

Integration of the Evolved Seasparrow Missile into Ships of the NATO Seasparrow Consortium Navies

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The multinational Evolved Seasparrow Missile (ESSM) program has been established to upgrade the Seasparrow missile to defeat existing and projected threats that possess low-altitude velocity and maneuver characteristics beyond its current capabilities. The Applied Physics Laboratory is working, on behalf of the NATO Seasparrow Project Office, to integrate the ESSM into the ship combat systems of the NATO Seasparrow Consortium nations participating in its development. In this article, we discuss integration activities as part of the systems engineering process and illustrate these activities using the ESSM program. ESSM is a good example because it illustrates system integration at two levels: (1) integration of the component parts of the missile and (2) integration of the missile into shipboard combat systems of the user navies.

INTRODUCTION

The NATO Seasparrow Project is supported by a consortium of the United States and allied nations. It provides an automated, fast-reaction, self-defense weapon system, the NATO Seasparrow Surface Missile System (NSSMS), that will defend the ships of these nations' navies against aircraft and missile attack. As threats to naval ships have become increasingly difficult to counter, improvements have been made to address them. The most recent improvement that the Consortium has embarked upon is to upgrade, or "evolve," the missile itself. This Evolved Seasparrow Missile (ESSM) is expected to be ready to be used in the fleets before the end of this decade. As work to develop and integrate the missile components proceeds, parallel efforts are also taking place for implementing changes to the ships' systems in order to integrate ESSM with other combat system elements. This system integration is being engineered with the same careful attention being given to the missile development.

What is system integration and why is it necessary? A system does something that no subset of its parts can do alone. How a system's parts work together, a critical characteristic of the system, is the focus of system integration. When defining integration, it is necessary to consider the human side as well. Because of the complexity of modern systems, their development is likely to involve many specialists and a few coordinators. The role of these coordinators (managers and systems engineers) is to separate a complex problem into smaller parts that the specialists involved can feasibly solve. It is subsequently necessary to integrate the many smaller solutions into a system solution (see Fig. 1). The principal drivers in this integration are communication among the development team members and advance planning. Thus, integration can be viewed from at least two perspectives: (1) as a technical challenge to system designers and (2) as a team coordination activity for managers.¹

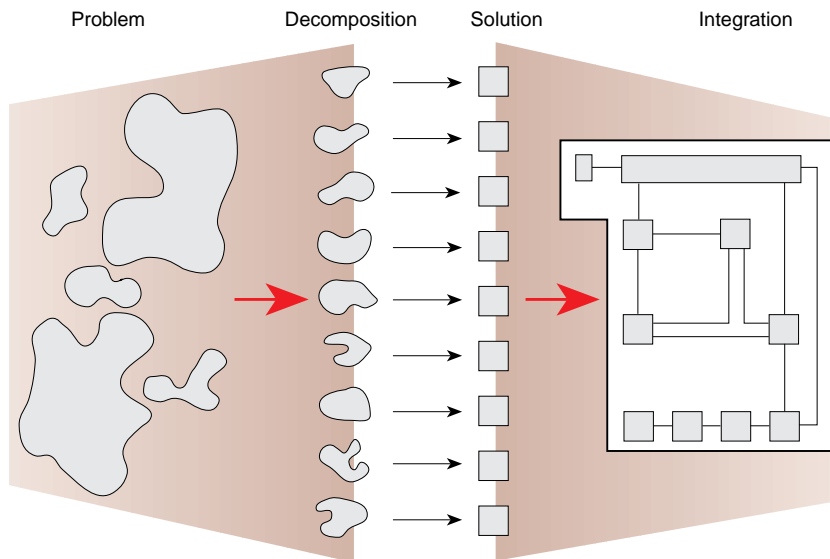


Figure 1. Complex problems must be decomposed into many smaller problems that resemble problems with known solutions or workable solutions. This decomposition results in many small solutions that must be integrated to bring about a satisfactory system solution.

SYSTEM INTEGRATION

Integration Activity Throughout the Development Process

Although the definition of integration leads one to believe that it occurs after much analysis and design have taken place, this situation is not so. Successful system integration requires planning and support from the earliest stages and cannot be separated from other activities such as requirements development, system design, and risk mitigation.

Successful integration starts with the development of sound requirements. Each requirement is directly traceable to a specific need of the customer. Sound requirements are developed and reviewed by a coordinated multidisciplinary team to ensure that they are harmonious and balanced, that is, that meeting any one requirement does not cause another requirement or standard to be violated. Sound requirements are also able to be measured and tested, leaving no doubt as to whether or not they have been satisfied. Since this is the first step in a concurrent engineering operation, this approach exposes problems encountered when system components are put together, ensures a robust design, and enables transitions to occur smoothly from one phase to another.

Mitigation of risks often involves taking steps to make sure that the components being brought together for the first time will function compatibly. Although no one component may present high enough risk for concern, integration of the components may reveal problems. The possibility of such problems requires

modeling and prototyping early in the process to allow the prediction of performance, the identification of incompatibilities, and the timely analysis and trade-offs necessary to develop solutions. Integration risks can also be reduced by using the “build a little, test a little” philosophy. At critical stages in the design process, compatibility checks, partial integration with other components, and testing should be performed. In this way, problems are identified before any design advances too far. This approach is often the only way to uncover integration problems.

