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AN OPERATIONAL COMPUTER PROGRAM TO CONTROL SELF DEFENSE SURFACE MISSILE SYSTEM OPERATIONS

The NATO Seasparrow Project Office is developing a new operational computer program for the Self Defense Surface Missile System, which will be delivered sequentially after the first product delivery in May 1991. Working with other government support activities, APL defined many of the program's features. When implemented aboard ships, the program will provide improved sensor integration and track management functions, multiweapon threat evaluation and weapon assignment processing, and other features that will enhance the ability of the system to counter antiship missile threats in the 1990s.

INTRODUCTION

The NATO Seasparrow Surface Missile System (NSSMS) (see the Glossary for definitions of acronyms) is an international, cooperative venture that provides a quick-reaction self-defense response to antiship missiles targeted against ownship (see the NATO Seasparrow article by Roe, this issue). ("Ownship" means the ship with the Self Defense Surface Missile System [SDSMS] installed.) The system is capable of fully automatic operation and fires the RIM-7 Seasparrow missile from one of several missile launchers, including both trainable and vertical-launch versions. A low-light-level television (LLLTV) subsystem aids in the acquisition and engagement of incoming threats and in target kill assessment. The NSSMS is installed aboard fifty-nine U.S. Navy ships, as well as on fifty-three ships of the other twelve members of the NATO Seasparrow Consortium. For U.S. Navy ships using NSSMS, a capable radar with automatic detect and tracking and Identification, Friend or Foe (IFF) was developed to provide detection, a basic combat direction system function, and a weapon direction function. This was the Target Acquisition System (TAS) MK-23, which, together with the NSSMS, constitutes the SDSMS (AN/SWY-1).

Because TAS repeatedly demonstrated the capability to process target detections rapidly through to target engagements, it became a candidate for additional roles in antiair warfare (AAW) self-defense for numerous ship classes.[1] Also, concerns about self-defense stand-alone operations necessitated more TAS interaction with other combat system elements. As a result, the initial operational capabilities of TAS were expanded as additional elements were interfaced and as TAS assumed an expanded role in ship sensor integration, multisensor track data management, threat evaluation and weapon assignment processing, and management of multiple weapon systems.

Currently, SDSMS interfaces (via TAS) with the Combat Direction System (CDS), UPX-29 IFF, and AN/SLQ-32 electronic warfare (EW) system, in addition to its own TAS radar and MK-XII IFF subsystems. In the near term, the rolling airframe missile guided missile weapon system (RAM GMWS)[2] and AN/SAR-8 infrared search and target designation (IRSTD) system will be integrated with SDSMS. On some ships, RAM GMWS is planned as a stand-alone installation with TAS; other ships will have both the NSSMS

GLOSSARY

AAW: Antiair warfare
ACDS: Advanced Combat Direction System
CDS: Combat Direction System
CIS: Centralized IFF System
CIWS: Close-In Weapon System
ESM: Electronic warfare support measures
EW: Electronic warfare
FCS: Fire Control System
FLIR: Forward looking IR
GMFCS: Guided Missile Fire Control System
GMWS: Guided Missile Weapon System
ICSTF: Integrated Combat System Test Facility
IFF: Identification, Friend or Foe
IR: Infrared
IRSTD: Infrared search and target designation
LLLTV: Low-light-level television
NSPO: NATO Seasparrow Project Office
NSSMS: NATO Seasparrow Surface Missile System
NSWSES: Naval Ship Weapon Systems Engineering Station
OCP: Operational computer program
RAIDS: Rapid ASM Integrated Defense System
RAM: Rolling airframe missile
SDSMS: Self Defense Surface Missile System
TAS: Target Acquisition System
TI: Tracker/illuminator

and RAM weapon systems. Future additions to the SDSMS combat system may include the Rapid ASM Integrated Defense System (RAIDS), the Centralized IFF System (CIS), the Close-In Weapon System (CIWS) (Phalanx), new CDS/Advanced Combat Direction System (ACDS) variants, and new computers and consoles.

