This document has been approved for public release and sale; its distribution is unlimited.

(1)

AD A055309

ASSOCIATION OF SCIENTISTS AND ENGINEERS

SEAMOD - A NEW WAY TO DESIGN, CONSTRUCT, MODERNIZE AND CONVERT U. S. NAVY COMBATANT SHIPS

Charles E. Lawson

DDC FILE COPY

DDC
JUN 19 1978
F

14TH ANNUAL TECHNICAL SYMPOSIUM

ASSOCIATION OF SCIENTISTS AND ENGINEERS OF
THE NAVAL AIR AND SEA SYSTEMS COMMAND
DEPARTMENT OF THE NAVY - WASHINGTON, D.C. 20360

1977

78 06 09 041

(6)

SEAMOD - A New Way To Design, Construct, Modernize and Convert U. S. Navy Combatant Ships

(1)

(10)

Charles E. Lawson
Marine Engineer
Advanced Technology Systems Division
Naval Sea Systems Command

(11) Mar[illegible], [illegible]977

(12) 38 p.

Approved for Public Release
Distribution Unlimited

391 345

78 06 09 041

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS

ABSTRACT

SEAMOD is a concept for designing a ship to receive a modularized combat system. This concept provides a means for exploiting technological improvements in combat system weapons and supporting components in order to attain the highest possible state of fleet effectiveness. Analysis of the life cycle characteristics and construction and design costs of a SEAMOD-configured ship show that its advantages outweigh its penalties. Feasibility has been established by development of guidelines for detailed design of the ship platform, combat system modules and means of ship/module connections. A key element of the concept is the module installation facility (MIF) where the modules will be assembled, checked out, installed in the ship, and integrated into a combat system. Subsequently, the MIF will perform module changeouts. Analysis indicates that a ship configured in this manner will be over 100% more mission effective than a conventional ship and its availability during its active service life will increase. The SEAMOD concept will be ready to enter the validation phase of development in fiscal year 1979.

SEAMOD - A New Way To Design, Construct, Modernize and Convert U. S. Navy Combatant Ships

BACKGROUND

The design, construction, outfitting and modernization of surface combatants has become increasingly complex in the last 20 years. Although some modular construction and payload techniques have been developed and applied, they do not yet offer fundamental relief to the increasingly severe problem of delivering ships and weapon systems into the fleet in a timely manner. It has reached the point where the span of technological generations in some significant cases is shorter than the acquisition cycle to introduce ships and equipment into the fleet. Additionally, reliance on large central computer installations in combat direction systems has resulted in highly complex, and vulnerable systems which are difficult to change and to update. There is no indication that the rate of technological change or of increase in threat parameters will diminish in the foreseeable future.

SEAMOD CONCEPT

SEAMOD (Sea Systems Modification and Modernization by Modularity) is a concept for designing and constructing Navy surface combatants and their weapon system payloads to resolve the incompatibility between long-life (30 yr) ship hulls and auxiliary systems and short-life (5 to 10 yr) combat weapon systems. A SEAMOD-configured platform will have standard weapon system interfaces to facilitate the installation and removal of various weapon system payload modules. Each station will be provided with standard ships service outlets sized for current and foreseeable system needs. Payload modules will be installed or exchanged at the stations any time after construction of the basic platform. The design and production of payloads as standard module packages thus expediting their exchange as the threat or mission dictates, may allow more flexible ship and weapon system acquisition and employment. The principal objectives of the SEAMOD concept are to: shorten the introduction of weapon systems into the fleet, increase the availability of ships and weapon systems at sea, and achieve a more effective mix of combat system payloads in the fleet.

The SEAMOD concept represents a fundamental change in ship design to achieve the objectives stated in the background above. It is not a system of itself, but rather it establishes comprehensive interface design standards and applies several key technologies to achieve physical and functional separation of a ship platform and its payloads. The inherent use of multiplexed, federated computer systems with standalone sensors and weapons provides a significant potential to reduce combat system vulnerability. The concept offers an opportunity to reduce the risks of concurrent platform and payload development by completely defining the interface constraints early in the design process and by eliminating the highly-centralized computer complex. Similarly, preparation for subsequent modernization or conversion can proceed with the ship at sea, with a sharply-reduced impact at the time of actual installation because of the physical and computer architectures employed. Engineering studies to this point have indicated that the concept is feasible and producible and that typical weapon systems can be constrained to the design interface standard without loss of effectiveness.

CONCEPT DEVELOPMENT STUDIES COMPLETED

Concept development studies have been completed that establish the following:

- SEAMOD technical feasibility.
- Technical measures of benefit/penalty.
- Requirements for a SEAMOD Module Installation Facility.
- Operational measures of benefit/penalty of the SEAMOD concept.

The results of these studies are described in the following paragraphs.

SEAMOD Technical Feasibility

The SEAMOD technical feasibility analysis shows that it is feasible to design and construct ships as general purpose platforms capable of carrying modularized combat systems that can be expeditiously replaced throughout the platform's life time. The analysis resulted in design guidelines for the ship platform, modules, and platform/module interfaces.

Ship Platform Design

Figure 1, shows the general layout of a SEAMOD-configured ship. The results of the studies of specific platform designs are discussed in this section.

The hull will be designed with a series of zones separated by watertight transverse bulkheads so that each major hull zone contains one major weapon system module. In so far as possible, all weapon system station deck openings for modules will be made the same to provide flexibility for interchanging modules. A coaming will be provided around the weather deck opening of the weapon system stations for structural integrity and for use in providing a water/gastight seal. Longitudinal and transverse bulkheads will be provided directly under the coamings around the deck openings, from the weather deck to the deck below, to resist the transverse forces experienced at the deck cuts. Continuous longitudinal girders will be provided under the port and starboard edges of the deck opening at each weapon system station for adequate strength. Use of HY80 steel is proposed instead of High Tensile Strength (HTS) steel for the weather deck hatch coaming and associated structural support members to carry module loads and to act as a crack arrestor. Bottom structure will be provided to support the full weight and vertical shock loads of the modules. Transverse supports which are fully integrated into the deep web frames will be used to transmit the module loads into the shell and bottom structure.

Sufficient bottom-fuel tanks, will be installed both forward and aft. to make it possible to shift liquids to compensate for weight shifts caused by module changes. Bolt-on steel armor or shielding may be installed around the inside of each major weapon system station for modules requiring protection. Port and starboard passageways will be provided on the sides of each major weapon system station to facilitate access to the payload module and for fore and aft traffic flow. Personnel hatches for access to the interior of the weapon system station will be limited to only one or two in order to provide for security and watertight integrity. All ships service interface terminals will be routed to the same standard locations within each weapon system station in order to provide a standard interface point for modules. Dedicated fan rooms will be installed in each zone, sized to provide the flexibility to meet the most severe heating, ventilation and air conditioning requirements for all modules. Chilled water will be provided to each fan room from a centralized system(s). External access to all electronics spaces in the ship's superstructure will be provided by means of soft patches for exchanging electronics equipment pallet modules.

Electronics spaces in the superstructure will be designed with piping, electric power, and data interconnect points positioned to interface with the pallet modules. Only the following kinds of electrical power will be provided to the modules from the platform:

Volts	Hertz	Phase	Type
115	60	1&3	I
440	60	1&3	I

Note: Modules will contain own frequency conversion (400 Hz, etc.) and power regulation devices.

The platform's firemain piping and eductor system will be sized to provide the flow rate required for missile magazine protection at each of the major weapon system stations.

