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RAM GUIDED MISSILE WEAPON SYSTEM

The SEASPARROW and the RAM are short range missiles intended for antiair self-defense of surface ships. Versions of SEASPARROW have been deployed for some time.The model RIM-7M SEASPARROW, now being developed, will be supplemented on SEASPARROW ships by the RAM, which will provide more firepower against specific threats. The RAM and its associated ship system may also protect small craft that have no other antiair defense.

INTRODUCTION

A defense in depth is required to defend individual ships and task forces successfully; different defensive weapons are necessary to engage at long, at medium, and at short ranges. The world's navies have developed many weapons to protect their ships against air attack. These weapons include aircraft, missiles, guns, and countermeasure devices to confuse the guidance systems of the attacking threats. While these weapons are reasonably successful in destroying attackers, increased firepower continues to be a very desirable attribute.

The RAM Weapon System currently being developed provides higher firepower than existing weapon systems because it uses different guidance principles. Less equipment is required on the ship to support the missile guidance function. This, in turn, also results in a reduced requirement for operating and maintenance personnel.

The unique design concepts required to achieve this capability were successfully demonstrated by APL, General Dynamics/Pomona Division, and Hughes Aircraft Co. in tests and analyses from 1966 to 1979. In June 1979, the governments of the United States, the Federal Republic of Germany, and Denmark entered into a contract with General Dynamics to proceed with full-scale engineering development of the RAM Missile and one of two systems to control and launch the missile. Since that time, APL has continued to assist the Navy in the technical development of this system. Recently, the Netherlands and Belgium have joined the program, while Canada and Norway currently participate as observer nations.

APL has provided technical support to both the Naval Air Systems Command and the Naval Sea Systems Command during the development and testing of both the SEASPARROW and RAM Missiles, has supported the integration of SEASPARROW Weapons Systems aboard ships, and presently is involved in the integration of the model RIM-7M and associated weapon systems into existing and future ships. APL and General Dynamics/Pomona Division jointly originated and tested the RAM guidance and control concept. The Laboratory provides technical support to the Naval Sea Systems Command in the development and integration of the missile and the shipboard system.

BACKGROUND

Air defense missiles must either hit the target or pass within the lethal range of the warhead (typically 5 to 50 feet). This requires that the missile either home on signals emanating from the target or that the missile be directed to the target by shipboard devices that accurately monitor target and missile locations. Most shipboard air defense missile systems home on signals that are produced by the defending ship and then are reflected from the target. A shipboard radar tracks the target and transmits additional signals directed at the target in a narrow beam. These additional signals are reflected by the target and are then detected and tracked by a receiver in the missile. Information obtained from these reflected signals is used to steer the missile toward the target. This method of controlling missile flight is called *semiactive homing guidance* because the transmitter is located on the ship and the receiver is located in the missile. Another form of missile guidance, *command guidance*, uses radars on board the ship to track both the target and the missile while command signals are transmitted to the missile to steer it. Missiles are also guided toward the target using *beamrider guidance*, in which shipboard radar tracks the target and the missile is launched into the radar's beam. The missile's beamriding guidance receiver detects modulations of the radar signal to maintain the missile at the center of the beam until intercept. Some combination of these methods may also be used.

The shipboard radars used for semiactive, command, and beamrider guidance must maintain track of the target until intercept. Ships will typically have more than one tracking radar aboard; however, the number of targets that can be engaged is limited by the number of these radars. Newer radars are being developed that can provide guidance signals to more than one target at a time, but they will be limited at first to cruisers or larger ships.

An attractive alternative approach is to derive guidance information from emissions from the target. The major air threat to ships today is the cruise missile. At least 27 different cruise missile weapons have been produced by nine different nations.[1] These weapons can be launched from aircraft, submerged submarines, surface ships, and land. A large percentage of these weapons use self-contained active radars for guidance. The RAM Weapon System was conceived in this context. It is designed to acquire and home on the radar guidance signals emanating from antiship missiles. Using target data from shipboard passive sensors instead of from dedicated tracking radars, the launcher is pointed in the direction of the threat and the missile is fired. The firepower resulting from this weapon is much greater than from systems requiring shipboard tracking radars for missile guidance. Advances in guidance technology are under continual consideration for enhancement of the capability of this weapon.

