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THE MOORE SCHOOL OF ELECTRICAL ENGINEERING
Philadelphia, Pa. 19104

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MAN-COMPUTER PROBLEM SOLVING IN REAL-TIME NAVAL DUELS (U)

by

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Command Facilities						
Pattern Recognizer						
Naval Duel						
Multilist Executive Language						
Multilang Procedure Capability						
Navigation and Tracking						
Strategy Development						
Active Sonar Readings						
Passive Sonar Analysis						
Documented Game Playing						
Decision Making						
Weapon Launching						
Interception Calculations						

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REAL-TIME NAVAL DUELS (U)

Abstract

The development of a new Man-Computer Problem Solving Methodology to be widely and effectively applied by the Navy has been the objective of this Research Project. The basic hypothesis that has been examined is as follows. If an interactive system would be available by which a human problem solver could put together, easily and quickly, a simulation of the problem and quickly perform tests of various solutions, perform an evaluation and then further improve the solution, then large scale economies and improved effectiveness would result. The research reported here may be considered to having taken the empirical approach. An experimental environment was selected, namely a Naval War. An interactive problem solving computer system was designed for this environment. To obtain an indication of the effectiveness of the system required the solution of problems in human engineering, computational methods and strategy in the areas of tracking and navigation, sonar applications and processing, and weapon application. New real-time interactive systems were incorporated to simplify the evolution of new problem solving methodologies.

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1.0 INTRODUCTION

1.1 Objectives of the Research Reported

Research described in this report has been conducted under Contract N00014-67-A-0216-0013 for the development of new man-computer problem solving methodology, which could be widely applied by the Navy.

The hypothesis that is examined in the research reported here is as follows. If an interactive system would be available by which a human problem solver could put together, easily and quickly, a simulation of the problem and quickly perform tests of various solutions, perform an evaluation and then further improve the solution, then large scale economies and improved effectiveness would result for two reasons:

a. the cost of implementing the simulation would be greatly reduced, but what is far more important,

b. the feedback cycle of

1) analysis-devise solution

2) test solution

3) evaluate-and-modify-solution

would be greatly shortened in time, and save major costs involved with real life testing.

Such systems are in existence, for instance, for chemical and electrical engineers engaged in design of chemical processing plants or electric circuits respectively. The problem posed to the researchers here was whether this approach could be applied widely in a large, diverse organization such as the Navy and in particular, whether the Navy could use this problem solving methodology for conducting operations, management, and engineering design.

It was recognized from the outset that a problem solving system for the Navy problem solver would have facilities beyond those available in a system for a chemical or electrical engineer. For instance, simulation of conflicts is required in aiding the work of the Navy weapon systems designer. Simulating a conflict implies several teams of antagonists participating interactively with the computer. Additionally, the complex problem of real time data acquisition and analysis must be handled by the problem solving system.

The research reported here may be considered to have taken the empirical approach. An environment was selected - that of a Naval war. An interactive problem solving computer system was designed for this environment. It is referred to in this report as a submarine vs. task force war game. The project staff then experimented with this system in the solution of problems to obtain an indication of the effectiveness of the system for problem solving. In particular, problems in:

a. human engineering

b. computational methods

c. strategy

have been solved. These problems have been in the three areas of

a. tracking and navigation - reported in Sect. 3,

b. sonar applications and processing - reported in Sect. 4, and

c. weapon application - reported in Sect. 5.

Section 6 of the report illustrates the operation of the problem solving system through the presentation of a scenario of a war game.

1.2 Special Credits

In the construction of this system, the project was highly indebted for many valuable suggestions to Cdr. Philip Charest, USN, then a graduate student in Computer and Information Sciences at the Moore School. Many of the strengths of the system are due to Cdr. Charest's ideas and suggestions. Without them the system would have been far less oriented to a realistic Naval situation. Nevertheless, design decisions were, of course, the complete responsibility of the Project Technical Staff.

In addition, other Naval officers assigned to the University Naval ROTC, and officers and civilians from ONR, Johnstown Naval Air Development Center, and elsewhere supplied pertinent comments during demonstrations.

1.3 Recommendations

In the course of the research, a Problem Solving Facility has been implemented which responds to the requirements of a naval systems designer or naval trainer. It includes a structure to simulate multi-antagonist conflicts. It is modular and has a command language and data management facilities that allow for easy and quick reorganization and modification of a simulation to suit specific problem solving situations. It is open-ended in that the user can readily add modules for the study of a particular interaction or features that he wishes to test. It allows simulation of roles of members of a team, or entire teams of participants.

While the results of our research have been only qualitatively evaluated, the rapid problem solving progress of our research staff using the problem solving system causes us to make the following recommendations to the Navy:

1. The man-computer problem solving methodology described in this report should have a strong impact on Naval problem solving effectiveness in commanding, conduct of operations, managing, and engineering.

2. The Navy should develop similar man-computer problem solving systems for several other broad Naval environments such as surveillance, various types of warfare, logistics, and intelligence.

3. The problem solving systems for the various environments should be disseminated throughout the Navy using widely available time sharing facilities. The ease and ready availability of these systems, training in their use, and their impact on effectiveness, should induce wide application of this methodology by the Navy.

1.4 Components of a Problem Solving System

When we refer in this report to a computer system used for problem solving, we mean a computer system interactively operating with human problem solvers, and having a program library available for the use of the human problem solver. In particular we imply the inclusion of the following components:

1. Interactive Computer Facilities - including keyboard, printer, and graphic terminals interacting on a real time basis with a major computer system [10]. In order to simulate properly the environment of conflicts, it is required that the problem solving system interact simultaneously with a number of human problem solvers who represent the various participants in the conflict. Additionally, many more people should be able to participate in an expansible and contractible system in which machine (program) modules may replace, or be replaced by, certain human participants on-line, interactively, and in real time. This permits both the augmentation of the number of users at any time and the machine simulation of any subsystem that might ordinarily be carried out by a human being.

2. Environmental Simulation Programs - As indicated above, these would simulate Naval environments such as surveillance, various types of warface, logistics or intelligence, respectively [1,2,3,4]. Each one of these environments represents a broad spectrum of Naval activities. The environmental simulators must be highly modular and open-ended for ready and easy enhancements and modifications by users. A simulator must be completely independent of, but capable of interacting with, the data management system that handles all the data acquisition, storage and retrieval as described below.

3. A Data Management System for Storage and Retrieval - capable of recording and updating information on a real time basis during the conduct of the simulation [7,8,9]. For instance, the simulation of a sonar data acquisition system involves storage and updating of the acquired information on a real time basis. The Data Management System responds to storage and retrieval commands made in the language of the Data Management System. The commands are included in the simulating program modules.

4. Command facilities that call on the Environmental Simulation with arguments that specify the Data Management System's storage and retrieval functions [5,6]. For instance, in the simulation of a Naval duel, the human problem solver may direct the simulation of a weapon fired at targets that are computed from simultaneous data acquisition by sonar devices. The data acquisition is handled largely by the storage and retrieval component. The command language must have a hierarchy of commands to provide easy grouping of primitive commands under a higher level command, thus effecting additions to the system. It should also be open-ended to include additional commands that can be programmed in a variety of levels of programming languages.

5. A Pattern Recognizer - This component is still being studied. We find it is necessary interactively to identify various patterns which developed through the simulation or the man-machine interaction.

The combination of the above five components was found in our research to be necessary to give the Naval problem solver the ability of easily and quickly putting together a simulation of his problem. These requirements exceed considerably those inherent in a simulating system for a chemical or electrical engineer as mentioned above.

1.5 Summary and Conclusions

To investigate the new man-computer problem solving methodologies we had first to select an environment which was suitable for truly broad Naval application, in which we would perform our experiments in problem solving. The wide applicability of the methodologies that we have been exploring has always been a prime requisite of the research. We have selected a simulator (game) for submarine vs. task force engagement as being applicable to a large cross-section of Naval applications. For instance, it would be useful in the development of navigation, sonar and fire controls. It would be useful for development of sonar processing techniques. It would be useful for developing tactics and strategies for command of forces. Finally, it could be a very useful vehicle as a trainer.

Once an initial system had been developed we planned to engage in problem solving in this environment and then evaluate the effectiveness of this problem solving methodology. In fact, through the problem solving, the system itself became richer and more powerful as it incorporated in itself the progress made in problem solving.

We have assigned three of the staff of the project to the areas of:

1. navigation,

2. sonar application and processing,

3. weapon application.

They have been instructed to pay attention in particular to the human engineering of the interface between the operator and the weapon system, the computational methods required to process acquired data into meaningful information for the operator, and finally, to the developing of strategies.

A man-machine interactive model capable of simulating the maneuvers between two naval forces is operating within the Problem Solving Facility of the University of Pennsylvania. We have therefore been able to experiment with, develop and analyze, in this environmental simulator, problem solving requiring multi-dimensional communication between man and machines. Because of the modularity of the design, it has been easy to incorporate refinements and extensions. Our accomplishments in the three areas listed below illustrate the effectiveness of the Problem Solving Facility:

A. Human Engineering - the development of new techniques and languages for communication between man and machine in a real-time problem solving facility.

B. Computational Methodology - the incorporation of new computational aids within the system by adding new modules to the game.

C. Strategy Development - By conducting experiments with the game, new ideas for interactive problem solving have evolved.

The advances made in human engineering have emphasized the need for short and flexible input formats. In a problem solving environment where rapid decisions are made, it is essential that man-machine communication be made through a concise and simple language. The users have been given a compact set of functions so that all requests for computer response may be expressed in a mnemonic form. New higher level commands may be developed by the user as he gains experience and finds the necessity for such additions.

Our commands have been made as English oriented as possible. Many parameters have been made optional, greatly shortening the commands. For example, such parameters as the number of sonar readings to be used in the next analysis and the type of weapons to be fired are assumed parameters which may be changed by the user. We have also provided the facility for the easy use of previously defined maneuvers which have become standard. To facilitate the use of our system, it is not even necessary to know the command language; English sentences may be used, and these are translated internally into the command language. Finally, results of computations are automatically stored and are readily available for future calculations or for output to the user in the form of displays or printout.

The utilization of a graphic display console has greatly extended our problem solving capabilities in many ways. We have developed a new display oriented language which almost totally eliminates the need for typing. Using a set of mnemonic instructions which is displayed on the screen, the user makes his requests to the computer by pointing at the screen with a light sensitive device and by pushing various buttons.

Instead of printed output, the user employs pictures as much as possible [3]. To analyze the present situation, he may obtain a display of his own sailing plan and his estimates of the opponents movements. He can then draw a new sailing plan using the old picture as a guide.

By displaying active sonar readings, it is possible to preprocess the readings at the console and then request further computation by the computer [4]. Thus, the commander interactively obtains an estimate of his opponent's position, speed, and course.

A record of the solution may be saved in the form of pictures showing, for instance, the sailing histories of the ships, the estimates they made of the opponents' movements, and the weapons that were used. Thus, an analysis may be made at the display console at any future time.

In the area of computational methodology, we have developed a new passive sonar ranging technique which requires only a generalized maneuver. This technique combines two solutions over the same time interval in order to obtain a reliability factor for the result. We have modified other components of our simulation as we have learned their weaknesses. The navigation function now allows relative turns and the specification of maneuvers to be started in the future. The analysis of active sonar readings uses a fit which emphasizes no one point and which minimizes the error with respect to both distance and time. In the weapon model, we provide interception calculations for multi-speed weapons, such as ASROC.

The major decisions of how to maneuver and when to fire weapons are still completely made by the user. The computer does assist by analyzing sensor data but, once its analysis is done and results presented to the player, no more aid is given. By accumulating data from game to game and by analyzing standard tactics, a computer system would be able to answer such questions as:

1. Has there been a pattern to the opponent's track?
2. From the opponent's sailing history, what maneuvers is he most likely to execute now?
3. What would be my optimal evasion strategy in the present situation?
4. What attack and firing patterns have been successful in previous encounters?

Before the actual encounter, the user can enter various standard tactics into the computer system. The solution of each problem can also be added, as it is solved, to continually update the total amount of data available. Upon the request of the user, the computer system could then relate the present problem to previous similar situations and present, in graphical form, a resume of maneuvers used in the past together with their likelihood of success.

Experience with the game has shown that reasonable strategies may be developed even by inexperienced players. In this environment, a user is immediately confronted with the operational problems of a naval commander. Satisfactory maneuvers for passive sonar analysis must be developed. Attack patterns and evasion tactics can be tried, analyzed, modified and stored for future use. The total environment facilitates the development of new problem solving methodologies within the interactive man-machine framework.

The following five sections describe in detail our experience with the system and the new problem solving methodologies we have developed. We feel that the evolution of such methodologies has been greatly simplified through the use of our real-time interactive system.

2.0 THE NAVAL PROBLEM SOLVING FACILITY

2.1 Introduction to the Naval Duel

To investigate man-computer problem solving methodologies, an encounter between two opposing Naval vessels was simulated. The design of this environment can be divided into three main subgroups - navigation, sensing and estimating, and weapons control.

The ships must first have the ability to determine position and maneuver. The navigation subgroup consists of two parts. One is the simulation of the performance of a ship; the other is the programs which allow the player to make his requests. These parts are characteristic of all components of the game. There is always an internal simulation problem, and an external request capability.

Sensing and estimating includes the simulation of active and passive sonar devices and programs to help the player analyze this data. The weapons capability needs the simulation of each type of weapon and certain computational abilities, such as determining an interception course for a weapon, to aid the player in the selection of firing parameters.

The play of a game consists of a series of cycles between ship commander and computer. A cycle is a set of requests supplied by a player and the resulting printed or displayed output from the computer. The cycles of each player are independent. The results of previous cycles influence the content of the current one; the strength of this influence is a measure of the effectiveness of both the player and the problem solving facility. A sample cycle might include a maneuver based on information in a previous cycle, a request to make a new active sonar estimate, and a request to display this estimate with the current sailing plan of one's own ship. An attempt to fire a weapon might also be included. The computer executes each of the above in succession and prints and displays the results.

In the original game the only interface between the man and machine was the teletype. Each player sat at a teletype which was connected to the main computer via a telephone line. Use of teletypes alone proved inflexible. The addition of a satellite display computer for one of the players has greatly influenced more recent work. At first the display was little more than a high speed printer. Then a function was developed which displays a picture containing items specified by the player. Usually the display has one's own ship's path and combinations of recent estimates made from active and passive sonar data. Weapon tracks can also be included. Alternately, active sonar points can be displayed to aid in visual pattern recognition and the player can select any portion of the readings displayed and make an estimate including just those readings. The display has assumed a more active role too. Most functions can be executed without any typing by using the light pen and pushbuttons alone. It is even possible to draw a new maneuver right on a picture of the latest estimate and path of the ship's sailing history.

Descriptions of the basic functions presently available for this environment are provided in Table 2-1. The reader will note the uniqueness of each function as well as the completeness of the list. Most of the building blocks necessary for a complete simulation are provided. A detailed discussion of these functions is given in Appendix C. One of the most important aspects of the research to date has been the ability of the system to grow with minimal strain and to grow not only in size and complexibility but in power as well. This system is modular; the addition of new blocks is simple. More important perhaps is that changes in existing blocks are relatively easy to make if care has been taken in design. This building block

Type of Function	Name	Functional Description
Referee	INTLZ	Initialize ships' characteristics
	INTCL	Initialize and control clock
	LAYER	Set thermal layer depth and sonar noise characteristics
	START	Set initial position of a ship
Player - Navigation	SETSP	Control of speed, course and depth
	POS	Print position
	RANGE	Print range and bearing from own position to estimate
	INTER	Calculate an interception course
	OPINT	Calculate opponent's interception course
	HISTORY	Display own path and specified estimates and weapon tracks
Player - Sonar and Estimating	USESN	Turn active and passive sonars on and off, control of frequency of readings
	ESTPS	Make an estimate using passive sonar
	ESTAC	Make an estimate using active sonar
	DISPLAY	Display active sonar points
	ELISA	Make an estimate based on display list interaction
	ASCOM	Determine if a new estimate is needed
Player - Weapons	WEAPO	Fire a specified weapon
	CNFRM	Print results of a weapon firing
	WEPST	Print number of weapons remaining
	WPARM	Sets parameters used in firing weapons

Table 2-1 - List of Game Functions

characteristic has proven to be of immense value. Several programs have been completely redesigned in the light of experience; in the case of the active sonar analyzer three different programs have been used at one time or another. Evolution is stimulated by flexibility and the ease of incorporating new and improved modules in the system.

To close this section a short summary of the flow of a game is presented.

The referee starts the clock and sets the initial positions and sailing plans of both ships. Then the players begin. Both would turn on passive sonar immediately. The surface vessel might also turn on active sonar. Next a request for a passive (or active) estimate would be made. If a response is noted then a maneuver may be warranted. Thus the first three cycles would be

1. turn on sonars
2. make an estimate
3. maneuver based on estimate.

The game continues with executions of cycles 2 and 3 until one of the players is in weapon range, whereupon he can fire if he so chooses. Other basic functions are executed as desired by the player. The encounter ends when one player is hit, runs out of weapons, evades, or gives up in frustration over his inability to damage the enemy. The goals of each player must be considered in evaluating the result if no hit was achieved.

The game itself is a specific environment. It has been found that it is a useful tool in determining characteristics which are desirable in any environment of even remotely similar needs.

2.2 The Multilist Executive Language

The naval war duel simulation is dependent on the Multilist information storage and retrieval system. This system is capable of manipulating data records and programs as well as storing and retrieving items satisfying certain constraints. This capability is used by the simulation to allow the user to retrieve previously defined or "built-in" functions when requested and to operate on all data records.

In order to communicate with the Multilist system, an executive language called Multilang [6] was designed. A request made of the Multilist system must be either a Multilang statement or a group of Multilang statements called a procedure.

A Multilang statement has the form:

```
LABEL      OPERATION/OPERAND1/OPERAND2/.../OPERANDk
```

A statement may begin with a label - an octal integer of one to five digits - or it may have a blank first field. When present, the label serves to name the statement so that the program it designates can be called and executed by other programs.

The operation part of a Multilang statement consists of the name or a description of the program that the user wants to be executed.

All "Naval war duel simulation" commands described in this report are Multilang statements. When the war duel environment is in operation there is an interpreter in the computer which reads the Multilang statements being inputted, retrieves the program to be executed (see Appendix C for a list of these programs) and passes control to the designated entry point of the program. A method is provided by which the program in control can examine the operands in the statement and generate further instructions to the storage and retrieval system.

2.3 The Multilang Procedure Capability

The Multilist Executive Language (Multilang) has the capability of grouping several Multilang statements together into a procedure. A procedure provides for the execution of the programs sequentially unless a transfer of control is made to another section of the procedure. This structure allows the programmer to write a simple procedure in which each statement can be a complex program. This type of structure allows communication of data between programs without having to make disc accesses, allows sequential and non-sequential transfer of control between programs and by the use of formal parameters, has the capability of executing a sequence of programs with different operands on every call. The use of the procedure in the manner described above leads to the construction of higher level commands, where each command is a sequence of the basic commands described in this report. In this manner the command language is open ended and can grow to meet the needs of each individual user. In practice it has been noted that different users develop these higher level commands to aid in the solution of those subproblems which they consider to be most important. Even higher level languages may be created by forming procedures which have other procedures in their bodies. By the use of a procedure, the amount of information that need be inputted in order to execute several programs is minimal.

When a Multilang procedure is defined, the Multilang assembler converts the console statements into a compact internal format which is stored. A procedure is originally constructed with formal parameters and has actual parameters substituted at execution time.

The user requests a Multilang procedure in the same manner as he would request a Multilang statement. When the interpreter reads the request it brings in a copy of the procedure, substitutes actual operands for formal operands and given control to the first program in the procedure body.

3.0 NAVIGATION AND TRACKING

3.1 General

A Naval captain must have the ability to easily issue commands and obtain the latest information as it is received and analyzed by his subordinates. In our simulation of a Naval war duel, we have been constantly concerned with the problems of communication in a real-time environment. We have developed solutions for both display and printed media. This chapter summarizes the evolution of the sailing plan control program, called SETSP (SET Sailing Plan), which enables the user to modify the speed, course, or depth of his ship. Because of the essential function performed, SETSP was one of the first programs on our system; it is also one of the most frequently executed. This long and frequent use has emphasized the shortcomings of the program as it was originally implemented and has provided an impetus towards improvements.

Modifications have been made to simplify the interaction with the machine, to increase the power of the simulation and to enhance the user's ability to develop strategies. Our problem solving system has a modular design and so these varied improvements were easy to add to our model.

3.2 Human Engineering

Various improvements have been made to the command language in order to simplify the user's interaction with the machine. The navigation function, SETSP, exemplifies many of these changes which were made to reduce the number of circumstances under which the program could not function because of user errors and to minimize the time necessary for planning and typing.

One basic consideration in designing our system was to maximize the information available to a user without overloading him with useless details. This can be done quickly and in an understandable format using the display and this form of communication is used as much as possible. Sometimes however, a printed comment is the best response. The printout of SETSP was expanded from the simple line

THE SAILING PLAN HAS BEEN STARTED. TIME=XXXXXX

to a full listing of the sailing plan changes made by the request. This includes the speed, course (the word TURN is substituted in turns), depth and the time that each block starts. This insures that the player is fully aware of the results of the request; it also provides easy reference to the time that a particular maneuver began.

Besides using the display as a form of output, it can also be used as a reliable and quick method of entering commands. All standard requests can be listed before the user who then chooses one by pointing at it with the light pen. Such a format is shown in Figure 3-1 which shows the standard functions displayed on the bottom half of the screen. There is a second similar list which is employed to start or stop the execution of a series of programs, generate displays, save displays on magnetic tape, recall old displays, obtain output and a few other necessary system commands.

In the example shown in Figure 3-2, the destroyer captain has previously obtained a display of his own sailing history and three independent estimates of a detected submarine which have been projected into the future. By hitting the appropriate pushbutton and then pointing at the phrase

SET SAILING PLAN

as shown in Figure 3-1, a program is initiated which permits the destroyer

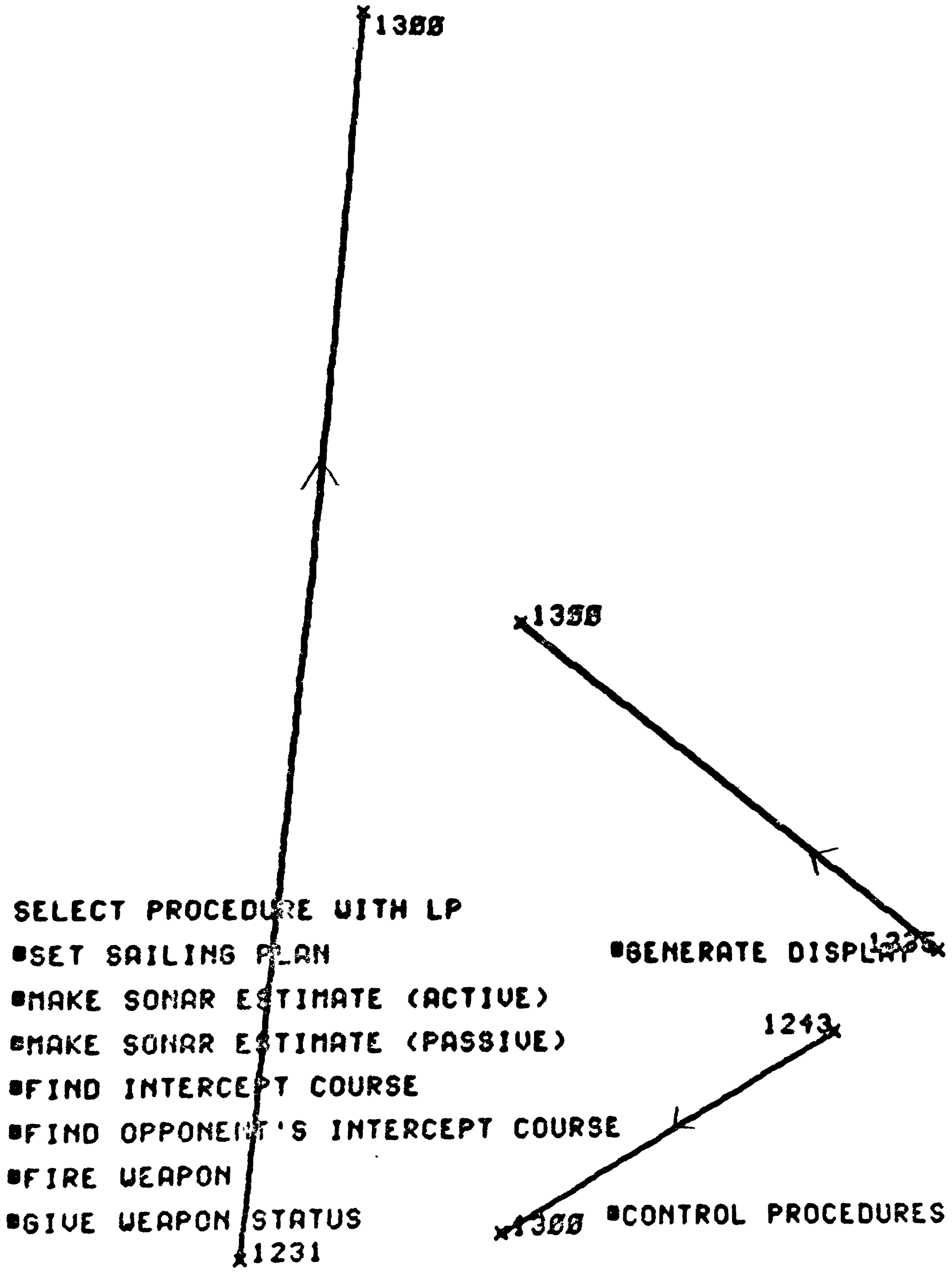


Figure 3-1
Using the Interactive Display Computer to Enter Commands into the System

