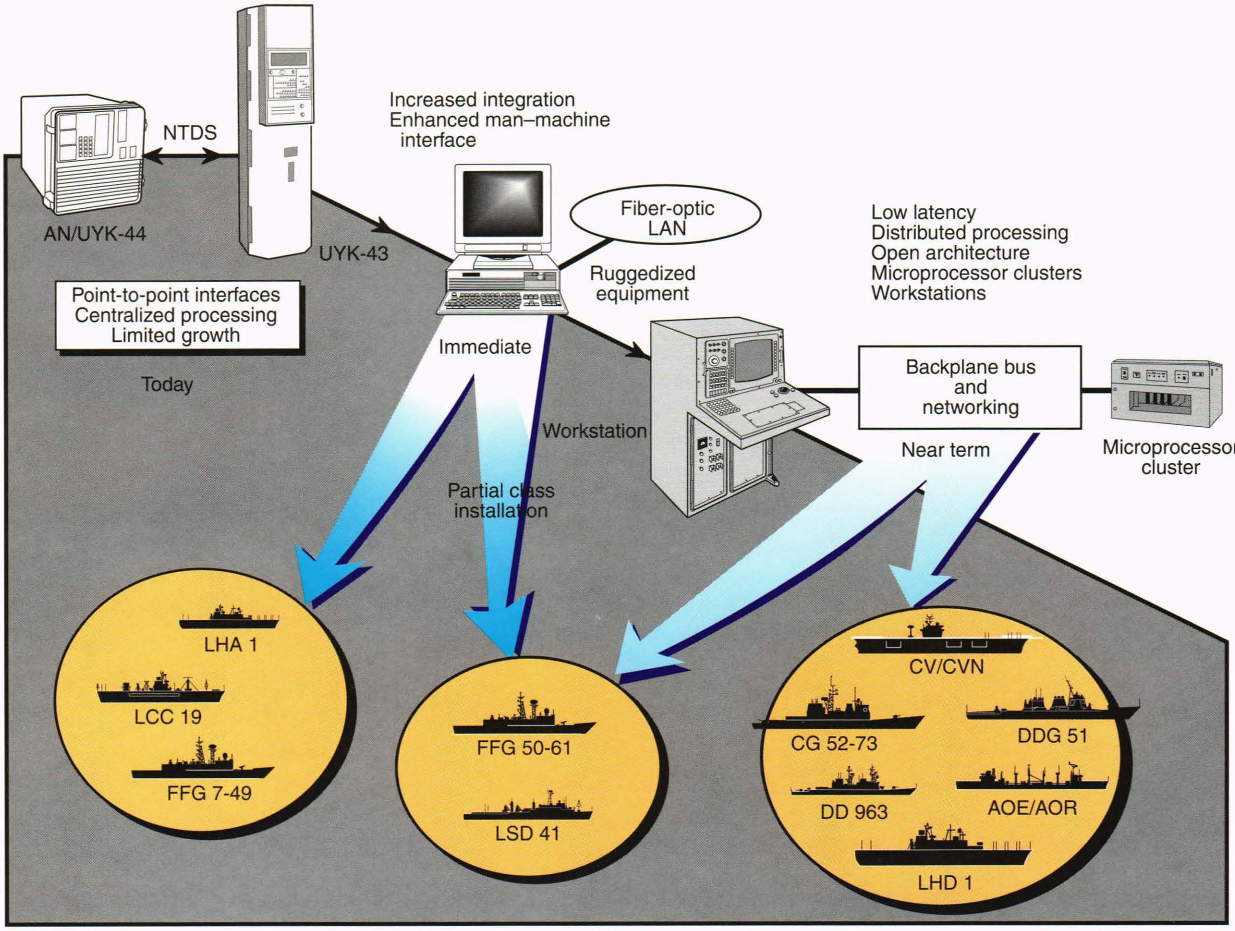


Figure 13. The system requirements allocated to the command and control element can be achieved through the insertion of current technology in computer processing, networking, and displays. Increased integration, data fusion, distributed-microprocessor-based processing, and enhanced man-machine interfaces enable rapid-response, low-data-latency weapon system operations. Ship class descriptions can be found in Ref. 11. NTDS = Naval Tactical Data System, LAN = local area network.

near-term missile is being developed in a joint effort by several nations of the NATO Seasparrow Consortium, including Australia, Belgium, Canada, Germany, the Netherlands, Norway, Portugal, Spain, and the United States.