To ensure successful integration, tests must be planned as carefully as the design of the system itself. This planning starts

during the development of requirements by making sure that each test has a clear objective that can be traced back to the original requirements and intended function. Test objectives must be simple and attainable. The timing of tests in the process is critical to their feasibility and success. For example, lower-level components must be tested before they are integrated with other components. This approach is expressed as “build a little, test a little” philosophy.

Integration Tasks and Issues

One of the first steps in any integration activity is to define the scope of the job. What are the system’s boundaries? What are the system’s external interfaces? What are the operating environment’s characteristics? By knowing the overall scope, one can begin to develop the top-level system vision necessary for successful integration. Figure 2 illustrates this concept by showing that all components and factors involved in a system must be considered. The top-level system vision is the understanding of how all these things affect the way that a system operates to meet the needs of its users.

One of the most important aspects of the top-level system vision is the way that the system being considered fits into a larger system or set of systems that already exist. In virtually any situation, the system being considered is located within a system. The larger system, or “supersystem,” will most often be the source of the constraints and requirements that must drive the development and integration process. Understanding the supersystem and the way it must operate is critical to successfully integrating any new system. Although

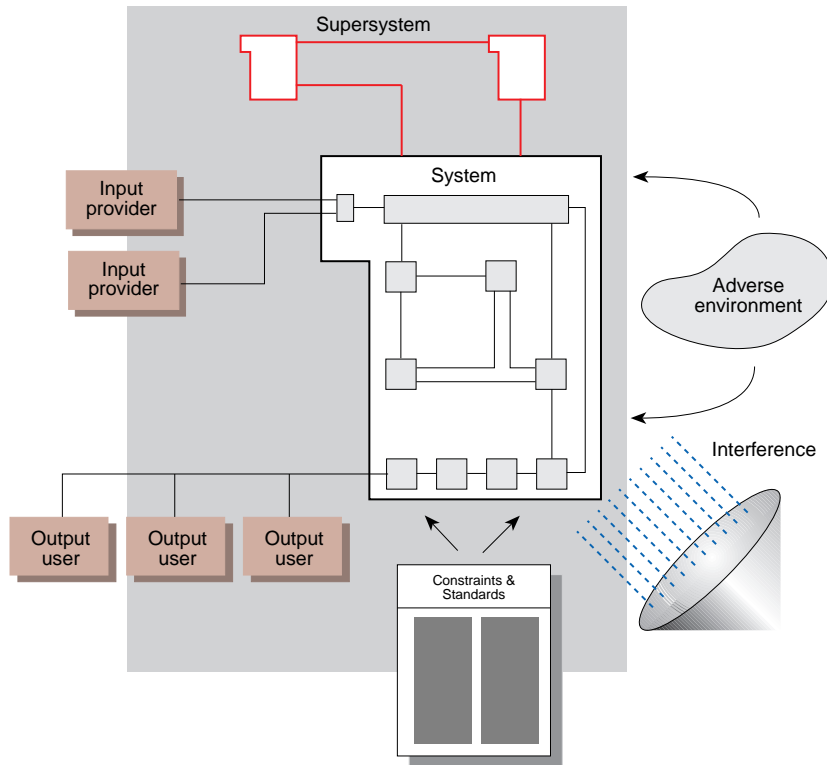


Figure 2. A top-level system vision includes all system components and influential factors such as providers of inputs, users of outputs, the environment of the system, and the supersystem of which the system is only a part.

the objective is to affect the supersystem as little as possible, modifications may be necessary to realize the complete potential of the new system being introduced. These decisions are the focus of many trade-offs and preparations that lie at the heart of the integration process.

Once requirements have been developed and a basic system architecture has been established, an understanding of the internal interfaces can be developed. This may require that some of the interface design be completed. A detailed look at the interfaces often provides the first indication of incompatibilities and problems among the system elements. These incompatibilities can be functional, mechanical, operational, or environmental. Once problems are identified, their solution involves analysis and negotiation of the interests and requirements of the component or disciplines involved.

A critical activity within system integration is conflict resolution. Because an integration problem can often be solved in more than one way, the solution that most benefits the system must be found. When changes are necessary, several questions must be answered: What elements can change? Can something be fixed more easily through a hardware or a software change? What ramifications does the change have later in the process?

The analysis required to answer these questions and support a solution makes up a large part of integration work. The earlier this work is done, the better it is for all involved. Conflict resolution may also need to consider nontechnical influences such as cost, schedule, and organizational, political, or social forces that may oppose an obvious technical choice. Each of these aspects of integration is faced in the development and integration of the ESSM.