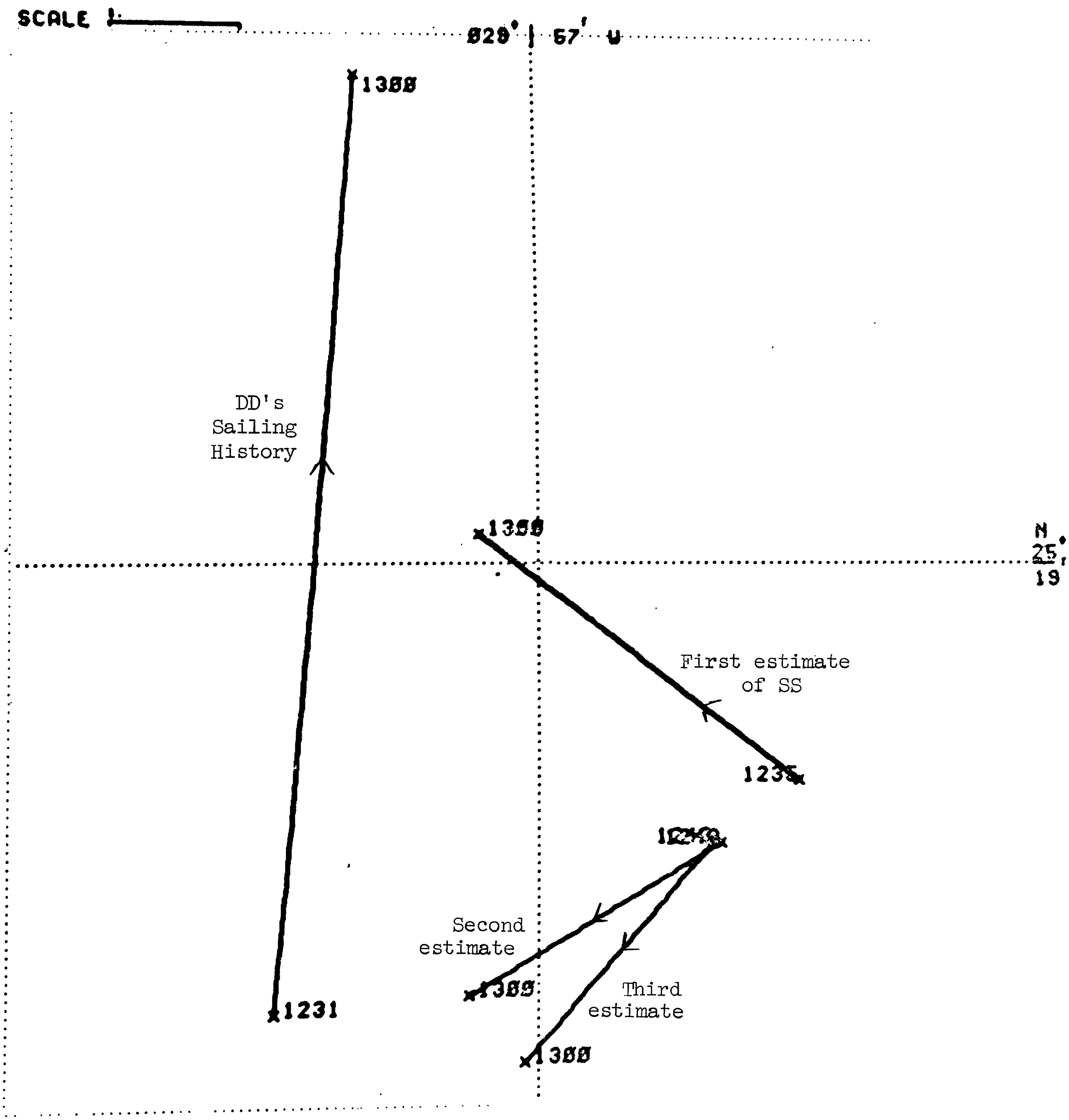


Figure 3-2
A Display of the Destroyer and Three Estimates
of the Submarine's Position

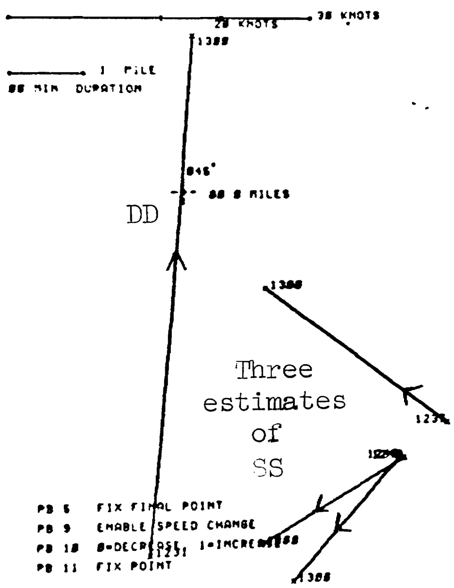
captain to draw or type (in this case, he chooses to draw) changes to his sailing plan. Using the present display as a reference, it is very convenient to draw a new sailing plan using the light pen. The DD captain decides to enter an attack maneuver. The speed of each leg of the maneuver is set by using a pushbutton and is shown in the upper left corner of the picture (Figure 3-3a). Below the "speed line" is the scale of this display and the time duration of the course presently being drawn. The speed, course and time duration of each leg can be altered until the appropriate pushbutton is hit which fixes that line on the screen. The total distance travelled and the course of each leg are shown next to the appropriate line. The final sailing plan is shown in Figure 3-4 and the result of its execution is shown below:

```
        SETSP/
=20/=112/=05/
=17/=154/=07/
=09/=192/=16/
=09/=249/0
        SPEED        COURSE    START TIME
        17.50         TURN       124639
        20.00          112       124719
        18.50         TURN       125139
        17.00          154       125155
        13.00         TURN       125839
        9.000          192       125853
  THE SAILING PLAN HAS BEEN STARTED.
```

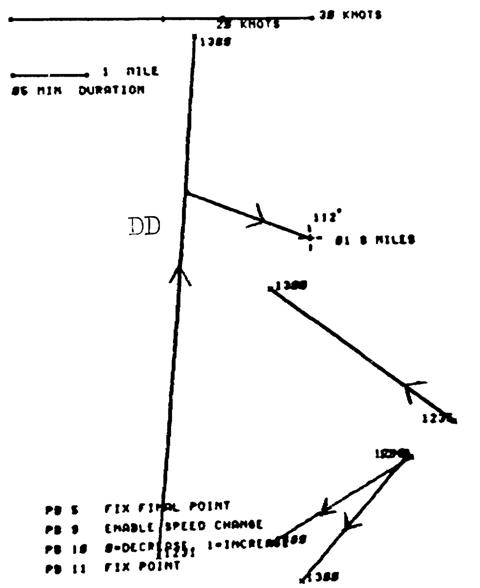
A display depicting this attack maneuver and the estimate of the submarine upon which it was based is shown in Figure 3-5.

Similarly, the user may type his navigation commands. The original format of the SETSP call was as follows:

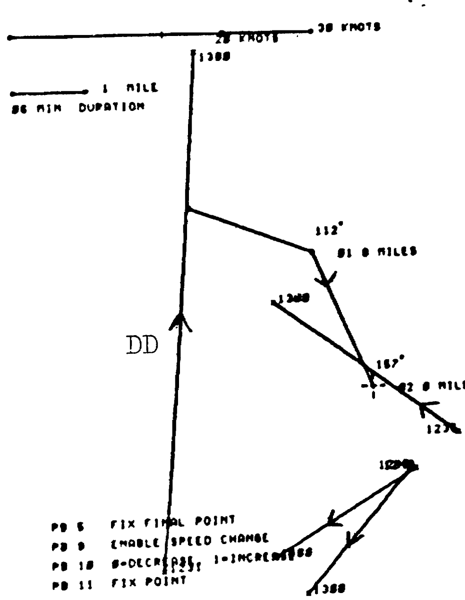
SETSP/(player's color)&OWN/=(speed)/=(course)/=(depth, if sub)



a) Initial point has been fixed



b) One turn has been requested



c) A second turn is drawn.

Figure 3-3
The Various Stages of Entering a Sailing Plan
Using the Display Facilities

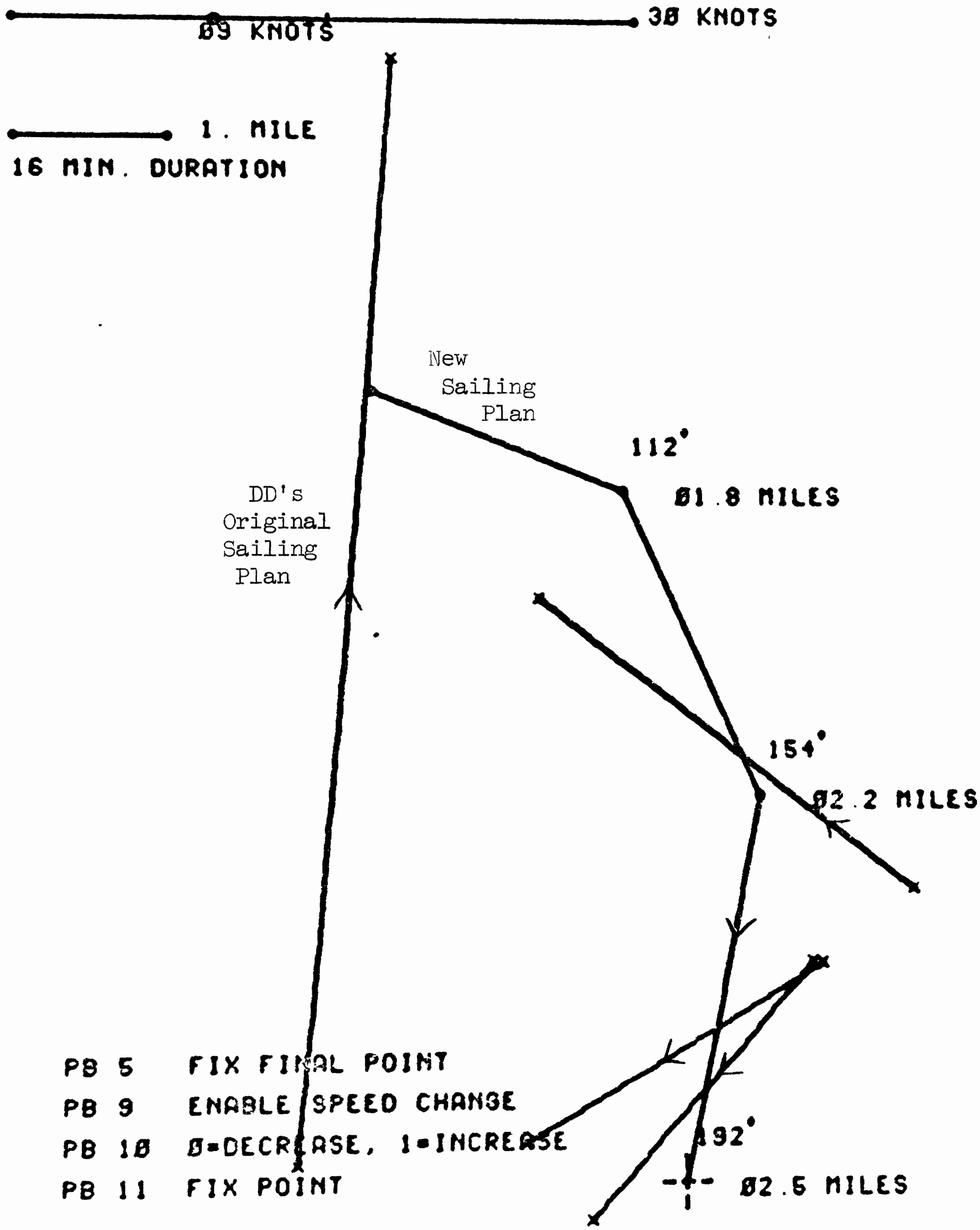


Figure 3-4
The Completed Sailing Plan as Entered by Captain
of Destroyer Using the Light Pen

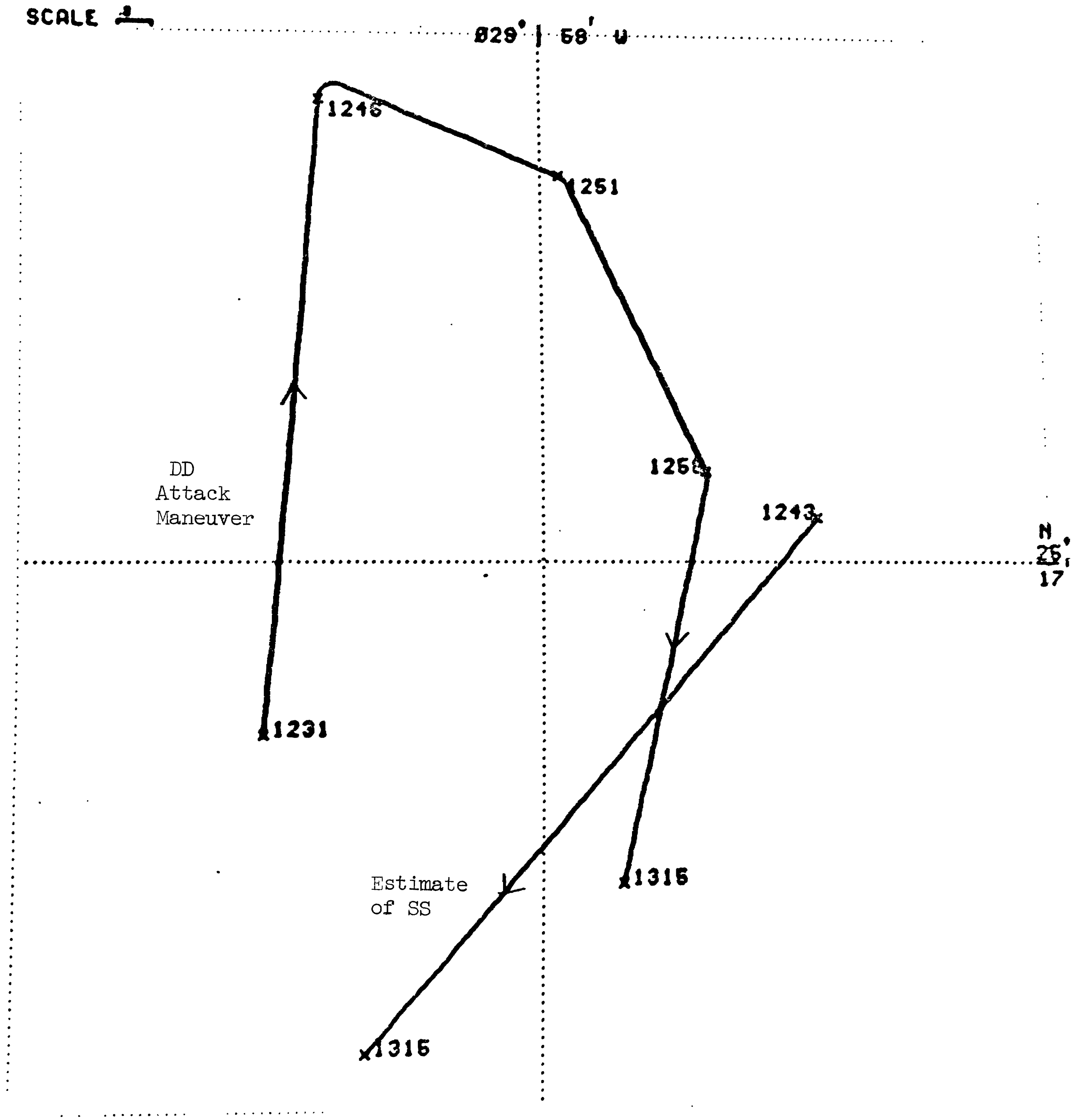


Figure 3-5
Display of Destroyer's Past and Future Track Together with an Estimate of the Submarine's Position

A quantity between two slashes is called a parameter; that part of a parameter within parentheses indicates that a substitution is to be made. The words RED and WHITE are used as the players' color or identifier. RED is usually used for the submarine and WHITE for the surface vessel; depth is of course not applicable for player WHITE. The parameter RED&OWN (or WHITE&OWN) specifies the name of the record containing the sailing plan to be modifed; an improper or insufficient name would cause chaos if the programs had not been designed to check for this possibility. The original version used the first parameter directly to retrieve the record; later versions retrieve indirectly and automatically tack on '&OWN' to insure that an OWN record is retrieved. The older specification RED&OWN is still valid since (RED&OWN)&OWN is equivalent to (RED)&OWN.

A major advance was made when the ability to identify a user was added. The system was already aware of the identity of the user. Picking this up automatically eliminates the necessity of supplying a user identification. To maintain compatibility, the first parameter can be the identification; if so, it is checked to insure that it is correct. If it is, then the second parameter is expected to be a speed. If the first parameter is not a user identification, then it is expected to be a speed. If the identity supplied is incorrect (e.g. WHITE at player RED's station) then an error message is printed and execution is skipped. In later examples, the color will usually be included to identify the type of ship.

Another change that was made was to eliminate the requirement that an '=' precede all of the other parameters. The special character is required to tell the facility that a number is to be supplied to the program; the change was made so that the program would be able to recognize the input parameter as a number whether or not the equal sign is used. This addition was dictated by the frequency with which players had to retype whole lines to add a forgotten '='.

These changes were made without affecting the basic logic of the program; they were made principally to simplify the input format. A typical request now looks like the following:

SETSP/(speed)/(course)/(depth, if sub)

This is effectively identical to the original format except that fewer characters need be typed; upwards compatibility is maintained so that any parameter which had been valid in the old version is still valid.

In the original version, all parameters except the identification (parameter 1) were limited to numbers, and all parameters had to be specified. It seemed desirable to expand the specifications to include some key words, particularly the word SAME. The ability to substitute this word for any speed, course or depth considerably expands the versatility of the program. In the past if a user desired to maintain a speed he had to know it; sometimes he lost valuable seconds looking back to check his current speed so he could maintain it. The addition of SAME means that he can just type SAME instead of the actual speed. Similarly the user can maintain his present course and/or speed if desired. To further simplify matters, a null parameter has been defined to be equivalent to SAME. A null parameter is either two consecutive slashes or if it is the last parameter, a blank after the previous parameter. This makes the following instruction pairs equivalent:

SETSP/RED//310/200	SETSP/RED/SAME/310/200
SETSP/RED/10/310	SETSP/RED/10/310/SAME
SETSP/RED/10	SETSP/RED/10/SAME/SAME
SETSP/RED//310	SETSP/RED/SAME/310/SAME

If two specifications are to be made then the duration must be in its normal position. Thus the following pair is equivalent:

SETSP/RED//310//2//260 SETSP/RED/SAME/310/SAME/2/SAME/260/SAME

The end of a statement is more difficult to determine now. Previously, a missing duration signified the end; now a specification with all speed, course and depth parameters null is also an end condition. If the first specification of a request is null then no action is taken except the printing of an error message.

The addition of SAME prompted other vocabulary additions. Speeds of SLOW, STANDARD, FULL and FLANK are defined for each ship; the submarine has different values for surfaced and submerged conditions. The word STOP does more. It is a speed specification of 0 and course and depth specifications of SAME. All the speeds but STOP are followed by a course; STOP is followed by a duration since it is in itself a full specification.

3.3 Computational Methodology

In the above ways, we have considerably simplified the format of the command language. Various changes have been made to improve our model once we gained experience with the original model and discovered its deficiencies. The SETSP command was found to be lacking in several ways. A logic change was introduced when the program was given the ability to interrupt a previously scheduled turn to begin a new maneuver. This change can be better understood after an examination of the structure of the OWN record, which stores the sailing plan.

The OWN record is formed by a succession of blocks which are of two types. The first is used by the program whenever the ship is to be on a constant course and consists of the following information:

1. latitude at start of straight section (degrees)
2. longitude at start of this section (degrees)
3. time of start of this section (minutes)
4. speed throughout this section (knots)
5. course throughout this section (degrees)
6. depth of ship for this section (feet) (for submarines only)

The other format is used for all turns and consists of the following:

1. latitude at start of turn
2. longitude at start of turn
3. time of start of turn
4. the negative of the speed throughout the turn
5. the turning radius for this turn (degrees)
6. depth of ship for this section (for submarines only)

The type of block can always be determined by the program by examining the sign of the speed word in the block. If it is negative, the ship is turning; otherwise the ship is maintaining a straight course. If the vessel is not a submarine then the length of both blocks is reduced to five as depth is not applicable.

The only restriction in the positioning of the individual blocks in the record is that every turn block must be followed by a straight block. This is necessary because the direction of the turn is determined by the program from the courses before and after the turn.

When a player initiates a sailing plan modification at a time "t" then a search is made by the program for the last block beginning before "t". If it is a straight block then either a turn or a straight block can be added after it. If it is a turn then only a straight block can follow.

Most maneuvers begin with a turn; the only maneuvers which don't are those where the new course coincides with the present course. Because of this, the original SETSP allowed the initiation of a new maneuver only during intervals covered by straight blocks. If a turn block was encountered, then the message

WAIT A MINUTE, YOU ARE IN A TURN.

was printed. Modern versions of SETSP function as the original unless a turn is encountered. When this occurs a short straight section is inserted before the new maneuver is even examined. The course used is the course calculated at "t" considering the portion of the turn completed; the speed and depth are set to the values in the turn. The length of the inserted section was arbitrarily set to .1 minutes. This simulates a time lag of 6 seconds when a turn is already scheduled.

A turn is terminated in the above manner only when a new request is made during a time when a previous request specified a turn. All turns in a request are scheduled to be completed when the processing of the request is finished. This sometimes requires adjustments in the timing of the maneuver as indicated below.

If more than two course specifications are to be included in a single request then they are separated by the duration of the first leg in minutes. For example, the request

SETSP/RED/5/30/100/1/5/150/100

has two specifications included. The first is to turn from the present course to 30° at 5 knots and 100 feet depth. One minute after the start of that turn, a second turn is to begin from 30° to 150° at 5 knots and 100 feet. It is possible that the first turn may require more than one minute to complete at this speed for this ship. The time necessary for a turn is a function of the degree of the turn, the turning radius and the speed of the vessel.

The formula can easily be derived. The result is:

$$T = \frac{20 \pi \phi R}{S}$$

where T is the time for the turn in minutes

ϕ is the number of degrees turned

R is the radius of the turn in degrees

and S is the speed in knots.

If more time is required to complete a turn than is available from a specified duration then several possible steps are possible. One is to consider the entire specification invalid. This was done by the original SETSP; it printed the message:

SAILING PLAN IGNORED, INCREASE DURATION WHEN CHANGING COURSE.

This seemed unsuitable so it was decided to seek a remedy. There are two other fairly obvious ways of proceeding. The first is to complete as much of the turn as possible in the allotted time; the second is to complete the specified turn by increasing the duration. Both involve making a change in the request. It was felt that the best choice was to complete the turn and set the duration to the time required for the turn plus an arbitrary .1 minutes. The extra time was used for a short straight section to avoid having two consecutive turn blocks.

Course specifications have been changed even more. Normally the course is a number representing the course in degrees. If the course parameter is either RIGHT or LEFT then a relative course change is indicated. The next parameter is the number of degrees to be turned. Thus, a relative course change requires two words; the first gives direction and the second magnitude. This flexibility is particularly useful when an evasion maneuver is needed. No longer is it necessary to calculate the new course from the old one in the player's head; the program does it faster and more accurately.

Depth changes can also be specified as relative. UP and DOWN are the direction words; they are followed by the increment in feet. If a depth specification would cause the ship to have a negative depth (flying) then the depth is set to 0. Similarly if the depth would exceed the maximum allowable for this vessel then the maximum is automatically substituted. The word SURFACE has also been defined.

The final major change incorporated allows a user to start a sailing plan in the future, if desired. The original version of SETSP always started the new sailing plan at the present time. It was decided that it would be useful to allow the change to start at some time in the future. This was accomplished by allowing the insertion of a time specification before any other parameters except the optional color identification. The player has two alternative ways to set the time. If the first parameter after the identification is the word TIME then the player is using one of these options. If the next parameter is the word PLUS then the third parameter is the number of minutes added to the present time to get the starting time of the new section of the sailing plan. If the second parameter was not PLUS then it is the time when the change is to be effective in four digit format (hrhrminmin). If the specified time is in the past then the present time is automatically substituted and processing continues as if TIME has not been specified. Sample SETSP requests using the time options are:

SETSP/RED/TIME/1345/ ...	the specified change is to start at 13:45
SETSP/RED/TIME/PLUS/4/...	the specified change is to start in 4 minutes

3.4 Strategy Development

The addition of the vocabulary and computational changes described above has had a remarkable effect considering how restricted it appears at first. The ease of specifying zig-zag patterns has been found to be particularly effective; the evasion patterns now show signs of ingenuity whereas before they tended to be uninspired and mechanical.