Module Design

The studies of combat system module design resulted in the development of the following design features. Each major weapon system module will be designed so that its weather deck completely covers the standard sized deck opening of the platform and so that its weight will be supported by structural foundations provided in the ship platform. Foundations will be designed to support the maximum permitted module weight plus the module's most severe anticipated vertical shock factor. The structural design developed is adequate for approximately 232 long tons and a vertical shock component of 18g's. The ships service interface connections on the modules will be positioned so that the connection is directly opposite the weapons station location for services. Module requirements for services in excess of those provided by the platform will be self-contained.

Modules will be designed to be preassembled and tested ashore at an integration facility prior to installation in the platform. Combat system electronics components selected for palletization will be mounted in their working positions on 1 foot high standardized electronic equipment pallet modules. Pallet modules of standard dimensions are capable of being transported in ISO (International Standard Organization) or MILVAN (Army-Procured Military Van) containers. Pallet modules will be designed to contain all required piping and wiring and to have standard fittings for ships service piping and wiring connections in the base of the module for rapid connection.

Platform/Module Interface Design Development

The design studies of ships service requirements for the platform resulted in the development of the following criteria. Jumper cables with lug terminals will be used to connect electric power from platform power distribution panels and automatic bus transfer equipment to the terminal boxes on the module. Electrical connection points on the module will be located underneath or on the lower right side of the module. A makeup-section of hose or pipe will be used for salt water. Connection points on the major weapons modules will be located just below the weather deck on the right side of the module. Makeup-sections of piping will be used for steam, condensate, and eductor drain piping. Flanges, flexible hose connections, and/or ducting supplied from the port or starboard side, or from underneath the module will be used for heating, ventilation and chilled water. Water/glycol, nitrogen gas, and electric heating systems will be supplied with the module.

Guidelines for Combat System Design for SEAMOD Application

Studies were made to determine a combat system architecture that would be least affected by module exchanges. Minimum changes to computer programs and signal cabling are obviously desirable. The studies have shown that both of these objectives can be met by providing each sensor and weapon with its own computer and standardizing the information exchange with the combat direction system (CDS). The primary benefit of such a combat system architecture is the minimum cost of the computer program changes associated with the equipment changes. Costs are limited in both the component computers and the CDS computer. The component computers are planned to be low-cost microcomputers. Programming these computers will be relatively inexpensive, typically $33 per instruction, because ample memory is affordable and there are a minimum number of functions in each program. Studies have shown that programming is least expensive when there are minimum memory limitations and when the number of interacting program functions is minimum.

Standardization of the information transmitted from sensors and weapons to the CDS will limit the impact of component changes on computer programs. For example, standardization of the data and format transmitted by a two-dimensional search radar to the CDS will potentially make the introduction of a new two-dimensional radar transparent to the CDS program.

The component microcomputers will be connected to the CDS by means of either input/output cabling or a data multiplex system. Both will significantly reduce the amount of cabling required while providing for redundancy thereby decreasing vulnerability and enhancing survivability. A tradeoff study will be made to determine which is the more cost effective.

Technical Measures of Benefit/Penalty

Technical measures of benefit/penalty (MOB) have been derived in order to quantify the impact of the SEAMOD concept on ship characteristics, construction and design. These MOBs show that over its life the advantages accruing to a SEAMOD-configured ship far outweigh the penalties. The method of analysis used was to compare a SEAMOD-configured DD-963 class ship with a conventionally-configured ship during the three phases of their life cycles, namely initial construction, modernization, and conversion.

The ship characteristics affected by modularization are displacement, volume, maximum speed, endurance range and stability.

Ship Displacement and Volume

The extra structure required to strengthen the hull for all future payloads and the design margins required for ships services result in a higher initial displacement for the SEAMOD-configured ship. The requirement to provide standard size major armament weapon system stations during initial ship construction resulted in the SEAMOD-configured ship initially having a greater ship volume because of the extension of the after part of the 01 deck. The displacement and volume differences between the two ships become negligible after modernization and conversion. This is because the conventionally-configured ship is enlarged and strengthened during modernization and conversion and acquires more ships service capacity to accommodate its new payloads. These differences are compared in Table 1.

Ship Maximum Speed and Endurance Range

For this study, both the SEAMOD-configured ship and the conventionally-configured ship would have the same hull form, propulsion plant, and fuel capacity. Because they also have only minor differences in displacement, both configurations have comparable maximum speeds and endurance ranges. Comparisons between the conventionally-configured ship and the SEAMOD-configured ship during the three phases of their life cycles are shown in Table 2.

Ship Stability

GM, the metacentric height, is the measure of the initial stability of the ship. It is limited to small angles of inclination, from zero degrees up to a range of seven to ten degrees. Above this range, a new factor of overall stability (i.e., righting moment) comes into play.

The GM of a SEAMOD-configured ship was calculated for its baseline configuration and for its configurations after modernization and conversion. The initial stability of the SEAMOD-configured ship is comparable to a conventionally-configured ship. To have safe initial stability, the minimum acceptable positive GM for ships of this size is approximately 2 feet. The GM values determined are shown in Figure 3.

Elapsed Shipyard Times

An analysis of the construction schedules disclosed that a complete SEAMOD-configured ship, with its baseline weapon system payloads onboard, can be delivered 4 months earlier than a comparable, conventionally-configured ship, because of the construction time saved in installing and testing the weapon system payloads. System integration time was considered in time calculations, and, conservatively, was assumed equal for both platforms during ship construction.

A SEAMOD-configured ship can be modernized or converted in approximately 3 months of ship off-line time because it is designed for the exchange of payload modules. Without consideration for system integration, the weapon system payload modules examined can be removed and installed including preliminary functional tests within 2-3 weeks. Assuming an additional 2-month requirement for integration, most modernizations or conversions of a SEAMOD-configured ship, including other routine ship overhaul work, can be accomplished within 3 months. Modernization and conversion elapsed times were determined for payload exchange, lightoff, and alignment; the 2-month period for system integration was applied to both ships.

Shipyard elapsed time for initial construction includes all events from the contract award date through start of fabrication, keel laying, launch, system integration, builder's and acceptance trials, to ship delivery. Shipyard elapsed time for both modernization and conversion includes all events from the date the ship enters the shipyard through removal of the old systems, installations of the new systems, system integration, builder's and acceptance trials, to ship delivery. A principal operational advantage of SEAMOD, however, accrues not from installing all weapon systems during conventional modernization or conversion periods, but by installing each new weapon system on a ship as soon as possible after the system's IOC. Elapsed shipyard time comparisons are shown in Table 4.

Single Ship Design/Platform/Payload Costs

The combined ship design, ship acquisition, and payload acquisition costs during initial construction for the SEAMOD-configured ship are $1.5M more than the conventionally-configured ship. This represents a penalty of 1.5%.

The combined costs for ship design, ship structural modification, and payload acquisition during modernization of the SEAMOD-configured ship are $1.1M less than the conventionally-configured ship. This represents a benefit of 4.0%.

The combined costs for ship design, ship structural modification, and payload acquisition during conversion of the SEAMOD-configured ship are $0.8M more than the conventionally-configured ship. This represents a penalty of 3.2%. Cost comparisons are shown in Table 5.

Single Ship Design Costs

Ship design costs represent estimated labor costs only. The cost for the initial design effort (conceptual design through detailed design) was estimated at $5M and was the same for both conventional- and SEAMOD-configured ships. The difference between the initial design efforts for the conventional- and SEAMOD-configured ships lies more in a "shift of goals" rather than in a change in the amount of design work. The conventionally-configured ship is designed to accept a specific group of combat systems, and design margins are provided to allow for minor changes. The SEAMOD-configured ship is designed to accommodate a varied set of combat systems with known maximum constraints, and large design margins are provided to accommodate all projected payload requirements.