Concurrent with these integration efforts, the NATO Seasparrow Project Office (NSPO SEA-06P) is pursuing a vigorous program of upgrades and improvements to the overall system.[3] These include performance improvements in TAS, such as automatic frequency agility, detection/acquisition sensitivities, and adaptive filtering processing. Antenna relocation on some ships will also provide better low-altitude coverage to support NSSMS. An electro-optical adjunct is being considered to improve the performance of the LLLTV by means of an automatic tracking function, an improved operator display, and forward looking IR (FLIR). Improvements in the Fire Control System (FCS) are being made with processor upgrades, the formulation of intelligence for the missile via prelaunch messages, and improved test/training capabilities. The Seasparrow, which can be fired from vertical launching systems (MK-41 and MK-48), will be capable of dual-mode guidance (RF/IR) with improved low-altitude and kinematic performance when RIM-7P and RIM-7R are introduced. Many of these upgrades have been proven by means of a comprehensive program of test firings and fleet exercises.

Managing this complex and growing combat system requires powerful new processing capabilities to meet integration, coordination, and management responsibilities. In early 1989, NSPO set out to provide an operational computer program (OCP) resident in TAS to be used for SDSMS sensor integration and control, system command/control, and weapon coordination processing. The intent was to have the OCP available to support RAM GMWS fleet introduction and AN/SAR-8 testing and to upgrade fleet SDSMS capabilities. Accordingly, NSPO formed a working group with technical representation from APL, Vitro Corporation, Naval Ship Weapon Systems Engineering Station (NSWSES), and Hughes Aircraft Company (the design agent) to establish the requirements and specifications for the OCP, which would be developed by the Hughes Ground Systems Group in Fullerton, California.

The resulting requirements[4] specified that the following actions be designed into the OCP:

1. Upgrade present radar track-to-track correlation logic to include TAS, CDS, and FCS sources.
2. Provide multisensor track-to-track association of radar, infrared (IR), and electronic warfare support measures (ESM) tracks.
3. Provide the ability to evaluate threats and assign weapons for up to three NSSMS and/or three RAM GMWS.
4. Provide adaptive doctrine determination of weapon system, salvo size, and designation type on the basis of ship configuration, ship readiness state, rules of engagement, order of battle, environmental effects, and weapon loading.
5. Implement automatic kill/survive assessment of engaged threats on the basis of multisensor data sources.
6. Provide the operator with the ability to selectively filter and clarify the tactical display.
7. Provide the ability to cue the NSSMS fire control radar on the basis of passive (IR and ESM) data.
8. Provide interfacing with the UPX-29 IFF, AN/SAR-8 IRSTD, AN/SLQ-32 EW system, RAM GMWS, and CDS.

The program was written to take advantage of the reusability of existing code. A modular approach was taken to ensure maintainability and future use of program elements. The SDSMS OCP is resident in an AN/UYK-44 Navy standard computer.

GENERAL DISCUSSION

The SDSMS OCP (Fig. 1) being developed builds on a proven design that has evolved through fleet use and fleet-tested methods; it incorporates lessons learned and feedback from operational experience. The design is being supplemented with innovative features, as noted earlier, that facilitate the automatic operation of the system elements, allow for system growth, and provide the flexibility for alternative equipment layouts and installation on other ship classes.

The processing tasks for SDSMS can generally be regarded as consisting of the following three functional areas: sensor integration and control, system command and control, and weapon coordination.

Additionally, capabilities are provided to simulate sensor, weapon, CDS, and navigation inputs and to record information stored in computer memory, to verify operability of the SDSMS (hardware and software), and to exchange tactical data with CDS on board ownship.

A disciplined, structured approach to computer program design was taken for the OCP. The program consists of twenty-two modular elements that are exercised by the program executive on a periodic or aperiodic basis, depending on their specific functions. It can operate in automatic, semiautomatic, and manual modes (target detection through weapon designation). Provision is made for manual and CDS override in any mode at any time. The SDSMS OCP also provides for operating, training, and test states in which the states are mutually exclusive and do not interfere with each other.