The use of the procedure definition abilities of the problem solving facility has greatly increased since these changes were made. It is relatively easy to define and save (for a user's exclusive use) a named procedure with parameters. This definition can later be used as often as desired by specifying the name and parameters in a manner which is identical to that used with the original basic commands. One type of procedure which has frequently been used is a sailing plan with four turns, the first two to the left and the last two to the right. The first and third turns are the same amount as are the second and fourth. Two speeds can also be specified. The first sets the speed in the first two legs while the other sets the last two. A sample definition of such a procedure is as follows:

XTRANS PROC EVADE	begin the definition of the procedure named EVADE
FPARAM A,B,SPD1,SPD2	define parameter list

SETSP/RED/SPD1/LEFT/A//3/SPD1/LEFT/B//4/SPD2/RIGHT/A//3/SPD2/RIGHT/B

	definition of procedure including substitutional arguments
END	indicate end of procedure
XENTER/RED	save this in file RED

In this definition A and B are relative course parameters while SPD1 and SPD2 specify speeds. If RED should want to execute this procedure at some later time then he could do so by typing EVADE followed by the parameter values to be substituted. An example is:

EVADE/30/20/8/FULL

The sailing plan changes would be made as indicated in the original definition with 30 substituted for A, 20 for B, 8 for SPD1 and FULL for SPD2. If desired, any of the parameters could have been null; this has the same effect as a null in the original definition. For example, EVADE/30/30 has the effect of two 30° left turns followed by two equal right turns; the speed is unset so it is equivalent to SAME. If a single left turn followed by a single right turn is desired, then the second parameter is deleted and both speeds should be supplied. This makes the statement equivalent to:

SETSP/RED/SPD1/LEFT/A//3/SPD1///4/SPD2/RIGHT/A//3/SPD

If only the first parameter had been supplied then the request degenerates to a single left turn. This is because the second leg is completely null. (the sequence /LEFT// is equivalent to /SAME/)

The example given above for an evasion procedure is relatively simple in form, but it is quite versatile. More complex definitions can easily be made as desired and old ones deleted too. By storing the procedure in RED, full protection is gained since WHITE has no access to that file. WHITE of course has his own private WHITE file for his use.

It is hoped that the discussion of the evolution of this major function has illustrated the value of a flexible problem solving facility. It is further hoped that the reader has gained some insight into the types of evolution that can occur on a problem solving system. The function discussed has undergone many changes. The two main classifications of these changes are:

1) the correction of deficiencies discovered through use, and

2) the addition of new powers.

The first stage of SETSP evolution was principally to reduce the number of circumstances under which the program was unable to function. The second phase added some completely new powers to make the program more flexible.

4.0 SONAR ANALYSIS AND PROCESSING

4.1 General

The experience in development of the techniques of sonar analysis, on-line, at the display console give a concrete example of the power of an on-line Problem Solving Facility. In this section is described the evaluation of two key portions of the overall system, as they were developed by an individual researcher aided by on-line facilities. At all times the system was in operation; its performance level (and capability) changed markedly over the course of this interactive experiment.

In any real naval encounter sensor data plays a prime role. To simulate such an environment, sources of such data must be supplied. Two types of sensor data are presently provided:

1) Active sonar gives data on the range and bearing to the other ship at specified times.

2) Passive sonar provides only bearing information.

All sonar data is obtained from system programs which calculate the true range and bearing, insert noise, and then pass the readings to other programs. The amount of noise and some characteristics such as layer depth are controllable by a user in the non-competitive referee state.

The analysis of sonar data is a major task of the user. To facilitate solutions of sonar data, two basic sonar analysis programs were prepared. The first is used for active sonar. It takes a set of time, range, bearing triads. representing active sonar points and generates an estimate having constant course and speed. The method of fitting the points to the line is discussed in detail in Section 4.2. The basic analyzer is imbedded in several functions. The function ESTAC (ESTimate using ACtive sonar) uses a group of n readings ending at the present time or a selected time in the past. ELISA (Estimate with LISt Active) is used in conjunction with the display to allow the user to select a group of readings with the light pen and then make an estimate using just the selected readings. Both of these functions are also available in versions which allow higher level active sonar analyzers to call them and pass parameters internally. The higher level analyzers are discussed in detail in Section 4.3.

The second basic analyzer is used with passive sonar and is called ESTPS (ESTimate using Passive Sonar). It requires a fixed number of points (4) to create a straight line fit. It does however select points to a limited degree to make the solution possible. This process is discussed in detail in Section 4.4.

Both estimating programs print an estimate of the relative position, course and speed of the opponent. In addition an ESTO (ESTimate of Opponent) record is created which saves the information in the data management system for use by other programs if desired by the user.

The area of active sonar analysis is being further developed so that the user will have more flexibility in selecting how a solution is determined. He will be able to choose different levels of computational complexity as desired depending on the time which is available and the confidence he has in the computer generated solutions. He will still be able to select points using the interactive display, and the facility of having the computer computationally select points according to criteria controlled by the user is being added. Two new programs are under development which add much to this problem area.

The program ASSEL (Active Sonar SELect) will provide the user with the option of having the computer computationally select the best points to be used by an internal version of the active estimating program ELISA. The program ASCOM (Active Sonar COMpare) can be used to determine when an existing estimate should be replaced. ASCOM includes the facility that the user can have either function ESTAC or ASSEL executed automatically when a new estimate is needed; this is controlled by ASCOM parameters.

The four basic programs to be available to the user are ESTPS for passive sonar and ESTAC-ELISA, ASCOM and ASSEL for active sonar. These will provide an extremely flexible and powerful computational group.

4.2 Active Sonar Estimates

The design of the sonar analysis programs has been influenced greatly by experience gained on-line using the original active sonar processing program ESTOP (ESTimate OPponent). ESTOP and ESTAC are identical in function. There are several differences in implementation which make the newer ESTAC much more effective.

Computationally both programs fit a line to a group of active sonar points. ESTOP used a technique which emphasized the first and last points in the interval. Speed was determined from the distance between those two extreme points and their times. Position at the time of the final reading and course over the interval were obtained by applying a Least-Square-Fit technique to minimize the sum of all the squares of the perpendicular distance from each point to the line. This technique was sufficiently valid when ESTOP was in use because no noise was present in the readings. ESTAC uses a line fitting technique which stresses no single point. This is achieved by a least-square technique which considers the time of all of the points rather than just the two extreme times. The line resulting from ESTAC minimizes the sum of the squared distance from the point to the position on the line corresponding to the time of that sonar reading. Comparison testing has shown the newer method to be far superior in the presence of noise.

Another significant difference between the two programs is the manner in which the sonar readings are obtained. The older ESTOP used sonar records directly; each record was a sequential set of sonar readings which had been requested at a time prior to the earliest reading in the record. ESTOP used all of the readings in a specified record which were available at the time of the ESTOP request.

The procedure followed when an estimate of the opponent was desired was first to request that n sonar readings be taken by executing USESN (USE SeNsor) at a time before the sonar readings were needed. USESN created a sonar record with the name specified by the user, which could then be used by ESTOP, with the actual reading computation done by a system program. A sample USESN call was as follows:

USESN/RED&SON4&STEP/=Δt/=n

where RED was the user's identifying color, SON4 was the name of the sonar record to be created, STEP specified that n readings were to be taken at interval Δt with the first reading immediately. Since Δt was commonly between .25 and 1 minute, at least .25 minute had to elapse before the minimum number of readings (2) required to make an estimate would be available in the new record. The user therefore had to execute ESTOP on an older sonar record and request a new record each time he executed any functions, to insure that an up-to-date sonar packet would always be available.

After a sonar record was created then ESTOP could be executed. ESTOP performance required that the user supply the sonar record name and the name of the ESTO record to be created. A sample ESTOP call was

ESTOP/SON4/DD4

where SON4 was again the sonar record name and DD4 was the ESTO name to be used. ESTOP provided a printout which included the estimated course and speed of the opponent, and the time that the estimate was made. ESTOP stored internally an ESTO record which could be used by other programs. It did not print out the range and bearing to the opponent; it was necessary to execute RANGE to get this information. A sample range call is:

RANGE/RED&OWN/DD4

which means: calculate the present range and bearing from RED's true position to estimate DD4.

These three functions had to be executed every time a new estimate was desired. It was felt that this essential task was needlessly complex for the user, so several improvements were installed in a new active sonar analyzer and the name was changed from ESTOP to ESTAC to emphasize that it is an active sonar analyzer only.

The first change was to add the ability to turn the sonar on and leave it on until it is turned off. ESTAC gets its sonar readings indirectly from another program (for internal use only) which has the ability of searching for a group of sonar readings ending at the time specified by ESTAC. ESTAC supplies the time of the last reading desired and the number of readings, and the system provides a list of the data specified. This change eliminated the necessity of frequent USESN calls; now the sonar is usually just turned on and left on.

A minor change eliminated the necessity of executing RANGE each time; the ESTAC printing was simply expanded to give the range and bearing too.

These two changes reduced the number of programs specified by the user to the bare minimum - one. Further modifications reduced the data requirements.

One advance was achieved by giving the computer the ability to automatically give a name to the ESTO record if desired. With ESTOP the user had to supply a unique name to each ESTO record since only the last record of a particular name is available. The user now has the option of supplying the name to ESTAC or having the computer assign it for him. The ESTO name whether supplied or assigned is printed out for use with other worker programs. This change transferred the last bookkeeping task from the user to the computer.

The computer also has assumed the task of identification; the user no longer has to specify identification on each call to ESTAC.

The format for an ESTAC call is as follows:

ESTAC/(number of readings)/(time of last reading)/(ESTO name)

If the ESTO name is not supplied then the computer generates and prints its own. If the time of last reading is not specified or if the time is in the future, then the computer uses the present time. If the number of readings is not specified then the computer assumes 4. Note that all parameters are optional! This is a far cry from the requirements of ESTOP. To get the same information as obtained by executing

```
ESTAC
```

the player previously would have had to execute the following functions:

```
USESN/RED&SON4&STEP/=.25/=4
ESTOP/SON4/DD4
RANGE/RED&OWN/DD4
```

The sonar record in the above example is SON4; DD4 is the name assigned to the ESTO record. A count of the characters shows that what used to require 58 characters for a typical request now needs only 5; also only one program is specifically called instead of three thus reducing the time needed for execution.

These changes have considerably improved the effectiveness of the game. Normally only 5 characters are typed for each active estimate; more time is available for tactical decisions. Since no parameters are necessary there is little chance for error; as yet no one has misspelled ESTAC, and that is the only possible error. The active sonar problem has been reduced to a minimum for this level of processing.

The active sonar analyzer ELISA (Estimate LISt Active) is available for use with the display. It is identical to ESTAC except that it uses a list of the times of sonar readings which has been selected by the player, on the display for analysis, rather than a sequential group ending at a specified time. ELISA requests are normally generated by the display system automatically.

4.3 Preprocessing Active Sonar Readings

Extensive use on-line of the ESTAC-ELISA functions showed that further work in the active sonar analysis process was desirable. It was found that the user was making new estimates continually to insure availability of recent data; frequently no new estimate was necessary. The program ASCOM was implemented to give the user a method of determining when a new estimate is needed, and to provide for automatic execution of ESTAC if desired by the user. This function uses an estimate previously created, and successively compares each sonar point with the estimated position at that time to determine when the error between the readings and the estimate exceeds any of certain criteria.

The criteria used include the distance of individual points from the extrapolated position on the estimate, the average distance, and the RMS distance. Errors in distance components are available such as error parallel to the estimate (speed error) and error normal to the estimate (course error).

A total of seven rejection criteria is presently available; these can be turned on and off by the user and all values are adjustable as often as desired. Of particular value to this function is the fact that all parameters can be set at the beginning of the encounter to the values desired by the user; these values are used until specified otherwise. Any subsequent use of ASCOM can include changes in parameters, but these are for single runs only unless the word SET is included in the parameter list in which case the present parameters become the new standard set for this user. In addition the amount of output is under player control. He can choose any one of four output levels ranging from data on each point which runs at least one line per point to a level which prints just the reason that the estimate is no longer valid. This allows the experienced (and trusting) player to save printing time. Of course the output level is similar to the rejection criteria in that a standard level is set and that it can be adjusted for each run of ASCOM. The current values of all rejection criteria are printed if a player includes the word LIST in the parameter list. A description of all parameters and their current values is printed when the word DESCRIBE is present.

It is felt that the program ASCOM is quite a bit more effective because of the above characteristics, many of which are available only in ASCOM at present. To make ASCOM more useful, we have added the ability to specify the action to be taken when an estimate is rejected. The possibilities include no action, use ESTAC, and execute the program ASSEL.

The other area in which further development was felt to be desirable is a way of having the computer select a list of points to be used for an estimate computationally to augment the power of visual selection available with the display and ELISA. The program ASSEL is under development to do this; it will provide the internal version of ELISA with a list of times to be used for an estimate.

ASSEL will use readings over a specified time span. A line will be drawn between the average of a small group of readings at the start of the span and that of a group at the end. Then the program will calculate the position estimated by the line at the time of each reading. Rejection of a single point occurs if any rejection criterion is exceeded. If too many points are deleted, then a new try can be made using later readings. All parameters of rejection are to be handled as those in ASCOM so as to minimize typing by the user and to shorten the computation time by reducing the number of parameters handled.

4.4 Passive Sonar Analysis

Initially, active sonar was the only sensor available to a user and ESTOP was the only function to make an estimate of the opponent's path. It was felt that a passive sonar facility would be a useful addition; the development of ESTPS was therefore initiated.

The analysis of passive sonar information is considerably more difficult than for active sonar data; active sonar yields the range and bearing to the opponent at each point while passive sonar provides only the bearing. The solution is also more sensitive as there are circumstances under which passive sonar alone cannot possibly make an estimate, whereas no such conditions exist with the active sonar estimating procedures used by ESTOP and ESTAC. As an example, consider two ships which are on an exact interception course; there is no change of bearing under this circumstance, but there is a change in range unless the two ships are moving with identical speeds and courses. There is no way of telling how far away the ships are using only bearing information, but ESTAC could easily solve the corresponding active sonar problem. Under many circumstances a passive sonar analysis can be achieved; the rest of this section is a discussion of such a method of solution and some problems inherent in it.

An initial assumption was necessary before any progress could be made; it was that the opponent does not change either his speed or course during the interval over which the estimate is made. The quantities desired are the opponent's speed, course and range. It was found that it was possible to get three linear equations with just these quantities as unknowns if three sonar readings were given. Unfortunately, these equations were not independent; the determinant was zero. After-thought showed that this should not be surprising as linear equations have the property that there can be either zero, one or an infinite number of solutions to a system of equations. If both ships are moving with constant velocity then there are at least two solutions, hence an infinite number must exist. A first version of ESTPS was implemented which required that the player supply an estimate of one of the three unknowns and then the other two would be calculated. This version was satisfactory as long as the supplied value was accurate, but was of little value when it wasn't.

A major reason that the above approach is unusable is that the paths of both ships were solutions of the equations. The question was raised as to the effect of requiring that the sensor ship be maneuvering during the interval, thus reducing the number of solutions known to exist to one. At about the same time, the maneuvering board was introduced to the project personnel. This tool provided new insight into the problem and pointed the way towards a reasonable method of solution. It was found that a unique solution was indeed possible when the sensor ship was maneuvering. A derivation of the solution is provided in Appendix A.

A second version of ESTPS was prepared which used this method of solution. It was considerably more useful than the first but was still unsatisfactory.

One of the problems was the difficulty in insuring that a maneuver was included. The program used four consecutive readings which were normally about .25 minute apart; the total time span was only .75 minutes. It is not natural that a ship changes course or speed appreciably every 45 seconds or less. When an ESTPS was executed on a set of readings which did not include a maneuver, then the program provided only the present bearing and bearing rate since no solution was possible. This problem was largely overcome by having ESTPS always request the last 12 readings and then checking them until a change in sailing plan was found. The position of the sensor ship is known at each time. Let the most recent time be t_0 and the oldest t_{11}. (Note: the reverse numbering is for convenience in Appendix A.) The course and speed between t_0 and t_1 are calculated using the position at those times. This line is then extrapolated to the earlier times t_2 to t_{11}. As soon as the distance between the true position and the extrapolated position at the same time is non-zero then a maneuver is included in the time spanned; let the time of that reading be called t_i. For practical purposes it has been required arbitrarily that this distance must exceed .06 miles to be considered a sufficient maneuver. The most recent sonar reading used by ESTPS is t_0 and the earliest is t_i. Any readings earlier in time than t_i are ignored; if all 12 readings are examined without a maneuver being encountered then a message is printed which gives the present bearing and bearing rate. The selection technique uses the smallest possible time span including a maneuver. In practice this additional ability has more than doubled the effectiveness of ESTPS.

The other major problem noted while using the second ESTPS was caused by the initial assumption; if the opponent is not moving with constant velocity during the interval, then the answer must be wrong. The technique used to alleviate this difficulty was to make two estimates over the same interval and compare the results. To reduce computation time, only the most critical computations are run twice. This was accomplished by using one extra sonar reading to make a total of 5. The first pass calculates the range, relative speed and relative course using sonar readings at t_0, t_1, t_2, and t_i; the second is identical except that the values at t_0, t_1, t_3 and t_i are used. After both passes are complete then the average value of the two estimates of each of the unknowns is used in the remaining calculations, thus somewhat smoothing out any errors. To provide the player with a measure of the agreement between the two passes, an unreliability factor is computed and printed out. This factor is the percent deviation of each of the unknowns. It is computed from the following formula, where the '‾' indicates the average of both passes.

unreliability factor =

$$\frac{100}{3}\left[\frac{1}{\bar{R}}\sum_{i=1}^{2}\left|R_i-\bar{R}\right| + \frac{1}{\bar{\phi}_R}\sum_{i=1}^{2}\left|\phi_{R_i}-\bar{\phi}_R\right| + \frac{1}{\bar{V}_R}\sum_{i=1}^{2}\left|V_{R_i}-\bar{V}_R\right|\right]$$

where R is range

ϕ_R is relative course

V_R is relative speed.

When the two passes are not in agreement then either there is noise in the data or the opponent is turning. In a noiseless environment a high unreliability factor means the opponent is turning. A low unreliability factor provides only the information that the two passes agree closely; it is possible that they give a similar wrong estimate. Tests with a noiseless sonar model showed that the unreliability factor was successful; a factor below 1% just about guaranteed a good estimate and above about 2% did guarantee an invalid one. The introduction of noise changed this. A factor above 20% usually meant that the opponent was turning, but little correlation was found in the range 5% to 20%. It is expected that in the future the ability to compare estimates will be added in order to determine which of these are probably valid. It seems that this problem is best approached using the display so that a player could visually select a consistent set of estimates. This ability seems necessary in a noisy environment.

If the noise sensitivity is too high and sufficient computation time is available, then additional solutions using different combinations of readings could be made and combined to give an even better estimate.

Under some circumstances one or both passes through ESTPS will be suppressed because of an obvious inconsistency. For example it is impossible for the relative speed of the two ships to exceed 60 knots; if V_{R_i} exceeds 60 then that pass is suppressed internally by ESTPS. Similarly, the maximum range of passive sonar is about 30 miles; a pass is suppressed if the estimated range exceeds 35 miles. In both cases this was done to avoid a possible division by zero; the relative magnitudes of the numerator and denominator are checked before the division to insure that the result is reasonable. Usually, although not always, only one pass is affected in this way; the other continues normally except that it is used directly for the later calculations and no unreliability factor is available.

The present version of ESTPS includes all of the above features and also the advances inherent in ESTAC which are applicable. In the absence of noise it performs well; its performance degrades when incorrect bearings are introduced by noise simulation.

Some maneuvers yield better results with this passive sonar analyzer; this affects the tactics used. It is desirable to avoid a course which yields a direct or near interception. More generally, estimates are best when the bearing rate of change is high. Thus to intercept, one reasonable tactic is to make occasional durations of course on the order of 60 or more degrees and try to make estimates during the time of this rather violent maneuver thus using periods of high bearing rate of change.

5.0 WEAPON SYSTEMS

5.1 General

A major area that must be considered in the construction of a valid and realistic environment for a Navy war duel simulation is that of weapons systems. Having a system that can fire a weapon and then track it along its path provides the motivation for the development of strategies in the areas of navigation, sonar acquisition and estimating as well as weapons control. In an environment in which the problem is to locate and sink an enemy ship, navigation strategies are concerned with maneuvering to get good sonar data, preventing being sunk by an opponent's weapons and maintaining a good firing position. The validity of strategies developed by users in all of the above areas can be fully evaluated only by the employment of a weapons model.

In the use of on-line problem solving for evolution of a weapons system, actual experimental trial and error aided greatly in the testing of competitive strategies for the individual commander. Both human engineering and performance weaknesses were discovered on-line and changed. Mistakes in analysis were naturally discovered during on-line competitive duels and then corrected. Man machine decision making was continually added to the system. A player oriented "decision tree" was also introduced.

The model that has been implemented in the war duel simulation consists of four user functions. These are:

WPARM (Weapon PARaMeters) - to preset or change any of various decisions which have to be made in order to fire a weapon.

WEAPO (WEAPOn) - to launch the weapon,

CNFRM (CoNFiRM) - to trace the path of the weapon and determine if during its allotted running time the opposing player was hit, and

WEPST (WEaPon STatus) - to inform the player what weapons he has remaining in his arsenal.

The weapons model has had several improvements made in its structure as information and experience were gained by continuous use of the problem solving system. The rest of this chapter will explain the original design of the model, point out the weaknesses that were discovered during its evaluation and the modifications that were made to strengthen it.

5.2 Launching a Weapon

5.2.1 General

When firing a weapon, the most difficult problem that must be solved is to accurately determine where the opponent is and where he is heading. This information depends upon the constant acquisition of sonar information and the continuous processing of the sonar points into estimates of the enemy's course, speed, bearing and range. Since the war duel simulation is in a real-time environment, the opponent can change his course often and make an estimate invalid in a very short period of time.

5.2.2 Initial Model

The initial weapons launching function was:

WEAPO/(name of weapon)/(ESTO item description)/(number of weapons).

Using this function, the destroyer could elect to fire asrocs, torpedoes, or hedgehogs while the submarine was limited to torpedoes.

Since the weapons systems simulation was a relatively new functional module to be added into the war duel environment, the original design drew upon experience gained during the evaluation of other programs.

The initial weapons model contained improvements over the older versions of existing programs in several areas.

The first areas of improvement were concerned with human engineering factors such as

1) simplifying the amount of input the user must give the computer,
2) blocking together several input statements into a procedure so that many user functions might be executed after a simple command was inputted.

These improvements tended to decrease the likelihood of the user making a typing error, forgetting a necessary parameter in a program which required numerous parameters, and speeding up the process of inputting information. (This is usually the slowest link in an on-line, interactive problem solving system.) These improvements also freed the user to make strategic decisions in the time that would normally have been spent typing.

In the original versions of most programs, the user's identification (red or white) was a required parameter. The addition of a mechanism which automatically retrieved the identification from an area in storage (which was created when the user signed into the system) made the input of this extra information unnecessary. This mechanism added an additional feature to the model since it provided an internal method of protecting one user's weapons from interference by an opponent.

Another method by which the input necessary to launch a weapon was considerably shortened was through the use of default conditions. Each of the three parameters in the WEAPO call had a default value which was used when the parameter was not specified explicitly. If the first parameter (name of weapon) was left empty, it was assumed that the destroyer commander wanted to fire an asroc, and the submarine commander, a torpedo. If the ESTO item description was not supplied, then the firing was based on the last active estimate that was made by the user. Lastly, it was assumed that only one weapon was to be fired if a number of weapons was not specified.

The most important feature that was present in the original model was the use of a procedure to allow maximum input requests with minimal typing. The major problem in firing a weapon is to get the best possible estimate. If we chose to fire several weapons - all based on a single estimate - we might very well find that each weapon fired was further and further away from the actual enemy position. For this reason it was necessary to develop a means by which the user could ask the computer to make new estimates for him just prior to a weapon's firing and to provide a mechanism which could continue this automatically when several weapons were to be fired in succession.

In order to make these estimates one must call on the programs described in Chapter 4. The most apparent way to accomplish this would be to create an entry point to the estimating programs which could handle calls from the weapon firing program and then transfer control back. This method would have required changes to ESTAC and ESTPS; it was considered advisable to avoid this. The result of this effort was the decision to use the Multilang procedure capabilities.

5.2.3 Weapons Firing Using a Procedure

The player function WEAPO is a Multilang procedure. The major component of this procedure is the program WEAP which performs the necessary interception and bookkeeping computations. As an example of the construction of a procedure, consider part of WEAPO:

```
    XTRANS PROC WEAPO
    FPARAM COLOR, WPNAM, ESTO, WPNUM
    SET/L(50)/WPNUM/PLUS/=1
    BRNCH/ESTO
      :
30  SET/L(50)/L(50)/MINUS/=I/L(45)
    ESTAC/COLOR
    WEAP/WPNAM/LASTA/COLOR
    GOTO/L(30)
      :
45  NULL
    ENDSTA
50  =2
    END
```

In the first statement we are telling the Multilang system that we are defining a procedure which is to be called WEAPO. Then in the second statement we declare that there are to be four formal parameters: the user's color (COLOR), the name of the weapon to be fired (WPNAM), which of the several ESTO descriptions (to be discussed later) to be used when firing (ESTO), and the number of weapons to be fired (WPNUM). For each of the ESTO descriptions that can be chosen by the player, there exists a sequence of programs similar to the four beginning with statement 30. Suppose, for example, that the user wants to fire three torpedoes and take a new active estimate before each is fired. To do this he would type

WEAPO/TORPEDO/NARNA/=3.

In this statement the word NARNA is the ESTO item description and stands for "fire the first torpedo on a New Active estimate and fire the Remainder also on New Active estimates".

When the Multilang system sees the procedure call WEAPO, it retrieves a copy of the definition from secondary storage and substitutes all the actual parameters in the call for every occurrence of these parameters within the procedure body. It then transfers control to the first executable statement (which is a program). In this case the first program that is executed is SET which initializes the procedure (SETs the contents of label 50 to the number of weapons to be fired plus 1 = 4). Since the system is designed to be as easy as possible to use, the lack of a WPNUM parameter results in one weapon being fired and the contents of label 50 containing 2. The next program to be reached is BRNCH, which branches to label 30 after reading the second parameter (NARNA). At label 30, we again encounter the program SET which acts as loop control (subtracts 1 from label 50). We execute ESTAC which gives us a new estimate and then fire a weapon using WEAP, where the ESTO parameter of WEAP is LASTA. This means that the ESTO item just created will be used in the interception calculations. These two programs are executed sequentially n times, where n is the number of weapons to be fired - in this case 3. Each time WEAP is executed, control is transferred back to label 30 by the GOTO program and the counter (program SET) is decremented by one. After 3 repetitions label 50 is zero, and control is transferred to label 45 which is effectively the exit from the procedure.