EVOLVED SEASPARROW MISSILE

For the past three decades, the protection of U.S. and allied navies from attack by antiship missiles has been a continuing and complex effort. Plans for early defensive systems were given added impetus by the sinking of the Israeli destroyer *Elath* by an antiship missile in early 1967. Subsequent to this event, several NATO nations formed the NATO Seasparrow Consortium and undertook to develop an antiship missile defense system around the Sparrow air-to-air missile with a guided missile fire control system and trainable launcher.² This system became the NSSMS, which is now used by 13 nations of the Consortium as well as by the navies of Japan and Korea.

Through the years, the NSSMS has served the member countries well. The Seasparrow missile has undergone numerous upgrades in response to threat challenges. The current version uses guidance techniques that enable it to counter low-altitude and steeply diving threats in adverse electromagnetic environments. However, recent threat advances, coupled with intelligence of what is technologically feasible, have resulted in postulated threats with speed and maneuverability profiles beyond the Seasparrow's capability to engage.

In the late 1980s, a program was initiated by several NATO countries, including the United States, to develop a total self-defense system. This system was based on distributed architecture concepts with a multifunction active array radar and a missile kinematically superior to other self-defense and local-area-defense missiles such as the Seasparrow. This program, fully supported by APL, was called the NATO Anti-Air Warfare System (NAAWS) and proceeded through a

detailed definition phase. The NAAWS program was terminated in early 1991 because of budget cutbacks. This was unfortunate because the NAAWS threat drivers continued to proliferate.

Several nations active in NAAWS were also members of the NATO Seasparrow Consortium. Recognizing that threats to naval ships were continuing to advance and were proliferating, they asked the NATO Seasparrow Project Office (NSPO) to evaluate the possibility of upgrading the Seasparrow to approximate the improved performance that had been planned for the NAAWS local-area missile. APL participated in a NSPO effort to derive initial requirements for a kinematically improved Seasparrow missile (i.e., ESSM). At the April 1991 meeting of the NATO Seasparrow Project Steering Committee, the NSPO provided a plan based on these requirements to develop the ESSM to meet the postulated threat and integrate with the fire control systems and launchers of the member nations. Seven nations, including the United States, joined the effort at that time. Since then, the number of countries participating in the ESSM development has grown to ten, with the three remaining NATO Seasparrow Consortium nations voting for approval while not actively participating.

Concept Definition

After the NATO Seasparrow Project Steering Committee approved the ESSM program, a Concept Definition Phase (CDP) was initiated and led by APL and the Naval Air Warfare Center to assess the viability of adapting Seasparrow to counter the stressing NAAWS threat. The ESSM CDP focused on validating the conclusions of the engineering, cost, schedule, and performance trade-off studies performed as part of the NAAWS program, along with a further series of studies designed to establish the missile baseline in accordance with threat drivers and constraints as a result of combat system integration of ESSM (i.e., launcher cell size, weight limits, and available ship systems support elements).

To achieve the required level of kinematic and maneuver capability, the CDP baseline established that ESSM would have a rocket motor with an increased diameter (10 in.) and be tail controlled as opposed to wing controlled (as with existing Seasparrow missiles). It further established that ESSM would be equipped with thrust vector control to be compatible with vertical launch. Analyses and simulations confirmed that these, along with a limited set of guidance section and warhead modifications, would provide the requisite capability to counter supersonic maneuvering threats.

Concurrent risk reduction efforts ensured that all engineering and performance risk areas were examined

and either resolved or mitigated. An ESSM 6-degree-of-freedom simulation was used to evaluate guidance performance with low-altitude guidance algorithms optimized for the threat spectrum and the increased ESSM kinematic profile. Analysis also resulted in definition of warhead improvements needed to provide increased lethality against the threat.

The U.S. Assistant Secretary of the Navy for Research, Development, and Acquisition [ASN(RD&A)] directed that a cost and operational effectiveness assessment be conducted to assess the effectiveness of the proposed ESSM, relative to several identified missile alternatives, in providing the self-defense capability needed. APL provided support to the NSPO and to the Center for Naval Analyses staff conducting the assessment. As a part of this assessment, APL performed a further study to determine the sensitivity of the alternative missiles to technically feasible threat growth in terms of reduced signature. It was concluded that a semiactive-based approach, such as ESSM would use, was preferable to an active seeker approach in order to provide a robust baseline for future preplanned product improvement.

At the end of this assessment, it was determined that ESSM was the most promising alternative, and the ASN(RD&A) approved the transition of ESSM into engineering and manufacturing development (EMD). As of this writing, ESSM is in the early stages of EMD.

Missile Program and Integrated Product Development

A multinational team led by Hughes Aircraft Missile Systems Company of Tucson, Arizona, won the development contract for the ESSM. The team consists of 20 companies assembled by Hughes and includes at least one from each nation that will use the ESSM. Such a team was called for by the Development Memorandum of Understanding negotiated among the participating governments. The Hughes design includes dorsal fins along the full length of the 10-in. aft end as shown in Fig. 3. This design provides additional lift to permit low angle of attack intercepts. Hughes plans to leverage technology from earlier missile developments into some of the ESSM components to lower the development risk.