Sensor Integration and Control

The sensor integration and control function provides sensor control, detection, tracking, identification, and track management tasks for SDSMS (Figs. 2 and 3). Although the TAS radar and IFF subsystems satisfy the primary self-defense active surveillance and detection requirements, the ability to process detection and track data from other shipboard sensors (active and passive) is provided. The source of these data may be other combat system sensors that report via the CDS, AN/SAR-8 IRSTD, AN/SLQ-32 EW system, AN/UPX-29 IFF, and/or the NSSMS fire control radar.

Report control processing includes tasks to begin and maintain digital communications with the various sensor systems, to monitor their operational status, and to set up reporting criteria. Interface controls allow the operator to specify track reporting zones, reporting categories,

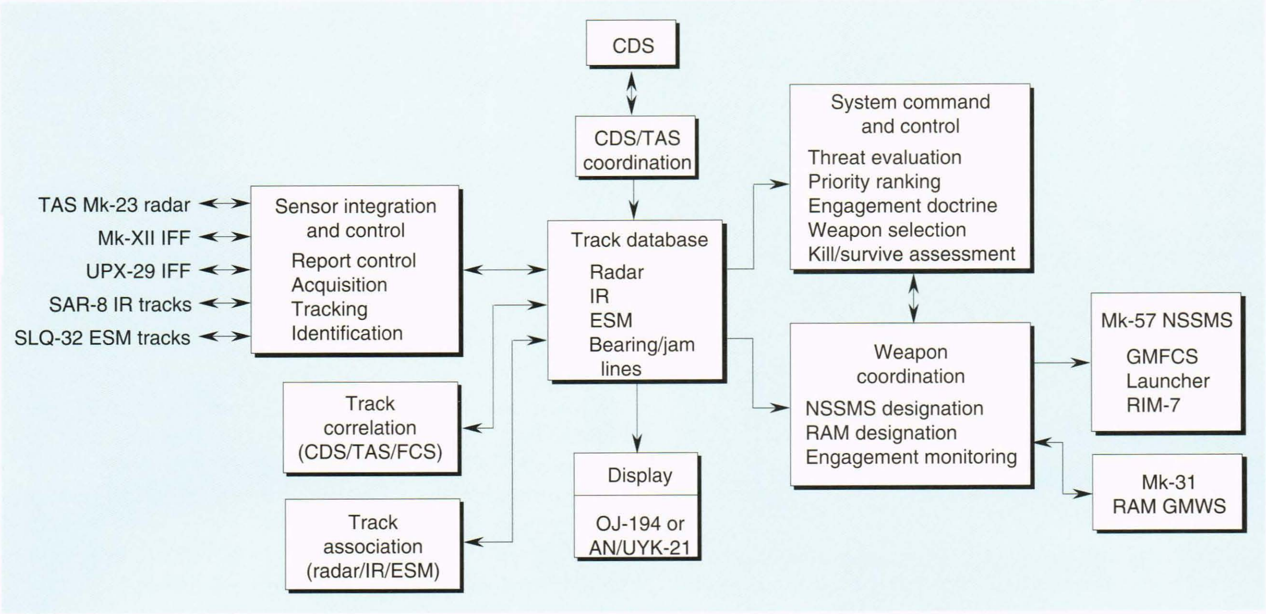

Figure 1. Overview of the SDSMS OCP. Automatic processes with operator override capability are stressed.

