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ANTISUBMARINE WARFARE SIMULATION ON A MINICOMPUTER

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Simulation has long been considered an effective technique in the area of military applications, especially in systems analysis and in personnel training programs. In this study, a simulation model designated as SEASIM (Surface Escort Antisubmarine Warfare Simulation) was developed to simulate an antisubmarine warfare engagement between surface escorts and an enemy submarine. The model development was sponsored by the Surface Sonar Department of the Naval Underwater Systems Center, New London, Connecticut. The original model was developed to run on a desktop minicomputer to take advantage of its easy accessibility, real-time graphics capability, interactive special features, and low costs. The simulation models specifically the acoustic detection of a submarine by a destroyer and the attack on the submarine by a torpedo-carrying helicopter.

1. INTRODUCTION

1.1 Overview

An antisubmarine warfare system, like any other warfare system, is complex and extremely difficult to study and analyze. The many variables and parameters such as the number and type of ships involved, interaction between ships, long distances, time of the year and day, sun, wind, currents, shipping noise, and other constantly changing ocean environmental factors make mathematical modeling extremely difficult. Laboratory experiments or real-life exercises are time-consuming and costly; often they are prohibitive. Hence, simulation is the most effective technique for studying these systems.

SEASIM is a computer simulation of a hypothetical wartime engagement between surface escorts (destroyers) and an enemy submarine. The fundamental model was developed in 1980 and has since been refined and expanded.

The simulation model was designed to analyze surface-ship antisubmarine warfare (ASW) in the 1990 to 2000 time frame; the specific goal was to quantify sonar system performance, identify shortfalls, and recommend technological improvements. Consequently, the input and output modules of SEASIM were designed to facilitate the variation of sonar parameters and the collection of statistical data on escort effectiveness in detecting, classifying, localizing, and attacking the enemy submarine.

Two different variants of the SEASIM model were developed. The single-escort model simulates an interaction between one surface ship and an evading enemy submarine. The multi-escort model simulates two or three surface ships conducting ASW against one enemy submarine. The multi-escort model can deal with the additional problems associated with multiple-ship ASW such as communications delay and mutual interference. In addition, both models extensively simulate the prosecution of long-range sonar contacts by torpedo-carrying Light Airborne Multipurpose System (LAMPS) helicopters.

The desktop minicomputer was selected as a major tool for the analysis for a number of reasons. First, the minicomputer does have some excellent features which cannot be found on a large computer. The real-time graphics capability on the CRT gives the analyst a visual display of the progress of the engagement. This is invaluable in analyzing tactics and often in understanding the statistical results. Second, the model is written in BASIC, a language that is easily understood and modified. Third, the minicomputer is accessible in many places: classroom, office, laboratory, and conference room. Also, the minicomputer can easily be placed onboard ships. Because the program itself is stored on a cassette tape, it can be readily transported and used.

1.2 Background and Issues

The objective of surface-ship antisubmarine warfare is to detect the enemy submarine at long distances and to

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attack with torpedo-carrying aircraft. The destroyer itself would prefer to stay out of range of the submarine's weapons. The attacking aircraft in SEASIM is the LAMPS helicopter, which is embarked on the destroyer. The usual scenario is that the destroyer detects the submarine on a particular bearing. Although a bearing to the target is known, range usually is only estimated. The LAMPS consequently is launched and flies out on the line of bearing. It drops acoustic sensors and attempts to detect and localize the submarine on these sensors so that he can attack with a torpedo.

Estimates of likely ranges can be made by studying the theoretical sound propagation paths for the environment in which the destroyer is operating.

The propagation of sound in the ocean can follow a number of interesting and unexpected paths. The sound emitted by a submarine may be heard by another ship for a range of a few miles if the sound travels along the surface duct. The sound can also travel down into the ocean and bounce off the ocean floor back to the surface. In certain situations, the sound path can bend and converge back to the surface at a long distance. Consequently, a destroyer may be able to hear a submarine if they are within 10 miles of each other or if they are separated by 30 to 35 nautical miles. The destroyer would not, however, be able to hear the submarine if they were separated by 10 to 30 nautical miles. Figure 1 shows these various sound ray paths.

