Standard Missile: A Cornerstone of Navy Theater Air Missile Defense

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Standard Missile is the primary Navy Fleet anti-air missile system. Its history stems from requirements established by the Navy in 1945, and it has evolved continuously as driven by continual changes in the threat and operating conditions of our naval forces. Over the years, the need for an advanced weapon capability has led to intense systems efforts involving universities, government laboratories, and industry. This article examines the history, major development efforts, and future of Standard Missile.

INTRODUCTION

In 1965, the Advanced Surface Missile Systems (ASMS) Assessment Group issued a report (The Withington Study) stating that the Navy needed a new missile system to address the future threat. However, limited by budgetary considerations, the Navy, as it had done previously, considered upgrades to Standard Missile (SM) to achieve its requirements. These upgrades applied to both SM predecessor systems, Terrier and Tartar, as well as to the emerging system, Aegis. Thus, with SM viewed as the primary Anti-Air Warfare (AAW) weapon for the Aegis Weapon System, significant enhancements have been made to major missile elements, including propulsion, guidance, and fuzing. This close coordination of missile and ship systems has been absolutely critical for the Navy.

The operational use of any guided missile requires direct support from a combat system, whether it is fired from land, sea, or air. In the surface Navy, many missile system requirements are unique, not only because of the sea environment, which is incredibly harsh, but more significantly because the supporting systems are combatant ships with varied missions and tactical requirements. Therefore missile weapon system designs are under severe constraints in terms of physical size, weight, and shipboard location. Additionally, the missile system must be totally consolidated within the ship command structure, which encompasses all weapons aboard the ship. Because of this close weapon-to-ship integration requirement, it is technically and economically practical to upgrade the missile system's performance, provided that forethought goes into the planning and special design concepts are incorporated.

The development of SM has followed these systems engineering principles throughout its history. That is, necessary incremental missile upgrades have been made based on long-term system requirements in which improvements are made by building solidly on existing resources and knowledge (Fig. 1). Each module is designed with a tolerance to change so that missile upgrades have a minimum impact on other ship elements and support

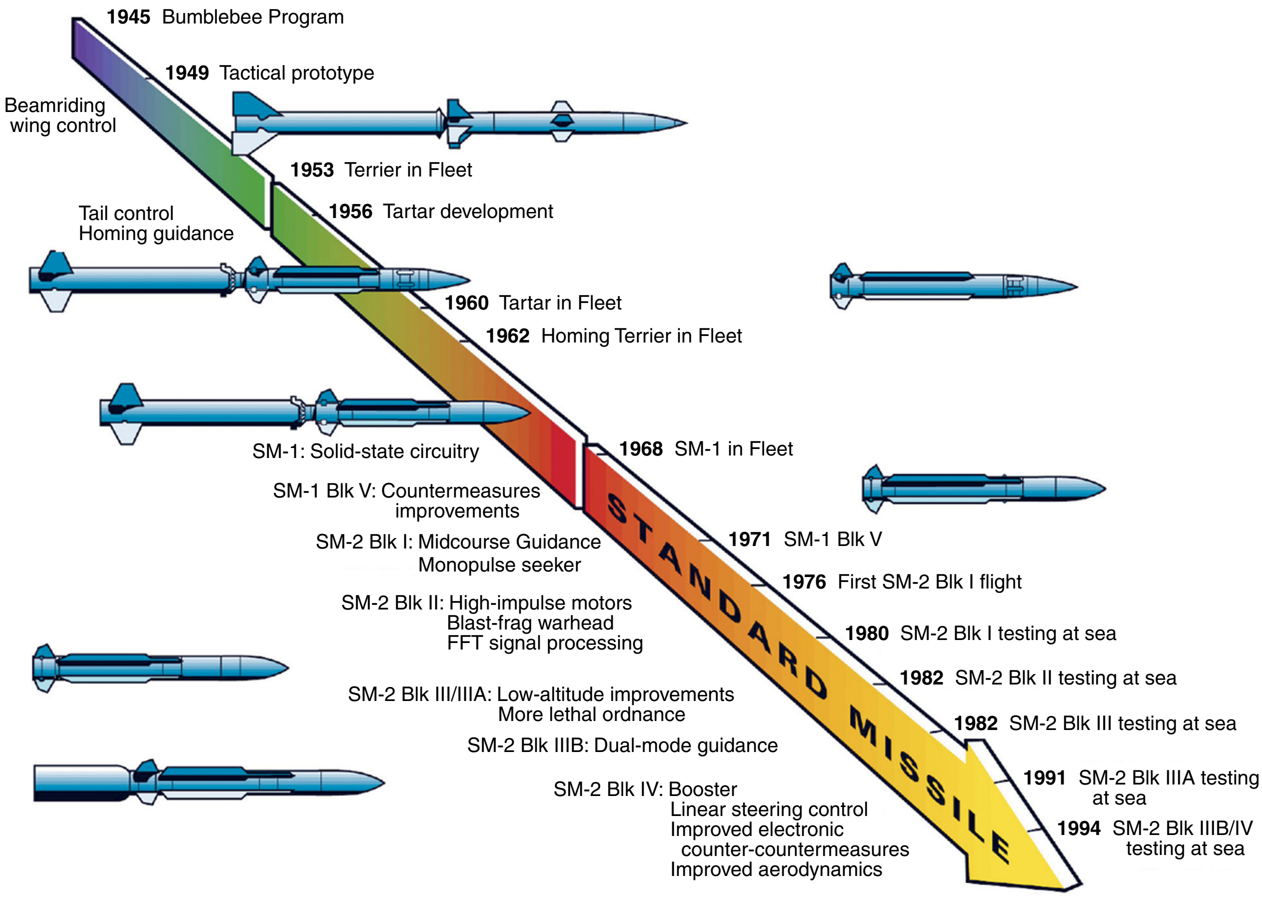

Figure 1. The evolution of in-service Standard Missiles.

activities. In a word, SM is based on commonality: commonality of critical components within the missile from one generation to the next; commonality among versions fired from Terrier, Tartar, and Aegis ships; commonality of interfaces with supporting radar and launching systems; and commonality in engineering expertise, technical data, and logistic support.

Thus, as the Navy looks to the future, SM is viewed as the point of departure for many developmental efforts. Production and in-service efforts for SM-2 Block IIIA, Block IIIB, and Block IV provide the backbone for current Fleet capability. However, engineering, manufacturing, and development efforts for SM-2 Block IVA for Area Ballistic Missile Defense (BMD) requirements, SM-3 for Navy Theater Wide requirements, and SM-4 (Land Attack Standard Missile) for Naval Surface Fire Support requirements provide for the Navy's near-term and future multimission needs. Finally, looking at future advanced threats and environments, trade studies are currently being initiated, under the direction of the SM Program Office, PEO(TSC) PMS 422, to address the Navy's multimission requirements with upgrades to variants of SM-2 Medium Range (MR), SM-2 Extended Range (ER), SM-3, and SM-4. A systems approach will continue to be used as it has been for SM since post–World War II to accomplish these goals.

ORIGINS OF STANDARD MISSILE

In 1944, a glaring deficiency in Navy AAW defenses was clearly exposed during the Battle for Leyte Gulf: On 19 October at 0740, the escort carrier USS *Santee* became the first victim of a kamikaze attack. The original kamikazes were Japanese fighter aircraft armed with 500-lb bombs. Continued attacks, although countered by concerted anti-aircraft fire, were devastating, particularly at Iwo Jima and Okinawa. Before the war ended in August 1945, such attacks on U.S. ships resulted in about 15,000 casualties. Proximity fuzed anti-air gunfire (Fig. 2),[1] complemented by Navy fighter aircraft, was unable to effectively cope with the kamikaze attack concept.