Design costs for modernization and conversion are significantly lower than for SEAMOD-configured ships, because no design effort for major structural and ships service changes is required.

Cost comparisons are shown in Table 6.

Requirements for a SEAMOD Module Installation Facility

A SEAMOD Module Installation Facility (MIF) would be a facility, where equipment and combat system modules would be assembled, groomed, installed in the ship platform, and tested. In addition, the site might be assigned the tasks of computer program integration and hardware/software integration. The following aspects of an MIF are under consideration:

- Integration tasks to be assigned
- Facilities required
- Ownership and operation
- Number of sites and location

Tasks To Be Assigned An MIF

Under the SEAMOD concept, combat system and equipment grooming (inspection, operation, and testing) would be performed prior to installation aboard each ship in order to minimize the possibility that system or equipment defects will slow down shipboard testing. Equipment grooming can in some instances include the installation of modifications.

In ships presently under construction, computer programs written by the system designers reside in central computers. Integration of these programs is carried out at a site dedicated for this purpose. In order to assure the validity of the integration process, these sites usually include most of the equipment that sends data to or receives data from the computer. By this means, both computer program integration and hardware/software integration takes place. This integration effort locates and eliminates computer program errors and hardware defects.

For the DD-963 program, computer program integration and hardware/software integration was carried out at a site in Culver City, California, using the last ship set of equipment. Equipment grooming is being carried out at the shipyard at Pascagoula, Mississippi. This consists of equipment inspection, installation of modifications, operation, and checkout on an individual basis, i.e., not as a combat system.

Combined MIF and LBTS

By including facilities required for a Land-Based Test Site (LBTS) at an MIF, one less site would be required for development of a combat system. Once established for the first ship class, there would be significant economies for succeeding ship classes because the existing building, services, and certain of the combat system equipments could be used. Only the new equipment would have to be installed. Because the integration process is lengthy (2 to 3 years), requirements over the next 10 to 15 years would have to be studied to determine if space for more than one ship class would have to be provided. Space for more than one ship class is provided at the LBEF at Newport. Another advantage of such a facility would be that a permanent nucleus of highly skilled personnel who would expedite the integration process could be developed.

MIF and Remote LBTS

A combat system engineering development site is to be installed at RCA, Moorestown, New Jersey, for the integration of the DDG-47 class combat system. By design, the combat system for the DDG-47 will be common to the CSGN. There are differences, but they are minor from an integration point of view. Accordingly, an MIF to support these ship classes would only assemble and groom the equipment prior to its installation in the ship. Further study would be required to determine if each ship set of equipment should be groomed as a combat system prior to installation. Review of the DD-963 and TRIDENT experience would be helpful in this regard.

Final selection of the best approach will require detailed consideration of cost and scheduling factors, as well as the characteristics of the combat system to be integrated. It is evident that, in the future, many functions now resident in central computers will be distributed to subsystem computers. This will tend to lessen the integration task, because problems previously discovered at integration time will be discovered and corrected in the course of subsystem checkout. The trend toward microminiaturization will also tend to lessen the integration problem because of the increase in equipment maintainability.

Ownership and Operation

There are three options available for ownership and operation of an MIF. They are:

(1) Government owned and government operated

(2) Government owned and contractor operated

(3) Contractor owned and contractor operated

The selection of one of these options will be strongly influenced by funding and manning considerations. Costs could be significantly reduced by making use of an existing facility. Amortization of the cost by use of funds from two or three ship classes would also reduce the cost impact. Government ownership and operation would provide better control of the MIF operation than contractor ownership and operation.

It would appear advantageous to the government to establish, at an MIF, a nucleus of employees who would become highly skilled in system integration. These employees would be able to expedite the integration of each ship class. They would be especially valuable as troubleshooters when problems resulting from equipment failure are encountered in combat system checkout aboard ship. At present, integration sites exist for one ship class at a time and talent at each site is disbursed as soon as the work is completed.

As a minimum, it would appear that there should be an MIF on each coast. Analysis of potential workloads might indicate that more than one is needed. A second facility would reduce shipbuilding vulnerability to attack and create a greater pool of skilled personnel.

Rotatable Pool Concept

An integral part of the SEAMOD concept is the establishement of a rotatable pool where modules are maintained for rapid installation in the event of:

- A change in a ship's mission
- Availability of more effective equipment
- Major casualty to a module
- Training requirements

Rotatable.pools must have the necessary facilities for handling large, heavy modules, and providing the proper environment for long-term storage of electronic equipment.

Stocking of the rotatable pool will be determined on the basis of the need to meet anticipated changes to ship class mission requirements, availability of more capable equipment, anticipated need to replace damaged modules, and training requirements.

To date, no estimates have been made of the cost of a rotatable pool. The rotatable pool would be located near a MIF in order to keep module transportation to a minimum. Proximity to the MIF would probably influence, but not necessarily determine, ownership and operation. The options would be the same as for the MIF, namely:

a. Government owned and government operated

b. Government owned and contractor operated

c. Contractor owned and contractor operated

Operational Measures of Benefit/Penalty of SEAMOD Concept

A fleet of SEAMOD-configured ships will be more effective than a fleet of conventional ships because it will be comprised of modernized ships that have superior mission readiness. Greater fleet effectiveness will also be achieved because they can be rapidly converted to meet changing missions.

Ship mission readiness is defined as the product of its operational effectiveness and its availability. A ship's operational effectiveness is its ability to counter a threat in each of its assigned warfare areas such as AAW, SUW and ASW. Its availability is the ratio of the time the ship is fully or substantially ready in all primary mission areas to the total time it is considered to be an active fleet unit.

Ship Operational Effectiveness

A ship's operational effectiveness is determined by the ability of all of its weapon systems to counter the threat at any point in time. Based on observations of a selected set of systems over the life cycle of a ship, it was determined that the composite effectiveness of a ship can be quantitatively modeled by a set of exponentially decaying functions. This model is expressed by the following equation.

$$E = Ae^{-k(t_1-B)/AH}$$

where E = system effectiveness at time t ($t \geq B$). varies from 0 to 1

A = initial system effectiveness at $t = B$

B = constant to normalize $t = 0$ to the end of a reference year

$k = -\ln(0.5) = .6931$

H = half-life of the system (years)

The value of A for a new system is unity at its year of initial operational capability (IOC). A value of B is defined as the difference in years between the new system's IOC and the reference year. The value of A, for most modules was determined through a comparative analysis of performance factors between an existing system and a new system at the year of the new system's IOC. In some cases, it is appropriate to define A by the value of E of IOC. Additionally, the value of H (system's half-life) for the existing system is adjusted to equal the product AH', where A is the initial (or reevaluated) effectiveness of the existing system of the new or replacing system's IOC year, and H' is the assumed half-life of the new system. Operational effectiveness of a ship over an interval of time, t_1 through t_2, is represented by the relationship:

$$\text{MOE} = \frac{AH}{k} \left[E\ (\text{at } t_1) - E\ (\text{at } t_2) \right]$$

where

MOE = measure of effectiveness

E, A, k and H are as defined above

This model was applied to the DD-963 in order to determine quantitatively the increase in operational effectiveness that would be realized if that ship had been SEAMOD-configured. The 30-year life of the ship was postulated to cover the period from the beginning of 1976 to the end of 2005 with all module removals and installations under analysis taking place within the first 18 years from 1976 to 1993. Table 7 identifies the representative payloads selected for removal and/or installation. Ten removals and installations involving 12 specific systems were examined at seven locations on the ship.