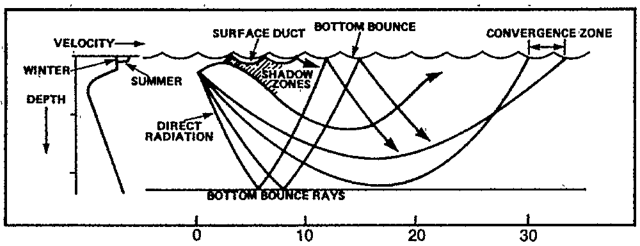


Fig. 1

The SEASIM program addresses the following three basic issues:

1. Detection and Classification Performance. Early detection of a submarine is important for successful ASW operations; therefore, a primary objective of SEASIM is to quantify the expected detection performance against enemy threats. Detection is quantified in terms of probability of detecting, range of detection and percent of time detection is held after initial detection. Once a signal is detected, it must be classified. The signal could emanate from an enemy submarine, a merchant ship, marine life, or from a number of other sources. The classification process is modeled and the probability of correctly classifying a detected signal and the time between detection and classification are recorded.

2. Localization Capabilities and Techniques. Localization, the determination of the position of a contact with sufficient accuracy to prosecute, is one of the most pressing problems in passive ASW. It is especially crucial to surface ASW operations, which rely heavily on the use of aircraft to prosecute contacts gained initially by destroyers and frigates. Several localization techniques are being developed for implementation on surface ASW units. Some are single-platform techniques, while others (e.g., crossfixing) require two or more ships. The various localization techniques have different advantages and disadvantages that relate to the operational and environmental settings in which they are applied. The influence of sensor capabilities on these techniques can be analyzed using SEASIM.

3. Tactics. Because the only information that the escort may have on the submarine is a bearing, the escorts must use appropriate tactics to maintain sonar contact, to keep the threat at a distance, and to localize the target for LAMPS helicopter attack. The continuous CRT display of the progress of each simulation run enables the analyst to study tactics as the scenario evolves and to develop follow-up tactics that depend on a series of previous moves.

1.3 Data Base

One of the first tasks in preparing the simulation was to perform the research for three data books that contain most of the inputs for SEASIM. An environmental data book contains environmental-acoustic data for winter and summer seasons in six ocean environments.

Propagation-loss curves were generated for a number of frequencies for numerous target-sensor depth combinations. These curves are stored on magnetic tape for use by the SEASIM model. Additional curves can be generated if SEASIM is to be used in a different type of ocean environment than the ones available. No environmental data must be entered into the simulation other than the choice of ocean and the season of the year.

A baseline systems data book describes in detail the systems installed on the surface escorts. Data on all applicable sonar systems were collected and documented. Baseline data for all sonar parameters are automatically initialized in the program. Consequently, the analyst does not have to collect and enter numerous data every time the program is used. (Sonar parameters may be changed before running the model if desired.)

A threat data book contains extensive information on the projected enemy submarines. Pertinent threat acoustic data are initialized in the program. Other threat data such as course, speed, depth, and estimated counterdetection range are inputs.

1.4 Inputs

The program begins with a carefully constructed section of interactive prompted inputs. Default values are initialized in the program for all inputs.

The inclusion of default values for all inputs greatly simplifies the use of the program, and, more importantly, increases the accuracy of inputs. Because the program was specifically designed for a sensitivity analysis on sensor parameter variations, the analyst can easily vary the default inputs by responding to prompted questions. The operator has only to vary a few values rather than enter many values.

1.5 Geometry

The geometry for the one-on-one model is derived from a scenario in which a surface escort is directed to locate and track a submarine that was detected by intelligence. In the model, the escort is placed at the lower left (southwest) corner of the engagement area and the submarine is at the upper right (northeast) corner. They start on closing courses, 100 nautical miles apart. The initial position and course of the submarine are randomly varied on each run to avoid repetition.