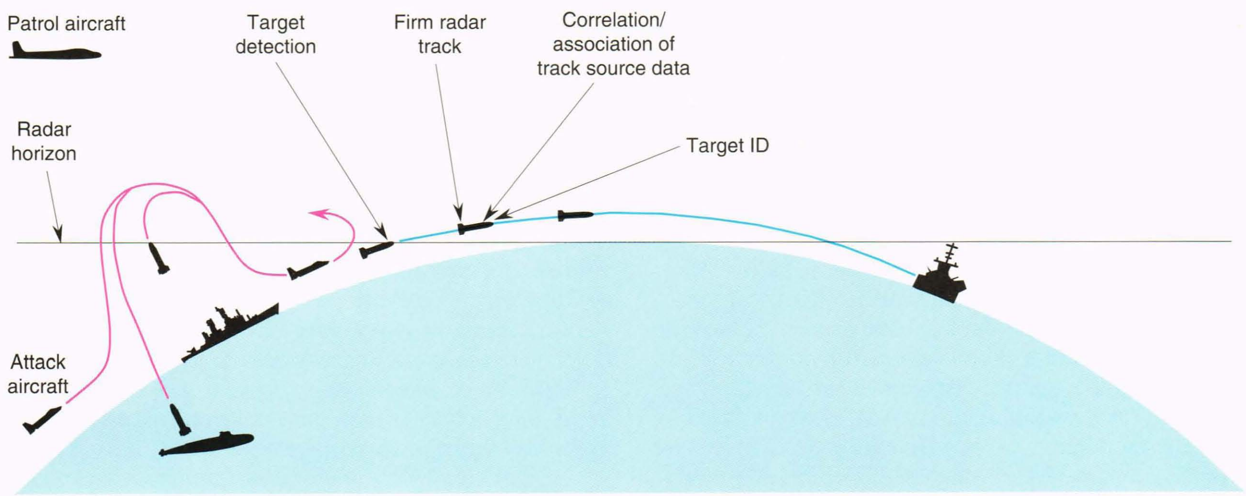

Figure 2. Target detection and track phase. Antiship missiles launched from surface, subsurface, or air platforms are detected by the SDSMS combat system integrated surveillance suite.

cease/suspend reporting, and other management functions necessary to coordinate and maintain the surveillance picture.

Track management provides processing and controls to accept tracks from the sensor systems and to establish and maintain a system track file that is always available to the other processing functions. The track file is constantly updated with new detections and is maintained at or near capacity by filtering and purging. All required track data and status information are stored for each track.

For tracks that have been reported by the surveillance suite, the SDSMS OCP performs a correlation to determine which tracks correspond to the same point source. The correlation process compares positions, rates, categories, and identifications in making this determination. If the correlation is made among similar source tracks (i.e., CDS, TAS, or FCS radar), tracks are selectively retained in the track file to ensure an adequate composite picture. If the correlated tracks are from dissimilar sources (i.e., radar, IR, and ESM), the tracks are linked by software, and both (or all) tracks are retained.[5] Another fusion of the track data is performed at the time of track designation to ensure that the most recent and precise parameters are used to form the designation message.

System Command and Control

The SDSMS system command and control function processes all incoming unknown and hostile air tracks and all missile tracks to determine the relative threat

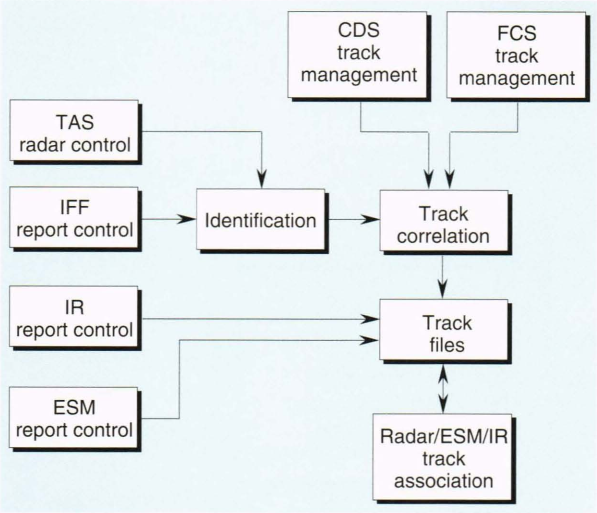

Figure 3. The sensor integration and control function of the SDSMS OCP provides sensor control, detection, tracking, identification, and track management tasks for SDSMS.

potential to ownship and to rank the threats by priority accordingly (Figs. 4 and 5). The threats are then processed to determine if they can be engaged, or will be engaged, by the available weapon systems. A weapon system and a recommended salvo size are selected, and the designation is scheduled in accordance with the threat's priority and selected doctrine. At the appropriate time, a designation message is formatted, and the threat is ordered for engagement by the assigned weapon.

Although actual engagement control is the responsibility of the specific weapon system firing officer, positive control over target engagement processing within the SDSMS command and control function is provided to the TAS console operator. This includes break-engage (meaning to stop engaging the threat), hold-fire, assign, and engage actions, as well as the ability to reinitiate engagement of targets that have been terminated or suspended. These controls are consistent in function and definition with those in CDS. The operator can also specify engagement doctrine; however, the SDSMS OCP can operate autonomously, and an engagement can be processed from detect to engage through the SDSMS without operator intervention.