By employing the procedure method, the player has the option of electing one of nine ESTO item descriptions when firing a weapon. These are:

LASTA: fire all n weapons on the last active estimate made

LASTP: fire all n weapons on the last passive estimate made

"a name": fire all n weapons on the named estimate

LARNA: fire the first weapon on the last active estimate and fire each of the remaining n-1 weapons on new active estimates

LPRNP: same as LARNA but with passive estimates

NARNA: make a new active estimate before each of n firings

NPRNP: same as above with passive estimates

NEWA: fire all n weapons on one new estimate

NEWP: same as above for passive

Since each of the ESTO item descriptions represents a sequence of programs, it is very easy to add new descriptions. All that would be needed is a minor change in BRNCH and a list of the new programs.

The major part of the WEAPO procedure is the program WEAP. In the original implementation, the program was designed to make some decisions on its own to relieve the player from unimportant decisions that he otherwise would have had to handle himself.

When WEAP was called it checked to see if the weapons specified were available, computed an interception course based on the specified estimate of the opponent and fired a weapon. The extensive mathematics necessary to compute the earliest possible interception position is described in detail in Appendix B. In the course of execution, several situations may have arisen which were handled automatically. One assumption that was continually made is: when a player tried to fire a weapon, and one of the parameters specified in the request was incorrect, the computer was to correct it automatically, if possible, and execute the corrected program instead of printing an error message and halting. For instance, if the user asked to have a weapon fired based on the last passive estimate, and there was no last passive estimate, the program would state that no passive estimates had been made and proceed with the last active estimate (and vice versa). A situation that occurred much more frequently was that of selecting the correct weapon to be launched. In many instances, the destroyer was about three miles away from the sub when he tried to fire a torpedo; and the program computed that the distance that the torpedo would have to travel to intercept the submarine was greater than its maximum range. In this case the player was informed and an attempt was made to launch an asroc. For each situation, the program had the capability of choosing the correct weapon to be fired.

5.3 Testing and Evaluating the Original Model

5.3.1 Decision Making

During the period when this model was tested and evaluated, it became apparent that the model could be made into a more adequate problem solving tool if further strengths were included in its design.

The first area in which additions were deemed to be necessary was the area of decision making on the machine level. The original model had assumed that it was to fire a weapon if at all possible, and would choose to use an active estimate if no passive could be found. It would choose the correct weapon to fire if the distance to the enemy ship was incorrectly specified as well as making other necessary decisions. These decisions were done automatically and in some instances the action carried out by the computer was not to the liking of the user. To make the man-machine decision process a more interactive and more powerful one, a method was added to the problem solving system which would allow the user to set the decisions to be made automatically by the computer and to change the "decision tree" on-line at any time and as often as desired.

The implementation of this new area was not restricted to just the simple decisions stated above. By writing a program which could set and reset parameters, a new powerful structure was added to the system which includes:

1) branching to one of several new actions when an impasse has been reached in the program. For instance, if there is no last active estimate one can now instruct the computer to a) use the last passive estimate, b) make a new active estimate, c) stop execution and state the reason why.

2) default conditions for all parameters can be specified and changed on-line. Whereas, previously, all default parameters were preset, they can now be changed as often as desired. This is of particular value in the new

weapons launching model which will be described in the next section.

3) many new complex decisions that are dependent on a user introduced value may be added to the automatic decision process carried out by the computer. These types of decisions include performing a specified action if:

a) an estimate is too old (user specifies the maximum allowable age), or

b) an estimate is too unreliable, or

c) if the weapon will run too long before a scheduled interception, etc.

To aid the user in specifying the parameter values that he wants to have, the program WPARM (Weapon PARaMeters) was devised. WPARM is called by:

WPARM/(keyword)/(parameter name)/(value)/(parameter name)/(value)...

In this program call, the keyword is optional and may be:

ALL - set all non-numerical decisions "on". Between decisions stemming from the same impasse, an automatic precedence is built in.

NONE - all non-numerical parameters are turned off. Numeric parameters are set to original default values.

EXPLAIN - an explanation is printed of how to specify the values of all the parameters available.

LIST - a list is printed of all parameters and their current values.

The parameters are separated into groups of EST (estimating) parameters and WEP (weapon firing) parameters. To enter a value to be stored the input would be as above with no KEYWORD parameter.

When the program reads these values it stores them in a record in secondary storage which is always retrieved and examined when a weapon is to be launched. In this manner it is possible to change the values of parameters as often as desired. It would be feasible to change them before every weapon launch if so desired.

5.3.2 Weapon Launching

Although WEAPO, the weapon launching function, had drawn on the experience gained through the use and testing of all the preceding programs in the naval war duel simulation, it was found that the design of a more complex model would provide a better vehicle for the determination of strategies involved with sinking an opponent.

In the original model, if one desired to fire more than one weapon at an opponent, one had to specify the number of weapons to be fired and the area in the procedure to which to branch. If, for example, one wanted to fire 3 weapons, the program WEAP had to be executed three complete times. Since the program employs involved and complex computational methodologies, this was more time consuming than desired. In the use of the procedure, the user could employ old estimates or make new estimates, and the computer did all the interception calculations and fired the weapons. In the above example, when firing three weapons, the user had no control over the angle between the weapons and the bearing that each weapon was fired on.

For the above reasons and because the user may be able to get a more accurate picture of how to fire a weapon by studying several estimates of the enemy instead of just using one, it was decided to revise the weapons model to include firing spreads of weapons and firing on a bearing without using an estimate. By adding this complexity to the model, a method has been provided by which an additional "human decision" can be inserted, if desired by the user, in the string of machine problem solving decisions. Since user decision making is involved in these cases, the complex calculations determining the projected position of the enemy ship and the course of the weapons can all be avoided, as their values are supplied. This cuts down the computation time of the program and allows execution of the desired strategies much more quickly.

The new WEAPO function is called by:

WEAPO/(name of weapon)/ (ESTO item description) or (bearing to fire on) /(number of weapons in spread)/

(the number cf degrees between weapons)/(vertical angle of launch for ASROC)/(NOFIRE option)/

(number of spreads)

WEAPO still has the same procedure structure as was described in Section 5.2. The program WEAP, which does the necessary computations, has been revised. The program now has many new capabilities which include all previous capabilities plus: 1) the ability to fire a spread of 2 or 3 weapons using a specified center course or having the computer find the center course (by using the type of estimate described by an ESTO description); 2) firing more than one spread of weapons with the option of making a new estimate between spreads (in the manner that was mentioned in the procedure discussion); 3) electing to have all the calculations done and then have the information on what would happen if one had fired the weapon without actually firing (NOFIRE option above).

The preceding addition marks a major improvement in the area of man-machine interaction in the solution of a problem. By allowing as much or as little involvement in the step-by-step solution, a maximal system is evolved. It is also noteworthy that additional human interaction is achieved in this part of the process, since such default conditions as the assumed spread between weapons can be set and reset by use of the parameters program (WPARM).

When a weapon is fired, a record describing the position, time and course of firing is created and stored for future use. If the weapon was fired using an estimate projecting the enemy ship's future position, the calculated position and time of interception are also stored in this record. This record has a similar format to the sailing history record, and therefore, the path of the weapon can be displayed by using the display program. An example of this type of record is shown in Table 5-1.

5.4 Confirmation of Weapon Firing

5.4.1 General

After launching a weapon, the primary interest of the user is to determine the success of that weapon. He therefore needs a method by which he can determine whether the weapon launched hit, missed or damaged the enemy ship. To determine this the program CNFRM (CoNFiRM) was written.

5.4.2 Original Model

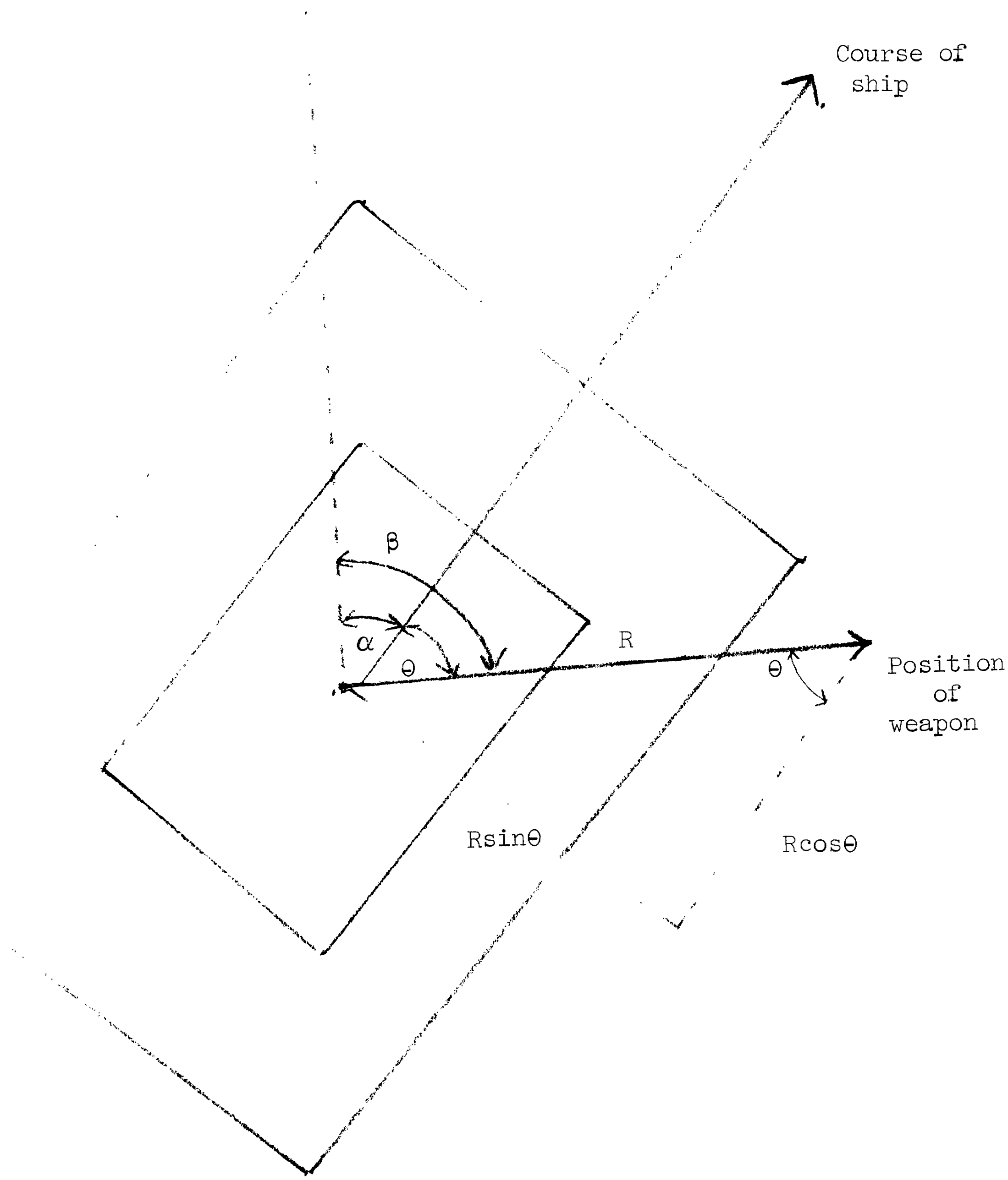
In the original model CNFRM was called by:

CNFRM/(name of the record created when weapon fired).

The first action taken by CNFRM was to retrieve the record which was set up when the weapon was fired (Table 5-1). If the present time was earlier than the expected interception time, then the player was informed that it was too early to confirm a hit. If the inquiry occurred after the calculated interception time, the computer determined where the enemy ship actually was at the interception time (by looking at the opponent's sailing history) and computed the distance (R) between it and the position at which the weapon was fired (see Fig. 5-1).

Table 5-1 Record Created by WEAP (Example)

Key	Element	Contents
1	3	player's identification color
2	4	this is a WEAPO record
3	6	weapon name and number
	200	your latitude at time of firing
		your longitude at time of firing
		time of firing (in minutes)
		speed of weapon in air
		course of weapon
		latitude of weapon hitting water
		longitude of weapon hitting water
		time of weapon hitting water
		speed in water
		latitude of interception
		longitude of interception
		time of interception
		opponent est. lat. at time of firing
		opponent est. long. at time of firing
		opponent est. speed at time of firing
		opponent est. course at time of firing
		opponent est. depth at time of firing
		your course
		your depth
		name and number of weapon
		weapon sunk opponent (0-miss, 1-sunk, 2-damage)
		record was confirmed (0-unconfirmed, 1-confirmed)



α : course of ship
β : bearing from ship to weapon
Θ : $\beta - \alpha$
R : distance from ship to weapon
$R\sin\Theta$: distance along width of rectangle
$R\cos\Theta$: distance along length of rectangle

Figure 5-1
Determining if Weapon Hit Enemy Ship

To evaluate the results of the weapon firing two rectangles were drawn. The inner rectangle simulated the size and shape of the ship, while the outer rectangle had dimensions twice those of the ship. If the position of the weapon was outside of both rectangles then the weapon missed. If the weapon was within the outer rectangle the enemy ship was damaged. If it was also within the inner rectangle the ship was sunk.

Once the confirmation had been completed the WEAPO record was marked as having been confirmed and the results were placed within the record as well as being supplied to the player. In this manner if either the referee or the player checked the results of the weapon firing again, the calculations would not be repeated; the program would see that everything was previously computed and print out the results.

5.4.3 Improvements in Weapon Confirmation

The preceding model was a very simple one. The program knew where the weapon would be at the calculated interception time and also knew where the enemy was at that time and just determined the distance between the two. This model did not take into account any variations in the opponent's actual speed and course which would have resulted in an interception at some time different from the calculated time.

Other than the above mentioned shortcomings in the original model we were now faced with an entirely new situation due to the changes made in the weapons launching simulation. If a weapon was fired without the use of an estimate, the assumed position of interception and time of interception would not be calculated and the original model could not even be applied.

To account for all of the preceding, a new and complex method of confirmation of simulated homing weapons was devised and implemented. The better features from the old model were retained. These included accounting for previously confirmed weapons, telling the user when he was inquiring too early and using the rectangle method to tell whether the weapon was close enough to hit, miss, or damage the opponent.

In the new model, after the weapon record is retrieved and the preliminaries are carried out, the program begins tracing the weapon from its point of arming. At selected time intervals (which become smaller as the weapon approaches the opposing ship) the position of the weapon and the enemy and the distance and bearing between them are calculated. The weapon is assumed to have its own small active sonar unit. If no sonar contact is made, the time is incremented and the calculations are repeated. If the incremented time is greater than the present time, the user is told that he has not gotten a hit as of the present and he should finish confirming the weapon a little later. If the incremented time is greater than the maximum run of the weapon the user is informed that his weapon has missed.

When the weapon is within sonar range of the ship, the rectangle method is employed to determine if the weapon has hit as yet. If it hasn't, the weapon course may be changed, depending on the sonar information, to bring the weapon in on a closer interception. The time is then incremented by a small amount and the calculations are repeated until a hit, miss, or damage results.

If a weapon hits or damages the enemy ship, the user is told of his success and the opponent is informed that he has been hit. If he was sunk, he becomes immobile in the water. If he was damaged, his maneuverability is reduced by a predetermined factor. In this manner each succeeding damage would result in the opponent having less maneuverability than before.

Each time a series of calculations to determine the relative position of the enemy and the weapon is done, the results are placed in the weapon record. In this manner, the exact course of the weapon can be displayed and analyzed, detailing all the turns that were made by the weapon as it bore down on the enemy ship.

5.5 Weapon Status

At any point during the course of a game, a player may want to know how many weapons, of a particular type, still remain available to be fired. This information is of great importance in the planning of strategy; the player has to know if he has the strength to stay and fight or if he should save his last weapons to protect himself during a retreat.

It is also possible that the referee, monitoring the progress of both players, would like to know the weapon status at a particular time. With this information he can execute CNFRM on any of the fired weapons to see if they were successful. He could also retrieve the weapons records to get an insight into why and where they were fired. This allows the referee great flexibility in keeping an accurate move by move picture of the two players.

The weapon status of each player is kept in a small record along with the weapon parameters. It is automatically updated every time the program WEAP is executed successfully.

The weapon status program is called by

WEPST/(OWN item description)/(list of weapons).

If the "list of weapons" parameter is not specified, the status of all weapons available to the player is outputted.

The destroyer's list of weapons consists of TORPEDO, ASROC, HEDGEHOG, any combinations of the preceding three connected by 'AND' or the word ALL. For example, the call:

WEPST/WHITE/TORPEDO'AND'ASROC

would result in the printing of the number of asrocs and torpedoes presently available to the destroyer. The format of the output in this case would be:

YOU HAVE "number" ASROCS LEFT

YOU HAVE "number" TORPEDOES LEFT

The word "ALL" is equivalent to specifying all three names.

Except for the storage of the weapon parameters in the status record, the program WEPST has remained unchanged since its original implementation.

5.6 Conclusions

From the preceding discussions, it is evident that the weapons model has gone through a feedback cycle which has greatly improved the capabilities of the simulation. In the environment supplied by the use of a computer, strategies were developed, systems were tested, results were evaluated, and the necessary modifications were implemented. This process is much less complex and less costly than would have been involved in real life testing.

6.0 A DOCUMENTED GAME

6.1 Game Initialization

As an illustration of the ideas presented in this report, this chapter details the playing of a particular game. Each player sits at a console and via the computer terminal, enters queries and commands to the central computer. The computer simulates each ship's movements and carries out the instructions of the commanders. A detailed description of the basic functions are given in Appendix C. The two players are RED - a submarine - and WHITE - a destroyer. The goal of both players in this game was to attack any detected enemy ships. The figures in this chapter are actual computer generated displays. The game is started by the referee who, in this case, had previously stored the initialization functions in the procedure GAME1.

```
˺TRANS PROC GAME1
       INTCL/=2030
       INTLZ/DD
       START/WHITE&OWN/=25.2/=-30
       START/RED&OWN/=25.3/=-29.8
 ND
˺ENTER/GAME
```

The result of executing GAME1 was

```
       GAME1
203000 IS NOW THE PRESENT TIME
 INTLZ WAS ENTERED
 INITIAL POSITION HAS BEEN STORED FOR TIME =     203020
 INITIAL POSITION HAS BEEN STORED FOR TIME =     203023
```

The game is initialized. Initial positions are set: DD: 25.2°N, 30°W
SS: 25.3°N, 39.8°W

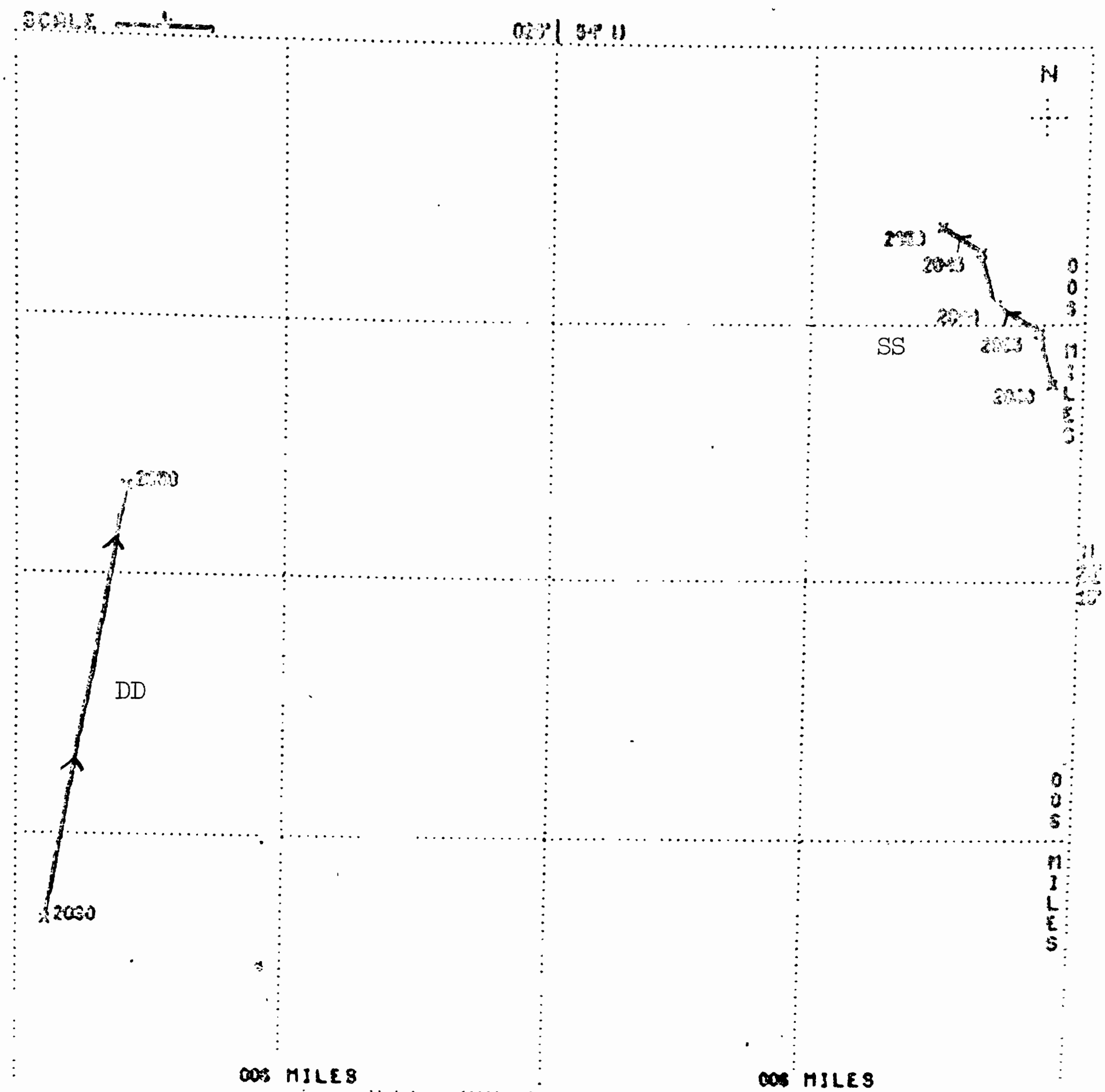
Thus, the ships are placed within passive sonar range of each other. Each player now sets his first sailing plan and requests sonar readings to be taken.

DD:

```
XTRANS PROC BEGIN
       SETSP/15/1Ø
       USESN/WHITE&PASSIVE/CONTN/=Ø.4
       USESN/WHITE&ACTIVE/CONTN
END
XENTER/WHITE
       BEGIN
       SPEED          COURSE         START TIME
       15.ØØ            1Ø             2Ø3Ø29
 THE SAILING PLAN HAS BEEN STARTED.
 SONAR READINGS WILL BE TAKEN
 SONAR READINGS WILL BE TAKEN
```

SS:

```
XTRANS PROC PATROL
       SETSP/7/345/100/5/S/LEFT/45/S/5/S/RIGHT/45/S/5/
S/LEFT/45/S
       USESN/RED&PASSIVE/CONTN/=Ø.4
END
XENTER/RED

       PATROL
       SPEED          COURSE         DEPTH          START TIME
       7.ØØØ            345            1ØØ            2Ø3Ø36
       7.ØØØ           TURN            1ØØ            2Ø3536
       7.ØØØ            3ØØ            1ØØ            2Ø3617
       7.ØØØ           TURN            1ØØ            2Ø4Ø36
       7.ØØØ            345            1ØØ            2Ø4117
       7.ØØØ           TURN            1ØØ            2Ø4536
       7.ØØØ            3ØØ            1ØØ            2Ø4617
THE SAILING PLAN HAS BEEN STARTED.
SONAR READINGS WILL BE TAKEN.
```



OPHIS/OWN/ALL/INCL/=2Ø3Ø/=2Ø5Ø

Figure 6-1

Initial Sailing Plans

Each side now, upon detecting an enemy ship, maneuvers to attack.