The Navy recognized immediately that a weapon system with very quick reaction, very high speed, and long enough range to engage an attacker prior to weapon release was vitally needed. Accordingly, in January 1945, the Navy Bureau of Ordnance directed APL as follows:

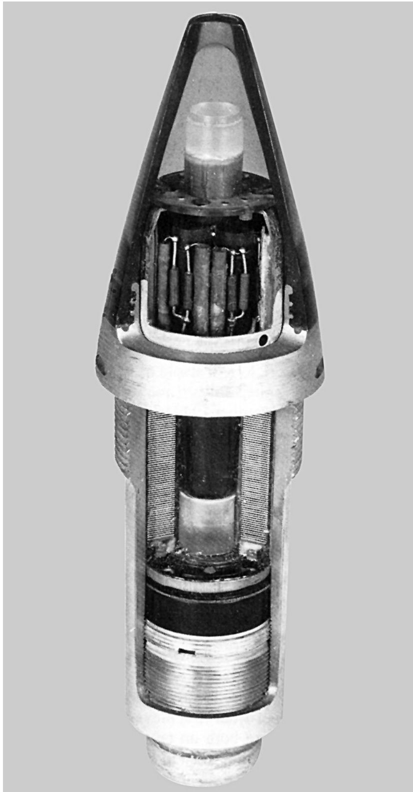

Figure 2. The VT fuze.

> A comprehensive research and development program shall be undertaken, embracing all technical activities necessary to the development of one or more types of rocket-launched, jet-propelled, guided, and anti-aircraft missiles. This program shall include pertinent basic research, investigations, and experiments, and the design, fabrication, and testing of such missiles, their component parts, and supplementary equipment.[2]

Thus was established the "Bumblebee" Program.

The scope of the program was vast. Never before had such a weapon system been developed. There was no technological base for designing a missile with the necessary characteristics: long-range guided flight at supersonic speeds. This ambitious goal required that several different technologies be explored and that a sufficient body of new knowledge be acquired to form a rational basis for engineering design. The greatest advances were required in the fields of jet propulsion, supersonic aerodynamics and control, and missile guidance, all infant technologies.

To answer the challenge posed by the lack of scientific and engineering foundations for developing guided missiles to defend the Fleet, APL applied a teaming approach that had proved so successful in the development of the VT fuze. The collaborating organizations were called associate contractors, and their contracts specified that their tasks would be under the technical direction of APL. As many as 17 university, industry, and government organizations were involved.

By 1949 the Bumblebee Program (Fig. 3) had established the feasibility of producing a tactical ship-to-air anti-aircraft guided missile. A supersonic test vehicle using solid-fuel booster and sustainer rocket motors was used to test and evaluate the radar-beam–controlled guidance and control system for the planned operational Talos guided missile. The first round was delivered on 31 January 1950 and flight-tested at the Naval Ordnance Test Station, China Lake, California, on 16 February 1950. This tactical prototype successfully demonstrated beamriding guidance against drone targets.[3]

A version of the test vehicle performed so well that the Navy decided to develop it for use as an AAW weapon in warships smaller than those deploying Talos. Thus, the Terrier Missile System came into being. The Terrier Program proceeded rapidly. In November 1955, the USS *Boston* (CAG 1) was recommissioned (Fig. 4), and, carrying Terrier Missiles, became the first guided-missile ship in the world. The event marked the culmination of the first phase of the Terrier Program.

The first significant upgrade to Terrier was the change in the control system from wing control to tail control. This was prompted by the need for better maneuverability to counter evasive tactics on the part of the attacker.[4] The second major upgrade was the change from beamrider guidance to semi-active homing guidance, a change that was made in coordination with the development of a small-ship missile based on the Terrier

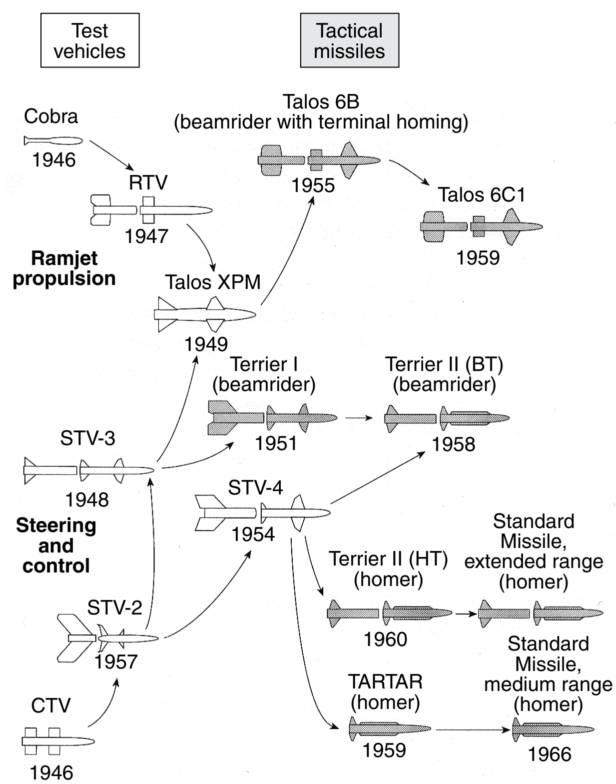

Figure 3. The Bumblebee Program.

Figure 4. USS *Boston* (CAG 1).

aerodynamic configuration and control system design.[5] For the smaller missile, designated Tartar, a dual-thrust rocket motor (DTRM) was developed to provide high thrust for the initial (boost) phase of flight, followed by much lower thrust for the sustain phase. The Navy established a shipbuilding program that resulted in the USS *Charles F. Adams* (DDG 2) class destroyer (Fig. 5), which, armed with Tartar, was first deployed in 1960.

In the years since the Bumblebee Program, the missile has evolved through many generations and upgrades. As the threat has changed and intensified, countering modifications have been identified and applied to the missile design—always staying abreast of prudent applications of new technology.

EVOLUTION

SM-2 Development/SM-1 Upgrade

In the early 1960s, the technological advances of solid-state electronics had matured sufficiently to justify the redesign of both the Terrier and Tartar missiles. Terrier became SM-1 ER and Tartar SM-1 MR. With the use of modular construction and a tail control configuration that is not sensitive to change in dimensional and weight characteristics, performance improvements by block changes (a collection of related design changes introduced during production) were possible.[6]

Figure 5. USS *Charles F. Adams* (DDG 2).

Block changes have led to a progressive family of SMs. SM-1 ER was a two-stage configuration having a single thrust booster that separated from the missile a few seconds after launch. The rocket sustainer then ignited for the remainder of flight. SM-1 MR employed a DTRM developed earlier for Tartar.

In the mid-1960s, air threats to naval forces began undergoing a transition from aircraft to anti-ship missiles. Such missile attacks would likely have been coordinated with the use of various countermeasures and special tactics. It was at this point, as noted earlier, that the ASMS Assessment Group recommended a new weapon system that would combine high performance, short reaction time, an inherent countermeasures capability, and high availability. In 1969, the Navy awarded a contract for the Aegis Weapon System, which would use improved versions of SM. This version, designated SM-2 Medium Range (SM-2 MR), incorporated a new inertial guidance system and missile/radar data link.

SM-2 MR performance in terms of intercept range, altitude, and terminal homing accuracy was greatly improved by this upgrade. More importantly, it now became compatible with and could be used by the Aegis Weapon System in an engagement scenario that required multiple missiles in flight (simultaneously) against different targets.

In the early 1970s the Navy sponsored a study to determine how these new capabilities might be used to upgrade the performance of the Terrier/Tartar combat systems. A concept evolved that adapted the new missile features for both systems. Tartar used the medium-range missile designed for Aegis with minimal changes. Terrier, incorporating a higher-energy propulsion system, was designated SM-2 Extended Range (SM-2 ER).