The near-term Evolved Seasparrow missile (Fig. 15) is an improved, larger-diameter (ten-inch versus eight-inch), quad-packable rocket motor with tail control providing twice the average missile speed, improved kinematic capability, and thrust vector control for rapid tip-over after vertical launch. Only minimal changes to the existing RIM-7P/R guidance section are necessary to accommodate the rocket motor improvements. These changes include an improved autopilot (for reducing the missile's time constant) and a digital inertial measurement unit. The improved missile agility and guidance capability reduce the miss distance and, thus, increase the effectiveness against advanced maneuvering targets. International and unique U.S. options are identified for the near-term missile, motivated primarily by combat system integration requirements. International options include a Mk 41 vertical launching system quad-pack configuration (i.e., four missiles per cell), X-band midcourse guidance uplink, and pulsed continuous-wave illumination for semi-active terminal homing. These options permit the missile to use the full capability of the multifunction Active Phased-Array Radar[14] being developed in the Netherlands. The U.S. unique options include modified ordnance to improve performance against supersonic, sea-skimming threats, a dual-mode terminal homing seeker (semi-active RF/IR) with improved sensitivity for low-signature targets, and S-band midcourse guidance for integration into the Aegis Combat System. The near-term Evolved Seasparrow missile will be compatible with the NATO Seasparrow Mk 29 guided missile launching system as well as the Mk 41 and Mk 48 vertical launching systems. It will be integrated into the SSDS Mk II.

The second phase of the Evolved Seasparrow missile development includes a larger-diameter (ten-inch) front end with an improved warhead and fuze, a dual-mode seeker with an RF capability matched to the broadband Horizon Search/Weapon Support multifunction radar,