The effectiveness models for the 12 systems are presented in Table 8 and are graphically depicted in Figure 2. It should be noted that, throughout the life of each system, a new model is determined when a potential replacement system is identified by an IOC.

Table 9 presents data necessary to evaluate each system's effectiveness as a function of system implementation dates within the SEAMOD and conventional scenarios for the 10 system changeouts. All changeouts associated with the SEAMOD scenario occur during regular overhaul (ROH) and restricted availability (RAV) periods from 1976 through 1984. All changeouts associated with the conventional scenario occur during the scheduled modernization period (1984) and the conversion period (1993). After 1993, both the SEAMOD-configured and the conventionally-configured ships have equivalent weapon system configurations, and consequently the same aggregate ship system effectiveness.

In examining each of the seven ship locations on the SEAMOD-configured ship and conventionally-configured ship, an effectiveness curve can be determined for each location and configuration over the 1976-1993 time period depending upon the system installed at the location during any year. For example, the effectiveness curve for the SEAMOD-configured ship at the original 5"/54 forward gun location can be determined from Figure 2 by following the 5"/54 curve from 1975 to 1976, then moving up to the 8"/55 curve in 1976 and following it to 1984, then moving up to the VLMS curve in 1984 and following it to 1993. This discontinuous curve would be based upon four models defined in Table 8, and the SEAMOD measure of effectiveness (MOE) at that location would be defined as the area under the curve from the end of 1975 to the end of 1993. The SEAMOD MOE could, therefore, be calculated by application of the formula given above.

Table 10 presents the calculated MOEs and measures of benefit (MOBs) over the 1975-1993 time period for each of the seven ship locations for the SEAMOD-configured and conventionally-configured ships. These calculations are based upon a unique set of implementation dates defined for the SEAMOD and conventional 30-year scenarios. The "optimum MOE" is the measure of effectiveness obtained when new payload systems are implemented at IOC. MOEs can be interpreted as the years of effectiveness over the 18-year period of analysis (1975-1993), and the SEAMOD MOB represents the increased number of years of effectiveness due to the SEAMOD concept of modularity.

The installation of new payload systems as they become available results in the favorable MOB for a SEAMOD-configured ship with respect to a conventionally-configured ship. The longer removal and installation periods required for conventional modernization and conversion prevent timely installation of new technology systems, whereas MOEs for the SEAMOD-configured ship can easily approach an optimum value as rapid removal and installation of a modular system can occur during an ROH or RAV period during the IOC year.

Figure 3 presents a graphical description of the optimum, SEAMOD, and conventional effectiveness curves from 1975 to 1993. These curves are normalized to represent the average effectiveness of the seven ship locations at any point in time. The area between the SEAMOD and conventional curves represents the overall SEAMOD MOB. The area between the optimum and SEAMOD curves represents the additional MOB that can be realized by fully utilizing the SEAMOD concept to install new technology systems during the year of their IOC.

Ship Operational Availability

Ship operational availability (A) is defined as the ratio of the time a ship is fully or substantially ready in all primary mission areas to the total time a ship is subject to the readiness reporting requirements of OPNAV Instruction 3501.2D. In terms of the combat readiness criteria, operational availability is expressed by the model:

$$A = \frac{T_1 + T_2}{T_1 + T_2 + T_3 + T_4}$$

where T_1 through T_4 are defined as follows:

T_1: Total time ship is fully ready and capable of performing effectively in primary mission areas. (C-1 status).

T_2: Total time ship is substantially ready and capable of performing in primary mission areas with minor deficiencies. (C-2 status).

T_3: Total time ship is marginally ready and capable of performing in primary mission areas with major deficiencies. (C-3 status).

T_4: Total time ship is not ready with loss in two or more primary mission areas. (C-4 status).

The readiness criteria are reported in four resource categories: personnel, equipment and supplies on hand, equipment readiness, and training. The life-cycle scenario of a ship can be categorized into 13 basic events in order to determine the total time a ship is in one of the above conditions, such that:

$$T_1 = \Sigma OPS + \Sigma DEP + \Sigma ENR$$

$$T_2 = \Sigma TAV + \Sigma POM$$

$$T_3 = \Sigma LVUPK + \Sigma SQT + \Sigma REFTRA + \Sigma RAV$$

$$T_4 = \Sigma ROH + MOD + CONV + \Sigma INT$$

The scenario events are defined as follows:

OPS - Continental U.S. Operations
DEP - Overseas Deployment
ENR - Enroute to/from Deployment
TAV - Technical Availability
POM - Prepare for Overseas Movement
LVUPK - Leave and Upkeep

SQT - Ship Qualification Test
REFTRA - Refresher Training
RAV - Restricted Availability
ROH - Regular Overhaul
MOD - Modernization
CONV - Conversion
INT - Integration

Figure 4 is a time-line plot of relative operational availability on a yearly basis over the 30-year cycle of each ship configuration. During only 9 of the 30 years is there any difference in operational availability between the two concepts. During 5 of those years (all occurring within the first 8 years of the life cycle), the availability of a conventionally-configured ship is slightly higher than that of a SEAMOD-configured ship. This is because payload systems are being frequently replaced on the SEAMOD-configured ship in order to maintain a high level of effectiveness, which requires 4 months additional off-line time. During 4 of the next 10 years, however, a SEAMOD-configured ship has considerably higher operational availability (8½ months) because this span of time includes the lengthy modernization and conversion periods scheduled for the conventionally-configured ship. The net result is that over this 18-year period the SEAMOD-configured ship is available 4½ months longer than a comparable conventionally-configured ship. If additional payload system change-outs were made on both ships over the remaining 12 years of the life cycle, the SEAMOD MOB would be increased even more.

Table 11 lists the time required for each scenario event and shows that over a 360-month life a SEAMOD-configured ship will be "operationally available" 274½ months (76%) compared to 270 months (75%) for a conventionally-configured ship, the difference being an MOB of 4½ months. This MOB is totally the result of system changeouts made possible by the SEAMOD concept of converting off-line to on-line time. "Substantially Ready" (T_2) and "Marginally Ready" (T_3) times are essentially the same for both configurations, since these categories are composed primarily of events which are necessary adjuncts to the assumed deployments and shipyard periods.

Ship Mission Readiness

The ability of a task group to carry out its primary mission depends on the availability of ships in the group and the effectiveness of the combat systems aboard each ship. A SEAMOD-configured ship maintains a significantly higher level of effectiveness (by 135%) than does a conventionally-configured ship, as previously shown above. It has also been shown that a SEAMOD-configured ship has a slightly higher operational availability (by 1.3%) than does a conventionally-configured ship.

As previously stated, a straightforward way of quantifying the inter- on of these MOBs is to define mission readiness (R) as the uct of ship operational availability (A) and ship operational ectiveness (E):

$$R = A \bullet E$$

Differences in readiness values for SEAMOD and conventionally-configured ships can then be obtained.

It is highly desirable that off-line time, such as overhaul and other shipyard time, be minimized so that a maximum number of ships will always be operationally available. It is also desirable to maximize ship operational effectiveness; but there are some practical limits to that, since to do so would require continual installation of technologically advanced payload systems.

Table 12 compares values of mission readiness for both ship configurations. Values of operational availability are taken directly from previous paragraphs.