Following recent directives from the Department of Defense, Hughes has structured the ESSM development in accordance with the guidelines of Integrated Product Development (IPD).³ IPD is a creative new way to produce quality products in a predetermined time within a set cost. The focus is on multifunctional teams working together and total integration of all products and processes. Hughes has formed integrated product teams (IPTs) around the components of the

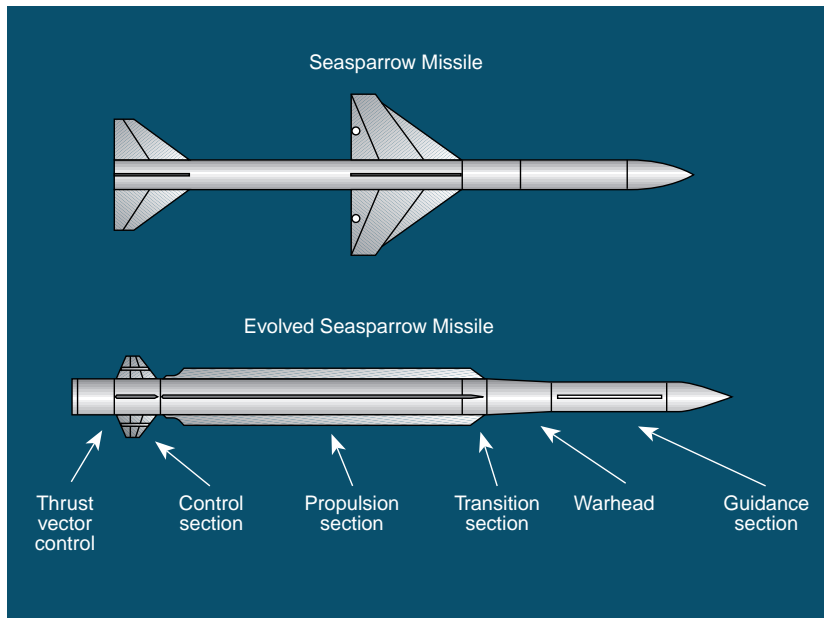


Figure 3. The ESSM uses a new 10-in. rocket motor with the 8-in. forward section of the current Seasparrow missile. New warhead and guidance section improvements will add to the overall capability of the ESSM to counter stressing antiship missile threats.

missile. The membership of these IPTs includes participants from the international industries as well as government and university laboratories (including APL) and government representatives.

In the IPD process, IPTs address the various components of the missile development. These teams bring in people from the various engineering disciplines as well as specialty groups (e.g., reliability, maintainability, safety, quality assurance). It is important to include the systems engineering methodology in this process. In many organizations, IPD training includes attention to systems engineering; thus, each member of the team is capable of observing good systems engineering practices and procedures. In other organizations, a systems

engineering specialist is assigned to each of the component IPTs. The shortcoming of this approach is that sometimes not enough systems engineers are available to support each IPT independently, forcing some engineers to participate on multiple IPTs simultaneously. This circumstance can disperse the systems engineers' focus and responsibilities, making them less effective. In any case, a systems engineering manager should ensure that the systems engineering methodology is applied effectively across the various components of the system.

In Fig. 4, the organization of an IPD approach to a system (such as ESSM) is shown. On a missile development program, the component IPTs would be accountable for different parts of the system (guidance, warhead, rocket motor, etc.).

Technical disciplines, specialty engineering, and systems engineering are incorporated into the process. An integration IPT oversees these efforts and ensures that the parts work together. This setup brings in systems engineering at a higher (system) level. Thus, systems engineering must be applied at the component level, the system level, and the level where the system will interface with a larger system (i.e., become a subsystem). These levels are illustrated with ESSM, which is designed at the component level, engineered into a system (missile), and integrated as an element of the combat system.

For ESSM, the EMD effort will provide the engineered missile and define its external interfaces.