At the onset of development of SM-2, SM-1 Block V was in production as the primary weapon for Fleet Air Defense by Terrier and Tartar ships. SM-1 employs home-all-the-way guidance with no midcourse guidance mode. The Navy planned to continue to use SM-1 exclusively in a substantial number of warships for the foreseeable future, since it was predicted that, by the time SM-2 was ready for initial operational capability, many of these ships would be very close to the end of their service life. It was prudent, however, to consider the upgrade of SM-1 with applicable features developed within the framework of the SM-2 Program. An SM-1 Block VI upgrade program was therefore established in the late 1970s with objectives identified as follows:

- Incorporate the SM-1 monopulse receiver (SM-2 Block I commonality)
- Incorporate the Mk 45 Mod 4 target detecting device (TDD) (SM-2 Block I commonality)
- Provide SM-1 Block VI guidance and ordnance sections as alternate and interchangeable with SM-1 Block V sections

- Provide production commonality between SM-1 Block VI and SM-2 Block I
- Establish production in FY1980

The listed attributes were incorporated in SM-1 Block VI production. In the meantime, SM-2 Block II development was proceeding. The principal threat for SM-2 was identified as fast, high-flying, anti-ship cruise missiles. Analysis, supported by flight testing of SM-2, concluded that an upgrade to the TDD, i.e., the proximity fuze, was needed to maximize missile kill performance against these targets. This resulted in the TDD Mk 45 Mod 5. Still striving to maintain production commonality between SM-2 and SM-1, the Navy upgraded the SM-1 TDD from Mod 4 to Mod 6 and replaced the continuous rod warhead with the Mk 115 blast/frag warhead employed by the SM-2. SM-1 so configured was denoted SM-1 Block VIA.

This process of SM-2 development followed by SM-1 upgrade to achieve comparable performance continued until the late 1980s. Finally, the Low Altitude Program for SM-2 Block III led to SM-1 Block VIB. However, in one very significant deviation from this development process, a missile receiver upgrade to eliminate susceptibility to a phenomenon known as clutter-derived noise was first incorporated in SM-1 Block VIB and subsequently in SM-2 Block III/IIIA. This missile upgrade is particularly significant since it resulted in effective missile performance in a domain that is viewed as the principal hostile environment within which the Navy is expected to operate in the foreseeable future (Fig. 6). SM-1 continues in service in a number of Navy warships worldwide, including the FFG 7 class combat systems.

SM-2 Medium Range

Blocks I and II

For SM-2 Block I, the first missile in the SM-2 family, both MR and ER versions were tested at sea from 1976 through 1979. The Chief of Naval Operations approved SM-2 Block I ER, after a successful flight test program off the USS *Mahan*, for service in 1979.

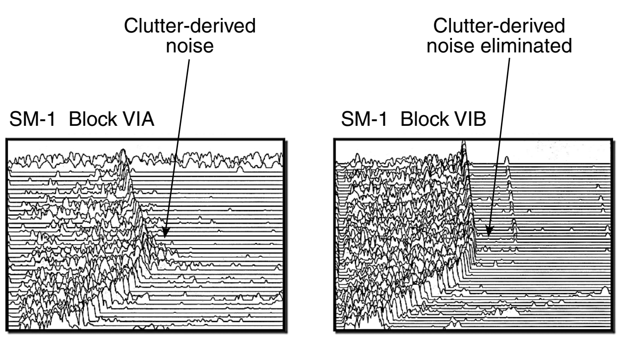

Figure 6. Clutter-derived noise comparison.

For SM-2 Block II, during the late 1970s to early 1980s, the perceived AAW threats to the Navy were the fast, high-flying, anti-ship missiles such as the AS-4 and AS-6 supported by heavy standoff electronic countermeasures. Operations analysis concluded that the threat could be successfully countered by upgrading SM propulsion and receiver signal processing. Accordingly, as stated earlier, the Navy had established programs to do just that for both the SM ER and MR versions. This resulted in a greatly increased impulse DTRM, Mk 104, for the SM-2 MR version. With this, SM-2 MR's approval for service occurred subsequent to the commissioning of the first Aegis warship, USS *Ticonderoga* (CG 47), in 1983. For SM-2 Block II ER (Terrier), a greatly increased impulse booster rocket, Mk 70, was added. The SM-2 ER (Terrier) missile system was put into service during the 1980s as well.

For both the SM-2 Block II MR and ER, the missile front radio-frequency (RF) receivers were upgraded by the incorporation of a digital-design fast Fourier transform signal processor employing off-axis logic to detect the presence of standoff jammers. Flight testing at White Sands Missile Range and at sea verified the effectiveness of the missile upgrades.

Blocks III, IIIA, and IIIB

As the threat evolved, and with the high-altitude domain effectively countered, it was time to focus on the low-flying anti-ship missiles proliferating throughout the world. As before, after detailed analysis and experimentation, it was concluded that an upgrade to SM was the answer. The missile that emerged was denoted SM-2 Block III.

The SM-2 low-altitude improvement program included three basic goals: (1) diminish the effects of target RF energy reflection from the sea surface, (2) derive missile altitude for low-altitude engagements, and (3) permit identification of low/slow targets. This missile system was successfully demonstrated during the late 1980s and subsequently fielded.

There was a further evolution of the Block III missile, Block IIIA. This was distinguished by an upgrade to the warhead and TDD sections. This missile system ordnance upgrade was successfully demonstrated and fielded in the early 1990s.

The latest evolution of SM-2 MR is SM-2 Block IIIB. This SM is equipped with a dual-mode RF or infrared (IR) homing seeker capability. SM-2 Block IIIB was successfully developed and operationally tested in 1994 and became operational in 1997. It serves as the basis for the Aegis low-altitude capability.

SM-2 Extended Range

The coordination of all available battle group resources in prosecuting the engagement of an attacking force has always been an underlying precept of Navy battle doctrine. The emergence of the Aegis Weapon System and its AN/SPY-1 radar provided a major element in the implementation of that precept. Using the Aegis system as a baseline, the Navy has progressively designed and developed companion system elements for incorporation into warships over the past 20 years. For example, the Cooperative Engagement Capability (CEC), based on the Mountain Top Program[7] to demonstrate the feasibility of a beyond-the-horizon capability, as well as recently successfully completed technical and operational evaluations, is working toward becoming a reality. For now, though, within CEC, the concept of a surface-launched, air-supported engagement of cruise missiles has been validated and has provided the impetus for follow-on Joint services pursuit of an extended, beyond-the-horizon engagement capability for defense of land sites from land-, air-, and sea-based missile defense systems.

A dominant attribute of CEC is the capability of a missile-firing warship to engage targets that are over its radar horizon but within the view of a forward-located companion warship, which can provide appropriate fire control solutions via the CEC link to the shooter. The forward-located ship, at an appropriate time, can assume control of the fired missile for the terminal portion of the engagement. However, the AAW missile in the Aegis Fleet in the mid-1980s was SM-2 Block II, powered by the Mk 104 DTRM. Since it lacked the necessary extended engagement range, a higher-impulse propulsion system was needed.

The groundwork had been laid for the required improvement to SM-2 beginning with the fifth Aegis cruiser, USS *Bunker Hill* (CG 52), in which the Mk 26 Launching System was replaced by the Mk 41 Vertical Launching System. The size of the Mk 26 strictly limited the missile's external configuration and dimensions to expand, whereas the Mk 41 system did allow for an increase in the size of the propulsion system needed for SM-2 ER. Accordingly, the Navy established a program to design and develop SM-2 Block IV (Fig. 7). Its major upgrade was the incorporation of a new thrust vector–controlled booster, the Mk 72, which was mechanically and electrically integrated with the propulsion system, the Mk 104, used on SM-2 Blocks II/III/IIIA/IIIB, which are now in the Fleet. In addition to the propulsion upgrade, Block IV was equipped with a new digital autopilot, a digitally controlled seeker head, and several guidance section improvements; electronic countermeasures resistance was also reinforced. With the higher speeds achieved, greater maneuverability was realized as well as longer-range engagements. The Block IV missile was successfully tested at White Sands in the early 1990s and at sea in 1994. It is now in low-rate initial production and serves as the baseline for the family of SMs that support BMD and future Theater Air and Missile Defense (TAMD) needs.