INITIATION OF THE VALIDATION PHASE

The SEAMOD program is currently in the conceptual phase of development and program efforts thus far have been supported by Category 6.2 Exploratory Development funds. Plans for validation of the SEAMOD concept are focused on programming RDT&E Category 6.3 Advanced Development funds for SEAMOD commencing with the CNO Program Objective Memorandum (POM) for fiscal year 1979. An issue paper for POM-79 has been prepared and status and decision briefings have been given to NAVSEA Ship Acquisition Project Managers (SHAPMS), Ship Logistics Managers (SLMS) and to various command levels in the Naval Sea Systems Command, the Naval Materiel Command, and the CNO Staff.

SEAMOD Program validation alternatives that are being considered range from the development of a land-based test site (LBTS) to the initiation of a preliminary design effort for a notional SEAMOD-configured ship. Briefly these alternatives are:

1. LBTS - Demonstrate the technological feasibility of a distributed processing combat system using a multiplexed data bus at an LBTS (to be followed by a preliminary design effort).

2. Test Ship - Acquire and modify a ship to serve as a test platform to demonstrate the full spectrum of standard weapon system station, weapon system module, and combat system partitioning designs.

3. Ship Modernization - Incorporate SEAMOD design features in a DD-963 shipboard station and install a modular weapon system in the ship during its modernization period.

4. Prototype - Prototype a single weapon station and exchangeable weapon system modules on an existing fleet asset (e.g., USS Hull DD-945) to demonstrate structural and operational (but not Combat Direction System partitioning) features of the SEAMOD concept.

5. Preliminary Design - Prepare a preliminary design of a SEAMOD-configured AEGIS ship using SEAMOD standards.

SUMMARY

Future U.S. Navy ship effectiveness will depend on timely installation of improved combat system components as new technology makes them available. Construction of ships so that they can receive modularized combat system components is a feasible means of meeting this need. The technical feasibility of designing the ship platform and combat system modules and providing for their interconnection has been established. Technical analyses clearly show that the benefits of the SEAMOD concept outweigh the penalties.

Detailed studies have provided design guidelines for the location, size and strength of the ship platform stations. Standard arrangements of the station for providing ship services to the modules have been established. Guidelines for partitioning the combat system into modules have been developed as well as guidelines for design of the modules. Implementation of the SEAMOD concept will significantly alter U.S. Navy shipbuilding practices in that shipbuilders will construct ship platforms and combat system modules will be installed and subsequently changeout at a new facility called a module installation facility. Ship completion risk will be reduced because the shipbuilder will be able to concentrate his efforts on ship construction. Experts at the module installation facility will expeditiously groom, install, and integrate the combat system equipment for new construction ships and when subsequent system changeouts are required. This approach can increase a SEAMOD-configured ship's mission readiness by 100% over its 30 year lifetime in comparison with a conventionally-configured ship. The SEAMOD concept will be fully ready to enter the validation phase of development in fiscal year 1979.

REFERENCES

(a) SEAMOD MOB Report (Measure of Benefit), April 1976, NAVSEA 0323.

(b) John J. McMullen Associates, Summary and Measure of Benefit Analysis, SEAMOD Final Technical Report, Volume I, November 1975.

(c) John J. McMullen Associates, SEAMOD Platform Design, SEAMOD Final Technical Report, Volume II, November 1975.

(d) John J. McMullen Associates, SEAMOD Module Design and Analysis, SEAMOD Final Technical Report, Volume III, December 1975.

(e) John J. McMullen Associates, Comparative Analysis of SEAMOD Scenario Events, SEAMOD Final Technical Report, Volume IV, November 1975.

(f) Presearch, Inc., Measure of Benefit Analysis of the SEAMOD Concept (U), Technical Report No. 287 (preliminary draft), 21 November 1975. CONFIDENTIAL

Acknowledgements

I wish to acknowledge in alphabetical order the personnel and organizations that have and are continuing to contribute to the SEAMOD Program. This paper would not have been possible without them and others:

Mr. Jack Abbott, Naval Ship Engineering Center
Mr. George Ball, John J. McMullen Associates
Mr. Dale Batchelder, Naval Weapons Center, China Lake
Mr. Tom Burt, Presearch, Inc.
Mr. John Commerton, John J. McMullen Associates
Mr. Donald Eddington, Naval Electronics Laboratory Center, San Diego
Mr. Edward Jordan, Advanced Technology, Inc.
Mr. Morgan O'Connor, Naval Ship Engineering Center
Mr. Dan Topousis, Northern Ordnance Division/FMC
Mr. Jack Varney, Advanced Technology, Inc.
Dr. Hubert Wang, General Dynamics