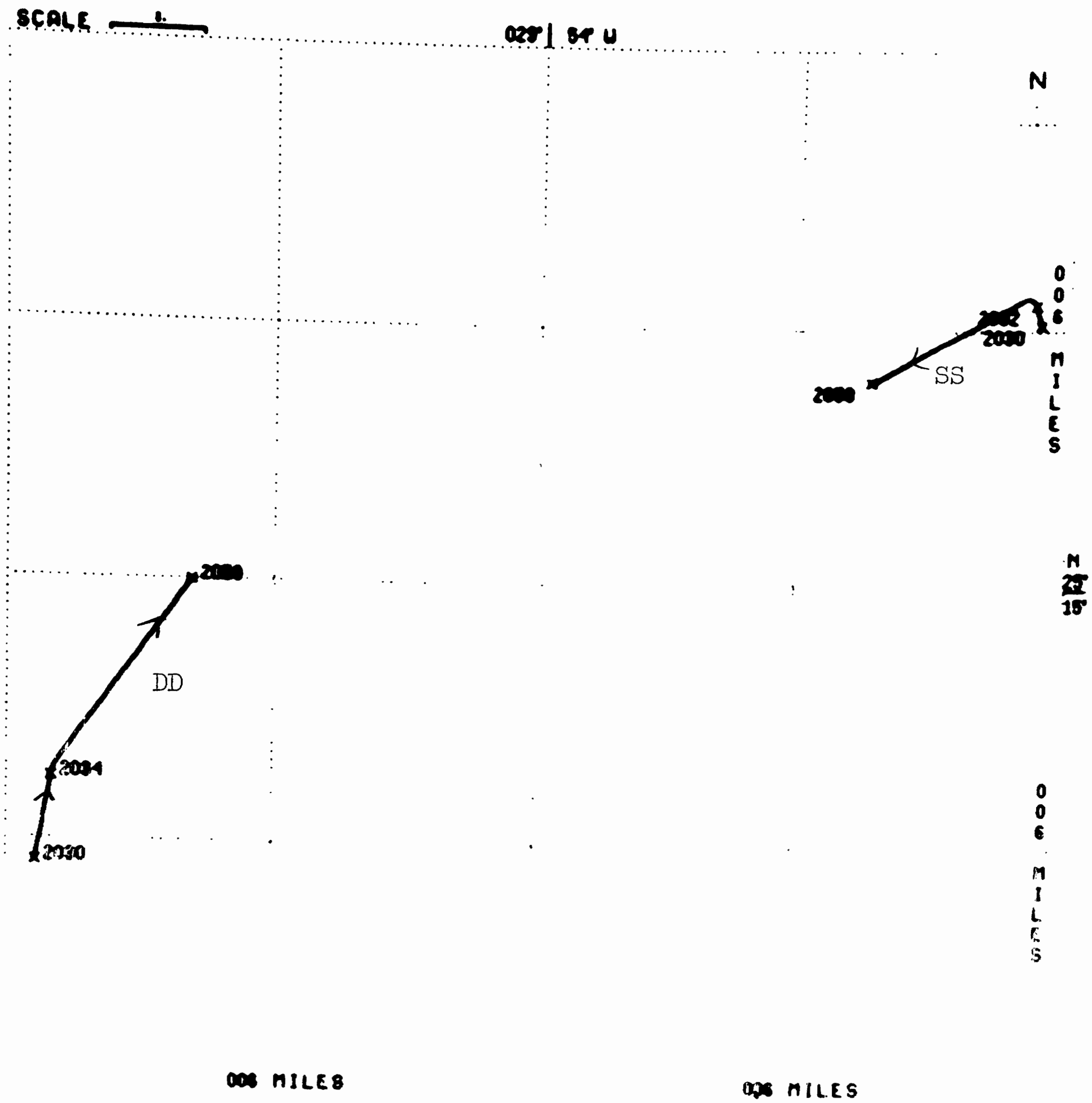
DD:

```
    ESTPS
TOO FEW READINGS FOR AN ESTIMATE   2Ø3152
 PRESENT BEARING Ø62  BEARING RATE      Ø DEG/MIN
```

```
    SETSP/WHITE&OWN/SLOW/=35
    SPEED          COURSE     START TIME
    12.5Ø           TURN        2Ø3418
    1Ø.ØØ            35         2Ø35Ø9
THE SAILING PLAN HAS BEEN STARTED.
```

SS:

```
    ESTPS
TOO FEW READINGS FOR AN ESTIMATE   2Ø3127
 PRESENT BEARING 241  BEARING RATE      Ø DEG/MIN

    SETSP//241
    SPEED          COURSE     DEPTH       START TIME
    7.ØØØ           TURN       1ØØ          2Ø3232
    7.ØØØ           241        1ØØ          2034Ø7
THE SAILING PLAN HAS BEEN STARTED.
```



OPHIS/OWN/ALL/INCL/=2Ø3Ø/=2Ø5Ø

Figure 6-2

The Sailing Plans are Changed

time is automatically substituted and processing continues as if TIME has not been specified. Sample SETSP requests using the time options are:

SETSP/RED/TIME/1345/ ...	the specified change is to start at 1345
SETSP/RED/TIME/PLUS/4/...	the specified change is to start in 4 minutes

SETSP version III incorporates all of the features detailed in this chapter. It is considerably more useful than version I. It is less prone to errors of the types made with I; it did add some new errors but the diagnostic messages are unusually helpful and complete.

It is hoped that the discussion of the evolution of this major function has illustrated the value of a flexible problem solving facility. It is further hoped that the reader has gained some insight into the types of evolution that can occur on a problem solving system. The function discussed has undergone many changes. The two main classifications of these changes are first the correction of deficiencies discovered through use and second the addition of new powers. The first stage of SETSP evolution was principally to reduce the number of circumstances under which the program was unable to function. The second phase added some completely new powers to make the program more flexible.

6.2 The Game as Played By the Submarine Captain

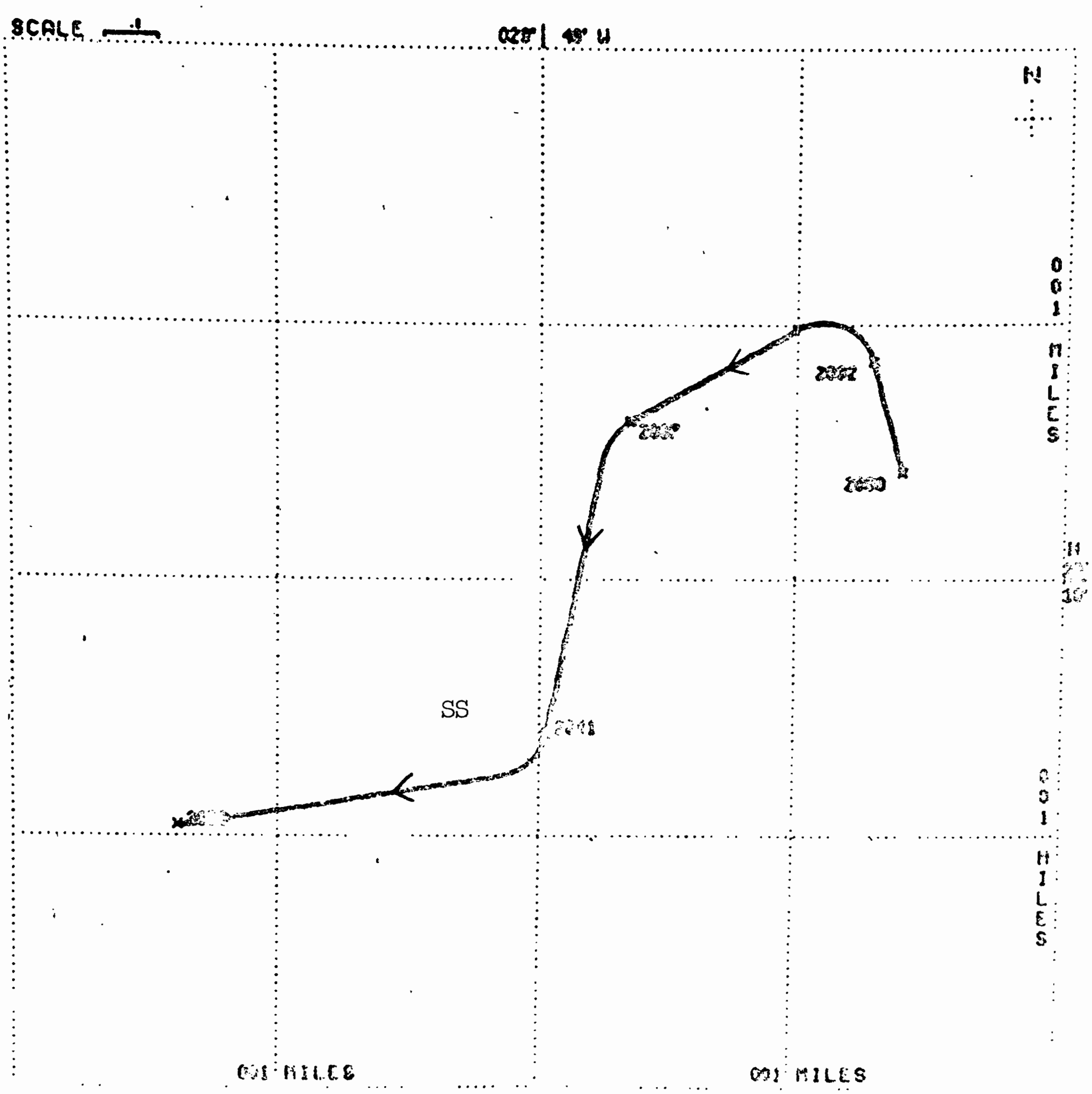
We will now give many of the functions executed by the submarine captain so that his decisions can be followed.

```
      ESTPS
RANGE 13.76 BEARING 242 TIME 203316
COURSE  340    SPEED  29      RELIABILITY +451.5
     NO ESTO RECORD CREATED
```

SS receives an estimate of opponent's position using passive sonar. The estimate is very unreliable - the larger the number, the worse the estimate - and only the bearing information is usable. Therefore no new record is created.

```
     SETSP/STAND/LEFT/50//4/SLOW/RIGHT/70
     SPEED        COURSE       DEPTH     START TIME
     8.500         TURN          100       203718
     10.00          191          100       203759
     7.500         TURN          100       204118
     5.000          261          100       204220
THE SAILING PLAN HAS BEEN STARTED.
```

SS maneuvers in order to continue using passive sonar.



OPHIS/RED&OWN/ALL/INCL/=2Ø3Ø/=2Ø5Ø

Figure 6-3

Submarine's Sailing Plan for First Ten Minutes of Game

```
    ESTPS/2035
PRESENT BEARING 243  BEARING RATE  .7193 DEG/MIN

    ESTPS/2036
RANGE 02.74 BEARING 244 TIME 203604
COURSE  094    SPEED  05      RELIABILITY +80.99
    NO ESTO RECORD CREATED

    ESTPS
RANGE 10.39 BEARING 246 TIME 203852
COURSE  040    SPEED  12      RELIABILITY +21.61
    NO ESTO RECORD CREATED

    ESTPS/2041
RANGE 06.24 BEARING 249 TIME 204052
COURSE  211    SPEED  28
    NO ESTO RECORD CREATED

    ESTPS/2043
RANGE 10.90 BEARING 250 TIME 204252
COURSE  284    SPEED  12      RELIABILITY +20.54
    NO ESTO RECORD CREATED
```

SS has difficulty obtaining reliable estimates.

```
    SETSP/TIME//2/RIGHT/10
    SPEED        COURSE       DEPTH     START TIME
    5.000        TURN          100        205140
    5.000         271          100        205152
THE SAILING PLAN HAS BEEN STARTED.
```

SS requests a course change to be started in two minutes.

```
    ESTPS/2045
RANGE 00.43 BEARING 252 TIME 204452
COURSE  255    SPEED  07      RELIABILITY +16.33
    NO ESTO RECORD CREATED

    ESTPS
INSUFFICENT MANEUVER FOR ESTIMATE,  TIME 205052
PRESENT BEARING 259  BEARING RATE  1.232 DEG/MIN

    ESTPS/2052
RANGE 03.99 BEARING 260 TIME 205204
COURSE  271    SPEED  23      RELIABILITY +14.30
    NO ESTO RECORD CREATED

    ESTPS
RANGE 02.24 BEARING 261 TIME 205316
COURSE  306    SPEED  04      RELIABILITY +18.52
    NO ESTO RECORD CREATED
```

SS continues attempts to locate enemy ship.

```
     USESN/RED&ACTIVE/CONTN
SONAR READINGS WILL BE TAKEN

     SETSP/FULL/RIGHT/70//4/SLOW/LEFT/60
     SPEED        COURSE       DEPTH      START TIME
     10.00         TURN         100         205652
     15.00          341         100         205745
     10.00         TURN         100         210052
     5.000          281         100         210138
THE SAILING PLAN HAS BEEN STARTED.
```

SS starts using active sonar.
SS starts another maneuver and at the same time continues on a general intercept course.

```
     ESTPS/2057
INSUFFICENT MANEUVER FOR ESTIMATE,  TIME 205652
PRESENT BEARING 265  BEARING RATE  .9643 DEG/MIN

     ESTPS/2058.
RANGE 07.62 BEARING 265 TIME 205804
COURSE  072    SPEED  45      RELIABILITY +3.917
     ESTO RECORD RP001  WAS CREATED

     ESTPS
RANGE 09.31 BEARING 263 TIME 210140
COURSE  345    SPEED  46      RELIABILITY +1242.
     NO ESTO RECORD CREATED

     ESTAC/12
ONLY ONE READING AVAILABLE AT TIME 210210
RANGE 07.05 BEARING 263

     INTER/RP001/=5
NO POSSIBLE INTERCEPTION AT THIS SPEED.

     INTER/RP001/=10
IF  YOU  TRAVEL  AT  +0010. KNOTS,
INTERCEPTION IN +0005. MINUTES AT 210728 CRSE=-0031.

   RANGE/RED&OWN/RP001/=2059/=2/=5
RANGE = +0006.880000 BEARING =  -0095.  AT TIME = 205900
RANGE = +0005.290000 BEARING =  -0097.  AT TIME = 210100
RANGE = +0003.620000 BEARING =  -0095.  AT TIME = 210300
RANGE = +0002.010000 BEARING =  -0087.  AT TIME = 210500
RANGE = +0000.660000 BEARING =  -0037.  AT TIME = @
```

SS obtains his first reliable estimate using passive sonar and determines an intercept course.

```
      ESTAC/12
RANGE Ø6.99 BEARING 265 TIME 21Ø255
COURSE  354   SPEED  2Ø
     ESTO RECORD RAØØ1  WAS CREATED
```

SS obtains his first estimate using active sonar.

```
      SETSP/TIME//4/RIGHT/2Ø
      SPEED          COURSE         DEPTH      START TIME
      5.ØØØ           TURN            1ØØ        21Ø918
      5.ØØØ            3Ø1            1ØØ        21Ø925
THE SAILING PLAN HAS BEEN STARTED.
```

SS sets a sailing plan to be started in four minutes.

```
XTRANS PROC NEAR
       USESN/RED'AND'PASSIVE/STOP
       USESN/RED'AND'PASSIVE/CØNTN/=Ø.25
END
XENTER/RED
```

Procedure NEAR stored previously by SS.

```
      ESTAC/12
RANGE Ø5.4Ø BEARING 271 TIME 21Ø925
COURSE  345   SPEED  37
     ESTO RECORD RAØØ3  WAS CREATED

      NEAR
SONAR STOPPED FINAL READING AT     21Ø94Ø
SONAR READINGS WILL BE TAKEN
```

SS changes the interval at which passive readings will be used for making estimates. The time interval can be reduced at small ranges.

```
      ESTPS/2112
RANGE 00.37 BEARING 274 TIME 211200
COURSE  063   SPEED  04      RELIABILITY +.7590
     ESTO RECORD RP002  WAS CREATED

      ESTPS
INSUFFICENT MANEUVER FOR ESTIMATE,  TIME 211230
 PRESENT BEARING 274  BEARING RATE  .1269 DEG/MIN

      ESTAC/12
RANGE 04.68 BEARING 273 TIME 211240
COURSE  059   SPEED  23
     ESTO RECORD RA004  WAS CREATED

  RANGE/RED&OWN/RP002
RANGE = +0000.660000 BEARING =  +0094.  AT TIME = 211411
```

SS obtains contradictory estimates from passive and active sonar.

```
      SETSP/TIME/2117/SLOW/270//5/FLANK/RIGHT/60//4/
SLOW/LEFT/150//4
      SPEED         COURSE       DEPTH     START TIME
      5.000          TURN          100       211700
      5.000           270          100       211711
      11.50          TURN          100       212200
      18.00           330          100       212222
      11.50          TURN          100       212600
      5.000           180          100       212656
 THE SAILING PLAN HAS BEEN STARTED.

      ESTPS
 INSUFFICENT MANEUVER FOR ESTIMATE,  TIME 211515
  PRESENT BEARING 272  BEARING RATE -1.069 DEG/MIN

      ESTAC/12
RANGE 03.27 BEARING 268 TIME 211840
COURSE  138   SPEED  11
     ESTO RECORD RA008  WAS CREATED

      ESTPS
RANGE 03.86 BEARING 266 TIME 211900
COURSE  125   SPEED  11      RELIABILITY +1.388
     ESTO RECORD RP003  WAS CREATED
```

SS gets estimates and maneuvers to confuse his opponent and to get into a good position for firing torpedoes.

```
XTRANS PROC FIREA
        ESTAC/12
        WEAPO//LASTA
END
XENTER/RED
```

A previously stored procedure to get a new estimate and to fire a torpedo using this estimate.

```
       FIREA
 RANGE 02.71 BEARING 260 TIME 212125
 COURSE  142   SPEED  11
      ESTO RECORD RA009  WAS CREATED

       TORPEDO 1 HAS BEEN FIRED AT TIME=  212153, ON COURSE= 238
CALCULATED TO INTERCEPT OPPONENT AT TIME= 212637
AT LATITUDE= 25.29 DEG. N LONGITUDE= 29.91 DEG. W
WEAP RECORD RED   'AND' TORP1  HAS BEEN GENERATED
FIRING BASED ON ESTO RECORD    RA009

       FIREA
 RANGE 02.20 BEARING 252 TIME 212310
 COURSE  099   SPEED  10
      ESTO RECORD RA010  WAS CREATED

       TORPEDO 2 HAS BEEN FIRED AT TIME=  212333, ON COURSE= 237
CALCULATED TO INTERCEPT OPPONENT AT TIME= 212652
AT LATITUDE= 25.30 DEG. N LONGITUDE= 29.90 DEG. W
WEAP RECORD RED   'AND' TORP2  HAS BEEN GENERATED
FIRING BASED ON ESTO RECORD    RA010

       FIREA
 RANGE 02.06 BEARING 221 TIME 212555
 COURSE  114   SPEED  08
      ESTO RECORD RA011  WAS CREATED

       TORPEDO 3 HAS BEEN FIRED AT TIME=  212623, ON COURSE= 201
CALCULATED TO INTERCEPT OPPONENT AT TIME= 213022
AT LATITUDE= 25.30 DEG. N LONGITUDE= 29.90 DEG. W
WEAP RECORD RED   'AND' TORP3  HAS BEEN GENERATED
FIRING BASED ON ESTO RECORD    RA011

       FIREA
 RANGE 01.94 BEARING 208 TIME 212810
 COURSE  157   SPEED  13
      ESTO RECORD RA012  WAS CREATED

OPPONENT OUT OF WEAPON RANGE-WEAPON NOT FIRED
TO CALCULATED INTERCEPT PO@
```

SS fires three torpedoes.

```
        CNFRM/RED&TORP1
CONFIRMATION OF    TORP1
WEAPON MISSED OPPONENT


        CNFRM/RED&TORP2
CONFIRMATION OF    TORP2
WEAPON MISSED OPPONENT


        CNFRM/RED&TORP3
CONFIRMATION OF    TORP3
THIS WEAPON FIRING HAS ALREADY BEEN CONFIRMED-RESULTS
WEAPON MISSED OPPONENT
```

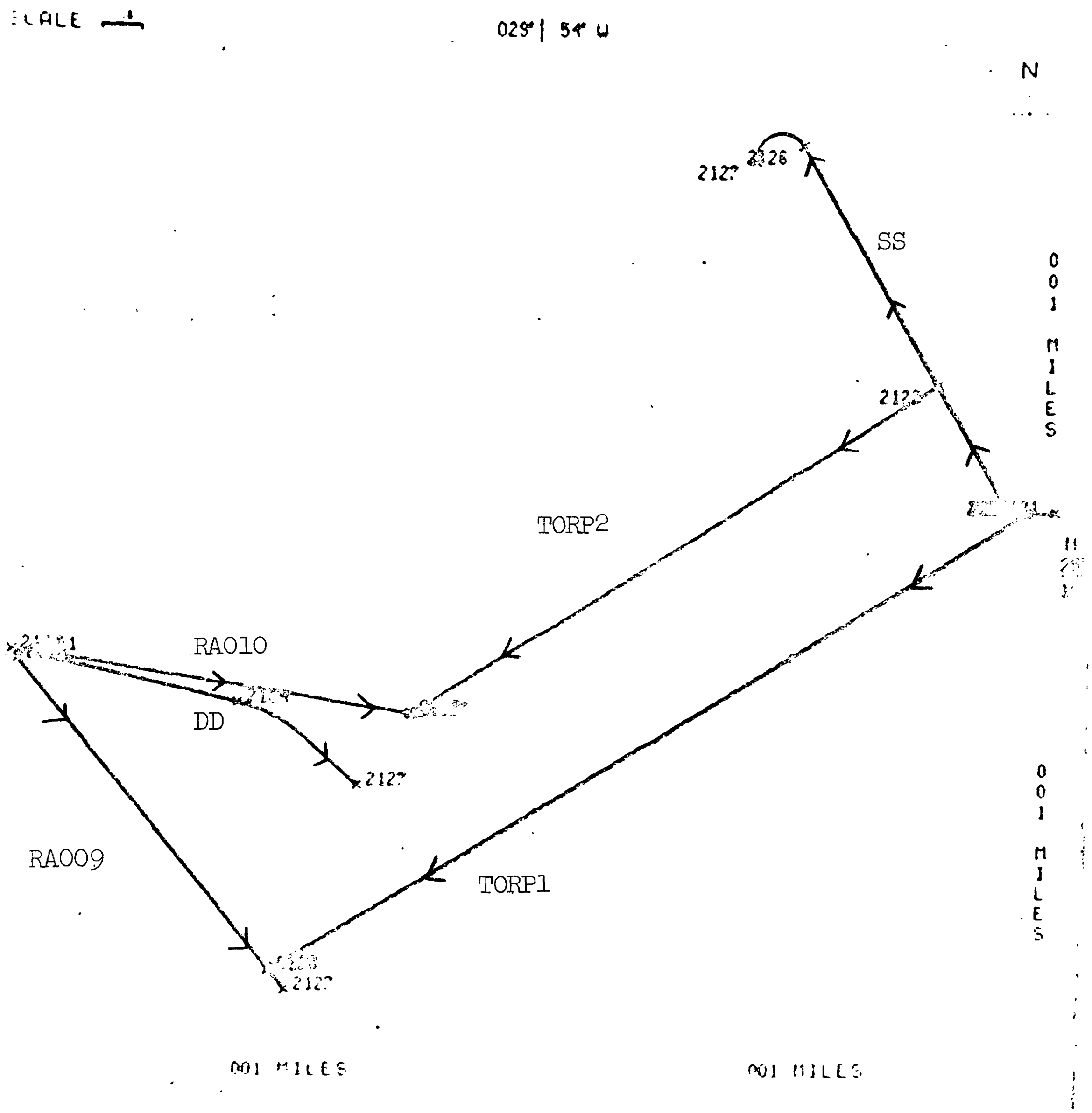
The three torpedoes miss as shown in the following figures.

```
      FIREA
 RANGE Ø1.88 BEARING 199 TIME 213Ø25
 COURSE  151   SPEED  12
      ESTO RECORD RAØ13  WAS CREATED

      TORPEDO 4 HAS BEEN FIRED AT TIME=  213Ø58, ON COURSE= 181
CALCULATED TO INTERCEPT OPPONENT AT TIME= 213629
AT LATITUDE= 25.27 DEG. N LONGITUDE= 29.89 DEG. W
WEAP RECORD RED   'AND' TORP4  HAS BEEN GENERATED
FIRING BASED ON ESTO RECORD    RAØ13

      FIREA
 RANGE ØØ.78 BEARING 215 TIME 213425
 COURSE  355   SPEED  1Ø
      ESTO RECORD RAØ14  WAS CREATED
TOO CLOSE TO FIRE TORPEDO-WEAPON NOT FIRED
TO CALCULATED INTERCEPT POSITION-
RANGE= .51Ø7, BEARING=   226.7,   AT TIME= 213459
TO OPPONENT'S POSITION-
RANGE= .6335, BEARING=   214.2
```

SS fires again

```
        CNFRM/RED&TORP4
CONFIRMATION OF    TORP4
WEAPON MISSED OPPONENT
```

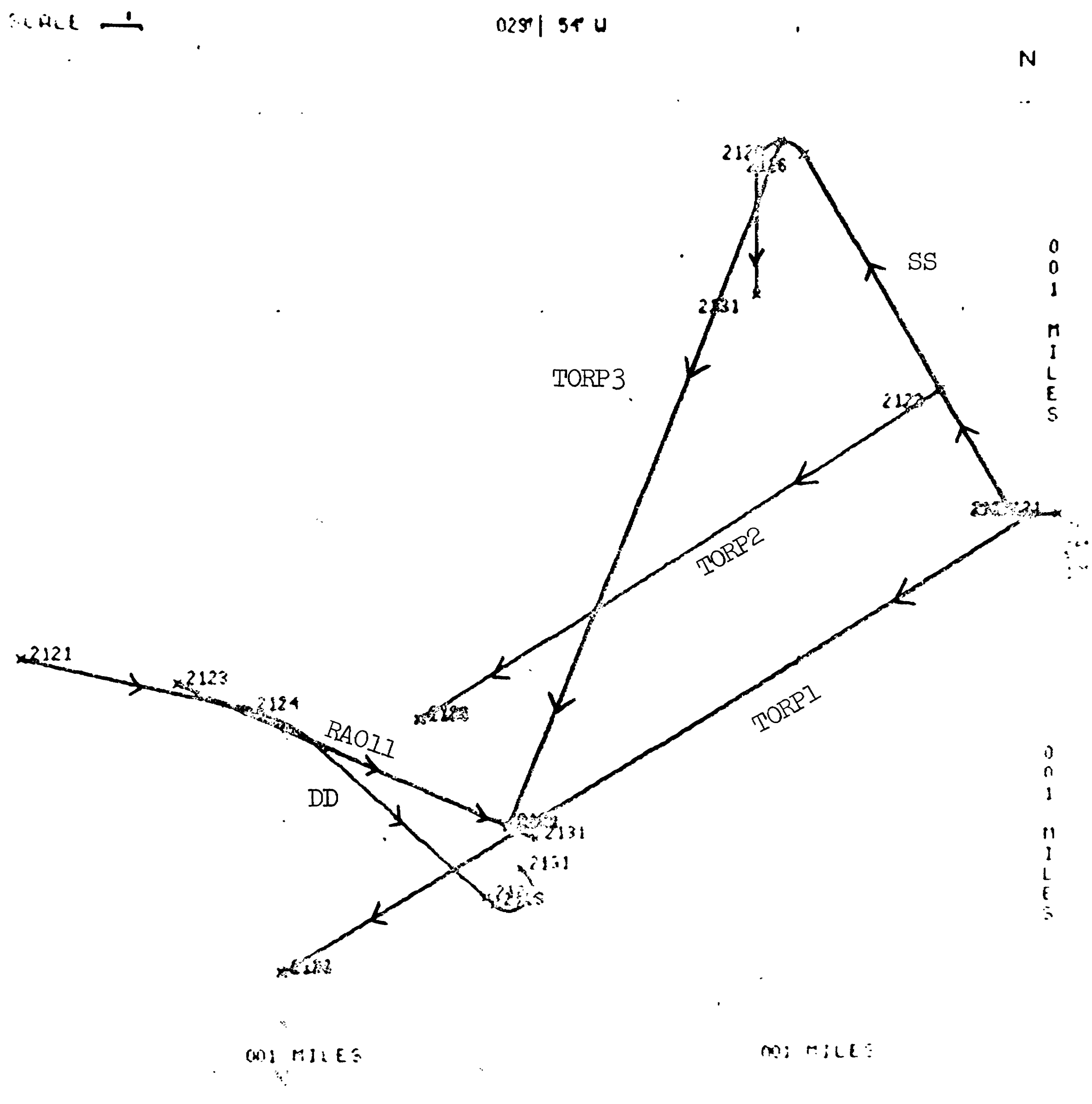
but misses.