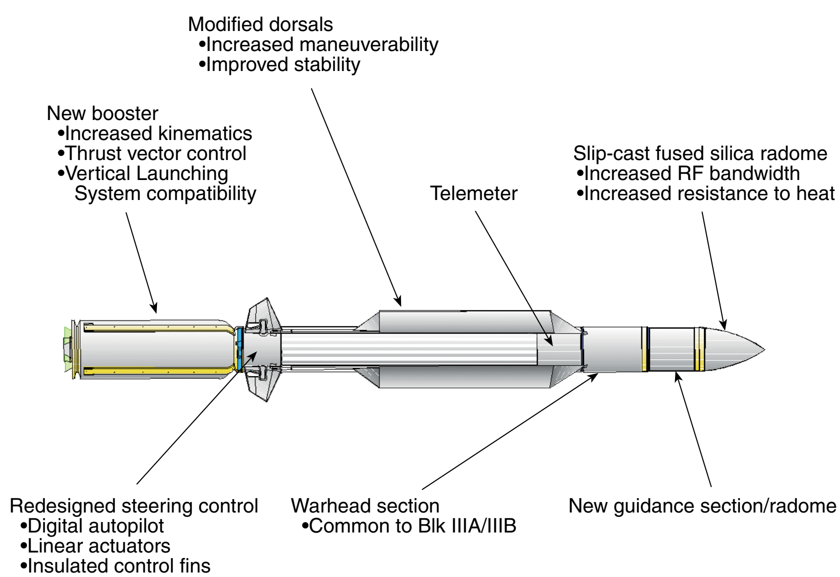

Figure 7. SM-2 Block IV.

Ballistic Missile Defense

Endo-atmospheric intercepts

Again, pushed by the ever-changing threat as demonstrated in Desert Storm and thereafter, the tactical ballistic missile became the dominant threat. As before, through analysis and experimentation, it was concluded that an evolved SM-2 Block IV, denoted SM-2 Block IVA, would provide protection against that threat. The design of SM-2 Block IVA, because of the threat characteristics and payload, would need to be equipped with dual-mode guidance, RF and IR, as was done in the IIIB program.

However, the demanding intercept accuracy requirements for SM-2 Block IVA dictated an entirely different missile IR system design. To address endo-atmospheric intercepts, a new seeker head with highly accurate rate integrating gyros was designed to be put on an SM-2 Block IV airframe. An inertial reference unit incorporating a ring laser gyro was designed for the guidance section, the autopilot was redesigned so that the missile could capitalize on the inherently higher "*g*" capability of the Block IVA airframe, and a forward looking fuze (FLF) was developed to address stressing

BMD endgame conditions. A successful SM-2 Block IVA Risk Reduction Flight Demonstration in January 1997, which had a representative flight configuration of the current SM-2 Block IVA, had allowed this program to continue. Results were promoted at the highest levels and were featured on the cover of *Aviation Week*. Thus, the Navy gained confidence enough to authorize the initiation of engineering, manufacture, and development for the SM-2 Block IVA Program in 1997.

Currently, two successful flight tests of control test vehicles have been accomplished under the SM-2 Block IVA Program. The outcome of these flights has allowed the program to continue with guided test vehicles, which are expected to be flown during 2001 and 2002, with a missile initial operational capability of 2003–2004.

Exo-atmospheric intercepts

To address exo-atmospheric intercepts during the early stages of BMD, requirements formulation and demonstration projects for a flight test program, denoted the Terrier Lightweight Exo-atmospheric Projectile (LEAP), were implemented (Fig. 8). Its goal was to demonstrate by experiment the validity of the analytic conclusions of the achievable kill effectiveness of kinetic warheads (KWs) mounted on SM Terrier (ER) airframes fired to achieve intercepts of tactical ballistic missile–like targets at their related altitudes. Two flight intercept tests in 1994 and 1995, although yielding less than sensational results, gave confidence that the program was on the right course and should be continued. The current LEAP concept, designated SM-3 and based on an Aegis launch and support system, has a four-stage approach to achieve the required intercept (just as Terrier LEAP):

1. Mk 72 booster rocket motor
2. Mk 104 DTRM
3. Third-stage rocket motor (TSRM) and avionics package
4. KW and avionics package

Each stage is supported by an associated control system to permit maneuvering during flight. The function of the first three stages is to deliver the KW to a point in space from which it can acquire, track, and use its own propulsion system to divert its own course to achieve an intercept of the target threat. The SM-3 operational concept is depicted in Fig. 9. Since the flight sequence of SM-3 differs dramatically from that of traditional SMs, we provide the following high-level description.

First stage (boost). The missile is fired with a launch bearing and elevation angle relative to the local level. It is fired vertically and pitches over to align its velocity vector with the initialized commands. AN/SPY-1 radar acquires and tracks the Aegis missile beacon during this phase. The Mk 72 booster separates at the designated time and conditions.

Figure 8. Terrier LEAP.

Second stage (endo-midcourse). The Aegis Weapon System, via the Aegis RF uplink, transmits acceleration commands to SM-3. The midcourse guidance law, a heading angle control law, aligns the missile velocity vector with the reference vector pointing at the predicted missile/target intercept point. The GPS is an integral element of the SM-3 guidance system. The second-stage Mk 104 DTRM separates from the missile assembly at burnout.

Third stage (exo-midcourse). The TSRM has a two-pulse rocket motor. During this phase, the uplink message provides new information, which includes target state vector data (position and velocity) from the Aegis Weapon System, that is merged with GPS-based missile-developed guidance. The third stage uses burnout reference guidance, calculated on the missile, to steer during TSRM burn. Missile and target positions at TSRM burnout are predicted, and steering commands to place the two on a collision course are used by the TSRM. The missile is thrust vector–controlled during both TSRM pulse burns. At the appropriate time-to-go to intercept, the KW is initialized by the TSRM and released.

Fourth stage. The fourth stage, the KW, is essentially a missile within a missile. It evolved from the Terrier LEAP kinetic kill vehicle technology and comprises four major assemblies: (1) a cryogenically cooled, staring long-wave IR seeker; (2) a guidance assembly which includes both signal and data processors, an inertial measurement unit, a thermal battery, and a telemetry