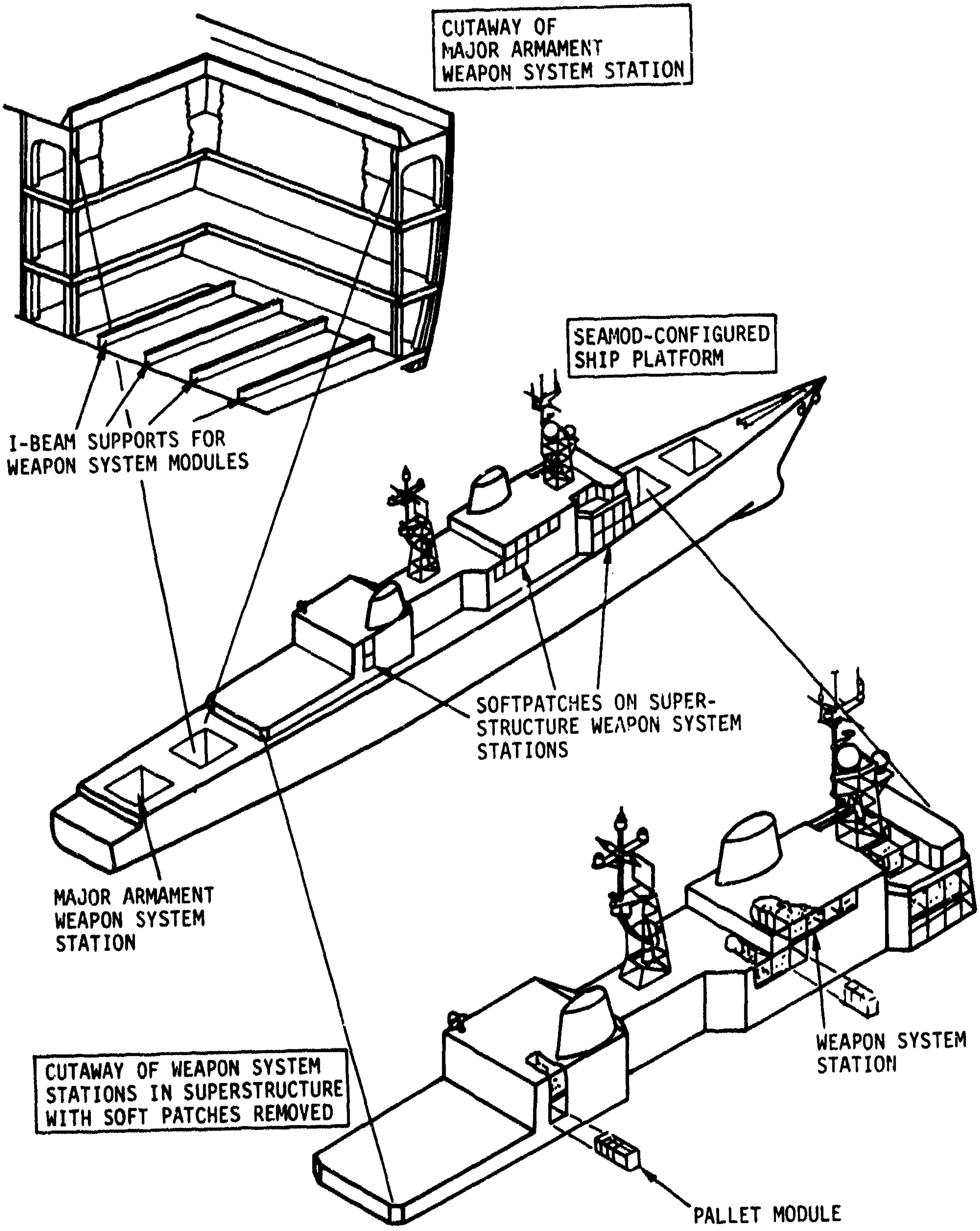

FIGURE 1

SEAMOD-CONFIGURED SHIP PLATFORM DESIGN CONCEPTS

TABLE 1

SHIP MAXIMUM SPEED AND ENDURANCE RANGE COMPARISONS

	INITIAL CONSTRUCTION	MODERNIZATION	CONVERSION
SHIP DISPLACEMENT			
SEAMOD (tons)	8097	8199	8234
Conventional (tons)	7870	8083	8194
MOB (tons)	+209 (2.6%) } ↓	+ 30 (1.4%) } ●	+ 40 (0.5%) } ●
SHIP VOLUME			
SEAMOD (K ft^3)	830	830	830
Conventional (K ft^3)	800	800	830
MOB (K ft^3)	+ 30 (3.8%) } ↓	+ 30 (3.8%) } ↓	None } ●

↑ ≡ Benefit
↓ ≡ Penalty
● ≡ MOB <2%

TABLE 2

SHIP MAXIMUM SPEED AND ENDURANCE RANGE COMPARISONS

	INITIAL CONSTRUCTION	MODERNIZATION	CONVERSION
SHIP MAXIMUM SPEED			
SEAMOD	VMAX-0.15 kt	VMAX-0.25 kt	VMAX-0.30 kt
Conventional	VMAX	VMAX-0.10 kt	VMAX-0.25 kt
MOB	-0.15 kt (<0.5%) ●	-0.15 kt (<0.5%) ●	-0.05 kt (<0.2%) ●
SHIP ENDURANCE RANGE			
SEAMOD	R-100 nm	R-160 nm	R-180 nm
Conventional	R	R-100 nm	R-160 nm
MOB	-100 nm (<1.7%) ●	- 60 nm (<1.0%) ●	- 20 nm (<0.3%) ●

↑ ≡ Benefit
↓ ≡ Penalty
● ≡ MOB <2%

Note: VMAX≡Unspecified reference maximum speed.
(classified, but >30 kts)
R≡Unspecified reference endurance range at 20 kts.
(classified, but >6000 nm)

TABLE 3

SHIP STABILITY COMPARISONS

	SHIP STABILITY (GM VALUES)		
	INITIAL CONSTRUCTION (ft)	MODERNIZATION (ft)	CONVERSION (ft)
SEAMOD	3.3	3.0	3.0
Conventional	4.3	4.0	4.0
MOB	-1.0 ●	-1.0 ●	-1.0 ●

↑ ≡ Benefit
↓ ≡ Penalty
● ≡ MOB <2% or NA

TABLE 4

ELAPSED SHIPYARD TIME COMPARISONS

	ELAPSED SHIPYARD TIMES			
	INITIAL CONSTRUCTION (mo)	MODERNIZATION (mo)	CONVERSION (mo)	TOTAL (mo)
SEAMOD	34	3	3	40
Conventional	38	12	8	58
MOB	-4 (11%) } ↑	-9 (75%) } ↑	-5 (63%) } ↑	-18 (31%) } ↑

↑ ≡ Benefit
↓ ≡ Penalty
● ≡ MOC <2%

TABLE 5

DESIGN COST COMPARISONS
(Dollars in Millions)

	SINGLE SHIP DESIGN/PLATFORM/PAYLOAD COSTS			
	INITIAL CONSTRUCTION	MODERNIZATION	CONVERSION	TOTAL
SEAMOD	101.5	26.2	25.6	153.3
Conventional	100.0	27.3	24.8	152.1
MOB	+ 1.5 (1.5%) } ●	-1.1 (4.0%) } ↑	+0.8 (3.2%) } ↓	+ 1.2 (0.8%) } ●

↑ ≡ Benefit
↓ ≡ Penalty
● ≡ MOB <2%

TABLE 6

SINGLE SHIP DESIGN COSTS
(Dollars in Millions)

	SINGLE SHIP DESIGN COST			
	INITIAL CONSTRUCTION	MODERNIZATION	CONVERSION	TOTAL
SEAMOD	5.0	0.4	0.1	5.5
Conventional	5.0	0.7	0.8	6.5
MOB	None } ●	-0.3 (43%) } ↑	-0.7 (83%) } ↑	-1.0 (15%) } ↑

↑ ≡ Benefit
↓ ≡ Penalty
● ≡ MOB <2%

TABLE 7

PAYLOAD SYSTEMS EVALUATED FOR REMOVAL AND INSTALLATION

SHIPBOARD LOCATION	OLD SYSTEM	NEW SYSTEM
1	5"/54 Gun Mount (Forward)	8"/55 MCLW Gun Mount
2	ASROC	MK-26 Mod 1 GMLS
3	CIWS	IRDS
4		IPDSMS
5	MK-86 Mod 3 GFCS	MK-86 Mod 5 GFCS
6	AN/SPS-40B Radar	AN/SPS-48C Radar
2	MK-26 Mod 1 GMLS	VLMS
7	5"/54 Gun Mount (Aft)	VLMS
1	8"/55 MCLW Gun Mount	VLMS
4	IPDSMS	VLMS

TABLE 8

EFFECTIVENESS MODELS FOR OLD AND NEW SYSTEMS

SYSTEM	EFFECTIVENESS MODEL*	APPLICABLE TIME INTERVAL (Value of t)
5"/54	$E=(.44)e^{-kt/(.44)11}$	1975(0) → 1982(7)
	$E=(.16)e^{-k(t-7)/(.16)9}$	1982(7) → 1993(18)
8"/55	$E= e^{-kt/11}$	1975(0) → 1982(7)
	$E=(.64)e^{-k(t-7)/(.64)9}$	1982(7) → 1993(18)
VLMS	$E= e^{-k(t-7)/9}$	1982(7) → 1993(18)
ASROC	$E=(.47)e^{-kt/(.47)9}$	1975(0) → 1982(7)
	$E=(.15)e^{-k(t-7)/(.15)9}$	1982(7) → 1993(18)
MK-26/1	$E= e^{-kt/9}$	1975(0) → 1982(7)
	$E=(.39)e^{-k(t-7)/(.39)9}$	1982(7) → 1993(18)
CIWS	$E=(.50)e^{-kt/(.50)9}$	1975(0) → 1993(18)
IRDS	$E= e^{-kt/9}$	1975(0) → 1993(18)
IPDSMS	$E= e^{-k(t-5)9}$	1980(5) → 1982(7)
	$E=(.86)e^{-k(t-7)/(.86)9}$	1982(7) → 1993(18)
MK-86/3	$E=(.50)e^{-kt(.50)11}$	1975(0) → 1993(18)
MK-86/5	$E= e^{-kt/11}$	1975(0) → 1993(18)
AN/SPS-40B	$E=(.22)e^{-kt/(.22)9}$	1975(0) → 1993(18)
AN/SPS-48C	$E= e^{-kt/9}$	1975(0) → 1993(18)

*$k = \ln 0.5 = .6931$.