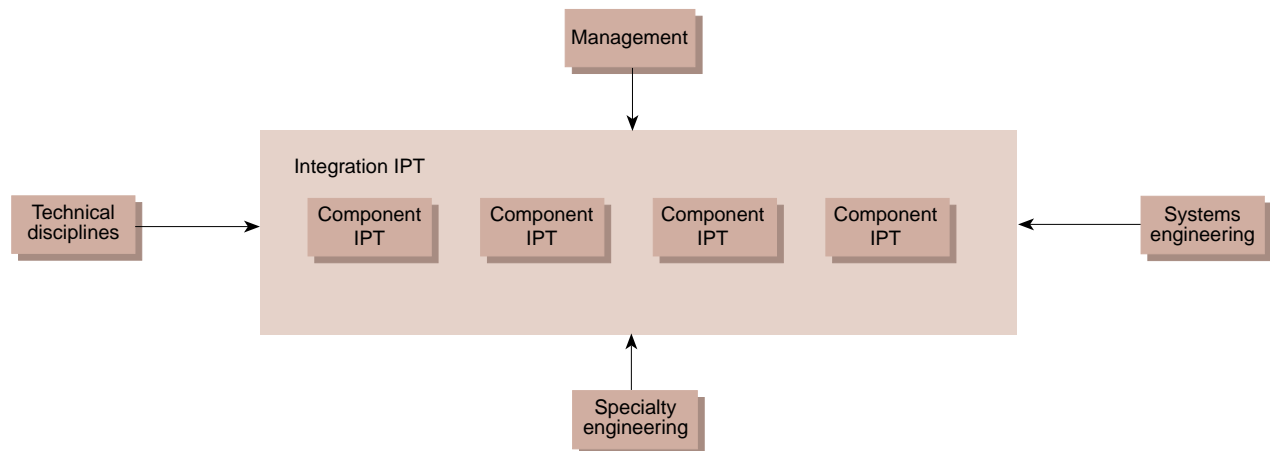


Figure 4. Integrated Product Development structure for system development. The system is decomposed into its components ("nodes"), and an Integrated Product Team (IPT) is assigned responsibility for each node. A second-tier integration IPT must assume responsibility for managing the interfaces and performing system-level analysis and testing.

Beyond this, an effort to integrate ESSM into the combat systems of the ships of the user nations is being addressed. This system integration is proceeding in parallel with the ESSM development. The following paragraphs outline this process.⁴

ESSM Integration Concurrently with EMD

ESSM is the newest development within the NATO Seasparrow Consortium. Unlike previous Seasparrow development efforts, which were pursued by the Naval Air Systems Command and adapted for shipboard use, this development is being managed within the NSPO. This arrangement provides an opportunity to pursue the integration of ESSM into NATO Seasparrow Consortium combat systems concurrently with its development to an extent not previously available to NATO Seasparrow systems developers.

The integration of ESSM into consortium combat systems concurrently with EMD is desirable because it allows support of early at-sea tests, demonstrations, and trials of ESSM when used with NATO Seasparrow Consortium systems adapted for ESSM. Combat system adaptations supporting the introduction of ESSM could range from making the minimum modifications necessary to allow ESSM to be used as previous Seasparrow versions have been used, to the development of completely new support systems that take advantage of the new capabilities made possible by ESSM such as midcourse guidance and interrupted continuous wave

illumination. This range of implementation is planned within the NATO Seasparrow Consortium, and testing of ESSM when deployed in such a variety of configurations requires that these combat system adaptations be pursued concurrently with EMD (Fig. 5).

Another reason for concurrent integration is to provide an opportunity for combat system requirements to influence the ESSM design early in EMD to minimize cost and schedule impacts if design modifications are necessary. If the development of ESSM were to lead the development of new systems that would make use of midcourse guidance and interrupted continuous wave illumination, the systems would have to accommodate the ESSM design without the opportunity to influence that design. For instance, unless a combat system requirement to implement command midcourse guidance exists, ESSM might only have the software needed to support radar-aided midcourse guidance, and the combat system would have to adapt to that. Concurrent development of combat system adaptations with ESSM EMD makes it possible for the effect of ESSM design decisions to be thoroughly evaluated with respect to the corresponding system effects. It may prove more cost-effective to pursue a minor ESSM design modification than to make extensive system adaptations to fully integrate ESSM.

In addition, ESSM integration into Consortium combat systems concurrently with EMD allows teamwork among Consortium system developers and ESSM developers that would otherwise not be possible. An



Figure 5. Ships from the navies of 13 allied nations may use ESSM. It is not only a design challenge to develop an antiair warfare missile to fulfill their needs, but it is also a challenge to integrate that missile into the combat system to achieve maximum performance. (APAR = Active Phased Array Radar.)

example is the coordinated use of integration resources such as 6-degree-of-freedom models and other analysis tools. Previously, combat system developers working to integrate Seasparrow missiles had to work somewhat independently of the missile community because of the way the program was structured. The system developers had limited access to missile-related information, which made it very difficult to get the most from what the missile had to offer. The development of system simulations that included the missile was difficult, and verification or validation with test assets or other hardware was possible only at considerable expense. Now, with integration concurrent with EMD, as is occurring with ESSM, the potential exists to use EMD resources to make integration easier and more effective while saving money.

Another benefit of concurrent integration is the establishment of integration requirements common among the various Consortium combat systems. These common requirements can ease configuration management and future combat system upgrades as well as simplify the ESSM design by providing common interface definitions and combat system utilization strategies.⁵

ESSM Integration Process

The benefits of integrating ESSM concurrently with EMD are many. However, this new opportunity for the

NATO Seasparrow Consortium will require a change in the way of doing things. An integration process that will realize the benefits is shown in Fig. 6.

During the process of defining the ESSM concept, top-level system requirements within the NATO Seasparrow Consortium were defined from which an international performance requirement for ESSM was established and upon which the ESSM Government Baseline design was based. Now that the ESSM initial design has been established, system performance and compatibility trade studies can be pursued to determine the combat system impact of ESSM integration. If significant integration issues are identified, there will be an opportunity to influence the ESSM design during the EMD process so as to mitigate the impact. On the basis of these studies, new and modified combat system support functions will be identified. It is important that this identification be done early during EMD since it influences the combat system conceptual design to implement ESSM, making the systems available to support ESSM testing.