The multiship geometry can describe a number of different scenarios. For example, two or three surface ships, escorting an aircraft carrier, are conducting an ASW search. They are positioned in a screen approximately 30 nautical miles ahead of the aircraft carrier. The mission of the enemy submarine, which is ahead of the group, is to penetrate the screen and attack the carrier.

1.6 Output

SEASIM output consists of five parts, any or all of which can be printed at the end of a run. The output was specifically designed to aid the analyst in studying the relationship of detection, classification, localization, and attack statistics to changes in inputs. The five parts of the output are:

1. Input summary. To identify adequately the inputs of a run, all manual inputs and all sonar parameters are printed. (Most inputs in the input summary shown in Figure 2 have been replaced by an asterisk so that the figure will not be classified.)

2. Statistical summary. Statistics are collected and printed for detection, classification, localization, attack, and counterdetection, as in Figure 3.

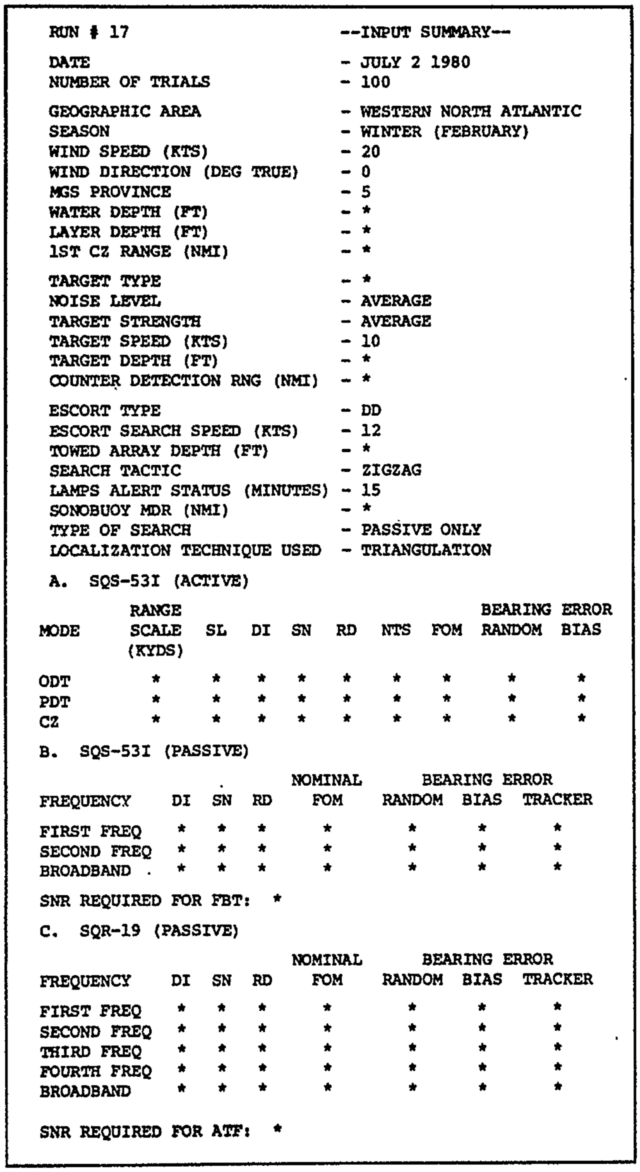
3. Histograms. A number of histograms of range and time distributions are also printed. Figure 4 is one example. A matrix of histogram values is also printed so that the analyst does not have to read values from the histogram.

4. Prop-loss curves. Propagation-loss curves (see Figure 5) can be plotted for all frequencies and depth combinations used in the run.

5. Track plots. The plot showing escort and submarine tracks as well as sonobuoy locations can be printed, as shown in Figure 6. This is especially valuable for analyzing tactics.

NOTE: All sample output is not from the
same run.