OPHIS/OWN!TORP1!TORP2!RA009!RA010/ALL/INCL/=2121/=2127

Figure 6-4

SS Fires TORP1, Based on the Estimate RA009 and TORP2, Based on RA010



OPHIS/OWN!TORP1!TORP2!TORP3!RAØ11/ALL/INCL/=2121/=2131

Figure 6-5

The Three Torpedo Firings with the Estimate RA011 Upon Which the Course for TORP3 was Based

```
      SETSP/SLOW
      SPEED         COURSE        DEPTH     START TIME
      5.000          258           100       214019
 THE SAILING PLAN HAS BEEN STARTED.
      SETSP//29
      SPEED         COURSE        DEPTH     START TIME
      5.000          TURN          100       214231
      5.000          29            100       214320
 THE SAILING PLAN HAS BEEN STARTED.

      FIREA
 RANGE 00.95 BEARING 026 TIME 214240
 COURSE  345   SPEED  09
     ESTO RECORD RA017  WAS CREATED

      TORPEDO 5 HAS BEEN FIRED AT TIME=  214314, ON COURSE= 12.
 CALCULATED TO INTERCEPT OPPONENT AT TIME= 214556
 AT LATITUDE= 25.33 DEG. N LONGITUDE= 29.91 DEG. W
 WEAP RECORD RED   'AND' TORP5  HAS BEEN GENERATED
 FIRING BASED ON ESTO RECORD    RA017

      SETSP/RIGHT/30
      SPEED         COURSE        DEPTH     START TIME
      5.000          TURN          100       214645
      5.000          59            100       214656
 THE SAILING PLAN HAS BEEN STARTED.
      FIREA
 RANGE 01.28 BEARING 037 TIME 214710
 COURSE  046   SPEED  10
     ESTO RECORD RA018  WAS CREATED

      TORPEDO 6 HAS BEEN FIRED AT TIME=  214738, ON COURSE= 39.
 CALCULATED TO INTERCEPT OPPONENT AT TIME= 215129
 AT LATITUDE= 25.34 DEG. N LONGITUDE= 29.89 DEG. W
 WEAP RECORD RED   'AND' TORP6  HAS BEEN GENERATED
 FIRING BASED ON ESTO RECORD    RA018
```

SS maneuvers and fires two more torpedoes.

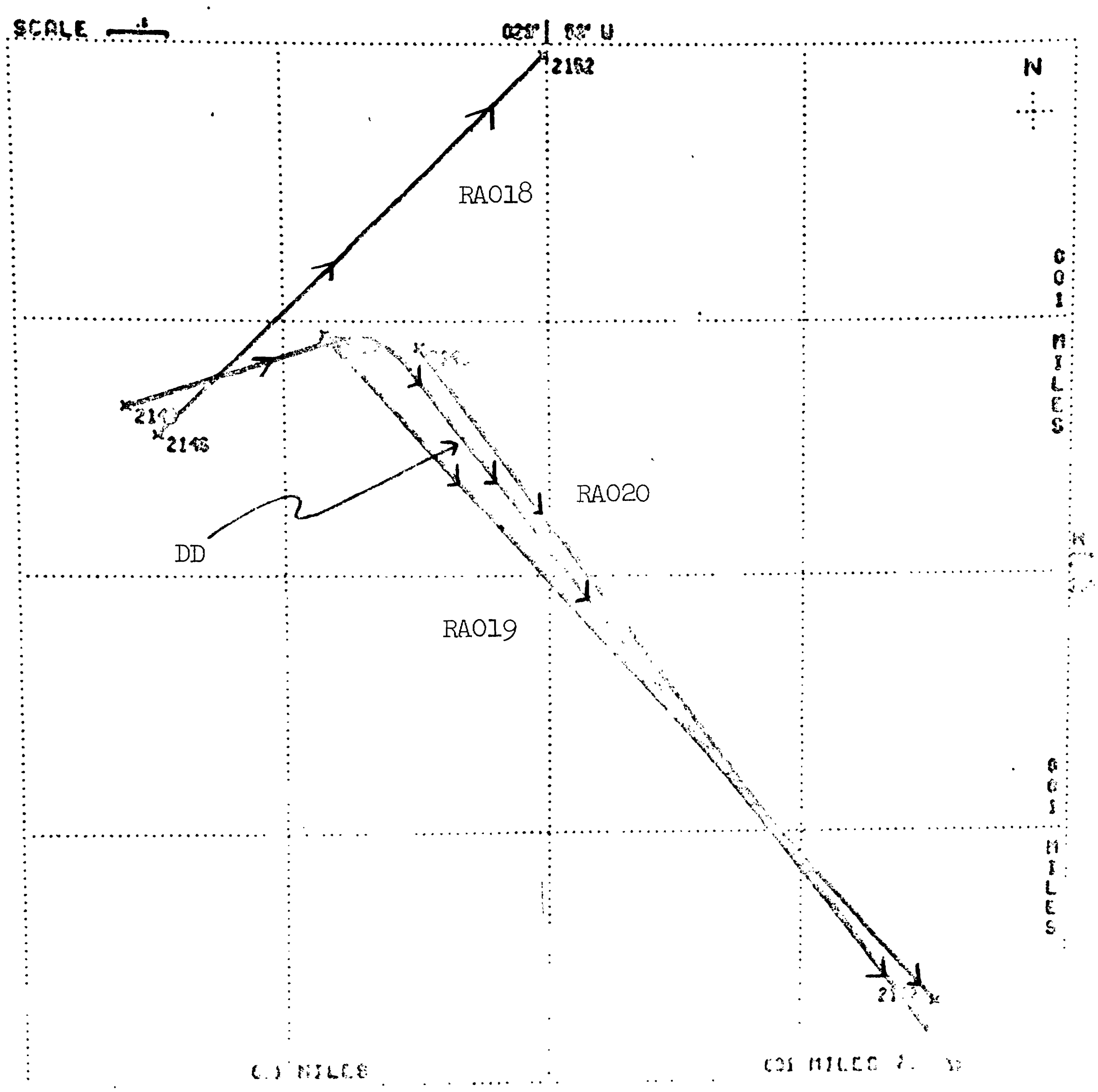
```
          CNFRM/RED&TORP5
     CONFIRMATION OF   TORP5
     WEAPON MISSED OPPONENT


          CNFRM/RED&TORP6
     CONFIRMATION OF   TORP6
     WEAPON MISSED OPPONENT
```

Both torpedoes miss their target.

```
        FIREA
  RANGE 01.43 BEARING 086 TIME 215040
  COURSE  138   SPEED  24
       ESTO RECORD RA019  WAS CREATED

 OPPONENT OUT OF WEAPON RANGE-WEAPON NOT FIRED
 TO CALCULATED INTERCEPT POSITION-
 RANGE= 6.076, BEARING=   127.7,  AT TIME= 215111
 TO OPPONENT'S POSITION-
 RANGE= 1.528, BEARING=   92.93

        FIREA
  RANGE 02.09 BEARING 163 TIME 215555
  COURSE  231   SPEED  28
       ESTO RECORD RA023  WAS CREATED

 OPPONENT OUT OF WEAPON RANGE-WEAPON NOT FIRED
 TO CALCULATED INTERCEPT POSITION-
 RANGE= 20.16, BEARING=   225.7,  AT TIME= 215621
 TO OPPONENT'S POSITION-
 RANGE= 2.186, BEARING=   169.4

        FIREA
  RANGE 03.32 BEARING 170 TIME 220455
  COURSE  229   SPEED  10
       ESTO RECORD RA026  WAS CREATED

 OPPONENT OUT OF WEAPON RANGE-WEAPON NOT FIRED
 TO CALCULATED INTERCEPT POSITION-
 RANGE= 4.285, BEARING=   187.3,  AT TIME= 220529
 TO OPPONENT'S POSITION-
 RANGE= 3.379, BEARING=   171.0
```

The two ships are diverging and no torpedoes can be fired.

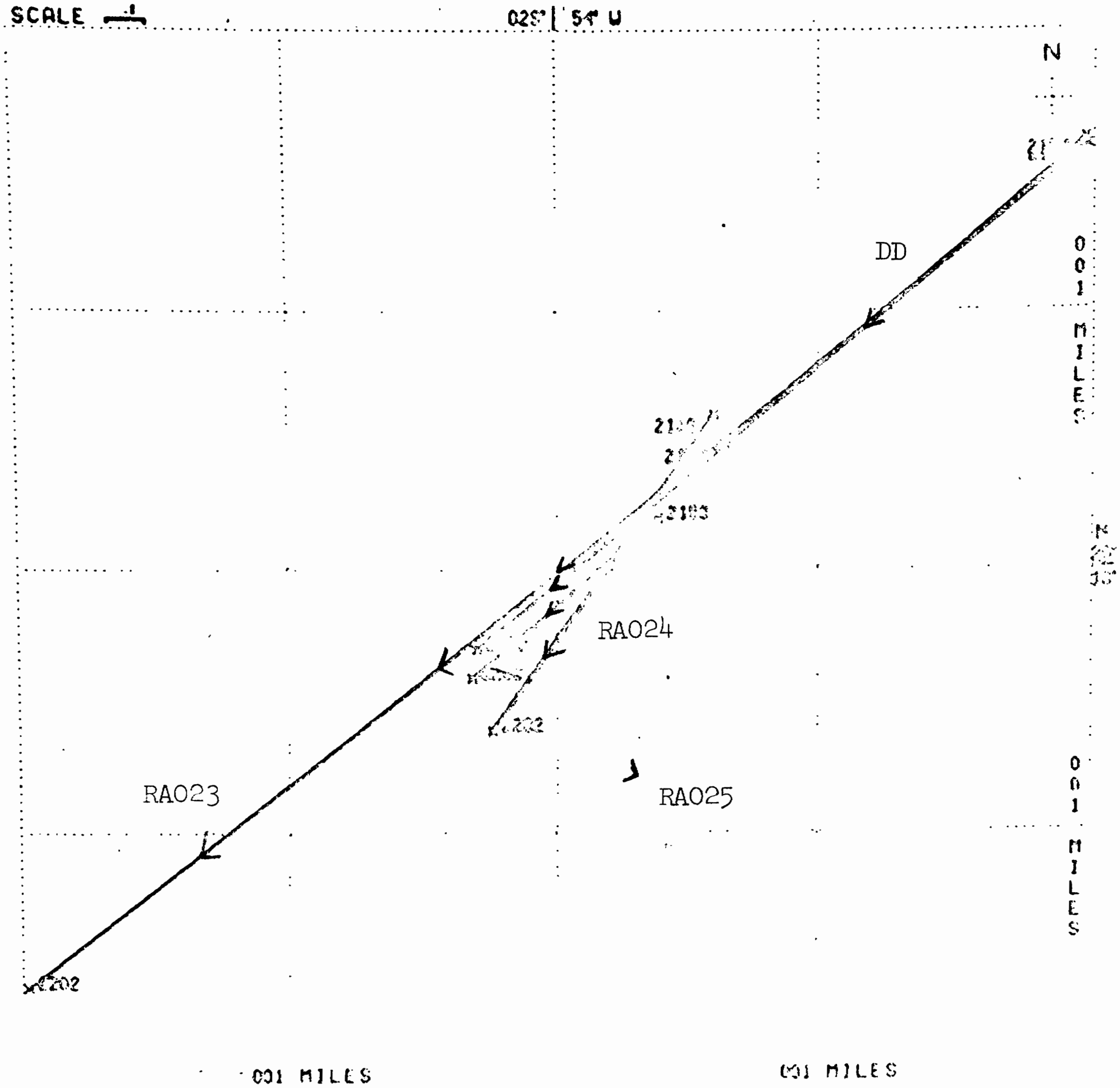
The actual positions of the destroyer are shown below together with six estimates made by the submarine.



OPHIS/RAØ18!RAØ19!RAØ2Ø!WHITE&OWN!RED/ALL/INCL/=2146/=2152

Figure 6-6

The Estimates RA018, RA019, RA020

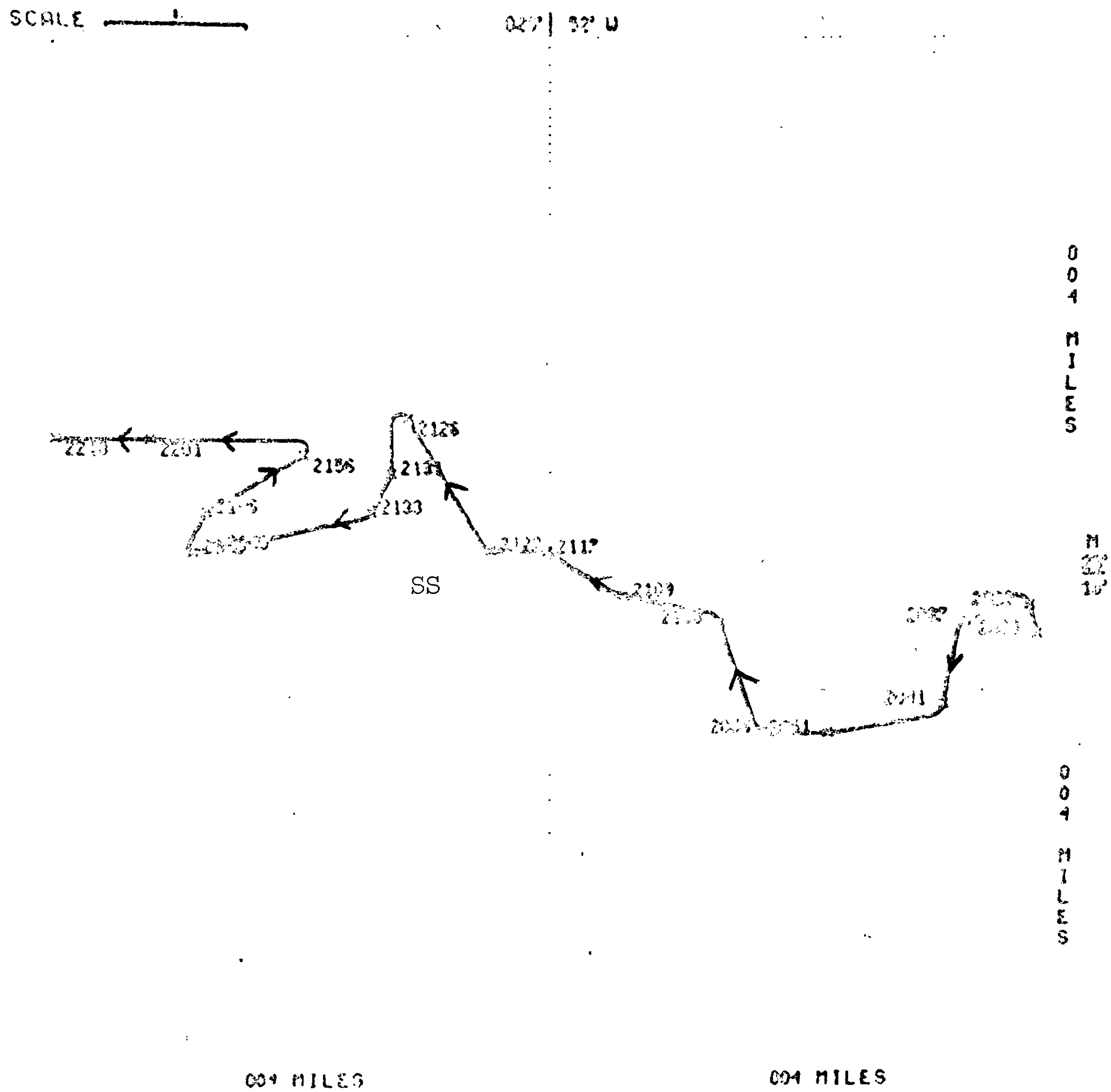


OPHIS/RAØ23!RAØ24!RAØ25!WHITE&RED!OWN/ALL/INCL/=2154/=22Ø2

Figure 6-7

The Estimates RA023, RA024, RA025

The game was stopped at 22:10.



OPHIS/SUB/ALL/INCL/=2Ø3Ø/=221Ø

Figure 6-8

The Sailing History of the Submarine for the Entire Game

6.3 Game As Played by Captain of Destroyer

The following are some of the commands and queries made by the destroyer captain.

```
     ESTPS/2Ø35
PRESENT BEARING Ø64 BEARING RATE .6934 DEG/MIN

     ESTPS/2Ø36
TIME REQUESTED WAS IN THE FUTURE.  PRESENT TIME USED
RANGE Ø9.8Ø BEARING Ø64 TIME 2Ø3531
COURSE  244  SPEED  47        RELIABILITY +    Ø
    ESTO RECORD WPØØ1  WAS CREATED

     ESTPS/2Ø36
RANGE 14.57 BEARING Ø64 TIME 2Ø3555
COURSE  Ø67  SPEED  34
    NO ESTO RECORD CREATED

     ESTPS/2Ø38
RANGE Ø1.39 BEARING Ø65 TIME 2Ø3755
COURSE  25Ø  SPEED  42        RELIABILITY +    Ø
    ESTO RECORD WPØØ2 WAS CREATED

     ESTPS/2Ø39
INSUFFICIENT MANEUVER FOR ESTIMATE,  TIME 2Ø39Ø7
 PRESENT BEARING Ø66  BEARING RATE  1.212  DEG/MIN
```

DD makes estimates using passive sonar.

```
      SETSP/12/LEFT/60/7/RIGHT/65
      SPEED          COURSE   START TIME
      11.ØØ           TURN     2Ø4249
      12.ØØ            335     2Ø45Ø4
      12.ØØ           TURN     2Ø4949
      12.ØØ             4Ø     2Ø52Ø5
THE SAILING PLAN HAS BEEN STARTED.

      ESTPS/2Ø46
RANGE Ø3.61 BEARING Ø73 TIME 2Ø4555
COURSE  Ø49   SPEED   19      RELIABILITY +  15.5Ø
     NO ESTO RECORD CREATED

     ESTPS/2Ø47
INSUFFICIENT BEARING CHANGE FOR ESTIMATE. 2Ø47ØØ
 PRESENT BEARING Ø74  BEARING RATE       Ø DEG/MIN

     ESTPS/2Ø49
TIME REQUESTED WAS IN THE FUTURE. PRESENT TIME USED
RANGE Ø4.94 BEARING Ø76 TIME 2Ø4755
COURSE  317   SPEED  Ø6      RELIABILITY +   Ø
     ESTO RECORD WPØØ3  WAS CREATED
```

DD maneuvers and continues to use passive sonar.

```
XTRANS PROC NEAR
       USESN/WHITE'AND'PASSIVE/STOP
       USESN/WHITE'AND'PASSIVE/CONTN
END
XENTER/WHITE
```

NEAR procedure - which was stored before the game began.

```
       NEAR
SONAR STOPPED FINAL READING AT         2Ø5154
SONAR READINGS WILL BE TAKEN

       ESTPS/2Ø5Ø
INSUFFICIENT MANEUVER FOR ESTIMATE,  TIME 2Ø4954
 PRESENT BEARING Ø78  BEARING RATE  1.2Ø5  DEG/MIN

       ESTPS/2Ø51
RANGE Ø2.51 BEARING Ø79 TIME 2Ø5Ø54
COURSE  328   SPEED  Ø9      RELIABILITY +4.277
      ESTO RECORD WPØØ4  WAS CREATED
```

DD starts using passive sonar at smaller time intervals and gets another estimate.

```
XTRANS PROC LEFT
      SETSP/WHITE'AND'OWN/=8/LEFT/=60/=3/=12/RIGHT/=65
END
XENTER/WHITE
```

This procedure was stored before the game began.

```
 LEFT
 SPEED           COURSE          START TIME
 1Ø.ØØ            TURN             2Ø561Ø
 8.ØØØ             34Ø             2Ø5837
 1Ø.ØØ            TURN             2Ø591Ø
 12.ØØ              45             21Ø149
THE SAILING PLAN HAS BEEN STARTED.
```

DD maneuvers to use passive sonar.

```
 WEAPO/ASROC/LASTP

TOO CLOSE TO FIRE ASROC-ATTEMPTING TORPEDO FIRING

   TORPEDO 1 HAS BEEN FIRED AT TIME=  2Ø5848, ON COURSE= 61.
CALCULATED TO INTERCEPT OPPONENT AT TIME= 21Ø1Ø3
AT LATITUDE= 25.29 DEG. N LONGITUDE= 29.96 DEG. W
WEAP RECORD WHITE 'AND' TORP1  HAS BEEN GENERATED
FIRING BASED ON ESTO RECORD    WPØØ4
```

DD fires a weapon based on the last estimate which used passive sonar (LASTP).

```
     CNFRM/WHITE&TORP1
CONFIRMATION OF   TORP1
WEAPON MISSED OPPONENT
```

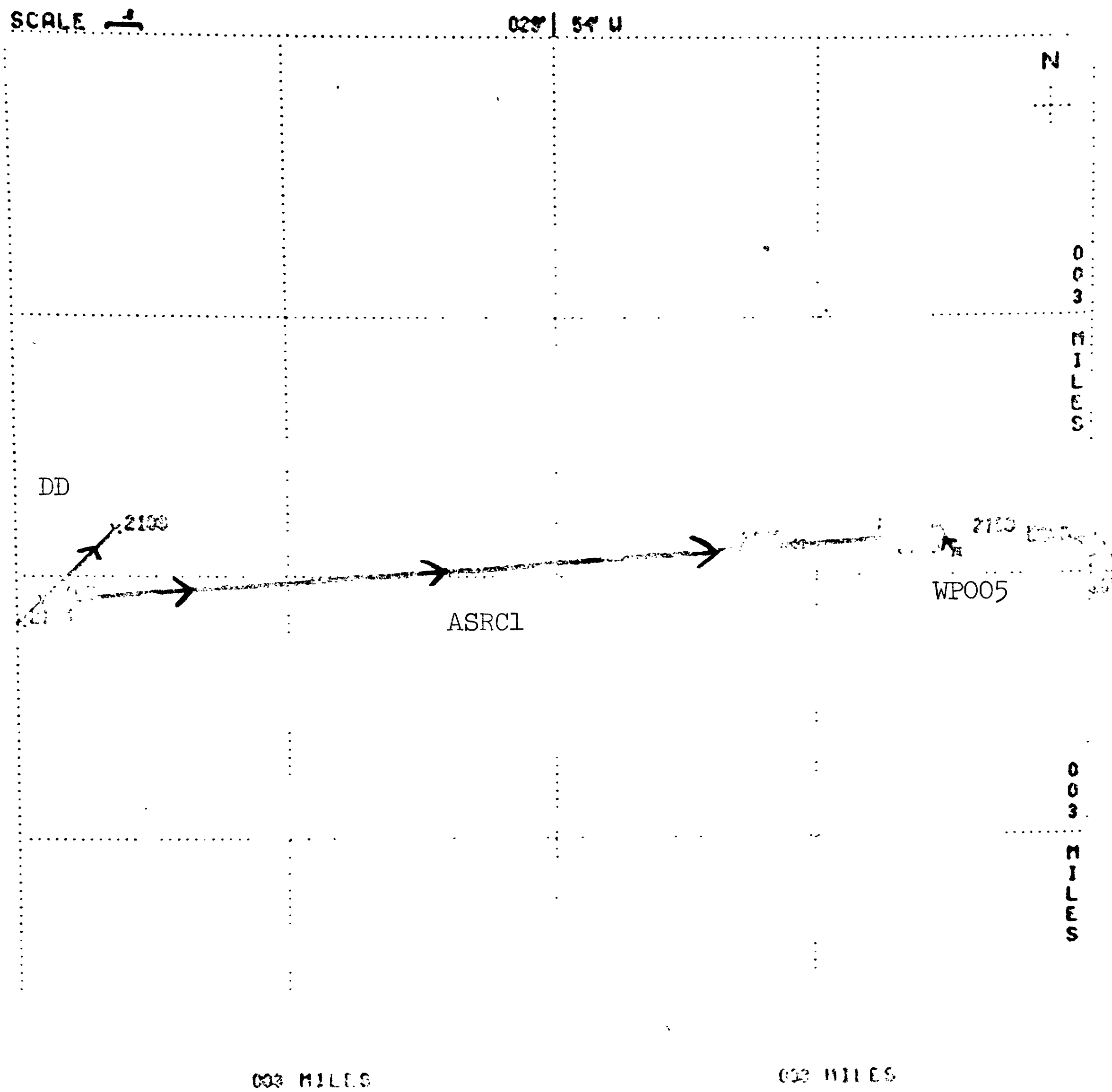
Torpedo misses target.

```
     ESTPS/2Ø59
RANGE Ø8.35 BEARING Ø84 TIME 2Ø5854
COURSE  284   SPEED  RANGE 1Ø.51 BEARING Ø83 TIME 2Ø5954
COURSE  Ø61   SPEED  43      RELIABILITY +27.73
     NO ESTO RECORD CREATED

     ESTPS/21Ø1
RANGE 2Ø.68 BEARING Ø83  TIME 21ØØ54
COURSE  3Ø3   SPEED  37
     NO ESTO RECORD CREATED

     ESTAC/12
NO READINGS AVAILABLE FOR THIS ESTIMATE.

     ESTPS/21Ø3
RANGE Ø5.99 BEARING Ø84 TIME 21Ø254
COURSE  319   SPEED  Ø3      RELIABILITY +6.345
     ESTO RECORD WPØØ5  WAS CREATED

     WEAPO//LASTP

ANTISUB ROCKET 1 HAS BEEN FIRED AT TIME=  21Ø557, ON COURSE= 85.
CALCULATED TO INTERCEPT OPPONENT AT TIME= 21Ø82Ø
AT LATITUDE= 25.3Ø DEG. N LONGITUDE= 29.87 DEG. W
WEAP RECORD WHITE 'AND' ASRC1  HAS BEEN GENERATED
FIRING BASED ON ESTO RECORD    WPØØ5
```

While no active sonar readings are available, another estimate using passive sonar is obtained and an antisubmarine rocket is fired based on this last estimate.

```
     CNFRM/WHITE&ASRC1
CONFIRMATION OF  ASRC1
WEAPON MISSED OPPONENT
```

The rocket misses the sub.