SYSTEM DESCRIPTION

Functional System Operation

The RAM Weapon System uses search radars and passive radar frequency sensors called electronic warfare support measures equipment to detect the presence of radiating threats. Figure 1 illustrates the functional operation of the RAM Weapon System.

Shipboard search radars detect targets and report target direction and range. Electronic warfare support measures equipment detects only targets that are radiating and measures their frequency and target direction. The data from these two sensors are then correlated by computers to establish legitimate targets for RAM engagement. As targets come into RAM engagement range, designation commands are sent to the RAM Weapon System, the launcher is slewed to the target direction, and a missile is fired. The missile radar frequency seeker acquires the target radar signals in flight and initiates homing. The missile also has an infrared passive homing receiver that detects infrared radiation from the heated skin and the engine exhaust of the target. When the missile approaches the target, guidance is transferred from the radar frequency seeker to the infrared seeker for the terminal phase of the flight. As the missile passes close to the target, an active optical target detector detects the presence of the target and triggers the warhead. When the missile scores a direct hit, a contact fuze triggers the warhead.

Hardware Configuration

A major feature of the RAM Weapon System is that it will operate with currently installed shipboard equipment with only minimal software and hardware modifications to the surveillance sensors and the Combat Direction System. The only sizable additions required are a launcher and its peripheral equipment, an operating console, and storage for additional missiles.

Surveillance and Weapon Direction Equipment—Modern warships have search radars and passive equipment that will satisfy RAM targeting requirements. The target data must be processed as rapidly as possible to support the high firepower of the RAM Weapon System. On U.S. warships, this information can be obtained from the AN/SLQ-32(V) Electronic Countermeasures Set and the Mk 23 Target

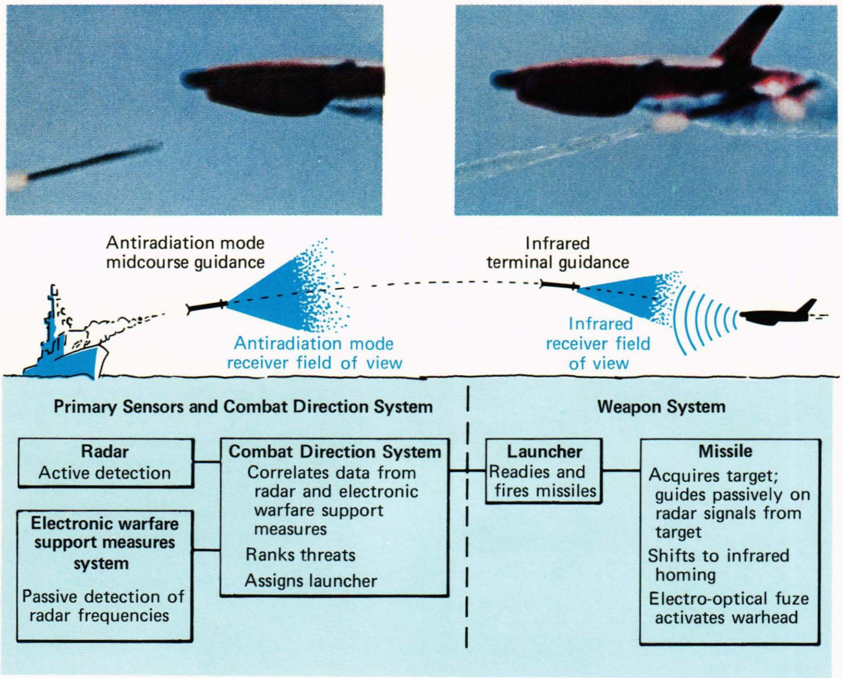

Fig. 1—RAM Weapon System functional operation. In a typical engagement, radar and passive tracks of a target are correlated by the Combat Direction System, which designates the target to the weapon system. A launcher is assigned to the target and subsequently a RAM round is fired. After launch, the RAM Missile detects radar emissions from the target to make midcourse guidance corrections. As the target is approached, guidance is switched to infrared homing for final corrections. Detonation of the warhead within lethal range of the target is initiated by a signal from the optical fuze. The inset shows a test intercept of a drone by the RAM Missile.

Acquisition System search radar. Both of these systems use digital computers to detect and track targets. Computer algorithms are being developed to correlate the data from the Target Acquisition System and the Electronic Countermeasures Set in order to rapidly identify radiating threats and to support the target selection and weapon assignment functions.