Threat selection is made in accordance with predetermined eligibility criteria that include identity, category, closest point of approach, and track characteristics (i.e., position, rates, and emissions). A priority is assigned on the basis of a computed threat factor, which is determined by the time remaining to engage the threat considering its current range, range rate, and heading; the ability of the threat to turn or maneuver is taken into account. Pop-up threats and CDS-ordered tracks can immediately be processed and ranked. Tracks that have been formed only on the basis of IR or ESM information (and thus do not have range data) are grouped into priority categories so that they can be processed for weapon assignment as engagement doctrine specifies.

In determining how the threat is to be engaged, the established engagement doctrine, which may be specified differently in operator-defined sectors about the ship, takes into account the association state of the threat, weapon availability and inventory count, threat loading on the various weapon systems, potential for weapon-to-weapon interference, and other threat characteristics. On the basis of the designation alternatives, a weapon type (NSSMS or RAM) will be chosen, along with the specific system, salvo size, and designation type (automatic or semiautomatic).[6] When available, an NSSMS FCS is assigned to assist a RAM designation in obtaining more precise targeting information (TAS does not presently provide elevation or height estimates) for launcher pointing and firing of the missile.

The SDSMS operator is given a comprehensive display of the tactical picture to enable him to monitor SDSMS operations and to interact appropriately with the process. Track symbology, controlled reaction zones, various alerts, and digital display indicator readouts are available to the operator. With the new OCP, the operator can also

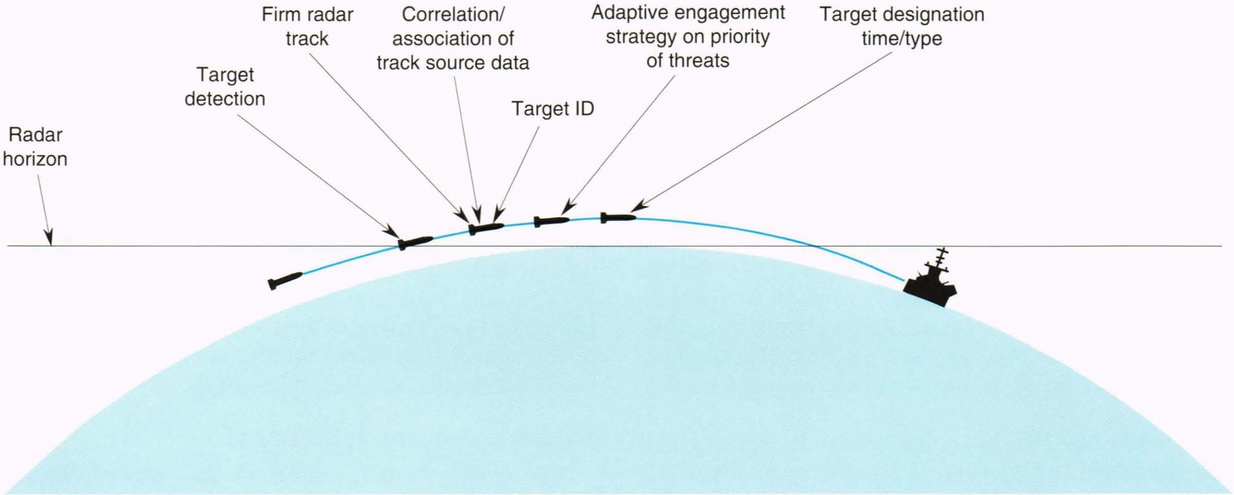

Figure 4. Control phase of the engagement process. In accordance with selected doctrine and rules of engagement, the hostile intent of detected tracks is determined and engagement decisions are made.