One version of SEASIM stores all output on disk. Thus, a data base is built which can be analyzed extensively using any of the many statistical packages available for computer analysis.



```
RUN # 17                          --INPUT SUMMARY--

DATE                              - JULY 2 1980
NUMBER OF TRIALS                  - 100

GEOGRAPHIC AREA                   - WESTERN NORTH ATLANTIC
SEASON                            - WINTER (FEBRUARY)
WIND SPEED (KTS)                  - 20
WIND DIRECTION (DEG TRUE)         - 0
MGS PROVINCE                      - 5
WATER DEPTH (FT)                  - *
LAYER DEPTH (FT)                  - *
1ST CZ RANGE (NMI)                - *

TARGET TYPE                       - *
NOISE LEVEL                       - AVERAGE
TARGET STRENGTH                   - AVERAGE
TARGET SPEED (KTS)                - 10
TARGET DEPTH (FT)                 - *
COUNTER DETECTION RNG (NMI)       - *

ESCORT TYPE                       - DD
ESCORT SEARCH SPEED (KTS)         - 12
TOWED ARRAY DEPTH (FT)            - *
SEARCH TACTIC                     - ZIGZAG
LAMPS ALERT STATUS (MINUTES)      - 15
SONOBUOY MDR (NMI)                - *
TYPE OF SEARCH                    - PASSIVE ONLY
LOCALIZATION TECHNIQUE USED       - TRIANGULATION

A.  SQS-53I (ACTIVE)

         RANGE                                     BEARING ERROR
MODE     SCALE   SL   DI   SN   RD   NTS   FOM   RANDOM   BIAS
         (KYDS)

ODT        *      *    *    *    *    *     *      *        *
PDT        *      *    *    *    *    *     *      *        *
CZ         *      *    *    *    *    *     *      *        *

B.  SQS-53I (PASSIVE)

                               NOMINAL       BEARING ERROR
FREQUENCY     DI   SN   RD       FOM      RANDOM  BIAS   TRACKER

FIRST FREQ    *    *    *        *          *       *       *
SECOND FREQ   *    *    *        *          *       *       *
BROADBAND     *    *    *        *          *       *       *

SNR REQUIRED FOR FBT:   *

C.  SQR-19 (PASSIVE)

                               NOMINAL       BEARING ERROR
FREQUENCY     DI   SN   RD       FOM      RANDOM  BIAS   TRACKER

FIRST FREQ    *    *    *        *          *       *       *
SECOND FREQ   *    *    *        *          *       *       *
THIRD FREQ    *    *    *        *          *       *       *
FOURTH FREQ   *    *    *        *          *       *       *
BROADBAND     *    *    *        *          *       *       *

SNR REQUIRED FOR ATF:   *
```

Fig. 2

1.7 Computer Versions

SEASIM was first developed on an HP 9845B desktop calculator with 187K of memory. The model was written in HP Extended BASIC. The model exceeds the core limitations of the HP 9845B and is executed in three segments that link automatically. The first segment is the input module. Once the inputs are completed, the simulation segment is linked into core. At the end of the simulation run, the summary section is linked into core to print the output. Because the entire simulation section fits in core, no coding has to be linked into core during the execution of the simulation algorithm.