Weapon System Configurations—At the present time, the RAM Missile is planned to be deployed in two weapon system configurations. The first uses the present NATO SEASPARROW launcher (Mk 132) in which two of the eight SEASPARROW's are replaced by two guide inserts containing five RAM rounds each (Fig. 2). Modifications to the SEASPARROW software, launcher, and firing officer's console will be made to accommodate the RAM Weapon System. The semiactive guidance NATO SEASPARROW has a longer range than RAM Missiles and can engage both radiating and nonradiating threats, while the RAM Missile measurably increases firepower at shorter range against radiating threats. Computer-assisted weapon employment doctrines are being developed to provide optimum use of these weapons in varying threat situations.

The second RAM configuration, called the Guided Missile Weapon System (EX-31, Mod 0), uses a modified gun mount from the Close-In Weapon System. (The Close-In Weapon System provides close-in defense using 20 mm guns against high speed, low flying missile or aircraft targets.) Twenty-four missile rounds, loaded individually from the rear, are housed in a launching guide assembly that replaces the gun and its associated radars (Fig. 3). The lightweight guide assembly is manufactured from fiberglass composite materials. Many of the components of the EX-31 Weapon System Launcher are being manufactured in Germany. Other major components of the weapon system include the Launcher Servo Control Unit, the Weapon Control Panel, and a small computer assembly for missile control and interfacing with the ship's combat system.

Missile Round—The RAM round consists of the XRIM-116A Missile enclosed in an EX-8 canister that provides environmental protection for the missile and serves as a launching tube. The missile consists of a guidance section, control section, ordnance section (active optical fuze and warhead), and a rocket motor (Fig. 4). The overall length of the missile is approximately 110 inches and the body diameter is 5 inches, although folded wings, tails, and clamps extend beyond this diameter. The nominal weight of the missile is 161 pounds. The missile will roll in flight, permitting use of a single-plane guidance and control system. The missile roll is achieved with a rifling guide designed into the launch tube.

The guidance section consists of an aluminum shroud, a clear infrared dome, four antennas, a modified STINGER infrared seeker, the radar frequency seeker, and guidance mode switching circuits (transition electronics). Facing forward are two wideband interferometer antennas whose output signals provide guidance information; the other two antennas (facing aft) are used in the rear sector gate circuitry to reject radar signals arriving from the rear of the missile. Since the radar frequency seeker provides initial and midcourse guidance and the infrared seeker provides terminal guidance, transition electronics are required to determine when radio- frequency to infrared changeover should occur and to channel the proper signals for steering.

The control section contains the fixed (rectangular) and movable (delta) wing assemblies. The delta wings are mounted on a common shaft and are driven from a single torque motor. The wings are folded into slots in the airframe before launch. All wings unfold from front to back and lock upon deployment. The rectangular forward wings are deployed after rocket motor burnout to compensate for the shift in the missile's center of gravity that occurs as the rocket motor burns out. Also contained within the control assembly are the servo motor, associated electronics, autopilot sensors, and missile batteries. The ordnance sec-

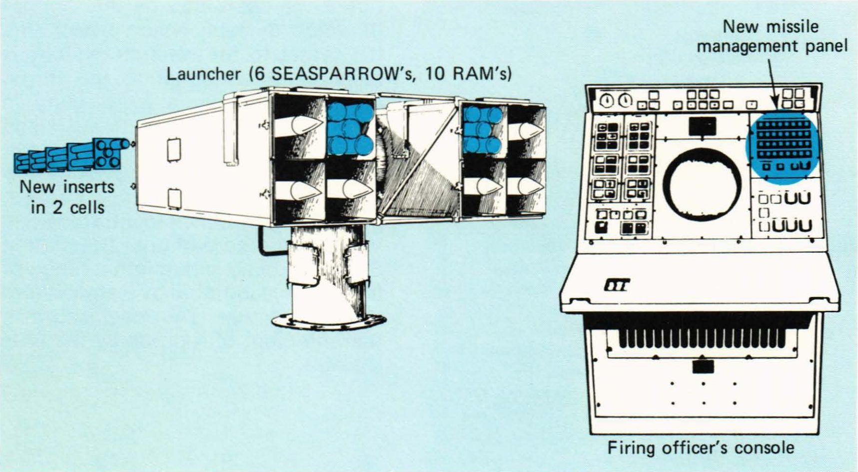

Fig. 2—The RAM modification to the NATO SEASPARROW Missile System. Two SEASPARROW Missiles will be removed from the launcher and replaced by two guide inserts, each able to hold five RAM Missiles in canisters. Modifications will be required in the launcher, in the missile system computer program, and also in the firing officer's console.