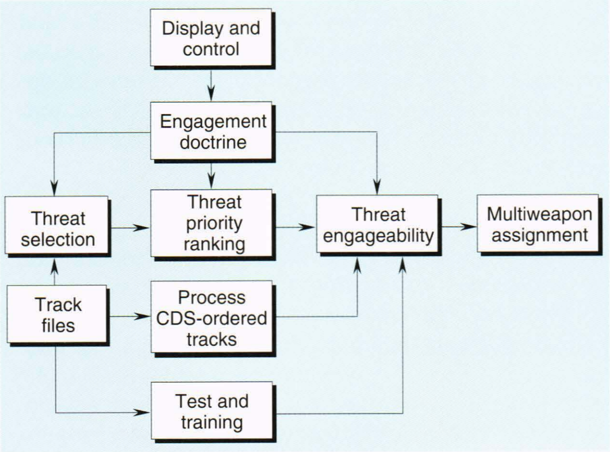

Figure 5. The system command and control function of the SDSMS OCP processes all incoming air tracks, determining which ones are threats to ownship, ranking them by priority, and scheduling them for engagement by self-defense weapons.

selectively filter certain information on displays to clarify the presentation. Human factors engineering has been used to solve man–machine interface problems for this very busy operator.

Weapon Coordination

The SDSMS OCP designates threats to the NSSMS and RAM GMWS and updates these designations in accordance with interface data exchange rules (Figs. 6 and 7). The designations and updates are made with extrapolated track coordinate data from the track files. Designation messages to the weapon systems are formatted by using the best parameters from the associated tracks (or, in selected cases, an averaged value) that represent the threat. Thus, a combined or fused track is sent to the weapon system. For NSSMS, this accurate designation can shorten the time for tracker/illuminator search and lock-on. To obtain accurate elevation, range, and range rate data for a RAM engagement, a designation may also be sent to NSSMS with a hold-fire.

The SDSMS OCP receives weapon status and engagement repeatback. It uses the status information to determine availability of systems, to verify that the correct track is being engaged, to detect interface errors or time outs, and to sense changes in operational states. The designation repeatback messages allow the SDSMS OCP and the operator to determine the progress of the ongoing engagements and alert the operator of the need to take such action as break-track or hold-fire. If the identification of a designated track changes to friend, the OCP will automatically cancel the designation. If designated tracks are lost, designations are continued on the basis of "coasted" or extrapolated data until the engagement can be terminated.

Kill/survive assessment processing attempts to determine whether an engaged threat has been killed or has survived. For an NSSMS engagement, the SDSMS OCP uses the radar set console operator's evaluation of the missile's success at intercept. Also, after receipt of an intercept alert from the NSSMS, other shipboard sensor information provided by the ship's surveillance suite will be used in the kill/survive determination. For RAM designations for which an NSSMS has been assigned, the tracker/illuminator (T/I) may remain assigned to the target to assist in kill/survive assessment if it is not needed to support a Seasparrow engagement. Threats that have survived the engagement are reevaluated for reassignment to all available weapons. Threats that have been killed are excluded from further automatic engagement processing.

The SDSMS OCP also can extract and record computer-stored data, monitor computer operational conditions and interfaces, verify operational readiness of the SDSMS and the individual subsystems, and provide test and training for the SDSMS combat system operators.