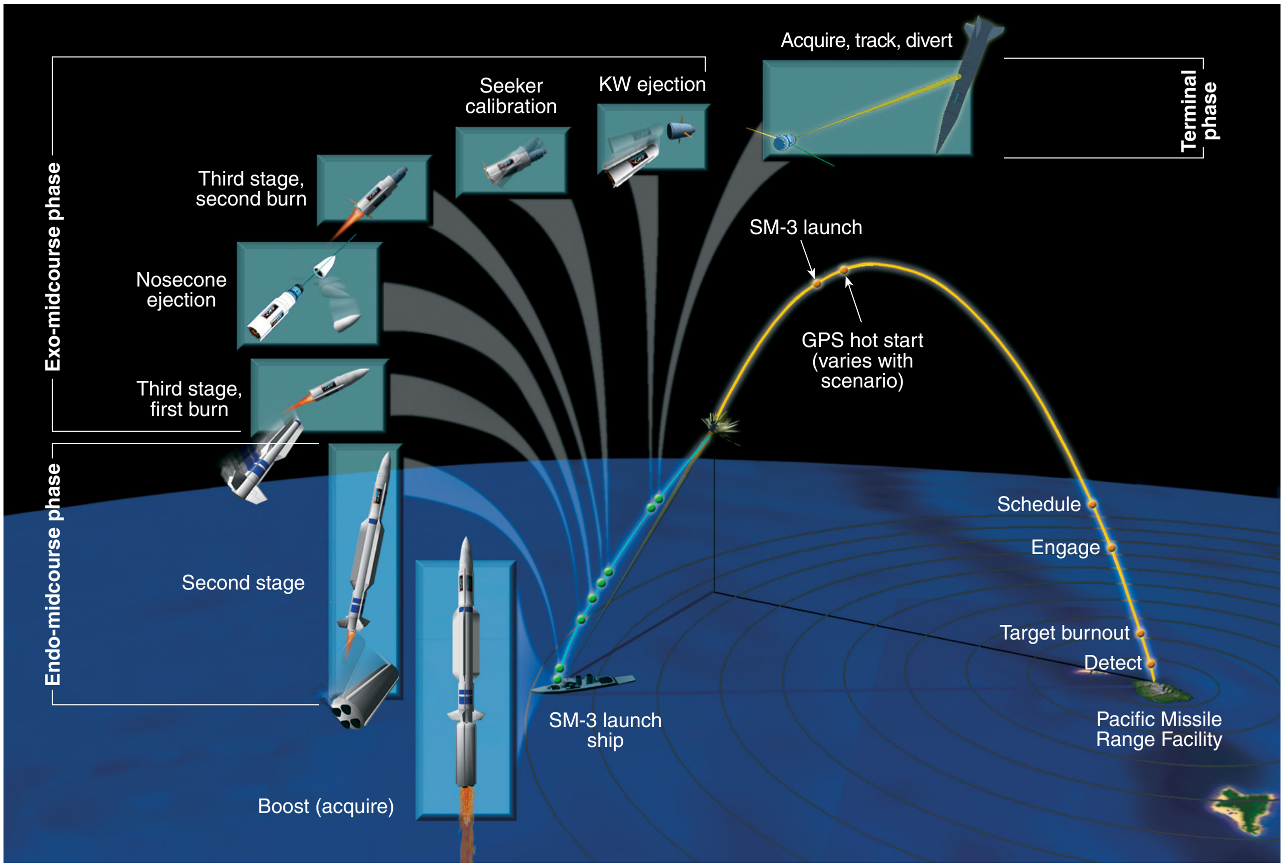

Figure 9. SM-3 concept of operations.

transmitter system; (3) a Solid Divert and Attitude Control System (SDACS) propulsion assembly; and (4) an interface and ejector mechanism, which provides both mechanical and electrical interfaces with the third stage as well as separation of the KW from the third stage in the exo-atmospheric endgame environment. The interstage assembly remains with the third stage upon ejection.

After the KW is ejected from the third stage, the SDACS is ignited and the KW points along the predicted line of sight to the target. The KW then acquires and tracks the target. The KW has an adequate field of view to detect the target from its initial pointing information provided at handover and is designed for appropriate homing times. Once the KW has acquired and is tracking the target, it uses a predicted impact guidance law for an intercept solution, ignites the divert grain of the SDACS, and begins homing maneuvers. The intercept requirement for the KW is to impact the target body and destroy it using kinetic energy.

BMD analysis and initial testing to date with SM-2 Block IVA and SM-3 indicate that Aegis employing these two weapons will provide an effective, credible defense against tactical ballistic missile attacks, and together will permit the Navy to achieve Area and Navy Theater Wide capabilities (Fig. 10).

Naval Surface Fire Support and Targets

In mid-1992, the Navy published two Mission Need Statements addressing Naval Surface Fire Support (NSFS) and Supersonic Sea-Skimming Targets (SSSTs). The former states that, “There is need for a combination of guns, rockets, and missiles with sufficient range, accuracy, and lethality to meet the wide range of requirements in support of amphibious operations and the joint land battle.” The latter states that, “There is a need to replicate the supersonic, sea-skimming anti-ship cruise missile threat in order to test and evaluate certain Navy weapon systems and to provide realistic training to the Fleet.”

In response to these statements, the Navy initiated two programs known as LASM and LASM-Targets with goals to field, respectively, a low-cost, near-term LASM for NSFS and a low-cost SSST and Terrier Missile Targets (TMTs) for Fleet training. A major policy within these two programs is to maximize the use of common components, software, and nondevelopment items from inventoried Terrier/Tartar SM-2 Block II/III, SM-3 LEAP, and ER guided munitions to reduce development and production costs and schedules.

LASM (SM-4)

As a result of an analysis of alternatives during 1999 for the near-term, low-cost solution for NSFS, LASM was chosen to support Navy needs. Because of cost, schedule, and performance requirements, the configuration for LASM is not completely new, but rather a conversion of existing assets. With this, the planned LASM (Fig. 11) contains seven missile section assemblies, six of which are from SM MR: the steering control section, Mk 104 DTRM, dorsal fins, autopilot/battery section, Mk 125 warhead, and nosecone shroud.

The "guidance" section will be a major evolution to SM MR. It can be characterized by removal of the RF seeker and associated AAW processor and flight software, and the addition of the GPS-Aided Inertial Navigation System similar to those used in early LEAP and SM-3 flight tests, LASM-unique control software, and a height-of-burst sensor to support NSFS requirements. The LASM tactical employment concept is depicted in Fig. 12.

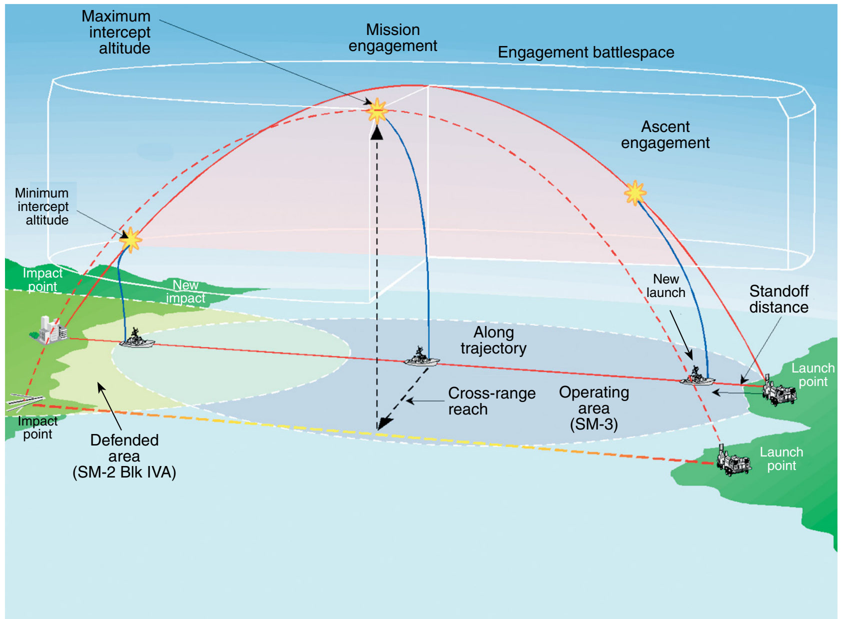

Figure 10. Navy Area and Navy Theater Wide coverage.

The viability of the LASM concept was strongly reinforced by the successful LASM-1 flight test in November 1997. All test objectives were achieved, including the use of GPS for guidance, with actual flight performance matching a six-degree-of-freedom simulation within 1.0% of nominal. Following this successful demonstration, two other flight tests were performed that showed the ability of LASM to successfully achieve an approximately 90° dive angle, with proper warhead action. Finally, warhead arena tests were performed to successfully demonstrate LASM's proposed endgame performance. The positive outcome of these events allowed LASM to continue.

The success of the retrofit and flight test of LASM rounds during 2002 is expected to result in approval for low-rate initial production and follow-on full-rate production. Initial operational capability is expected in 2003–2004.

LASM-Targets

Within this program two mission-specific configurations were under consideration: (1) SSST and (2) TMT.

SSST. Considering the possible SSST demonstration configuration first, of 10 missile sections, 6 are handovers from SM-2; the remaining 4 are the autopilot battery (a modified SM-2 section), guidance (an evolved SM-3 section), targets common destruct, and payload, the only section unique to SSST.

The SSST-Targets Demomonstration Program has five objectives, i.e., to demonstrate (1) rail launch from a land-based Mk 5 launcher, (2) missile guidance system initialization, (3) in-flight stability, (4) required velocity at specified range, and (5) fire-and-forget capability. At this writing, the Navy has not planned to procure SM SSSTs.