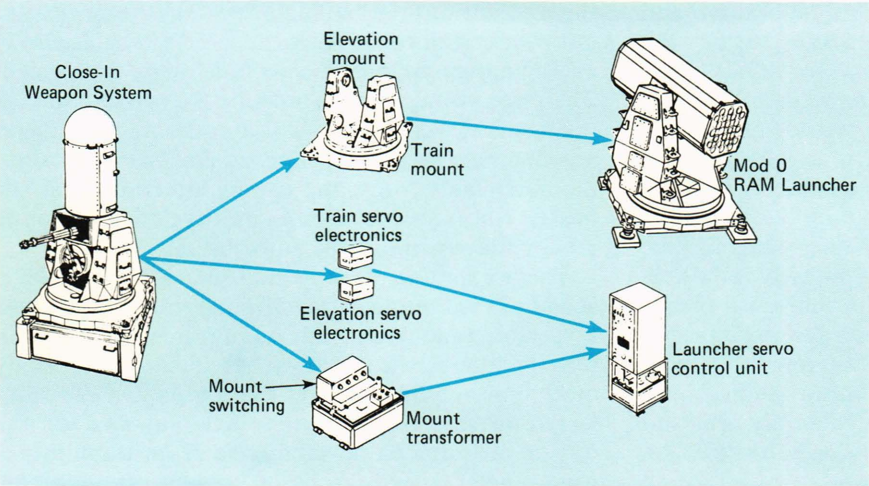

Fig. 3—Conversion of the Close-In Weapon System gun mount to the RAM application. To achieve this conversion, the gun and radar are removed, an additional casting is added in the elevation trunnions to permit clearance for the missile guide assembly, and the launcher base is removed. Electronics for providing control of the launcher are housed in a separate equipment rack. A reinforced fiberglass missile guide assembly is added to the mount, missile-selection electronics are mounted on the bottom portion of the guide assembly, shielding is added to protect the mount from the missile blast effects, and the entire mount is shock-mounted to the deck.

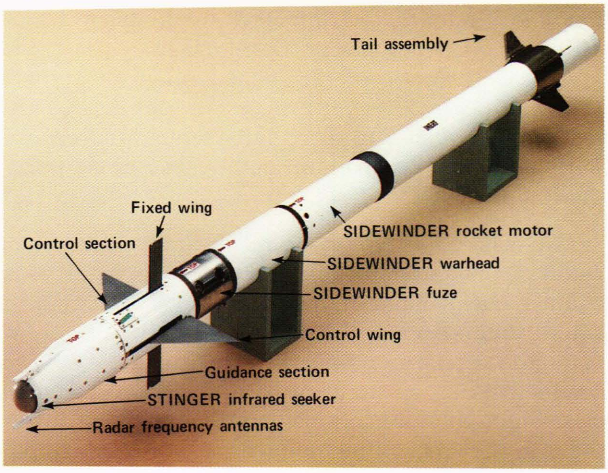

Fig. 4—RAM round. The RAM Missile is enclosed in a canister that also serves as a launching tube. The guidance section consists of a radar frequency seeker and interferometer antennas along with a STINGER infrared frequency seeker. The control section consists of an electromechanical system that directs the movable wings. The ordnance section (optical fuze and warhead) as well as the rocket motor are variants of the SIDEWINDER Missile.

tion contains the SIDEWINDER DSU-15/AB active optical fuze and the SIDEWINDER WDU-17/B warhead.

The rocket motor is a variant of the SIDEWINDER Mk 36 motor. It contains a solid propellant and provides mounting lugs for the folding fixed tail fins. The tail surfaces are folded within the launch tubes and are spring-erected and locked when the missile has cleared the tube after launch. The tails are arranged in a cruciform pattern interdigitated with the wings. To control missile roll rate during the flight, the tail surfaces are slightly canted with respect to the missile axis.