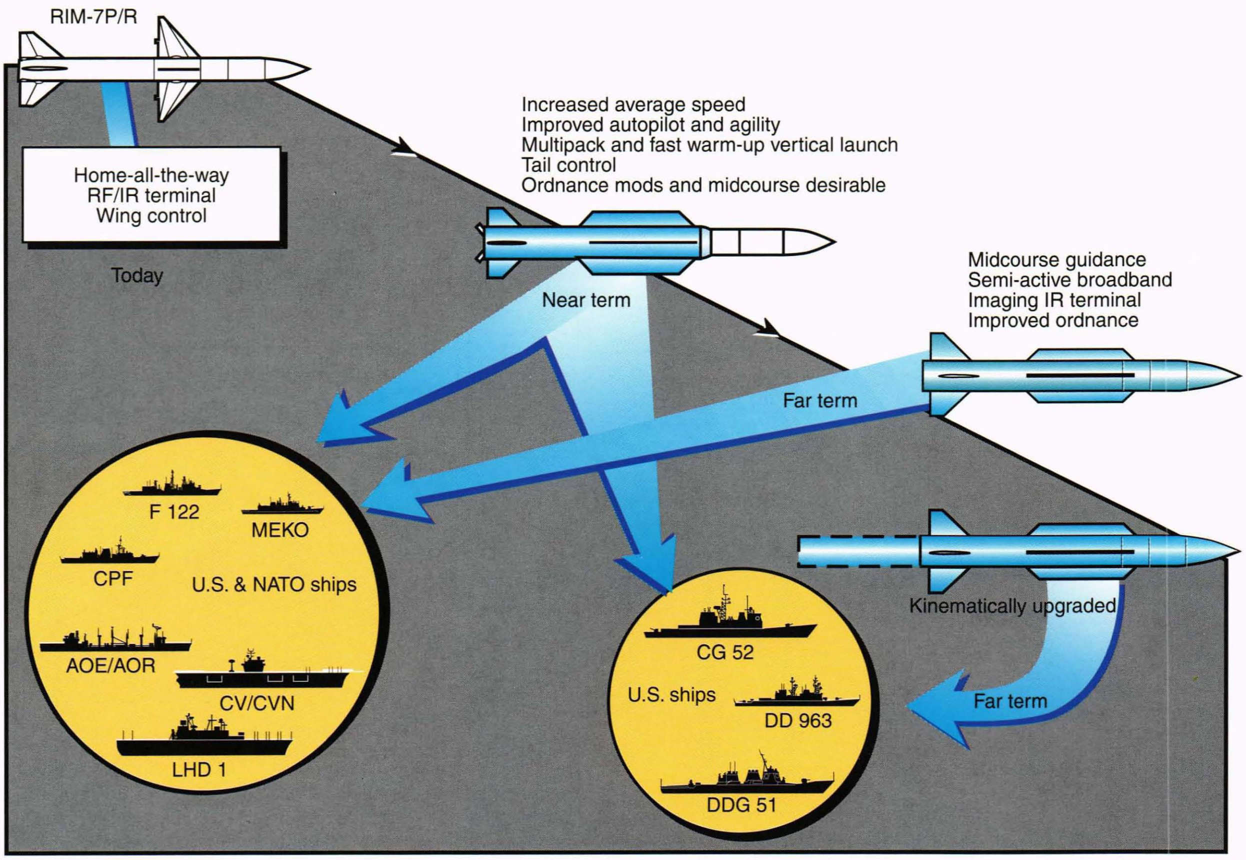


Figure 14. Evolution of the NATO Seasparrow missile (RIM-7) is critical to countering the advanced sea-skimming, maneuvering cruise missile threat. A two-phase development will yield a kinematically enhanced, agile, tail-controlled missile that can be launched from both trainable and vertical launchers in the near term and improved ordnance, boosted and nonboosted variants with a multimode seeker for the far term. Candidate ships, both U.S. and foreign, are identified. Ship class descriptions can be found in Ref. 11.

and an imaging IR seeker. The Phase II missile also has a midcourse guidance capability via the Horizon Search/Weapon Support radar uplink and is compatible with pulsed continuous-wave illumination for increased firepower. It has a boosted and a nonboosted configuration for continued compatibility with the Mk 41 and Mk 29 launching systems, respectively. The boosted version has a 50% greater average speed than the unboosted round and provides increased effectiveness against highly maneuvering targets. The Phase II Evolved Seasparrow missile will be incorporated in the SSDS Mk III.

INTEGRATED ELECTRONIC WARFARE

The integration of hardkill weapons (e.g., missiles and guns) and electronic warfare is key to achieving robust ship self-defense against the anticipated raid densities, particularly in ship classes not configured with the advanced Horizon Search/Weapon Support multifunction radar and Evolved Seasparrow missile. In those ship classes, an upgraded electronic warfare suite provides a cost-effective enhancement capable of defeating the less stressing threats. Performance against the supersonic, sea-skimming, multimode-guidance threat is stressed because of the inherent dependence of softkill effectiveness on alertment time (decoy deployment times), relative geometry (threat axis, launch tube, relative wind), ship signature (radar, IR, RF emissions), and specific threat identification and seeker characteristics (for tailored deceptive electronic countermeasures response). In many circumstances, however, electronic warfare enables a measured response to potentially hostile actions, which is both consistent with the rules of engagement and which does not further escalate hostilities. Decoys can be launched, for example, in response to emissions from a targeting radar that may be intended to provoke hostile action while awaiting the actual threat missile launch to execute the essentially irrevocable action of hardkill weapon engagement.

Effective employment of the combat system requires the integration of hardkill and softkill weapons, not only to prevent interference, but to enhance the effectiveness of each. This integration includes the use of radar-generated tracks to initiate decoy launch rather than relying exclusively on electronic support measures detections. It also includes selectively scheduling targets for electronic warfare engagements that would otherwise go unengaged with hardkill weapons because of resource limitations and employing hardkill and softkill weapons in parallel