SEASIM later was translated into FORTRAN and installed on a VAX 11/780. The VAX version was calibrated with the HP version. SEASIM has also been installed on a CDC 6600. Testing runs can be calibrated and repeated by controlling the initial random seed. All these versions provide identical output for a given set of inputs.

```
RUN # 33          --STATISTICAL PERFORMANCE MEASURES--
NUMBER OF TRIALS=  70            INITIAL RANDOM SEED WAS: 70972
AVG LENGTH OF TRIAL                359 MIN
PERCENT  DETECTION HELD             25 %
   (AFTER FIRST DETECTION)

DETECTION:
PERCENT  DETECTION|TRIAL = 79 %
AVG TIME OF FIRST DETECTION                      242 MIN
AVG RANGE  OF FIRST DETECTION                     26 NMI

STANDARD  ERROR OF TIME OF FIRST DETECTION        47 MIN
STANDARD  ERROR OF RANGE OF FIRST DETECTION        8 NMI

CLASSIFICATION:
PERCENT   CLASSIFICATION|DETECTION          96 %
AVG TIME  OF FIRST CLASSIFICATION          247 MIN
AVG RANGE OF FIRST CLASSIFICATION           25 NMI

STANDARD ERROR OF TIME                      45 MIN
STANDARD ERROR OF RANGE                      7 NMI

AVG TIME BETWEEN DETECTION                   7 MIN
   AND CLASSIFICATION

STANDARD ERROR OF TIME BETWEEN              16 MIN
   DETECTION AND CLASSIFICATION

SHIP PASSIVE LOCALIZATION:
PERCENT  LOCALIZATION|CLASSIFICATION         4 %
AVG TIME AT LOCALIZATION                   264 MIN
AVG RANGE AT LOCALIZATION                   25 NMI

STANDARD ERROR OF TIME                      33 MIN
STANDARD ERROR OF RANGE                      5 NMI

AVG TIME BETWEEN CLASSIFICATION             31 MIN
   AND LOCALIZATION

STANDARD ERROR OF TIME BETWEEN              13 MIN
  CLASSIFICATION AND LOCALIZATION

AVG TIME BETWEEN DETECTION                  33 MIN
   AND LOCALIZATION

STANDARD ERROR OF TIME BETWEEN              15 MIN
  DETECTION AND LOCALIZATION

AVERAGE ABSOLUTE ERROR:
     OF LOCALIZED BEARING                 1.34 DEGREES
     OF LOCALIZED RANGE                     19 NMI

LAMPS:
AVG NUMBER OF MISSIONS PER TRIAL          .63
LAMPS REDETECTION RATE(PER MISSION)        23 %
AVG LAMPS REDETECTION RANGE                20 NMI
TOTAL LAMPS ATTACKS                        10
TOTAL LAMPS KILLS                           5
PERCENT KILL|MISSION                       11 %
AVG LAMPS KILL RANGE                       19 NMI
ASROC:
TOTAL ASROC ATTACKS                         2
TOTAL ASROC KILLS                           1

TARGET COUNTERDETECTION RATE               76 %

SYSTEMS:
                                 FIRST DETECTIONS
FREQUENCY                    NUMBER           PERCENT

HULL
FIRST FREQ                      0            0.0 %
SECOND FREQ                    23           32.9 %
BROADBAND                       0            0.0 %

CZ ACTIVE                       0            0.0 %

TOWED ARRAY
FIRST FREQ                      4            5.7 %
SECOND FREQ                    24           34.3 %
THIRD FREQ                     10           14.3 %
BROADBAND                      12           17.1 %

PERCENT HULL NARROW BAND                    32.9 %

PERCENT TOWED NARROW BAND                   40.0 %

PERCENT HULL BROAD BAND                      0.0 %

PERCENT TOWED BROAD BAND                    17.1 %

PERCENT ACTIVE                               0.0 %

PROPAGATION PATH:

PERCENT  DETECTION|TRIAL=  79 %

FIRST DETECTION          PERCENT            AVG RANGE

DIRECT PATH                 3%               2 NMI
BOTTOM BOUNCE               0%               0 NMI
1 CZ                       67%              25 NMI
2 CZ                        9%              44 NMI
3 CZ                        0%               0 NMI
```

Fig. 3

Developing SEASIM on the minicomputer resulted in significant cost savings. The daily cost of leasing the HP 9845 was about $40, a fraction of the daily cost of the larger machines. Also, since BASIC does not require compilation after programming changes, considerable time is saved on the writing and debugging stages of building the model. On some heavily used time-sharing systems, compilation is painfully slow. Sample runs were made overnight at no cost. Since the HP 9845 model dumps the track plot of each trial and prints the random number that begins each trial, the programmer can repeat any trial that needs further analysis and can trace variables during the repeat trial.