MAJOR TECHNICAL DEVELOPMENTS

The RAM Program is in full-scale engineering development. At this time, much of the early development work has been accomplished. APL contributed heavily to the development of the missile guidance system, the most notable work being that associated with the design of the radar frequency guidance subsystem. Other Laboratory contributions to the missile guidance system were in missile body motion decoupling implementation and in infrared target acquisition. APL also supplied missile guidance hardware for advanced development flight testing.

The development of a high-performance, acceleration-feedback autopilot in a rolling airframe with a single-plane guidance system has been largely the product of General Dynamics. This work is an outgrowth of earlier rolling single-plane control missiles (including the STINGER) now in production and the operational REDEYE. Other major accomplishments have occurred in the areas of aerodynamics, autopilot design, and sensor development. Throughout this development, General Dynamics has conducted the overall missile design, fabrication, and testing activities.

The RAM Weapon System requires a means of rapidly correlating target reports from the search radar and the electronic warfare support measures equipment. The conceptual computer algorithms for this have been developed and tested by APL and Hughes Aircraft Co. The APL work was the outgrowth of other efforts associated with automatic integration of target reports from several search radar sensors.

Although a discussion of all these efforts is not included here, descriptions of the guidance system concept development, the radar frequency seeker design, and the radar and electronic warfare support measures correlation algorithm development are provided below.

Development of the Dual-Mode Guidance Concept

From 1966 to 1973, APL collaborated with General Dynamics/Pomona Division in the investigation of possible applications of these guidance concepts in various missile airframes. During that period, system analyses as well as laboratory and missile flight tests were conducted to develop the dual-mode guidance system required for RAM.

In 1974, work was initiated to develop a 5-inch-diameter rolling airframe missile to provide Navy ships with an improved self-defense capability against antiship missiles that use active radar guidance. Early in the program validation phase, dual-mode flight tests were successfully completed at White Sands Missile Range against target drones using an early radar frequency receiver design. During the validation phase, the missile configuration used an aerodynamically stable airframe in conjunction with a pitch rate feedback control system. The simulation studies indicated a need for additional maneuverability over that available from the validation missile hardware. An acceleration feedback autopilot was then added to ensure that the tactical missile would have the desired maneuverability.

Radar Guidance Design

As a prelude to final radar system design, a four-month radar study program was performed, which was completed in October 1976. The radar study program addressed the following areas: definition of the operational environment, definition of radar guidance candidate systems, and formulation of a detailed list of radar design questions to be addressed prior to actual hardware design.

In March 1977, a design effort was begun at APL that culminated in the fabrication of a radar guidance system for laboratory testing. System analysis and critical hardware experiments were completed prior to the selection of a candidate system for the detailed hardware design. During the radar guidance development at APL, a parallel design effort was being pursued by General Dynamics. Technical information was exchanged between the two design teams via written reports and design reviews. The resulting candidate system was one of four candidate systems defined in the 1976 study program.

In RAM Missiles, guidance information is derived from a single pair of interferometer antennas mounted on the rolling airframe. The interferometer measures radar frequency phase interference. Rolling both the infrared seeker and the radar frequency seeker along with the control system provides the advantage that only a single plane of guidance and control is required, greatly reducing the quantity of hardware involved in the guidance and control of the missile. The basic guidance information is sinusoidal, with a frequency equal to the missile roll rate. This is, in effect, a scan-on-receive angle tracking system, with the effective scan rate equal to the roll rate.

One of the benefits gained from intentionally rolling the radar interferometer antennas is that the classical angle ambiguity problem is solved. Antenna spacing and radar wavelength cause many electrical degrees of phase to be produced (i.e., more than 180 electrical degrees, which is the maximum field of view) for the geometric angle being measured. Under these conditions the actual direction to the target cannot be ascertained. Rolling the interferometer allows an unambiguous phase detection to be performed. The error voltage that represents the space angle between the target line of sight and the interferometer antenna pair becomes a sinusoidal signal. This alternating signal permits the use of integration (at the missile roll frequency) to obtain the desired pointing error voltage without any ambiguities.