Once the ESSM design has been iterated and approved through a preliminary design review, system algorithms will be developed and modeled to support the new systems' capabilities. These algorithms will influence the final ESSM design and must be developed prior to the ESSM Critical Design Review. Also, on the basis of these algorithms and the modified and new

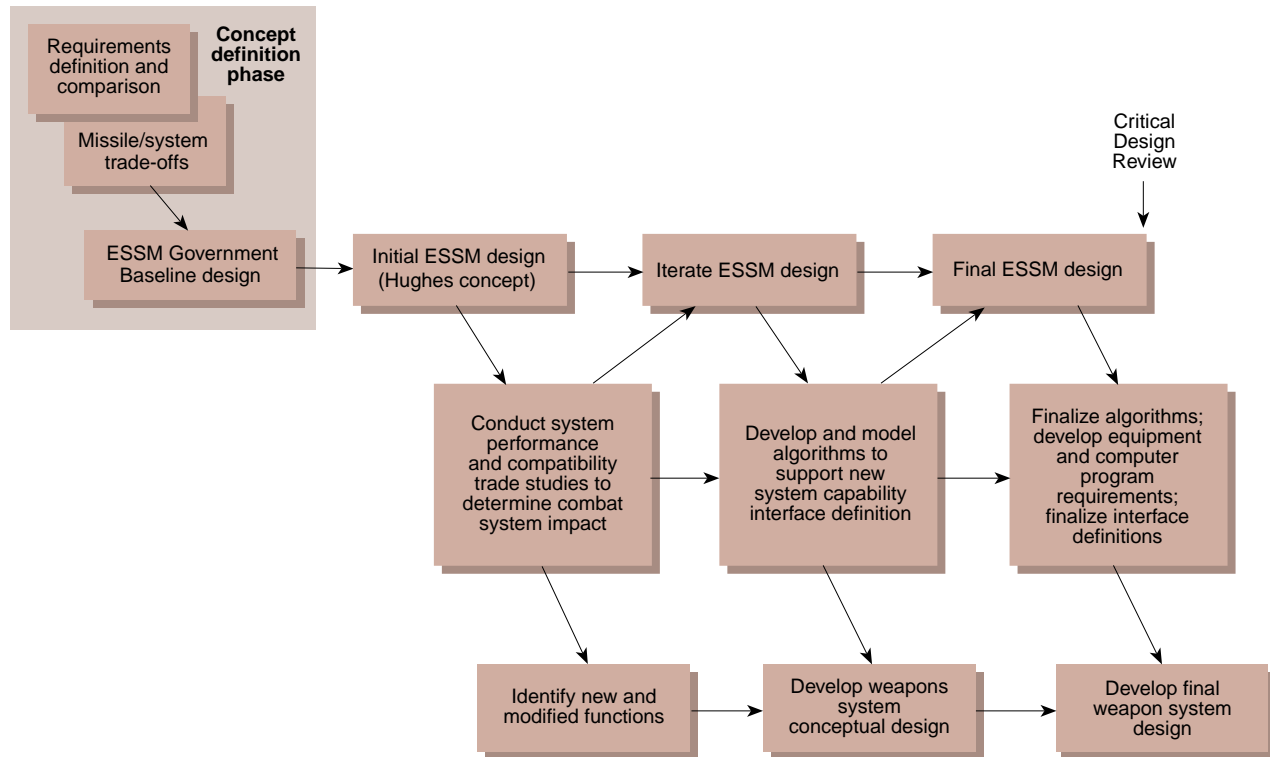


Figure 6. The ESSM integration process during the engineering and manufacturing development phase. Missile and system design trade-off analyses enable planners to minimize the effect of integrating the ESSM with other elements of the combat system.

combat system support functions previously identified, a combat system conceptual design will be developed. This design will include the preliminary development of policies for the use of ESSM.

The final ESSM design will be the basis for the finalization of systems algorithms soon after Critical Design Review. Once the algorithms are finalized, they will form the basis for the development of equipment and computer program requirements. These, in turn, will influence the final combat system design for implementation of ESSM.

The ESSM integration process remains largely unaffected by the allocation of responsibility for tasks within that process. The goal in allocating responsibility within that process is to accommodate combat system integration among the nations effectively and at the least cost, and with a minimum impact to the ESSM development process. This process also requires oversight, involving program scheduling, resource coordination, and conflict resolution among the various interests.

ESSM Integration Planning

The development IPTs are multifunctional, multidisciplinary groups focused on the primary task of designing their respective ESSM components. Engineering studies, trades, and analyses are planned by the prime contractor to address ESSM design issues, technical trade-offs, and implementation options. Studies to assess the effect of integrating ESSM into the combat systems must be made as well. If significant integration issues are identified, these studies will give the systems community an opportunity to influence the ESSM design so as to mitigate these impacts.