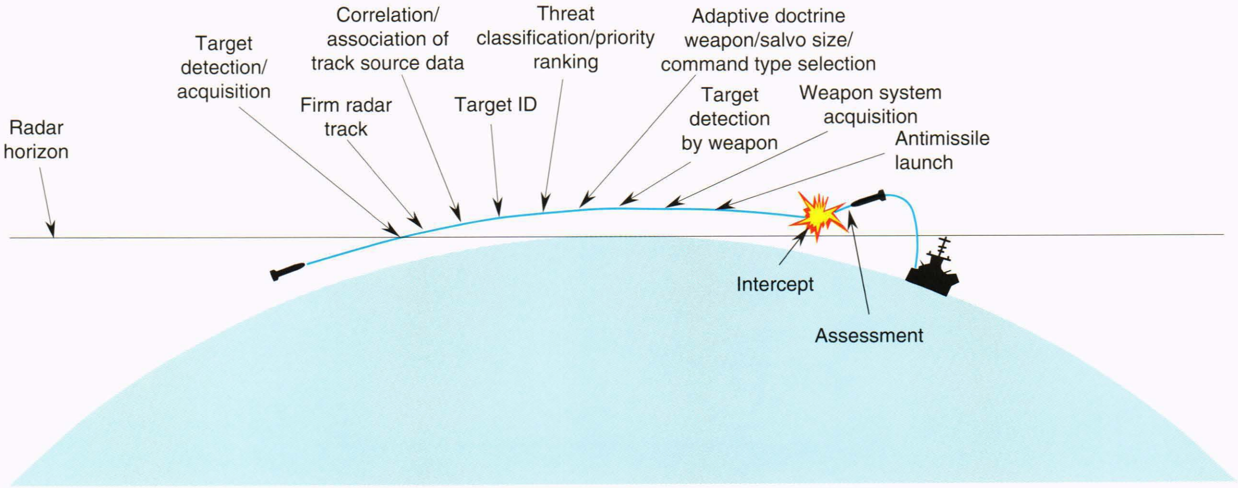

Figure 6. Engagement phase of the SDSMS in which the threat is engaged by the selected weapon system. A typical self-defense detect-to-engage sequence lasts 20 to 70 s.

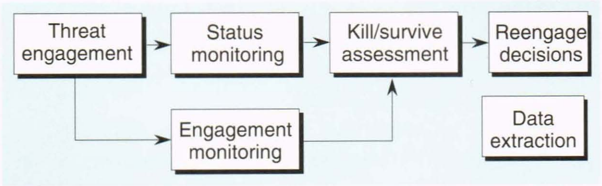

Figure 7. The weapon coordination function of the SDSMS OCP designates threats to the installed weapon systems, determines the outcome of the engagements, and causes reengagement, if appropriate.

FUTURE PLANS

The SDSMS OCP will become operational in the fleet after undergoing integration testing at the Surface Weapons Engineering Facility at NSWSES and the Integrated Combat System Test Facility (ICSTF) in San Diego. Shortly thereafter, two planned installations—the CVN-65 and LHD-5 (Fig. 8)—may provide additional opportunities to upgrade the SDSMS and the OCP further. The NATO Seasparrow Project Office is considering options for upgrading the computer processing capabilities in the SDSMS. Computers in both TAS MK-23 and the NSSMS are at or near tactical digital standard limits in core and timing reserves. More capable consoles are needed, and some operators are severely overloaded. The Laboratory is studying processor upgrades and the overall architecture and functional allocation of the system. Preliminary findings have resulted in recommendations for processor upgrades to computers having open backplanes that could be included in a local area network architecture. Conversion of the computer programs to Ada (the standard DoD language) has also been recommended. Although this is a costly one-time effort, it should have a long-term payoff in program maintainability and reusability.[7]

With the CVN-65 and LHD-5 installations, the OCP may be enhanced by further expanding the adaptive doctrine features of the program. Sensor data fusion, engagement rules, and soft-kill (deception and seduction weapons) coordination appear to be areas that lend themselves to adaptive doctrine techniques. The application of artificial intelligence to key doctrinal changes on the basis of system or environmental conditions is being considered. The ability of the SDSMS operator to interact with the doctrine should also be expanded.

More sensor information than is now used by SDSMS is available from the sensor suite—other radar and link information through the CDS, electro-optical reports from the LLLTV, and IR information. In many instances, this information becomes redundant; however, each of these detection sources could potentially provide the first indication of the threat. New or improved sensor data fusion techniques for SDSMS operations will be investigated. Coupled with these investigations is the requirement for improved sensor cueing techniques wherein intelligence indicating the presence of a threat in the ownship surveillance region can be used to cue other sensors. The sensors can then concentrate on a specific area or volume to verify the threat's presence and to obtain additional information about it. This intelligence could be used to formulate additional prelaunch messages to optimize missile performance.