The decoupling of body motion in RAM Missiles is accomplished at microwave frequencies by means of a variable time delay path (digital line stretcher) inserted in one of the microwave frequency lines. Body motion decoupling requires the component of the interferometer signal due to pitch and yaw of the missile airframe to be subtracted from the total interferometer signal in order to generate a signal related only to target motion. The delay inserted in the line stretcher is controlled by a gyro, which measures pitch and yaw of the missile body.

A block diagram of the radar guidance system is shown in Fig. 5. For purposes of discussion, the system is divided into three subsystems: microwave, automatic gain control and gating, and angle information processor.

Microwave Subsystem—The microwave subsystem receives the radar signals, provides discrimination against out-of-band signals by means of high-pass filters, and processes the radar frequency in a pair of orthogonal phase comparators to provide sine and cosine of phase angle information at video frequencies. Since the interferometer provides phase information, the target tracking information is not amplitude dependent. Furthermore, the rolling interferometer provides alternating voltage information (the phase information is basically sinusoidal, with a frequency equal to the missile roll rate). Hence, there is

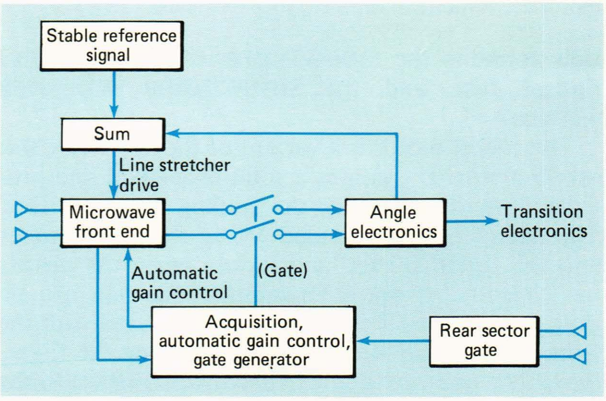

Fig. 5—The RAM radar frequency guidance system processes radar frequency signals from the interferometer antennas to derive seeker pointing and missile steering information. Automatic gain control is used to prevent saturation of the radar receiver. To prevent signals from one's own ship from interfering with guidance, gate electronics generate an inhibit pulse if the signals from the rear antenna exceed those from the forward antenna.

no fundamental requirement for direct-coupled information processing with its attendant bias problems. Since the line stretcher allows the angle information processor to be operated as a closed-loop system, wider tolerances can be allowed in the specifications for the angle-processor operation than would otherwise be possible.

Automatic Gain Control and Gating Subsystem—Because target tracking information is contained in the phase relationships of the incoming signals as opposed to the amplitude, there is no requirement for fast, tight gain control. However, an automatic gain control circuit is required to prevent limiting in the receiver. Two electronically variable attenuators provide automatic gain control at microwave frequencies. Front- and rear-sector signal amplitude information at video frequencies is provided to the automatic gain control circuit. The gating portion of this subsystem makes a pulse-by-pulse decision as to whether the pulse should be gated into the system by generating an inhibit pulse if the radar signal out of the rearward-looking antenna exceeds that out of the forward-looking antenna.

Angle Information Processor Subsystem—This portion of the system takes the in-phase and quadrature video (which represents periodic sampling of the sine and cosine of the sinusoidal radar frequency phase difference) and provides an output that is a sinusoidal voltage proportional to a filtered version of the sinusoidal phase.

The radar guidance system has undergone extensive testing at the subsystem and system levels. A missile digital simulation was designed and implemented at both General Dynamics and APL to support the testing phase. The microwave electronics tests and supporting analysis have indicated that the design is acceptable in terms of overall system performance across the specified radar frequency range (I and J bands). The experimental performance of the automatic gain control and gating subsystems agreed with that expected on the basis of analysis and also verified the analytical models of the various subsystems used in the system analysis.

Development of Radar and Electronic Warfare Support Measures Correlation Algorithm

The need for unambiguous and timely data from radars and passive sensors to support the RAM Weapon System has led to the development of sophisticated signal processing algorithms by APL and Hughes Aircraft. An automatic detection and tracking capability produces much more reliable and timely target data than human operators in complex antiair warfare situations. With these data, the radar and electronic warfare support measures (ESM) correlation algorithms can rapidly sort out radiating versus nonradiating threats. Without these developments, the RAM System's effectiveness would be significantly reduced in multiple target engagements because human operators would become saturated with data and the need for decisions.