To coordinate these studies and provide an interface to the design agent IPD process shown in Fig. 4, the NSPO has established a Systems Integration IPT. This team enables ship systems engineers to bring forward their concerns and issues for resolution with the ESSM

design team. The resulting structure parallels that of the ESSM development IPD, as shown in Fig. 7. Conflicts that arise between the ESSM development approach and the system integration activities are settled between the ESSM Integration IPT and the Systems Integration IPT.

Each of the ships' systems has activities responsible for combat system definition and integration. Representatives of these ship engineering and integration activities may bring their concerns to the attention of the Systems Integration IPT, which includes APL membership. This group then pursues the implementation details on behalf of the Consortium navies. Such details include establishing interface content and format, providing software algorithms and processes, specifying prelaunch and postlaunch messages, etc. The Systems Integration IPT works to find equitable solutions to issues that relate to performance or cost for either ship systems or the missile.

Each navy has unique operational requirements, doctrinal preferences, and mission complexities that set it apart from the others. In general, ESSM is planned for the newer classes of ships such as the Dutch/German/Canadian Consortium ship, the Danish Stanflex ship, the Australian ANZAC frigate, and the U.S. Aegis destroyers. Other navies with combatants still in the planning stages, such as the Norwegian F2000, are considering ESSM but have not yet determined all the elements of their combat systems. In the same time frame that ESSM will enter service use, new advanced technology capabilities will be available. These include Cooperative Engagement Capability, Integrated Ship Defense System, Force Anti-Air Warfare Coordination Technology, and upgrades of the Advanced Combat Direction System, for many of which APL is the Technical Direction Agent. A number of other sensor and weapon upgrades (and their integration programs) will occur along with those programs.

ESSM integration must take into account these planned integration efforts and the way that ESSM and its supporting equipments will interface and work synergistically with them. The reconfiguration of the NSSMS into a distributed architecture is planned to occur in time to support ESSM test firings from a self-defense test ship and at U.S. firing ranges. Coordination of test assets between the missile and integration programs is also an objective of the ESSM integration planning.

The navies of the participating governments have a number of options for using ESSM. These include using the ESSM in a "home

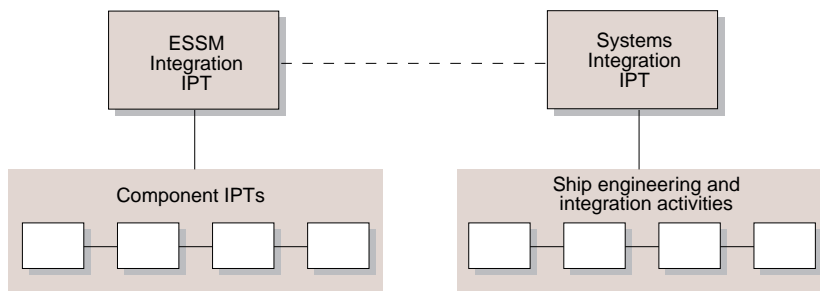


Figure 7. Early during the engineering and manufacturing development phase of the ESSM, a Systems Integration IPT was formed to interface with the ESSM Integration IPT and pursue integration issues on behalf of the participating navies. The Systems Integration IPT ensured that Consortium countries would be able to pursue their individual integration options.

all the way" mode, whereby the target must be illuminated continuously throughout the duration of the engagement; launch on search, with inertial flyout requiring accurate targeting information from a search radar; and midcourse guidance, which requires hardware and software implementation of an uplink to the ESSM. The benefits of implementing these options must be assessed and provided to the nations to assist them in determining the guidance method most suitable to their needs.

ESSM Support Studies

On the basis of the design parameters of the ESSM, requirements analyses are needed to accomplish a minimal ESSM integration without sacrificing current functionality. These analyses will be followed by systems-level benefits analyses to identify the benefits of integration options and address the appropriate additional requirements analyses needed.

Compatibility trade studies will determine the combat system impact of the ESSM integration. If significant integration issues are identified, there will be an opportunity to influence the ESSM design during EMD to mitigate these effects.

System performance studies will also be conducted. Their objective is to determine whether the ESSM as designed is capable of operating with the combat system to meet the requirements specified in terms of countering the threat and operating in the environments imposed. For these studies, digital, hardware-in-the-loop, and controlled environmental testing may be used.

Once the final ESSM design is established, system algorithms can be developed and interface design documents can be finalized. Engageability algorithms, scheduling of firings based on threat characteristics, prelaunch and postlaunch information, salvo spacing, and flyout optimization can then be performed. Scheduling of firings can be further defined in terms of the employment options, that is, home all the way, launch on search with inertial flyout, and midcourse guidance. In addition to software modifications for the fire control systems, requirements for ships' systems hardware modifications can be identified.

Interference Issues

Interactions between internal elements of the combat system and interactions between the combat system and external systems must be considered to avoid damage to the ship, ensure personnel safety, and ensure adequate system performance. Potential harmful interactions must be identified and analyzed. If a problem exists, recommendations for hardware or software modifications must be made to the combat system engineers.