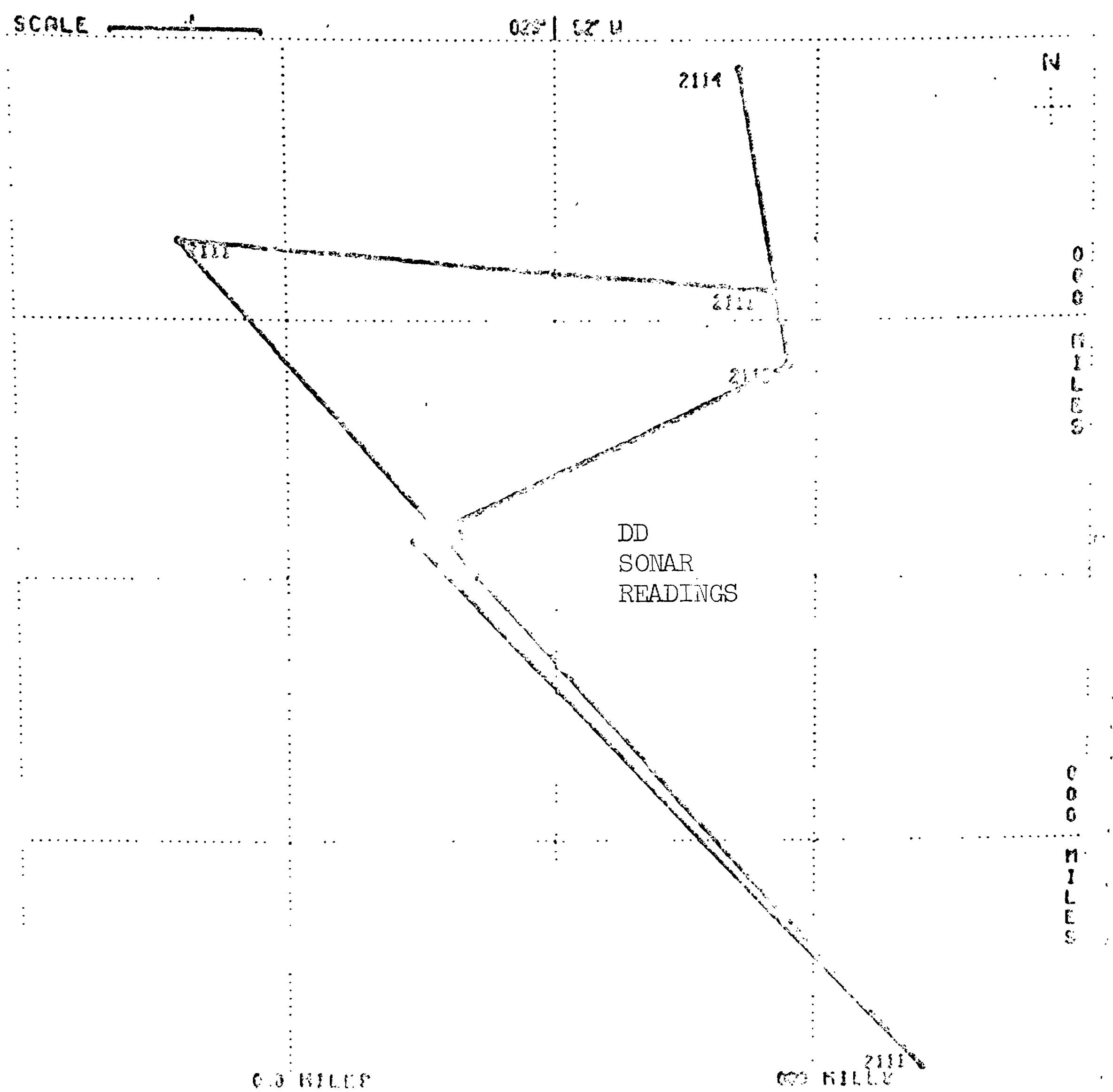
OPHIS/OWNASRC1!WPØØ5/ALL/INCL/=21Ø5/=21Ø9

Figure 6-9

The Firing of ASRC1 and the Estimate WP005 Upon Which Its Trajectory is Based

```
XTRANS PROC DISPLAY
      OPHIS/WHITE&ACTIVE&SONAR/ALL/BNSTEP/=24ØØ/-15
END
XENTER/WHITE
```

A previously stored procedure to obtain a display of the last fifteen active sonar readings.



DISPLAY

OPHIS COMPLETED

Figure 6-10

DD Obtains a Few Active Sonar Readings but They are Poor

```
     INTER/WPØØ5/=1Ø
 IF  YOU  TRAVEL  AT  +ØØ1Ø. KNOTS,
INTERCEPTION IN +ØØ26. MINUTES AT 21342Ø CRSE=+ØØ78.
```

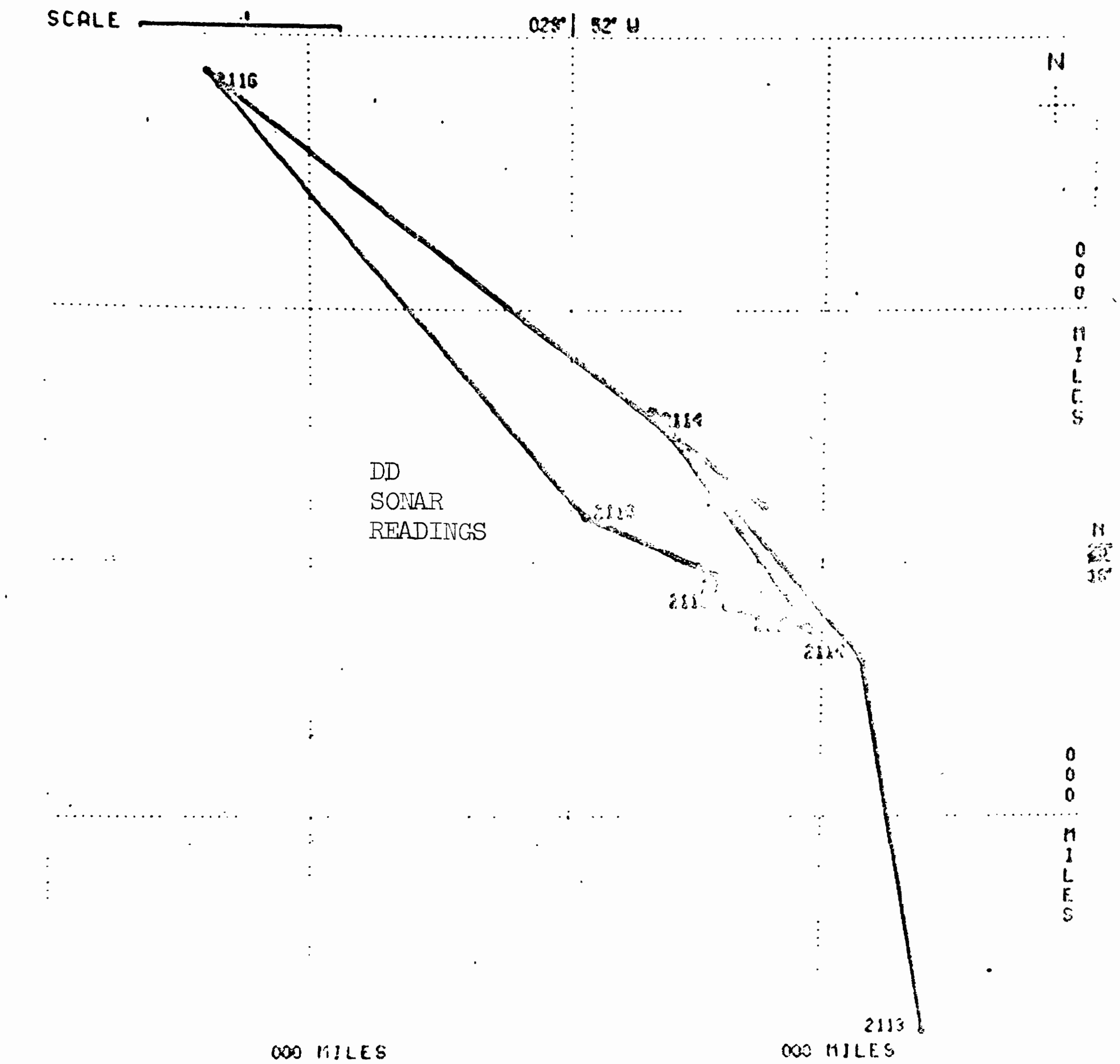
```
     INTER/WPØØ5/=2Ø
 IF  YOU  TRAVEL  AT  +ØØ2Ø. KNOTS,
INTERCEPTION IN +ØØ14. MINUTES AT 21223Ø CRSE=+ØØ84
```

DD obtains intercept courses at two speeds.

```
    SLOW/3Ø/2Ø
    SPEED            COURSE          START TIME
    11.ØØ              63              211143
    1Ø.5Ø             TURN             211149
    1Ø.ØØ              93              2113ØØ
    1Ø.ØØ             TURN             211649
    1Ø.ØØ              73              211738
    1Ø.ØØ             TURN             212149
    1Ø.ØØ             1Ø3              2123Ø3
    1Ø.ØØ             TURN             212649
    1Ø.ØØ              83              212738
THE SAILING PLAN HAS BEEN STARTED.
```

```
    SLOW/3Ø/2Ø
    SPEED            COURSE          START TIME
    1Ø.ØØ             TURN             211437
    1Ø.ØØ             123              21155Ø
    1Ø.ØØ             TURN             211937
    1Ø.ØØ             1Ø3              212Ø26
    1Ø.ØØ             TURN             212437
    1Ø.ØØ             133              21255Ø
    1Ø.ØØ             TURN             212937
    1Ø.ØØ             113              213Ø26
THE SAILING PLAN HAS BEEN STARTED.
```

DD maneuvers.



DISPLAY

OPHIS COMPLETED

Figure 6-11

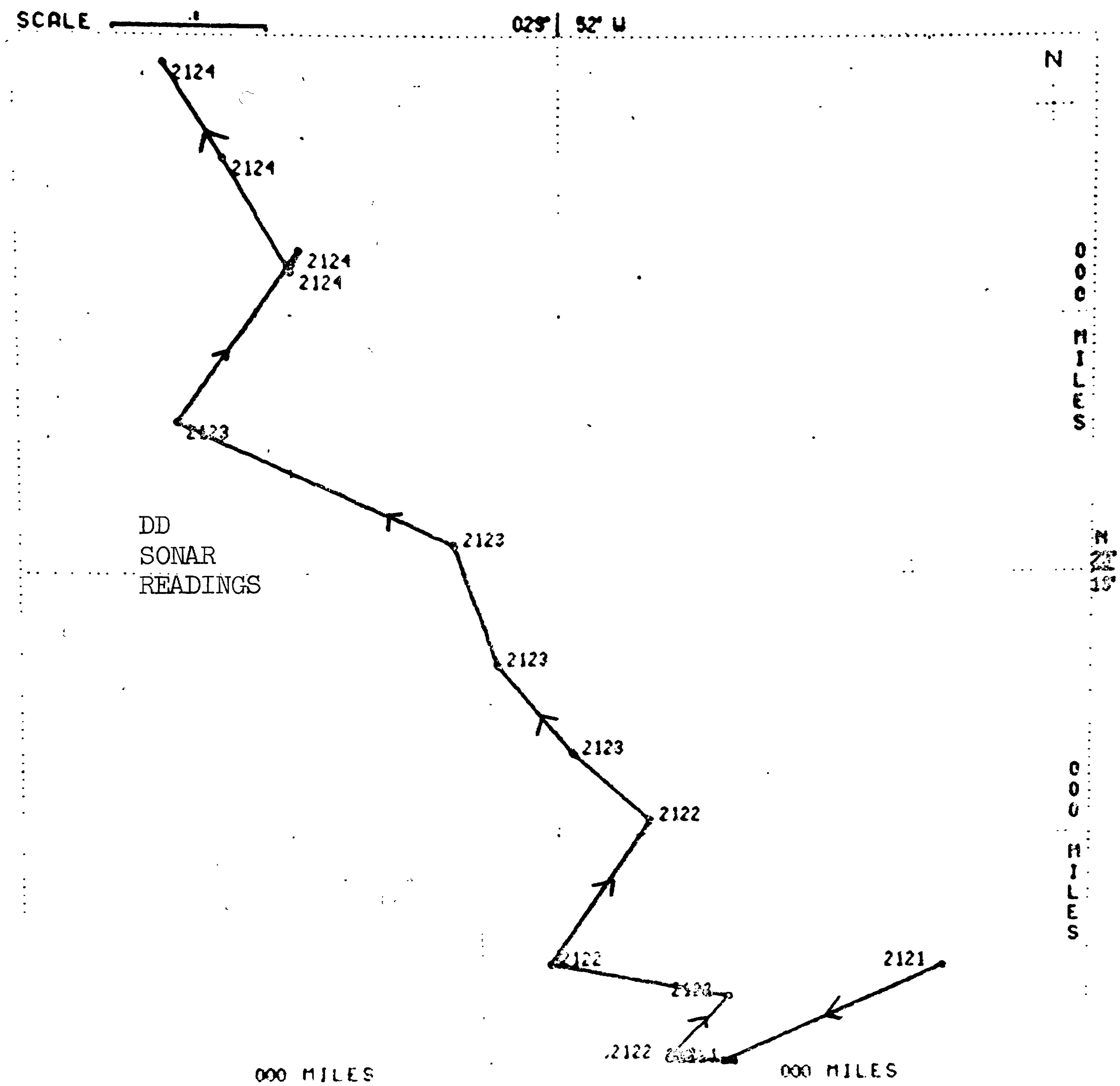
The Active Sonar Readings are Improving

ESTAC/12
RANGE Ø3.16 BEARING Ø84 TIME 211946
COURSE 129 SPEED 22
ESTO RECORD WAØØ3 WAS CREATED

ESTPS
RANGE ØØ.7Ø BEARING Ø83 TIME 212Ø39
COURSE 259 SPEED 36
NO ESTO RECORD CREATED

ESTAC/12
RANGE Ø2.Ø8 BEARING Ø6Ø TIME 212416
COURSE 334 SPEED 14
ESTO RECORD WAØØ4 WAS CREATED

DD Obtains More Estimates.



DISPLAY

OPHIS COMPLETED

Figure 6-12

Active Sonar Readings Look Reliable

```
     ELISA/WHITE/=212446,=212431,=212416,=212331,=212316,=2123
Ø1,=212246
 RANGE Ø2.Ø3 BEARING Ø54 TIME 212446
 COURSE  329   SPEED  18
      ESTO RECORD WAØØ5  WAS CREATED
```

Some readings are eliminated using the light pen and by hitting the appropriate pushbutton, the rest are used to make an estimate.

```
SLOW/5Ø/3Ø
SPEED            COURSE        START TIME
1Ø.ØØ             TURN           213141
1Ø.ØØ                2           2132ØØ
1Ø.ØØ             TURN           213641
1Ø.ØØ              332           213652
1Ø.ØØ             TURN           214141
1Ø.ØØ               22           2142ØØ
1Ø.ØØ             TURN           214641
1Ø.ØØ              352           214652
THE SAILING PLAN HAS BEEN STARTED.
```

```
     ESTAC/12
 RANGE Ø1.55 BEARING Ø27 TIME 213146
 COURSE  191   SPEED  Ø4
      ESTO RECORD WAØØ6  WAS CREATED
```

```
     ELISA/WHITE/=213216,=2132Ø1,=213146,=213131,=213116,=2131
Ø1
 RANGE Ø1.37 BEARING Ø27 TIME 213216
 COURSE  212   SPEED  11
      ESTO RECORD WAØØ8  WAS CREATED
```

DD continues to maneuver and makes more estimates, the last one using the interactive facility of the display.

WEAPO/TORPEDO/WAØØ6

TOO CLOSE TO FIRE TORPEDO-ATTEMPTING HEDGEHOG RUN
OUT OF RANGE FOR BOTH WEAPONS
TO CALCULATED INTERCEPT POSITION-
RANGE= .6981, BEARING= 62.22, AT TIME= 2136Ø2
TO OPPONENT'S POSITION-
RANGE= .7225, BEARING= 59.87

INTER/WAØØ7/=2Ø
IF YOU TRAVEL AT +ØØ2Ø. KNOTS,
INTERCEPTION IN +ØØØ1. MINUTES AT 213654 CRSE=+Ø138.

WEAPO/TORPEDO/WAØØ7

TOO CLOSE TO FIRE TORPEDO-ATTEMPTING HEDGEHOG RUN
TOO DISTANT FOR HEDGEHOGS, TOO CLOSE FOR TORPEDO
TO CALCULATED INTERCEPT POSITION-
RANGE= .233Ø, BEARING= 134.7, AT TIME= 21363Ø
TO OPPONENT'S POSITION-
RANGE= .2283, BEARING= 127.Ø

WEAPO/TORPEDO/WAØØ8

TORPEDO 2 HAS BEEN FIRED AT TIME= 2139Ø5, ON COURSE= 186
CALCULATED TO INTERCEPT OPPONENT AT TIME= 214147
AT LATITUDE= 25.29 DEG. N LONGITUDE= 29.91 DEG. W
WEAP RECORD WHITE 'AND' TORP2 HAS BEEN GENERATED
FIRING BASED ON ESTO RECORD WAØØ8

DD can use only one of these estimates to fire a weapon.

CNFRM/WHITE&TORP2
CONFIRMATION OF TORP2
WEAPON MISSED OPPONENT

The torpedo misses the sub.

```
     ELISA/WHITE/=213946,=213931,=213901,=213846,=213831,=2138
16,=213801,=213746
 RANGE 00.43 BEARING 211 TIME 213946
 COURSE  255   SPEED  10
     ESTO RECORD WA010  WAS CREATED

     WEAPO/TORPEDO/LASTA

 BEARING OF CALCULATED INTERCEPTION POSITION IS   153.7
    TORPEDO CANNOT BE FIRED AT THIS BEARING.
 TO CALCULATED INTERCEPT POSITION-
 RANGE= 2.221, BEARING=   228.5,  AT TIME= 214433
 TO OPPONENT'S POSITION-
 RANGE= 1.618, BEARING=   217.1
```

DD obtains another estimate but is not positioned correctly to fire a torpedo.

SLOW/5Ø/4Ø

SPEED	COURSE	START TIME
1Ø.ØØ	TURN	214445
1Ø.ØØ	72	2145Ø4
1Ø.ØØ	TURN	214945
1Ø.ØØ	32	215ØØØ
1Ø.ØØ	TURN	215445
1Ø.ØØ	82	2155Ø4
1Ø.ØØ	TURN	215945
1Ø.ØØ	42	22ØØØØ

THE SAILING PLAN HAS BEEN STARTED.

ESTAC/12
RANGE Ø1.19 BEARING 2Ø7 TIME 2145Ø1
COURSE Ø47 SPEED Ø4
ESTO RECORD WAØ11 WAS CREATED

FULL/7Ø/5Ø

SPEED	COURSE	START TIME
2Ø.ØØ	TURN	214816
3Ø.ØØ	142	214843
3Ø.ØØ	TURN	215316
3Ø.ØØ	92	215335
3Ø.ØØ	TURN	215816
3Ø.ØØ	162	215843
3Ø.ØØ	TURN	22Ø316
3Ø.ØØ	112	22Ø335

THE SAILING PLAN HAS BEEN STARTED.

ESTAC/12
RANGE Ø1.27 BEARING 232 TIME 2149Ø1
COURSE Ø51 SPEED Ø5
ESTO RECORD WAØ12 WAS CREATED

WEAPO/TORPEDO/LASTA

BEARING OF CALCULATED INTERCEPTION POSITION IS 239.Ø
TORPEDO CANNOT BE FIRED AT THIS BEARING.
TO CALCULATED INTERCEPT POSITION -

SETSP/FULL/23Ø/4/SLOW/S

SPEED	COURSE	START TIME
3Ø.ØØ	TURN	215237
3Ø.ØØ	23Ø	21531Ø
1Ø.ØØ	23Ø	215637

THE SAILING PLAN HAS BEEN STARTED.

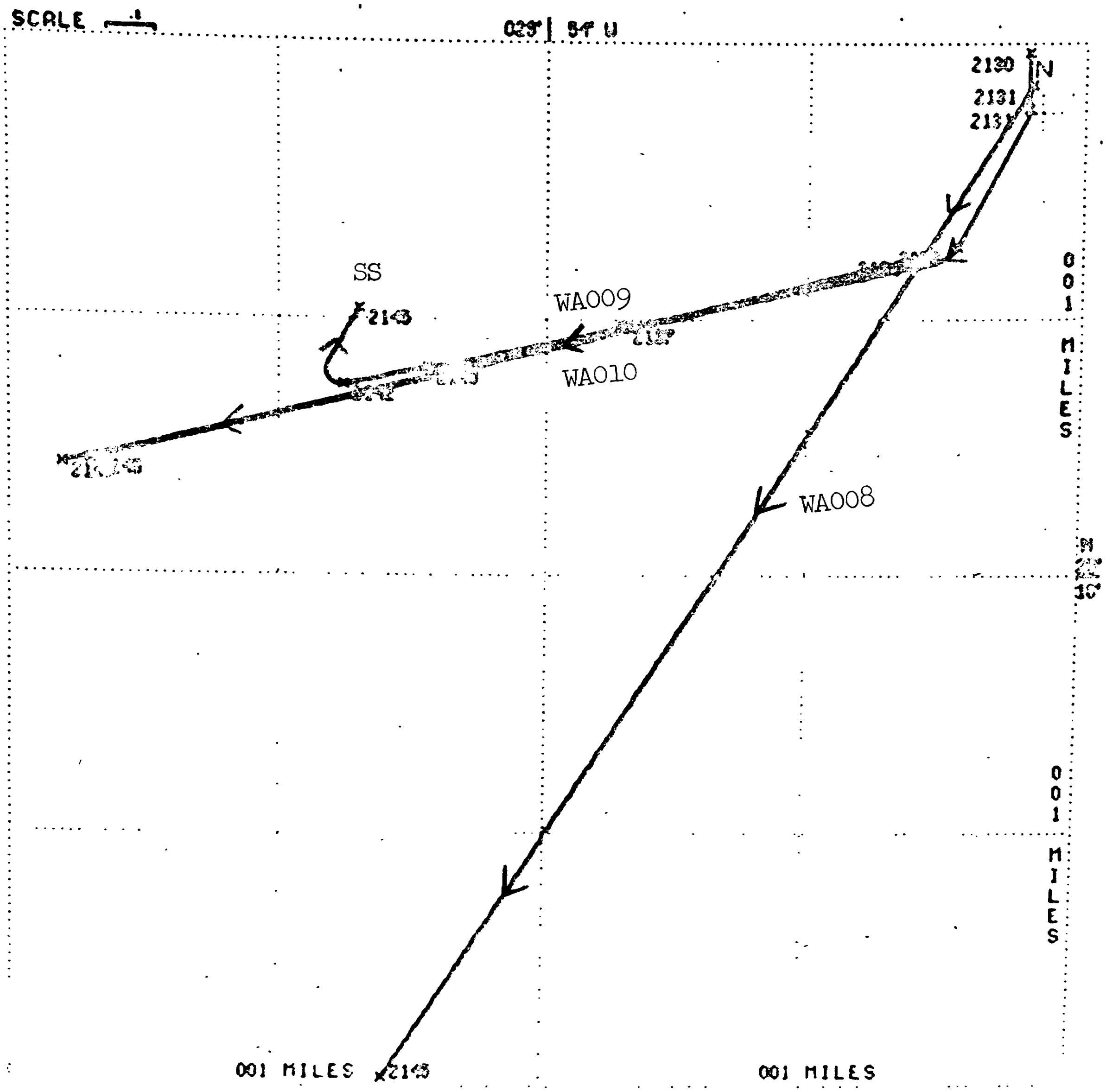
DD maneuvers but still cannot fire a weapon

```
       ESTAC/12
 RANGE Ø2.Ø2 BEARING 294 TIME 215246
 COURSE  Ø75   SPEED  Ø5
      ESTO RECORD WAØ13  WAS CREATED

      WEAPO/TORPEDO/LASTA

      TORPEDO 3 HAS BEEN FIRED AT TIME=  215341, ON COURSE= 315
 CALCULATED TO INTERCEPT OPPONENT AT TIME= 215712
 AT LATITUDE= 25.32 DEG. N LONGITUDE= 29.9Ø DEG. W
 WEAP RECORD WHITE 'AND' TORP3  HAS BEEN GENERATED
 FIRING BASED ON ESTO RECORD    WAØ13
```

DD fires another torpedo,

```
      CNFRM/WHITE&TORP3
CONFIRMATION OF   TORP3
WEAPON MISSED OPPONENT
```

but misses again.