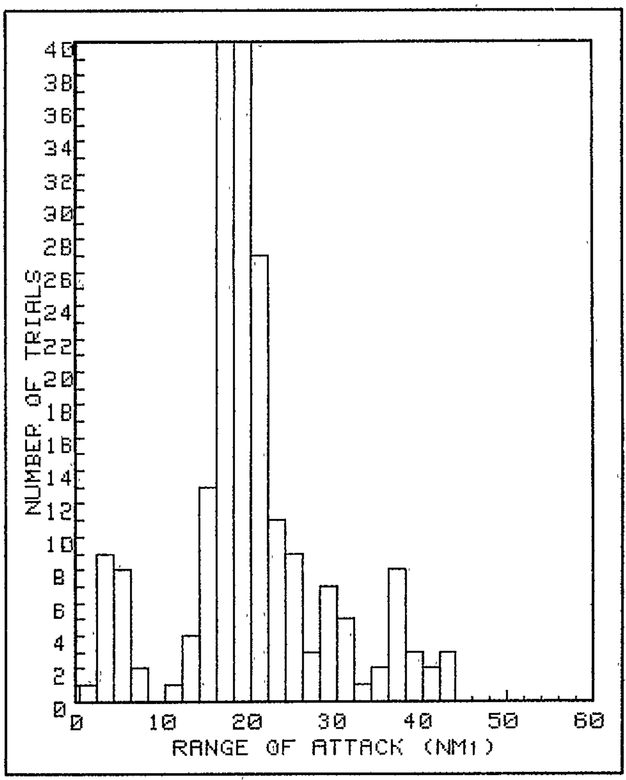


Fig. 4

Each version has decided advantages. The HP 9845B version requires about six minutes of real time to simulate a six-hour ASW engagement. The progress of the engagement, course changes, and sonobuoy drops can be monitored on the CRT as the program runs. This visual capability has been invaluable in studying, debugging,

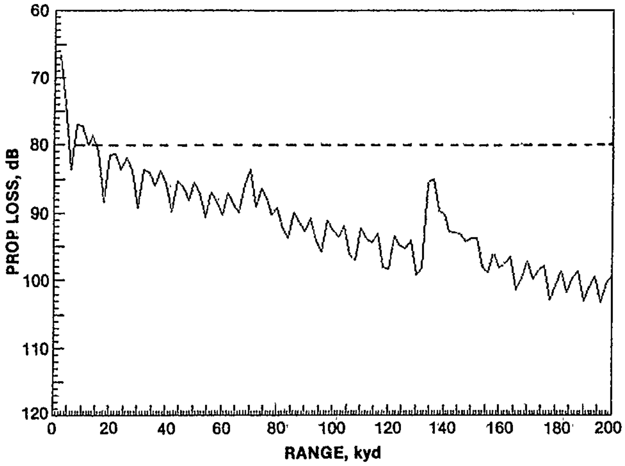
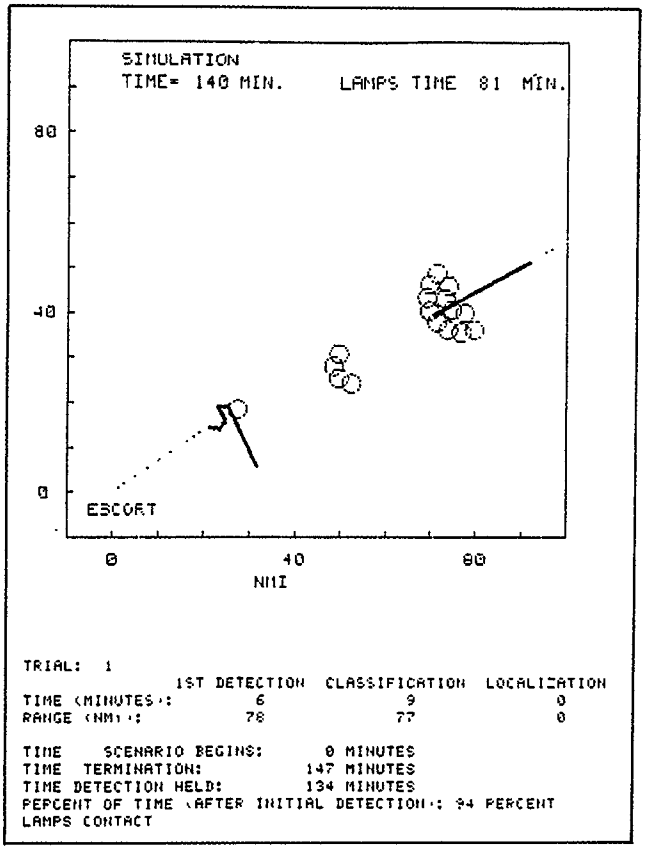