A more comprehensive scheduling process is needed for SDSMS. The current program provides weapon selection on the basis of doctrinal rules that are generally embedded in the program. When threats come within range of the installed missile systems (NSSMS and RAM), they are assigned to the appropriate weapon system with a specified salvo size. If threat density is such that weapons are unable to accept additional assignments, bumping techniques are used to ensure that the most threatening tracks are engaged first and that other tracks are queued up in priority order for designation at the first opportunity (i.e., when a system becomes available). Scheduling is required to project threats to ownship that are not currently engageable but will be soon. A schedule must be formed that will (1) project future loading on the weapon systems to provide engagement decisions that maximize the probability that assets will be available to counter future threats, (2) avoid conflicts that may lead

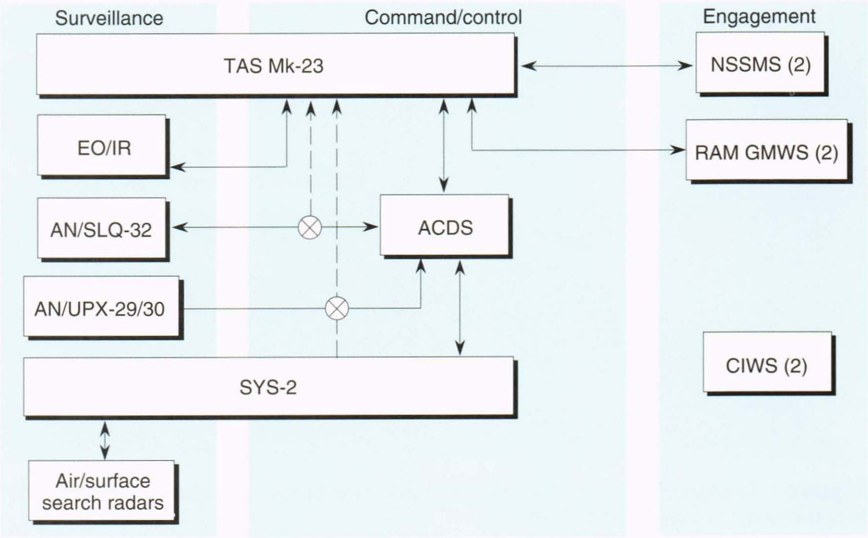

Figure 8. Proposed configuration of the LHD-5 combat system (circa 1996), the first ship to have both NATO Seasparrow and RAM GMWS capabilities. In the figure, the primary path is shown by a solid line; if the switch is thrown, the alternate (dashed) path is followed.

to fratricide or interference among a ship's assets, and (3) manage resources so that overexpenditure of assets on any one threat is avoided and the maximum number of threats are engaged.

The scheduling of hard-kill weapons (NSSMS, RAM) must be coordinated with soft-kill assets (electronic countermeasures, chaff, decoys) to use the joint ability to minimize an antiship missile hit on ownship effectively.[8] Soft-kill tactics must be developed that can be implemented in software. Depending on the integration and operational concepts that are developed, the functions ordering these engagements may reside on both sides of the hard-kill/soft-kill interface or in the overall SDSMS command and control area. Effective interaction of hard-kill and soft-kill elements will depend on a clear definition of responsibilities in detection, identification of the threat, engagement, and kill/survive assessment.

An expanded kill/survive assessment process is needed to reduce the response time for such processing and to produce a higher confidence assessment. Information from each correlated sensor viewing the track under engagement should be used in this evaluation.

CONCLUSION

The evolution of the SDSMS is important to ensure that fleet self-defense continues to pace the threat. Navy ships will have the SDSMS installed well into the next century. These ships and their missions must be supported. The SDSMS OCP described in this article will be deployed in 1992 and represents a major step in providing an enhanced self-defense capability for the fleet elements for which it is intended. Concurrent with the OCP development described in this article, APL is continuing to work with the NSPO to establish SDSMS detailed system-level requirements, as well as plans for development or upgrade of specific system components consistent with those requirements. The SDSMS community and APL are also working with other offices involved in AAW planning to ensure that our efforts are mutually supportive.

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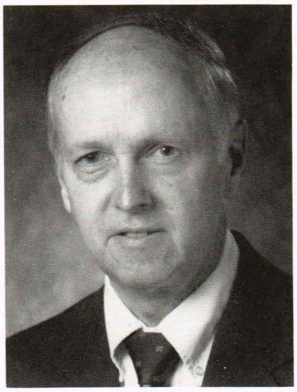

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