TMT. Because of the emphasis on BMD and the need for alternative target representatives, the SM TMT has been developed and used during a number of important BMD exercises. The configuration of TMT is a

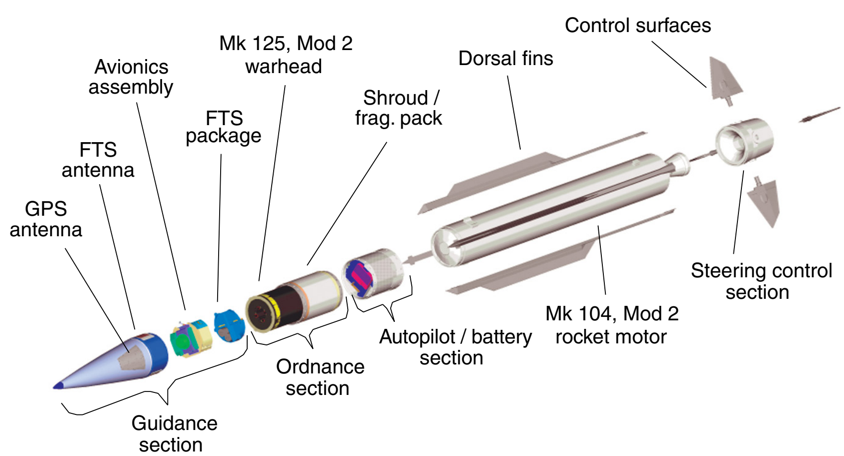

Figure 11. Land Attack Standard Missile (SM-4).

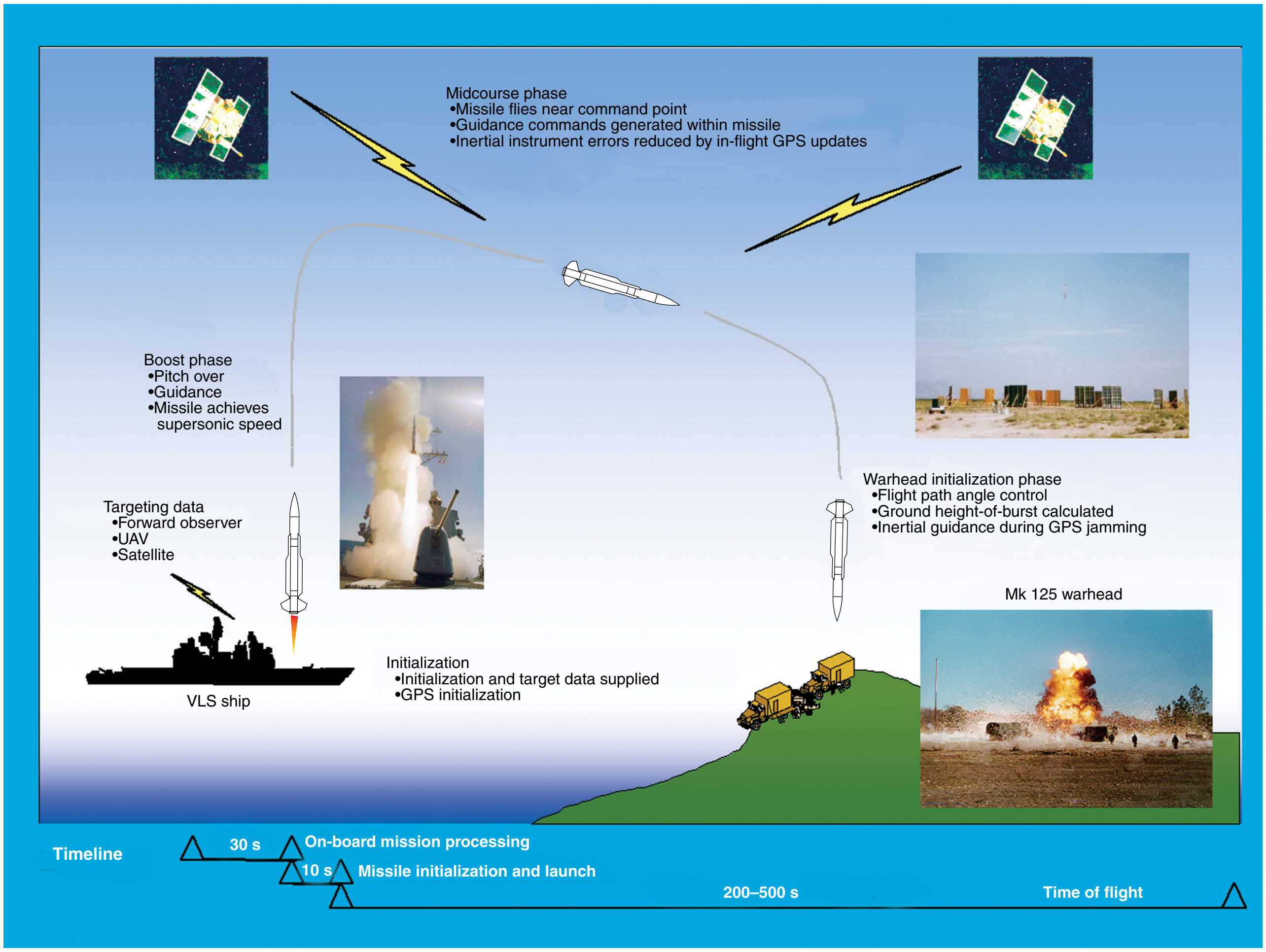

Figure 12. LASM concept of operations.

conversion of Terrier, with only minor modifications to support its use. To date, the Navy has successfully used approximately eight TMTs for BMD training exercises. Because of their low cost, simple implementation procedures, and ability to replicate representative threats, TMTs will continue to be used as a Fleet/BMD training target as the Navy presses to achieve a layered BMD capability.

Emerging Missions

With the end of the Cold War, it has become apparent that the immediate and future threat will be contained within the littoral environments where most realistic scenarios are characterized by low-flying cruise missile attacks (Fig. 13). This very high clutter environment, as discussed earlier, was addressed for SM with an upgrade to the receiver during the mid-1990s. The development of other AAW system elements to perform successfully also in this environment will result in a greatly expanded AAW battlespace.

One starting point for the realization of this expanded battlespace, and a new mission area for the Navy and SM, is the engagement of low-flying threats by ship-launched missiles beyond the firing ship's radar horizon. This concept was considered over two decades ago. By removing the limitation of the ship's radar horizon, such a concept envisioned the interception of targets much farther from the defended and engaging units, allowing time for additional engagements if necessary. The earliest version of the concept embodied the element of the beyond-the-horizon guidance of SM, fired from an Aegis ship, by an F-14 fighter aircraft modified to provide midcourse and terminal semi-active homing guidance, thus allowing the missile to home on the reflected illumination from the target. This concept was known as "forward pass."

A modified form of the forward pass concept emerged in the late 1970s. It featured a conceptual, long-range ramjet dual-mode guidance–capable missile fired from an Aegis cruiser and flown by a carrier-based surveillance and fire control aircraft. The aircraft would carry advanced, long-range sensors to detect anti-ship missiles launching enemy bombers and to take over midcourse missile control from the ship via an onboard

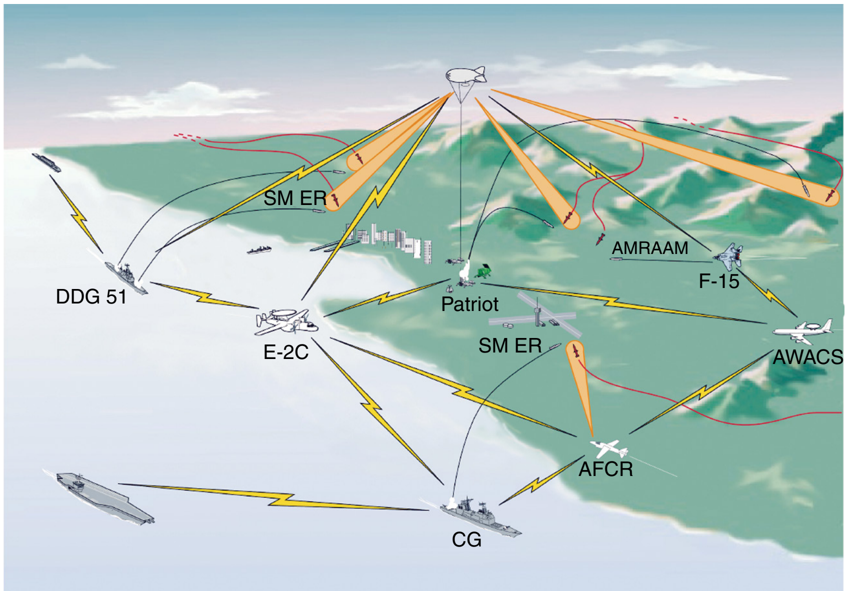

Figure 13. Notional littoral engagement scenarios.

aircraft-to-missile link. This concept, resulting from the Navy-sponsored Outer Air Battle Study, identified the need for a long-range form of SM (now known as SM-2 Block IV) along with the need for a "cooperative engagement link." The CEC Program evolved from the work described earlier, and provides a vital element in the development of an AAW capability to engage enemy, overland, incoming cruise missiles.