Fig. 5



```
TRIAL:  1
                   1ST DETECTION  CLASSIFICATION  LOCALIZATION
TIME (MINUTES):                6               9             0
RANGE (NM):                   78              77             0

TIME    SCENARIO BEGINS:         0 MINUTES
TIME  TERMINATION:             147 MINUTES
TIME DETECTION HELD:           134 MINUTES
PERCENT OF TIME (AFTER INITIAL DETECTION): 94 PERCENT
LAMPS CONTACT
```

Fig. 6

and tuning the model. Unfortunately, a single simulation run of 400 six-hour trials requires two days to complete. Such slowness of execution is prohibitive for generating analysis runs.

The VAX 11/780 version, on the other hand, runs 200 times as fast as the HP version, completing a trial in less than two seconds and a set of 3200 trials in approximately one and one-half hours. The VAX version has been coded to load runs for overnight batch execution. Hundreds of different runs can be completed automatically over a weekend. Data generated by VAX runs are also stored on a disk for future computer analysis of the data.

2. MODEL ORGANIZATION AND FUNCTION

2.1 Overview

SEASIM focuses on long-range (greater than five nautical miles) detection and prosecution. Therefore, each scenario begins with the target beyond escort maximum detection range on a closing course. At each time step, acoustic signal excess (SE) is computed, and if the SE meets specified criteria (e.g., SE is greater than zero for five consecutive time steps), a detection is called. At that point, the detecting unit maneuvers to conduct classification and localization procedures. If localization is achieved, an attack is launched. If contact is lost, the unit returns to its search plan.

If the submarine comes within counterdetection range of an escort, the submarine evades, returning to its original course after an appropriate delay. Otherwise, it continues on course until it is attacked or it reaches its objective. Either event terminates the run.

Functional characteristics of the detection, classification, localization, and attack modules of SEASIM are discussed in the following sections. Tactics for SEASIM were drawn from approved naval publications and from fleet experience.

2.2 Detection

The passive sonar detection criterion is that signal excess is greater than zero for five consecutive time steps (five minutes). Signal excess is computed using the formula below which contains both deterministic components and a random component:

$$SE = SL = [(AN - DI) \oplus SN] - RD - DL - PL + \beta$$

where

SL = target source level,

AN = ambient noise,

DI = array directivity index,

SN = escort self-noise,

RD = recognition differential,

DL = deviation loss,

PL = propagation loss,

β = β (t) = a time-dependent random fluctuation and

$\oplus$ = symbol for power addition.

The fluctuating term, $\beta(t)$, represents the net result of all short-term random changes in SE. Random fluctuations in SE are assumed to be governed by the Poisson distribution and to have a Gaussian amplitude distribution. Random SE components as a function of time are calculated for the environment and for each frequency. Both the environmental and frequency-dependent components are added to the deterministic component for each frequency every time SE is computed.

The remaining (deterministic) terms of the passive signal-excess equation are a function of many variables including frequency, range, target or escort speed, and target bearing. Propagation-loss files are entered via magnetic tape. Tables of other parameters such as ambient noise and directivity index are included in the program and appropriate values selected automatically based on input decisions.

Active detection is based on a criterion similar to that described for the passive case.