The correlation algorithm uses track file data (i.e., digital target information stored in computer memory) from both the radar and electronic warfare support measures systems to find and correlate radar and passive system track pairs that are likely to correspond to the same threat. The algorithm output is a list of correlated radar and passive system track pairs, radar tracks not correlated with a passive system track (radar-only tracks), and passive system tracks not correlated with a radar track (electronic warfare support measures (ESM) equipment-only tracks). Radar-only tracks result when a target is not radiating or when the target's radiation is not detectable. ESM equipment-only tracks typically result when the threat is beyond the maximum radar detection range. The following paragraphs describe the general method used to make the correlation decision.

The radar track file parameters are compared with the ESM equipment track file parameters to find the radar and other track pairs that should be correlated. Some examples of the track file parameters used to make the correlation decisions are shown below.

Radar

Target position — Obtained by measuring target bearing and target range. On some radars, target elevation can also be measured.

Target rate — Determined by differentiating sequential samples of target position data.

Update time — Time of last target report.

Target category — Targets are categorized as air or surface, based on target rate and detection range.

Target identification — Targets are identified as friend, foe, or unknown, based on (identification, friend or foe) equipment reports.

Track type — Indicates whether the target track is firm or tentative, based on the consistency of the target reports.

Electronic Warfare Support Measures System

Track bearing — Determined by the direction-finding capability of the receiver.

Update time — Time of last target report.

Target category — Targets are categorized as air or surface, based on the signal received.

Target identification — Targets are categorized as friend, foe, or unknown, based on the signal received.

Emitter frequency data — Emitter frequency information is obtained and stored.

These parameters are used in a two-step decision process. In the first step, radar and other system track pairs are subjected to a series of gate tests. These tests eliminate grossly mismatched pairs from further correlation processing by comparing parameters, such as bearing separation, to a threshold. Those track pairs that pass all the gate tests are then evaluated in the second step of the decision process.

The second step of the process combines several selected correlation likelihood estimates into a single number that is a measure of the overall likelihood of correlation for each track pair. This value is used to help select the best track pairings in high density situations. A two-hypothesis test of the log likelihood ratio is used to obtain these correlation likelihood estimates. The general form of the correlation likelihood estimate is the logarithm of a probability ratio:

$$LL(D_R,D_E) = \log_a \frac{P[D_R,D_E/H_o]}{P[D_R,D_E/H_i]}$$

where:

$LL(D_R,D_E)$ = log likelihood ratio of the parameters D_R and D_E,

D_R = observed parameter for the radar track,

D_E = observed parameter for the ESM system track,

$P(x/y)$ = conditional probability of observing x given that hypothesis y is true,

H_o = hypothesis that the radar and other system tracks correspond to the same target, and

H_i = hypothesis that the radar and other system tracks correspond to different targets.

The specific form of the correlation estimate will depend on the parameter used in the estimate. Observed parameter values are used either to compute a correlation likelihood or to index a correlation likelihood reference table containing values that were estimated *a priori*.

For example, the radar and the ESM receiver report target identification as either friend, hostile, or unknown. Conditional probabilities for each possible identification combination, i.e., RADAR-FRIEND, ESM-FRIEND/RADAR-HOSTILE, ESM-FRIEND, etc., are estimated *a priori* for the hypothesis that the target reports originate from the same target. Similarly, conditional probabilities are computed for all combinations for the hypothesis that the target reports originate from different targets. The logarithm of the ratio of the conditional probability under the first hypothesis to the conditional probability under the second hypothesis is computed for each identification combination to obtain the correlation likelihood for that combination. All these values are entered in the table and used for the track pair correlation estimate according to the identification categories produced by the radar and the ESM receiver. In a similar manner, other parameters are used to estimate other likelihood values. A number of likelihood functions are summed to obtain the overall likelihood of correlation.

Much effort has been involved in selecting an overall strategy, developing algorithms, determining the statistical models of the parameters and weighting functions, and programming the algorithm in an efficient manner. Limited flight testing involving radiating targets has been successfully conducted and this has led to refinements to the algorithms. Additional testing will be conducted during the remainder of full-scale engineering development.

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[1] R. T. Pretty, ed., *Jane's Weapon Systems, 1979-1980*, Tenth Edition, Franklin Watts, Inc., New York.

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