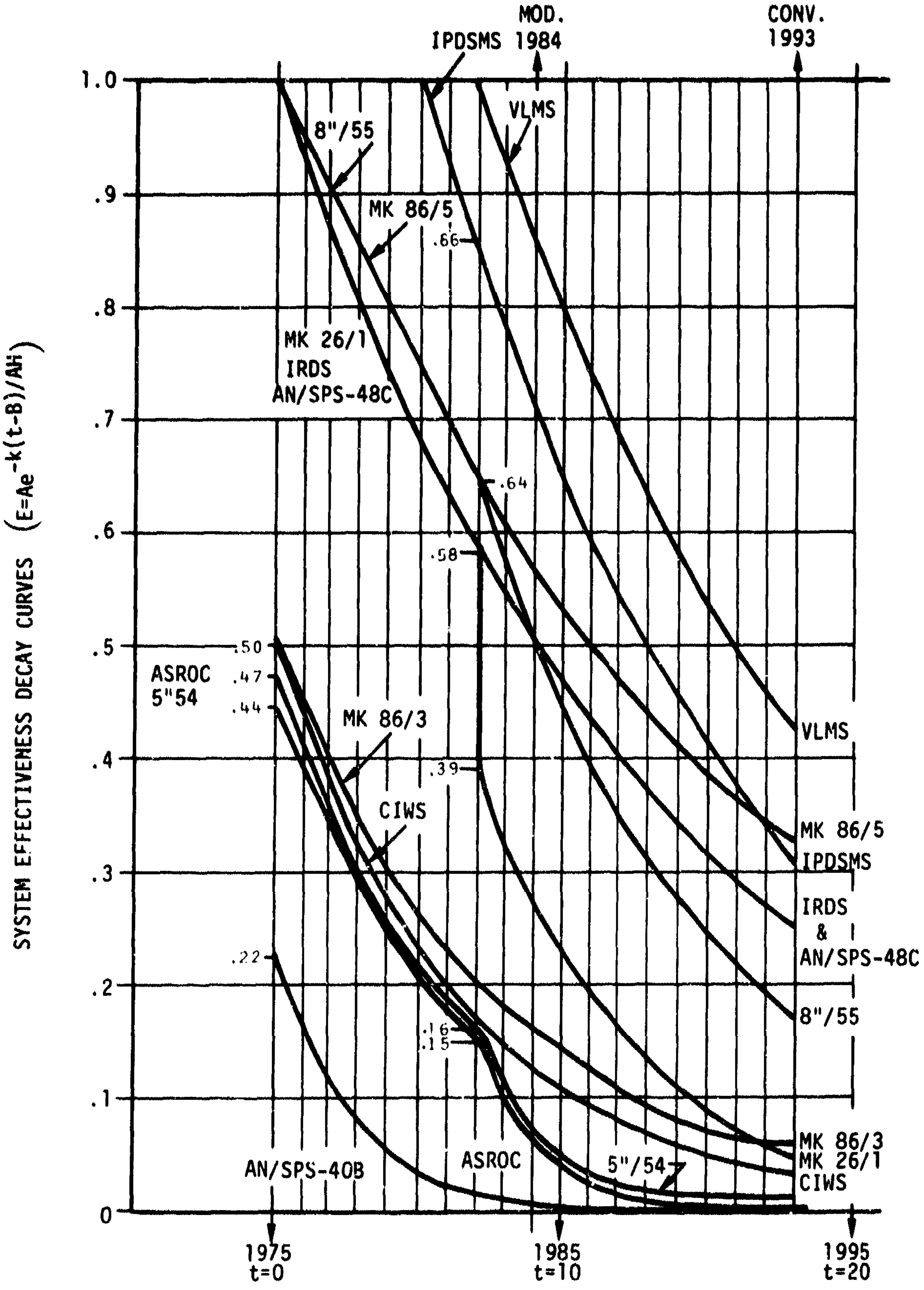

FIGURE 2

SYSTEM EFFECTIVENESS DECAY CURVES

TABLE 9

INITIAL EFFECTIVENESS MODEL PARAMETERS AND IOC DATES WITH SEAMOD/CONVENTIONAL IMPLEMENTATION DATES

			A	B
SYSTEM'S CHANGEOUT	NEW SYSTEM'S IOC DATE	IMPLEM. YR. SEAMOD / CONVENTIONAL	INITIAL EFFECTIVENESS AT NEW SYSTEM'S IOC DATE	NEW SYSTEM'S INITIAL HALF LIFE (YRS)
5"/54 (FWD) ↓ 8"/55	1975	Mod 1976/1984	0.44* 1.00	11
ASROC ↓ MK-26/1	1975	Mod 1977/1984	0.47* 1.00	9
CIWS ↓ IRDS	1975	Mod 1978/1984	0.50* 1.00	9
— ↓ IPDSMS	1980	Mod 1980/1984	1.00	9
MK-86/3 ↓ MK-86/5	1975	Conv 1982/1993	0.50* 1.00	11
AN/SPS-40B ↓ AN/SPS-48C	1975	Conv 1983/1993	0.22* 1.00	9
MK-26/1 ↓ VLMS	1982	Conv 1984/1993	0.39* 1.00	9
5"/54 (AFT) ↓ VLMS	1982	Conv 1984/1993	0.16** 1.00	9
8"/55 ↓ VLMS	1982	Conv 1984/1993	0.64** 1.00	9
IPDSMS ↓ VLMS	1982	Conv 1984/1993	0.86** 1.00	9

*Based upon independent analysis of old and new systems performance factor ratios.