To ensure that launch control and missile spacing are adequate to prevent unintended interaction between missiles in a salvo and between ESSM and other hardkill assets, the potential for this interaction to occur must be evaluated and preventative measures identified, if needed. In anti-air warfare layered-defense concepts and other warfare areas, layer boundaries must be determined and managed to minimize interference and ensure that "own weapon" kills are not made.

Transmitters and receivers in the combat system may interfere with each other if they share a frequency band or if they are in close proximity and generate sufficient power. Also, transmitters and receivers outside the combat system may interfere with or be affected by elements of the combat system. Potential electromagnetic interference must be identified. An operational power and spectral analysis will be performed to evaluate these problems. A related problem is evaluation of interaction with softkill measures such as chaff or deception techniques.

Missile launches should be governed by impact avoidance data, which are provided to prevent damage to the ship and topside equipment either from physical impact or missile plume impingement. Impact avoidance data are especially applicable to vertical launch systems that use quick missile pitchover techniques to reduce flyout time. Similarly, the effects of ship motion on a launched missile before it exits the launch canister must be determined to identify any mechanical problems or potential impact problems.

Test and Evaluation Coordination

A new warhead development is proceeding in parallel with the ESSM program. This warhead will be furnished to the ESSM prime contractor, who will integrate it into the missile. Similarly, another program is addressing the launcher canister and other issues for using ESSM with the Mk 41 Vertical Launching System. At the same time, the Dutch, German, and Canadian navies are planning the integration of ESSM with the Active Phased Array Radar, and the Aegis system is addressing S-band uplink and downlink support from its shipboard systems. These diverse integration efforts will require certain missile assets (complete missiles in some cases; missile components such as guidance and control sections in others). In some instances the schedules for these tests can be coordinated such that a test asset can support more than one program's objectives.

Planning is required to coordinate these test assets. To support test events, missiles, telemetry packages, launchers, and fire control systems must be planned. Test scenarios must be designed and events modeled to predict what should happen during the test. When a model or simulation can be used to provide an assessment of

performance, these will be designed and used to conserve assets. Much of this test and evaluation coordination can be done through the interaction of the missile and ship integration IPTs. APL's background in test planning, range safety, and flight termination methods is being used in the ESSM test and evaluation program.

Tactical Solutions

APL has been actively working with the Surface Warfare Development Group in the U.S. Navy and with the Dutch Analysis and Tactics Center, which heads Consortium tactics development, to formulate tactical employment strategies for NATO Seasparrow.⁶ Tactical considerations for operations in a variety of situations and against a variety of threats are provided in publications such as Tactical Memoranda and Tactical Notices to the fleets. Tactical doctrine includes procedures and guidance for setting equipment modes and specifying the degree of operator interaction desired. It also specifies how the combat system equipment is to be used in concert with the rules of engagement and the enemy's order of battle. It has to be flexible enough to take into account preferences of the commanding officer and the operators acting at his direction.

To maximize the benefits of the ESSM and to realize significant performance improvement at the combat-system level, proper tactical employment is essential. Tactical deployment will depend on specific characteristics of the defending ship, the attacking threat, and the environment. Analysis is required to generate a performance database that can be used to select ESSM tactics based on the situation (i.e., ship capability, threat scenario, environment). This database will support the development and implementation of general tactics and procedures. The database can potentially be used to drive real-time selection and execution of tactics judged to be best for the situation at hand. Similar analysis of the current Seasparrow missile performance has been used to evaluate the effectiveness of tactics against a variety of threat capabilities under various environmental conditions.

Missile probability-of-kill data and combat system effectiveness data (i.e., raid annihilation probability) will be produced for a variety of threats, attack types, raid sizes, and environmental conditions. The objective is to produce data that can be used to recommend how and where threats can be engaged. The effect of tactical selections such as missile spacing, firing policy, and kill assessment time will be analyzed. These data can then support an automatic command/control capability to determine the most effective course of

action from the viewpoint of raid annihilation and ship survivability. Algorithms consistent with the command/control system, engagement support systems, and general combat system configuration must be developed to use the data to support threat evaluation and weapon assignment processing, engagement scheduling, and missile support functions.

CONCLUSIONS

System integration is necessary in the overall systems engineering of a complex system. It is vital at the subsystem, system, and supersystem levels to ensure that the parts work together and accomplish what the designers set out to do. Tasks include establishing boundaries, understanding the functions of each component part, determining what trade-off studies are needed, understanding the system interfaces, and planning the integration testing.

The ESSM provides an example of a complex integration effort. It is being developed through an international consortium and must meet the needs of each navy. At the same time it must be integrated into the combat systems of a number of diverse ships. Integration is occurring at two levels: integration of the component parts of the missile and integration of the missile with the ships' combat system elements (launchers, fire control systems, sensors).

To ensure that ships' systems can accommodate the ESSM, design trade-off studies are required that can both influence the ESSM design and drive combat system modifications. These studies can result in mitigation of the effect of the integration and lead to identification of fire control system functions and algorithms for use of the ESSM. APL is working with the NSPO and the NATO Seasparrow Consortium navies to perform some of these studies, identify integration issues, and ensure the optimal integration of ESSM into the fleets.

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