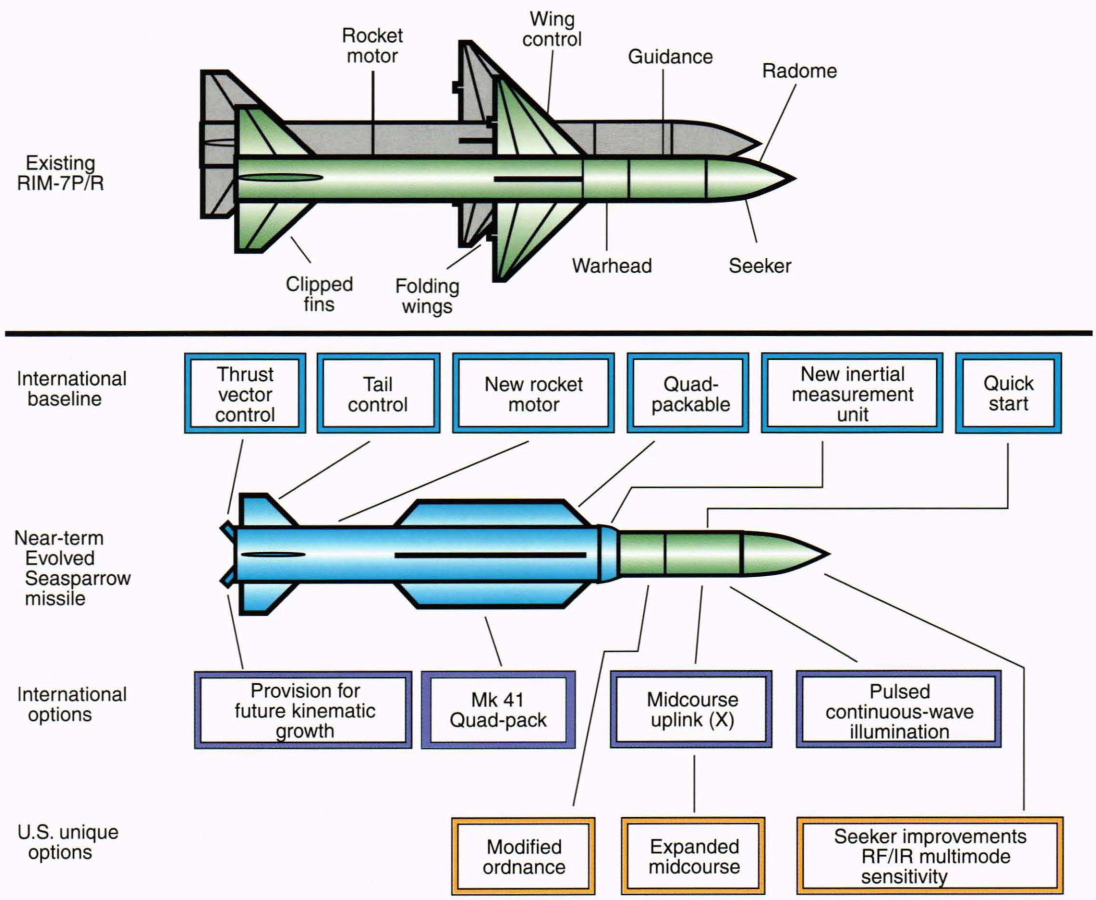


Figure 15. The near-term Evolved Seasparrow missile is being developed by an international consortium including Australia, Belgium, Canada, Germany, the Netherlands, Norway, Portugal, Spain, and the United States. International and U.S. unique options are identified; these options are influenced primarily by combat system integration requirements.

when softkill weapons alter the threat characteristics and increase the vulnerability to hardkill weapons.

Upgrades of existing electronic warfare elements (Fig. 16) are also needed to achieve the desired level of combat system performance. These upgrades include advanced digital signal processing for signal discrimination and integration, an adjunct high-sensitivity horizon electronic support measures sensor for sea-skimmer detection, and an offboard active electronic decoy matched to the reduced cross section of the ship. These upgrades will be integrated into the SSDS Mk II. The Mk III concept includes several additional new technology elements that are fully integrated in the Advanced Integrated Electronic Warfare System, including enhanced signal processing for threat identification, active IR countermeasures, and advanced active offboard decoys. This level of integration also requires electronic support measures data of milliradian accuracy as provided by the precision electronic support measures sensor described earlier. The SSDS Mk III integrated electronic warfare suite will provide increased effectiveness against the threat, particularly in those ship classes that do not receive the advanced hardkill weapon systems.