The ability to intercept low-flying threats beyond the horizon was demonstrated during the Mountain Top Advanced Technology Demonstration in 1995 and 1996. The system architecture for Mountain Top included an experimental airborne search radar (RSTER) and an Mk 74 fire control system located on a mountain in Kauai that enabled the detection, track, and development of a fire control solution for an incoming target beyond the radar horizon of an Aegis cruiser (Fig. 14). The fire control solution developed by the Mk 74 system was passed to the Aegis cruiser, via CEC, which then launched SM-2. The SM-2 was controlled during midcourse by Aegis command midcourse guidance, via uplinks from the Aegis cruiser. The Aegis cruiser developed the midcourse guidance commands from target tracks passed to it from the Mk 74 system and from its own tracking of the intercepting SM-2. The SM-2 transitioned to terminal homing and was supported with illumination from the Mk 74 system, not the firing ship, thus allowing the entire engagement beyond the firing ship's radar horizon.

To support this event, SM-2 Block IIIA was chosen. It had already undergone the receiver redesign upgrade noted earlier and was therefore suitable for use in the potential high-clutter environment (i.e., forward scatter and backscatter) in the Mountain Top geometry. The hope was to be able to use SM-2 Block IV, but it had just completed its operation testing, was preparing for its transition to production, and its development configuration did not directly support the requirements of the new receiver redesign.

Many risk reduction activities were done by APL for SM to support the Mountain Top demonstration, including:

- Round-level ground-based testing in the Guidance System Evaluation Laboratory
- SM six-degree-of-freedom simulation preflight predictions taking into account the architecture requirements, including CEC, Aegis, and SM receiver redesign features
- Captive flight tests with an SM seeker assembly and the Mountain Top system architecture and geometry for data verification and risk reduction

As a result of these very successful test-firing demonstrations, definition of the follow-on DoD Cruise Missile Defense Program has been vigorously pursued, with all services recommending roles and next-phase approaches. Advanced Air Force, Army, and Navy airborne platforms and missile variants are being considered with CEC and are expected to be integrated to create the required network and system to achieve the Joint services requirements.

A variant of SM will probably be used in future Overland Cruise Missile Defense system architectures. At this point, an evolution of SM-2 Block IV, has been pursued that includes an active RF seeker system which further facilitates beyond-the-horizon engagements owing to the lack of a requirement for an illumination radar. The latest SM ER will be followed up to allow the Navy to expand its capability to meet the emerging threat in the littoral, extended battlespace requirements, and beyond-the-horizon engagements needs.

International SM Development

Up to about 5 years ago, the sales and working environment of SM had been the purview of its developer, the U.S. Navy, while the role of our international partners had been that of recipient. Since then, however, these international partners have made technological advances in multifunction radar (MFR) systems, which has created the need for SM to adapt to interoperability in three capability areas: (1) terminal homing requirements due to the creation of interrupted

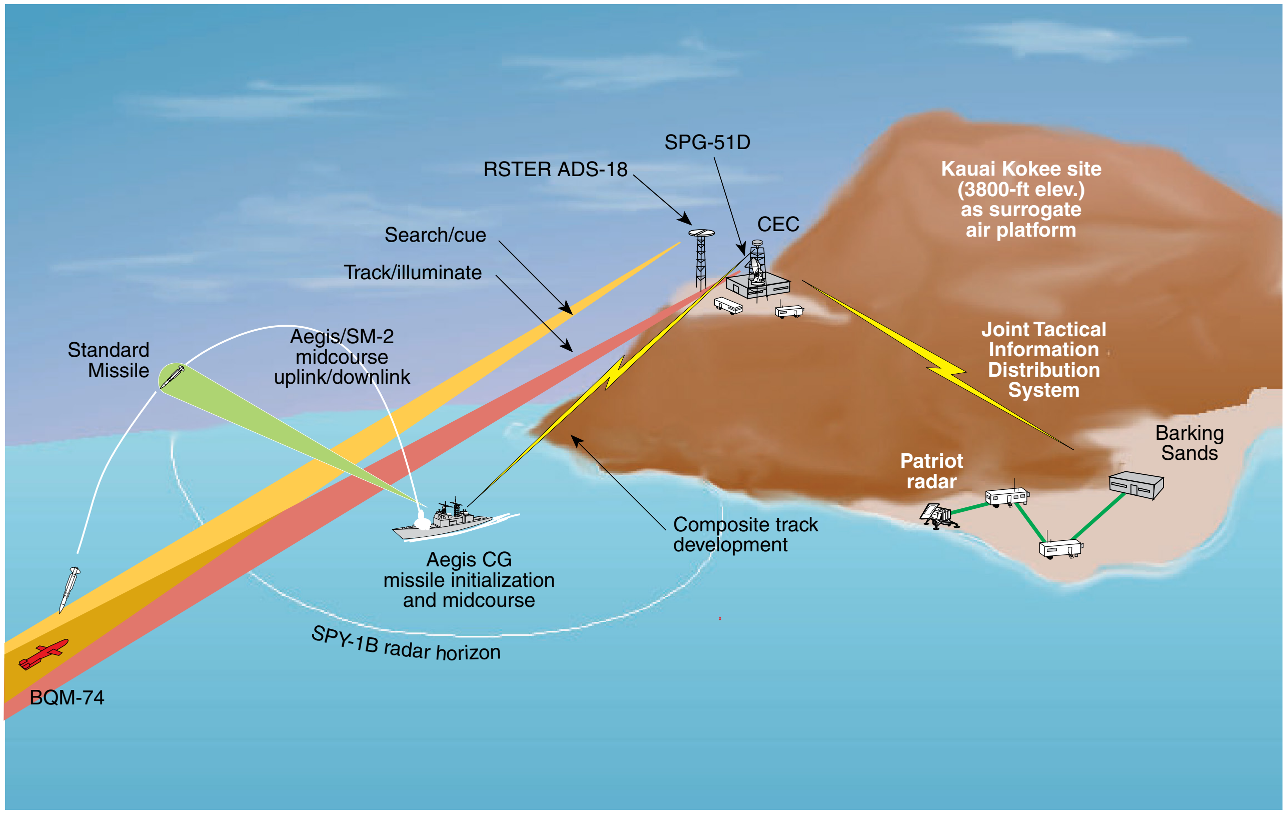

Figure 14. Mountain Top engagement architecture.

continuous-wave illumination (ICWI) with Thales's X-band active phased array radar (APAR), (2) link functional and interface requirements, also due to APAR, and (3) inertial midcourse guidance for SM-2 ER due to the need for portability of this missile system type to non-Aegis platforms that require an Area BMD and advanced TAMD capability. (Inertial midcourse guidance is simply the development and execution of missile acceleration commands onboard the missile, as opposed to being linked by the combat system as with the Aegis Combat System.)

The development of ICWI for SM started in the spring of 1997. This effort was initiated by the Tri-lateral Frigate Cooperation (TFC) Consortium consisting of The Netherlands, Germany, and Canada (Canada is only an industrial partner at this writing). The TFC Combat System is the next-generation combat system of The Netherlands and Germany (Fig. 15). These combat systems are based on the long-range L-band detection radar, SMART-L, and the X-band MFR APAR (Fig. 16).