2.3 Classification

Passive classification is called if a submarine-like signal is held for a specific duration. After initial detection, the destroyer will maneuver to ensure that the signal is not from own ship. Following this maneuver, the unit commences localization procedures. When a classification is called, the LAMPS helicopter is alerted. When the alert time has passed, the LAMPS helicopter may be launched either on a line of bearing search or to a specific bearing and range if sufficient information is available. If contact is lost, the ASW unit will return to its search plan. The LAMPS helicopter returns to the escort if detection is lost for 15 minutes.

2.4 Localization

Localization is defined as determining target position with sufficient accuracy to prosecute with the LAMPS helicopter. Initially, the localization process involves making use of a series of clues to arrive at a gross range estimate. Contact bearing rate is one of the best clues available for estimating target range. A high bearing rate strongly indicates a short-range target (less than five nautical miles) requiring immediate action.

Conversely, if the bearing rate is low and long-range detections are likely, the target may be in a convergence zone. In this case, the escort attempts to keep the contact in the convergence zone and vector the LAMPS helicopter to the contact bearing.

If the target bearing rate is between the high and low limits, the target is assumed to be in the intermediate range zone (five nautical miles to the convergence zone).

In cases where more than one escort is available, localization may be achieved by crossfixing, i.e., plotting simultaneous target lines of bearing from both escorts. Crossfix information (if available) would supplement or even override other localization solutions, depending on the relative accuracy and confidence assigned to the sources.

2.5 Attack

The baseline ASW units being studied carry the LAMPS helicopter; it is assumed that the primary surface ASW attack tactic is to conduct a LAMPS attack at the maximum practicable range. Therefore, the model includes an extensive LAMPS module that simulates LAMPS launch, transit, and search using various tactics and sonobuoy patterns as required by the situation. LAMPS attacks if the target is reacquired. The simulation terminates following an attack by the LAMPS.

3. APPLICATIONS

SEASIM was developed primarily as a tool to study the long-range ASW systems capability of 1990 to 2000 time-frame surface escorts; however, the program can be put to many other applications after minor modifications.

3.1 Training

SEASIM has been modified recently for a demonstration of its capability as a training tool for sonar supervisors and for commanding officers. Instead of having a submarine track appear on the CRT, the sonar bearings, frequency, and radar contacts are printed. The operator then makes decisions about escort course and speed, launching and retrieving LAMPS, sonobuoy patterns, etc. The special function keys are used to enter decisions.

3.2 Antisurface Warfare

SEASIM, with appropriate modifications and data collection, has been used to analyze an encounter between an American submarine and an enemy surface ship. Improvements in threat capabilities can be evaluated for their tactical impact. Probabilities for detection, classification, localization, counterdetection, and break-contact can be evaluated.

3.3 Tactical Development

SEASIM is constructed so that escort, aircraft, and submarine tactics can be readily analyzed from statistical results and also by visual monitoring of the engagement on the CRT. Single-unit and battle-group tactics can be evaluated at a fraction of the cost of evaluating them at sea, and the results are available much more quickly.

3.4 Advanced Platforms

Work has begun on the use of SEASIM to study the effectiveness of a fast hydrofoil in an ASW screen. The many-on-one version can be used to study the advantages of high speed, especially in cases involving crossfix.

3.5 Mobile Surveillance

SEASIM can be expanded in scale to allow analyses of towed surveillance systems in a range of areas and environments. By increasing the number of targets in the model, the problems of contact classification and management could be studied for these systems.

3.6 Summary

SEASIM is a highly realistic ASW model operating on two very different types of computer. One produces large amounts of statistical output very quickly. The other allows the operator to observe and monitor the progress of the simulated ASW engagement and, if desired, to control the engagement. Both models use the same algorithms.

SEASIM can be adapted quickly and accurately to different applications by adding coding to handle new tactics, additional systems and escorts, additional data collection and statistical analysis, and different output.

The documented data base contained in the data books and initialized in SEASIM is an invaluable aid in using the model. The usefulness of the simulation results is dependent on input accuracy. The availability of a library of propagation-loss curves on magnetic tape further enhances the versatility of SEASIM.