SUMMARY: AN ENHANCED DEFENSE FOR THE LITTORAL ENVIRONMENT

Although the recent dramatic geopolitical changes have all but eliminated the possibility of global war, they have introduced new instabilities and accelerated the proliferation of advanced-technology weapons. Motivated by geopolitical, ethnic, or religious instabilities, limited and regional conflicts in littoral environments are more likely than they have been in the past. In response to this changing threat, the Navy has focused on enhancing ship self-defense, and the Program Executive Office for Ship Defense has endorsed the overall roadmap described in this article for upgrading existing weapon system elements and integrating critical new technologies into the combat system.

The enhancements required are primarily driven by the advanced supersonic, maneuvering, sea-skimming threat in the cluttered littoral environment. Upgrades dependent on each ship class, including sensors, weapons, and their integration, will be required for effective defense. The necessary sensor improvements include upgrades to the existing Mk 23 Target Acquisition System and AN/SPQ-9

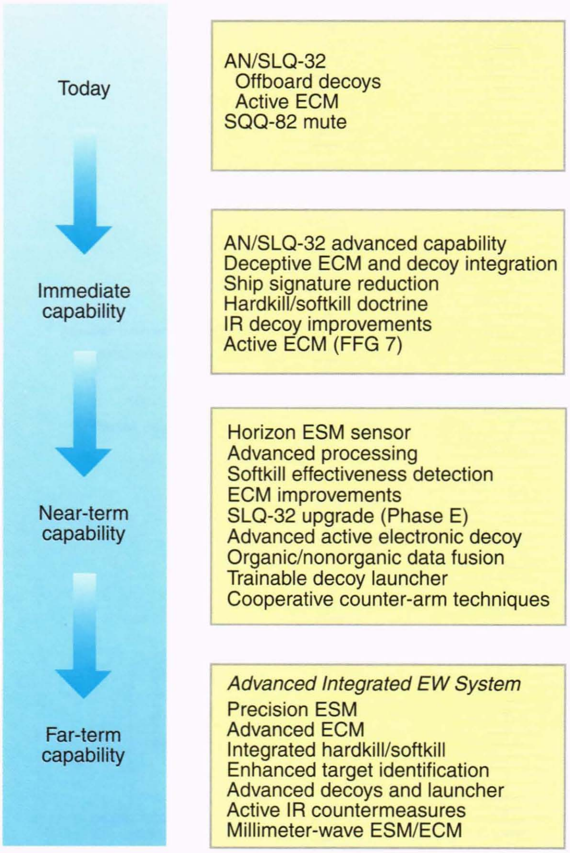


Figure 16. The required electronic warfare enhancements include sensor, deceptive electronic countermeasures, and offboard decoy upgrades, as well as softkill and hardkill weapon coordination. The upgraded electronic warfare suite provides a cost-effective contribution to air defense, particularly on those ship classes that do not receive the advanced hardkill weapon system (Ship Self-Defense System Mk III). ECM = electronic countermeasures, ESM = electronic support measures, EW = electronic warfare.

radars, in addition to the introduction of a horizon IR sensor, a precision electronic support measures sensor, and a multifunction radar based on active-element phased-array technology for horizon search and weapon support. Weapon improvements include the introduction of the Rolling Airframe missile to provide an immediate capability in selected amphibious ships, the evolution of the Seasparrow missile to address the advanced threat, a modest upgrade of the Phalanx Close-In Weapon System to the Block I Baseline 3 configuration, and electronic warfare enhancements. The integration of these sensors and weapons is essential to maximizing their effectiveness and includes multispectral sensor data fusion, precision cueing, weapon-level data integration, and hardkill/softkill weapon coordination.

With these upgrades, the application of new technology, and increased system integration, the surface Navy will be able to defend effectively against the air threat it may be forced to encounter in Third World regional/limited conflicts in the littoral environment well into the next century. Naval expeditionary forces will then be able to sustain littoral warfare operations while accomplishing their mission.

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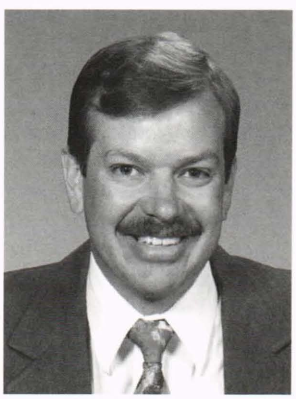

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