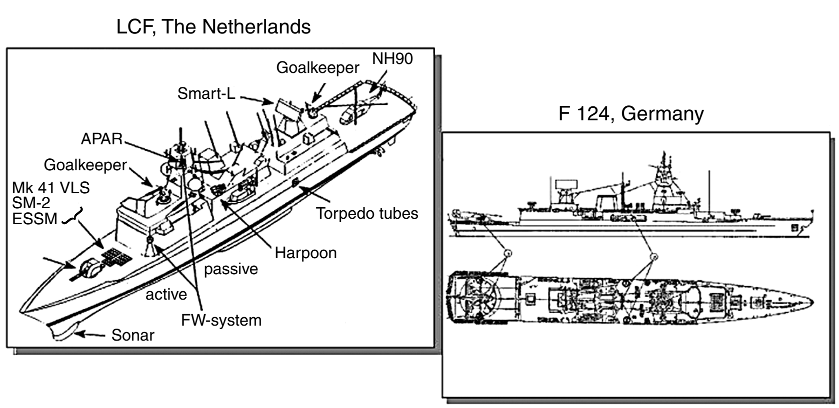

Figure 15. TFC combat systems.

Development of an ICWI-capable SM is first being implemented on SM-2 Block IIIA.

The concept of the TFC system is tactically, technically, programmatically, and fiscally sound: a single X-band, active-array MFR, based on commercial components, that supports detection, tracking, linking, and illumination. There are no dedicated illuminators on the TFC system. By having an MFR with this capability, and not having dedicated illuminators, the system is able to at least double its fire power; however, because the radar must coordinate RF resources for all

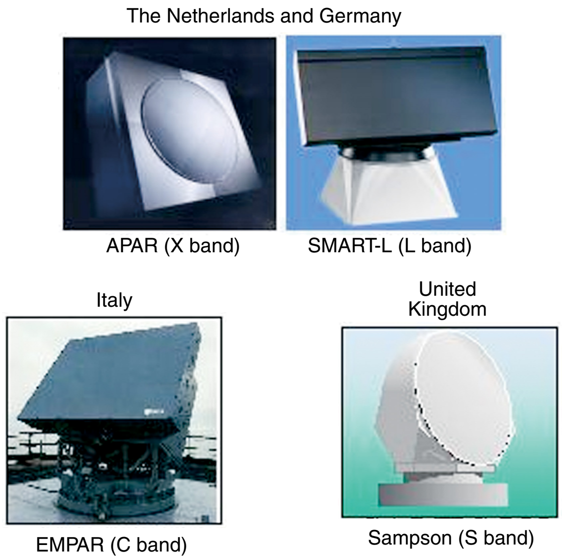

Figure 16. SM Allied navy multifunction radar options.

functions, and because it is a phased array radar (not a dish), SM had to be changed to support illumination with interruptions (ICWI). ICWI is possible on the current family of SMs owing to the creation of the digital rear receiver, discussed earlier, which is designed to remove clutter-derived noise. With the digital rear receiver, SM is able to synchronize in time and frequency with a MFR's waveforms, which makes ICWI possible. Older analog rear receivers on SM would not have allowed ICWI to be possible in such a capable and efficient manner.

APL has contributed to ICWI development for the TFC with systems engineering, requirements development, missile and radar model development, Guidance System Evaluation Laboratory testing, and Captive Seeker testing. The first live firing demonstrations of an ICWI-capable SM will take place from the German frigate (F 124) during the last quarter of 2003. The Netherlands' missile test firings have not been scheduled to date.

Also under way is the development of a multifrequency, adaptable, link communication system. The initial concept for a new link communication plate originated with the need to integrate SM-2 ER on TFC systems. Currently SM-2 Block IVA is only supported via a high-data-rate S-band link used on Aegis systems. However, since the TFC baseline system does not use an S-band radar system, and the consortium wishes to support Area BMD, the SM-2 ER communication system (as well as other SM systems) will be changed to support X band. In coordination with this effort, there is also a separate need to allow the SM family of missiles, along with the Evolved Sea Sparrow Missile (ESSM), to communicate with Raytheon's SPY-3 X-band MFR. All of these system requirements are being coordinated to develop a single, universal communication link for SM and ESSM.

The final requirements for this universal link are yet to be determined, but all evolving combat and radar systems from other countries (Fig. 16) will be considered in this effort. Development of this universal link began in mid-2001. Requirements development, prototyping, ground testing, and flight testing will be done around 2001–2006.

The last area evolving for SM in support of our international Allies is the potential development of inertial guidance for SM-2 ER, and possibly SM-3. Again, the origins of this need started with the TFC. As background, SM-2 Block ER performs midcourse guidance using the Aegis Combat System. Functionally, command midcourse guidance has the ship send acceleration commands to the missile, which the missile then executes, to allow for proper midcourse trajectory shaping that supports handover to missile terminal homing.

Currently the weapons used by the TFC system, SM-2 Block IIIA and ESSM, both have inertial midcourse guidance capability, so command midcourse guidance is not needed. However, the need for an Area BMD capability for the TFC countries creates the need to implement inertial midcourse guidance in SM-2 ER.

Initial feasibility studies have been performed by APL to ensure that this inertial midcourse guidance is robust and viable. Development and implementation will be done in a fashion that ensures that SM-2 ER is portable to any system platform, has minimum system requirements, and allows continued support to the Aegis-based Fleet (Fig. 17). System feasibility, requirements, development, and testing for this capability are planned for around 2002–2008.

Baseline SMs such as SM-2 Block IIIA (CW variant) are still being sold to our Allies to support their missile defense needs; however, a robust and flexible international interoperability life-cycle approach allows SM to implement missile system capabilities based on country-specific requirements and national needs.

CONCLUSION

The evolution of SM, which has its roots in the very beginnings of Navy surface defense, has maintained success throughout the years based on sound systems engineering principles as well as a validated upgrade approach. Thus, SM is the springboard for many of the Navy's developmental efforts. And, as the Navy addresses future missions, SM will evolve to fulfill these multimission needs with a systems approach, just as it has traditionally done since post–World War II.

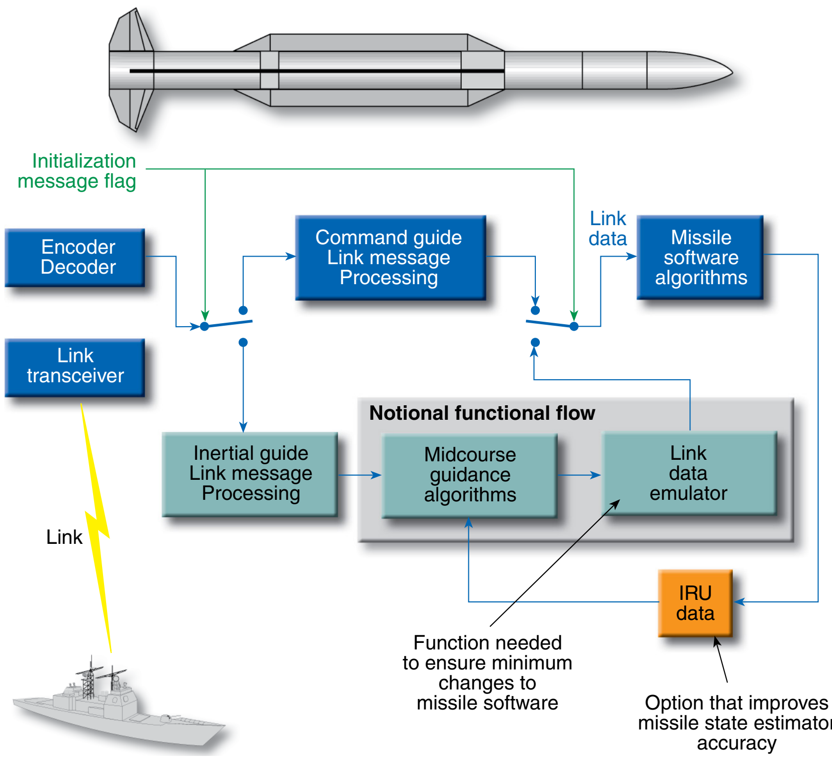

Figure 17. SM-2 ER midcourse guidance options (blue, unchanged from baseline; orange, modified from baseline; green, added to baseline).

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