**Based upon initial model effectiveness values at new system's IOC.

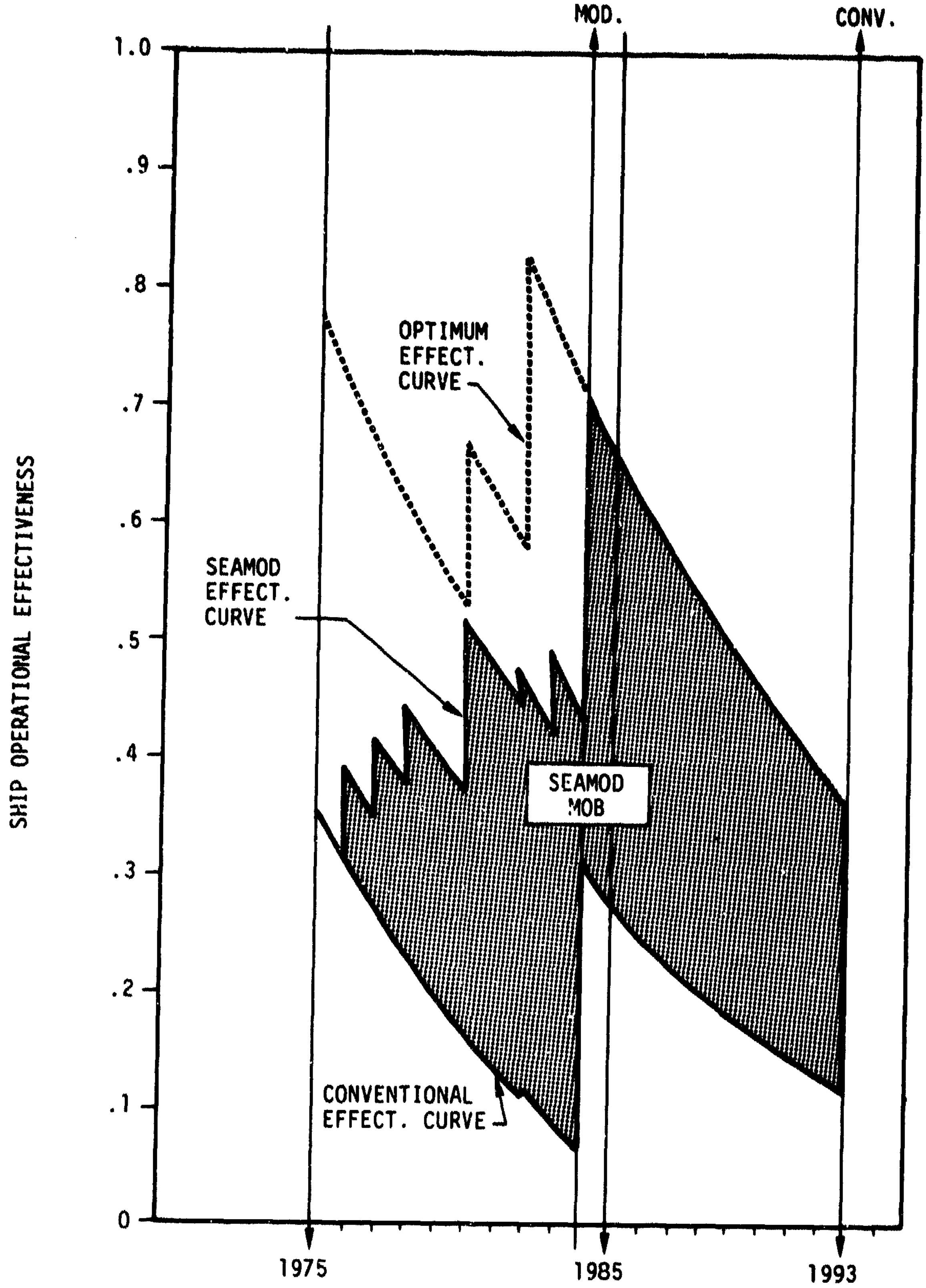

FIGURE 3
SHIP OPERATIONAL EFFECTIVENESS

TABLE 10

MOEs AND SEAMOD MOBs (1975-93)

ZONE	SYSTEM CHANGEOUTS	MOE			SEAMOD MOB*	IMPROVEMENT (%)**
		OPTIMUM	SEAMOD	CONV		
2	5"/54 → 8"/55 → VLMS	.73	.65	.27	.38	141
3	ASROC → MK-26 → VLMS	.71	.59	.18	.41	228
8	CIWS → IRDS	.54	.46	.32	.14	44
5	---- → IPDSMS → VLMS	.52	.50	.24	.26	108
8	MK-86/3 → MK-86/5	.60	.41	.20	.21	105
8	SPS-40 → SPS-48	.54	.24	.03	.21	700
6	5"/54 → VLMS	.52	.43	.13	.30	231
	Average	.59	.47	.20	.27	135

*SEAMOD MOB SEAMOD MOE - Conventional MOE

**Percent Improvement $\frac{\text{SEAMOD MOB}}{\text{Conventional MOE}} \times 100$

TABLE 11

LIFE-CYCLE SCENARIO COMPARISON

READINESS CRITERIA	SEAMOD		CONVENTIONAL	
	Months	Avail(%)	Months	Avail(%)
T_1 (Fully Ready)	241.5	67.1	237	65.8
OPS	124.5		120	
DEP	99		99	
ENR	18		18	
T_2 (Substantially Ready)	33	9.2	33	9.2
TAV	15		15	
POM	18		18	
Subtotal	274.5	76.3	270	75.0
T_3 (Marginally Ready)	47	13.0	46	12.8
LVUPK	18		18	
SQT	3		3	
REFTRA	14		14	
RAV	12		11	
T_4 (Not Ready)	38.5	10.7	44	12.2
ROH	36		24	
MOD	-		12*	
CONV	-		8*	
INT	2.5		- *	
Total	360.0	100.0	360	100.0

*A 2-month time period for system integration is included in each Modernization (MOD) and Conversion (CONV) period.

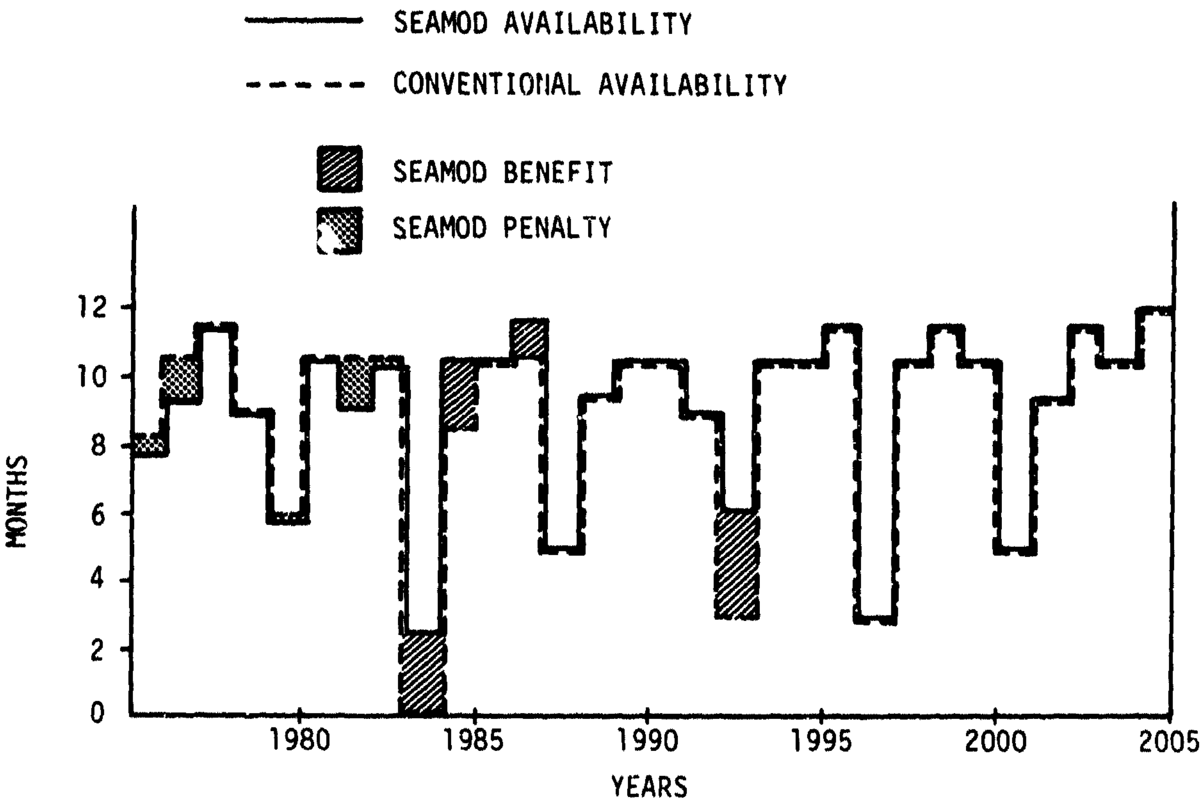

FIGURE 4

ANNUAL SHIP OPERATIONAL AVAILABILITY

TABLE 12

MISSION READINESS MOB

	OPERATIONAL AVAILABILITY	OPERATIONAL EFFECTIVENESS	MISSION READINESS
SEAMOD CONVENTIONAL	0.76 0.75	0.47 0.20	0.36 0.15
MOB	+0.01 (1.3%) ●	+0.27 (135%) ↑	+0.21 (140%) ↑

↑ ≡ Benefit
↓ ≡ Penalty
● ≡ MOB Less Than <2%