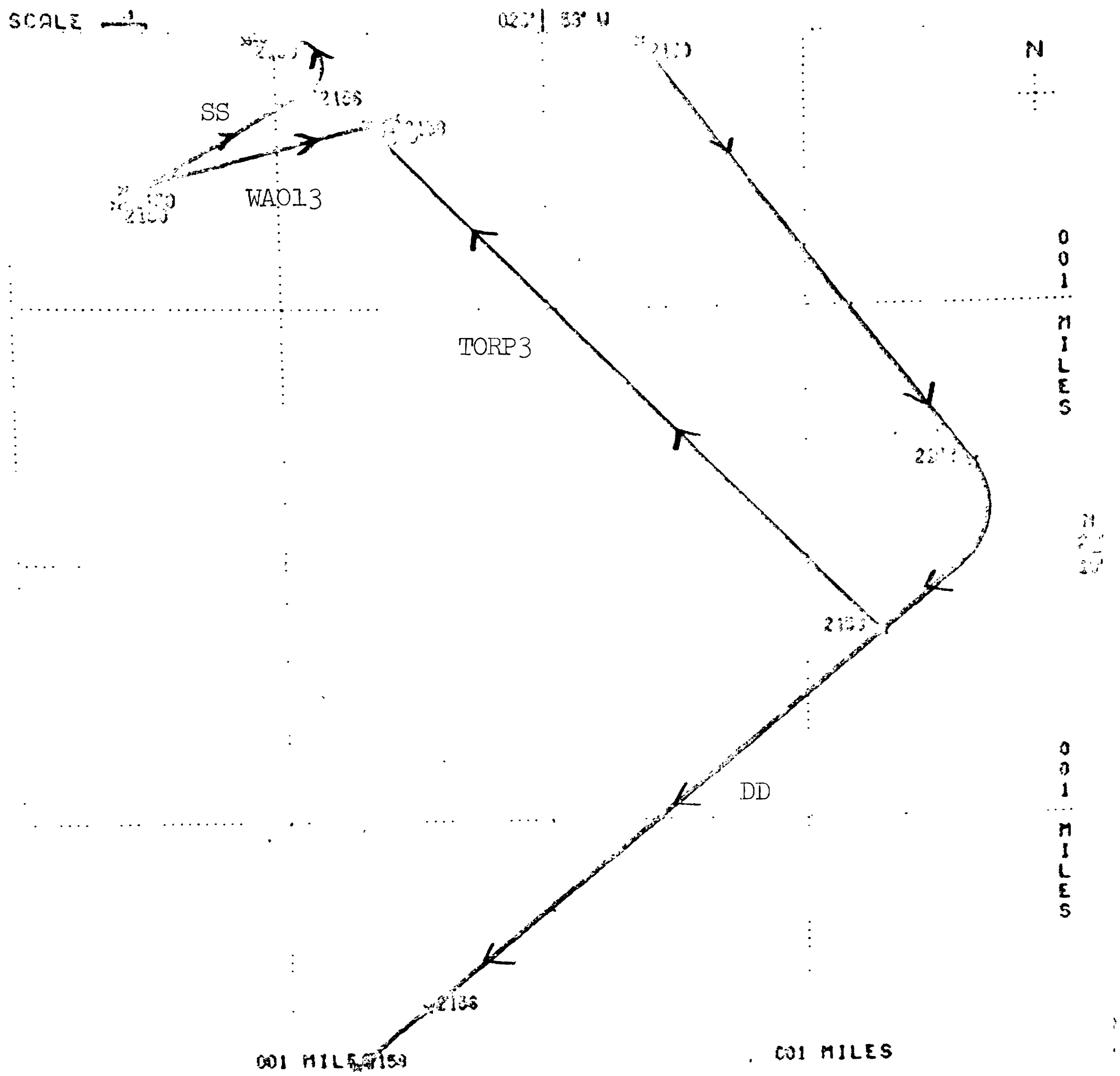
OPHIS/WAØØ8!WAØØ9!WAØ1Ø!RED&WHITE!OWN/ALL/INCL/=213Ø/=2145

Figure 6-13

The Submarine Overlayed With the Estimates
WA012, WA013, WA014 Made by DD

```
        ELISA/WHITE/=215301,=215246,=215201,=215146,=215116,=2151
01,=215031,=215016,=214946
 RANGE 02.02 BEARING 297 TIME 215301
 COURSE  064    SPEED  05
      ESTO RECORD WA014  WAS CREATED

        WEAPO/TORPEDO/LASTA

BEARING OF CALCULATED INTERCEPTION POSITION IS  218.9
    TORPEDO CANNOT BE FIRED AT THIS BEARING.
TO CALCULATED INTERCEPT POSITION-
RANGE= 2.649, BEARING=   11.09,  AT TIME=  215739
TO OPPONENT'S POSITION-
RANGE= 2.390, BEARING=   1.870

        ESTAC/12
RANGE 02.52 BEARING 355 TIME 215746
COURSE  358   SPEED  04
      ESTO RECORD WA015  WAS CREATED

        WEAPO/TORPEDO/LASTA

OUT OF TORPEDO RANGE-ATTEMPTING ASROC FIRING
OUT OF RANGE FOR BOTH WEAPONS
TO CALCULATED INTERCEPT POSITION-
RANGE= 2.737, BEARING=  357.2,  AT TIME= 215822
TO OPPONENT'S POSITION-
RANGE= 2.619, BEARING=  357.1
```

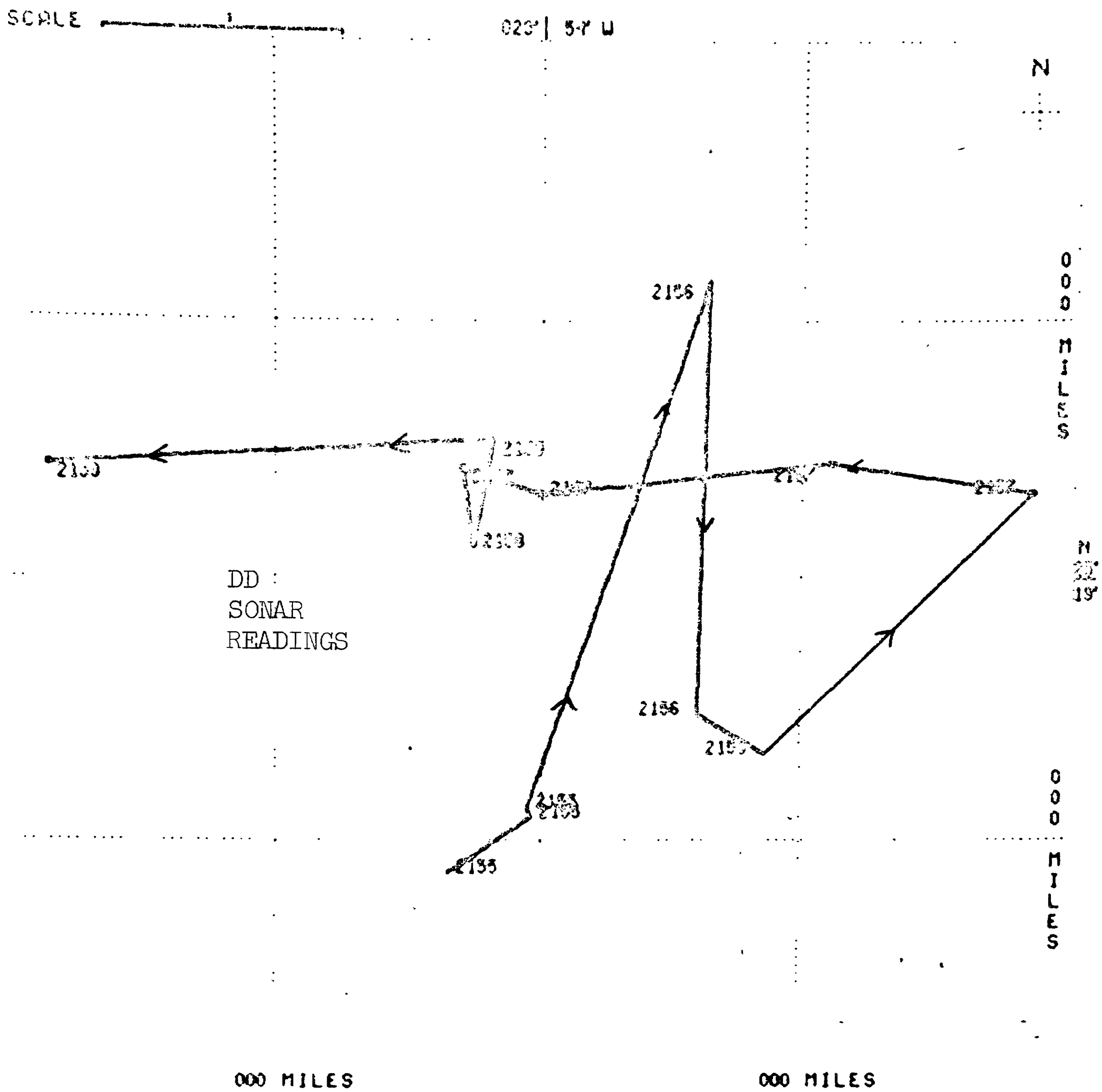
DD attempts more firings but is either at the wrong bearing or range.



OPHTS/OWN!TORP3!WA∅13/ALL/INCL/=215∅/=2158

Figure 6-14

The Firing of TORP3 and the Estimate WA013 Upon Which
Its Course Was Based



DISPLAY

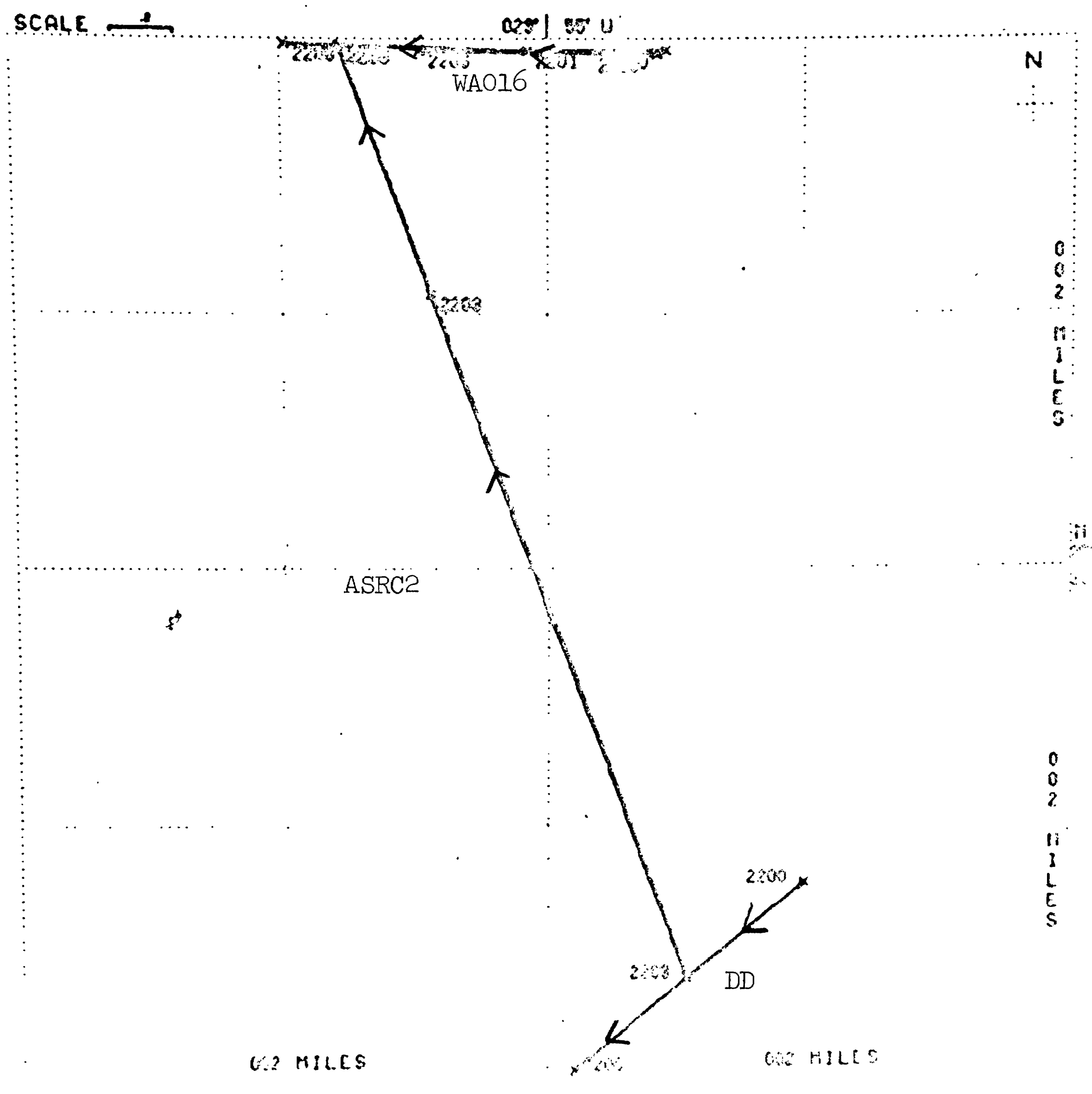
OPHIS COMPLETED

Figure 6-15

Active Sonar Readings

```
        ESTAC/12
  RANGE Ø3.Ø7 BEARING 347 TIME 22Ø216
  COURSE 271   SPEED 12
       ESTO RECORD WAØ16  WAS CREATED

        WEAPO/LASTA

  OUT OF TORPEDO RANGE-ATTEMPTING ASROC FIRING

  ANTISUB ROCKET 2 HAS BEEN FIRED AT TIME=   22Ø3Ø3, ON COURSE= 339
  CALCULATED TO INTERCEPT OPPONENT AT TIME=  22Ø5Ø7
  AT LATITUDE= 25.32 DEG. N LONGITUDE= 29.93 DEG. W
  WEAP RECORD WHITE 'AND' ASRC2  HAS BEEN GENERATED
  FIRING BASED ON ESTO RECORD     WAØ16

        INTER/WAØ16/=2Ø
  IF  YOU  TRAVEL  AT  +ØØ2Ø. KNOTS,
 INTERCEPTION IN +ØØ15. MINUTES AT 221843 CRSE=-ØØ49.

        CNFRM/WHITE&ASRC2
 CONFIRMATION OF   ASRC2
 WEAPON MISSED OPPONENT
```

DD fires another ASROC but misses as the submarine slows down from 15 to 5 knots.



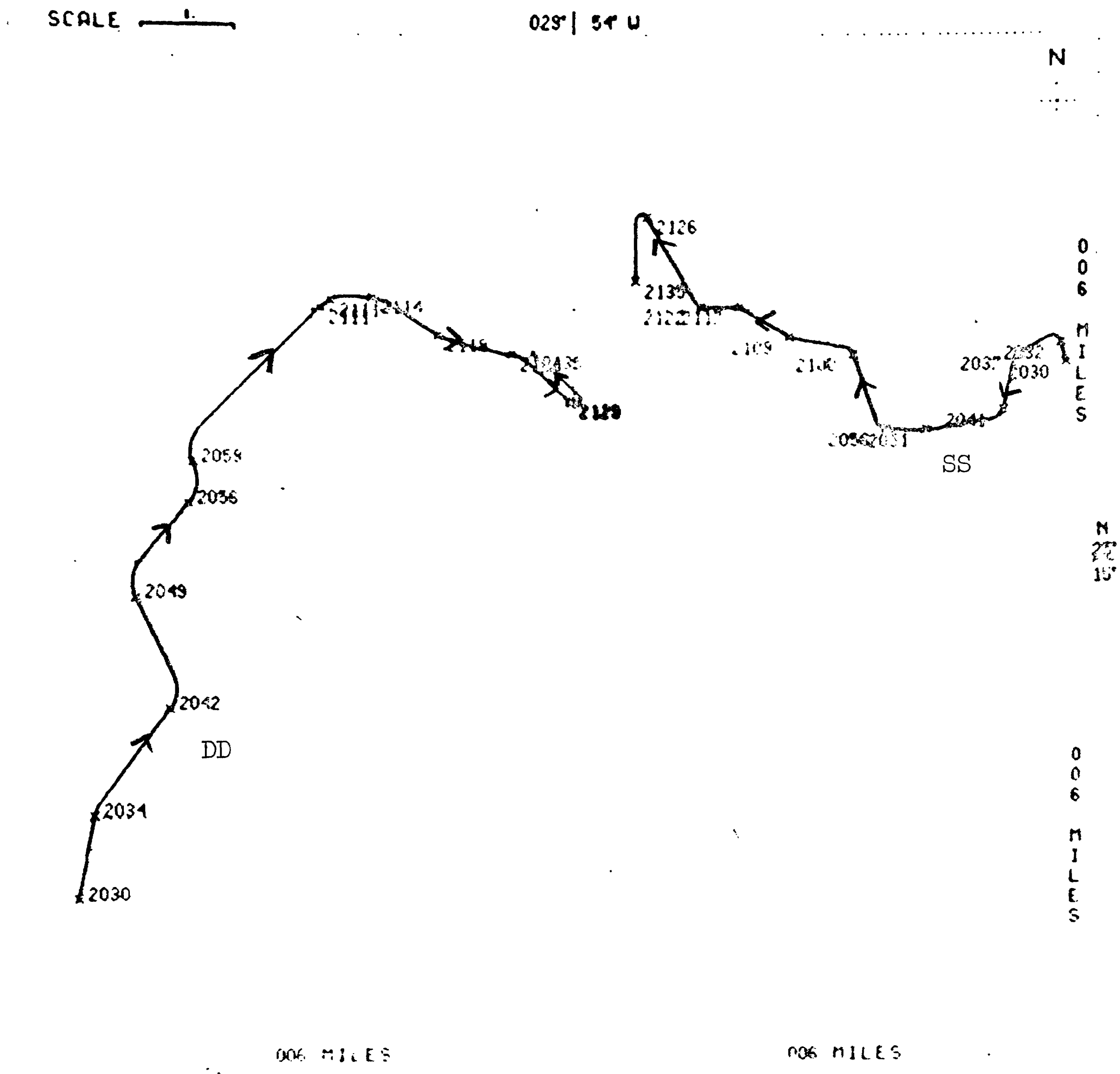
OPHIS/OWN!ASRC2!WAØ16/ALL/INCL/=22ØØ/=22Ø6

Figure 6-16

Firing of ASRC2 Based on the Estimate WA016

6.4 Results of Game

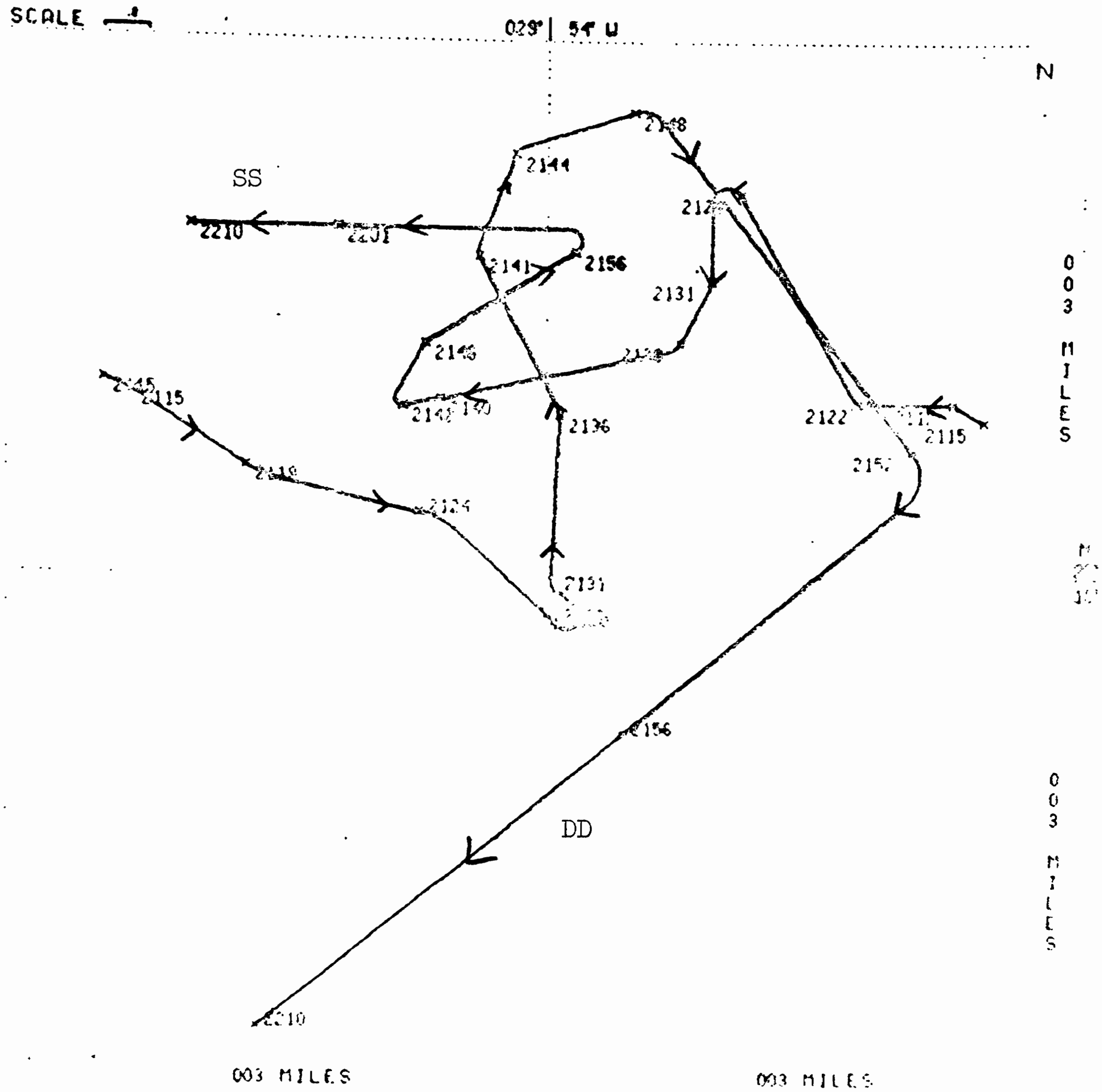
The game was stopped at 22:10 without either player being successful in attaining his goal of sinking the enemy ship. The sailing histories of both ships for the entire game is shown below:



OPHIS/OWN/ALL/INCL/=2Ø3Ø/=2135

Figure 6-17

Both Ships for the Interval 20:30 to 21:35



OPHIS/OWN/ALL/INCL/=2115/=221Ø

Figure 6-18

Both Ships for the Interval 21:15 to 22:10

APPENDIX A

FOUR BEARING SOLUTION OF PASSIVE SONAR

A detailed derivation of the solution used by the passive sonar analyzer ESTPS is presented in the following appendix.

The assumptions used are:

1. The opponent is maintaining constant speed during the time period.
2. The opponent is maintaining a constant course during the interval.
3. The ship making the estimate has made a maneuver during the period.

The problem is to find the range to the opponent and his speed and course given only the position of the sensor ship and bearing to the opponent at four discrete times, which are referred to as t_0, t_1, t_2, t_3.

The solution given here is based on maneuvering board techniques; knowledge of the maneuvering board is not needed for understanding the method of solution as all necessary details are supplied. It is useful to know however that all calculations are relative to the position, course and speed of the sensor ship rather than on an absolute basis.

The major steps in the solution are the following:

I. Solution of own ship's course, speed and position on the maneuvering board.

II. Solution of triangles formed by the intersection of extended bearings and own ship's position vectors.

III. Evaluation of opponent's relative course.

IV. Evaluation of the range at t_3 knowing his relative course.

V. Evaluation of opponent's relative speed knowing his relative course and range at t_3.

VI. Calculation of opponent's absolute course and speed.

Part I: Solution of own ship's course, speed and position on the maneuvering board. See Figure A1.

a) Calculate own ship's speed and course using positions at t_2 and t_3

average (middle) latitude = $\frac{1}{4} \sum_{i=0}^{3} lat(t_i)$	average latitude of own ship
coslat = cos (average latitude)	cosine middle latitude
dlat = $lat(t_3) - lat(t_2)$	distance traveled in N-S direction between t_2 and t_3
dlong = $(long(t_3) - long(t_2)) * coslat$	distance traveled in E-W direction between t_2 and t_3
courso = arctan (dlong/dlat)	own ship's course
speedo = $\frac{\sqrt{dlat^2 + dlong^2}}{t_3 - t_2}$	own ship's speed in degrees per minute

b) projected position at times t_0 and t_1

$$lat'(t_i) = lat(t_3) - dlat * \frac{t_3 - t_i}{t_3 - t_2} \qquad i = 0,1$$

$$long'(t_i) = long(t_3) - \frac{dlong}{coslat} * \frac{t_3 - t_i}{t_3 - t_2} \qquad i = 0,1$$

c) difference between projected position and true position at t_0 and t_1

$$elat(t_i) = lat(t_i) - lat'(t_i) = lat(t_i) - lat(t_3) + dlat * \frac{t_3 - t_i}{t_3 - t_2} \qquad i = 0,\ 1$$

$$elong(t_i) = \left[long(t_i) - long(t_3) + \frac{dlong}{coslat} * \frac{t_3 - t_i}{t_3 - t_2} \right] * coslat \qquad i = 0,\ 1$$

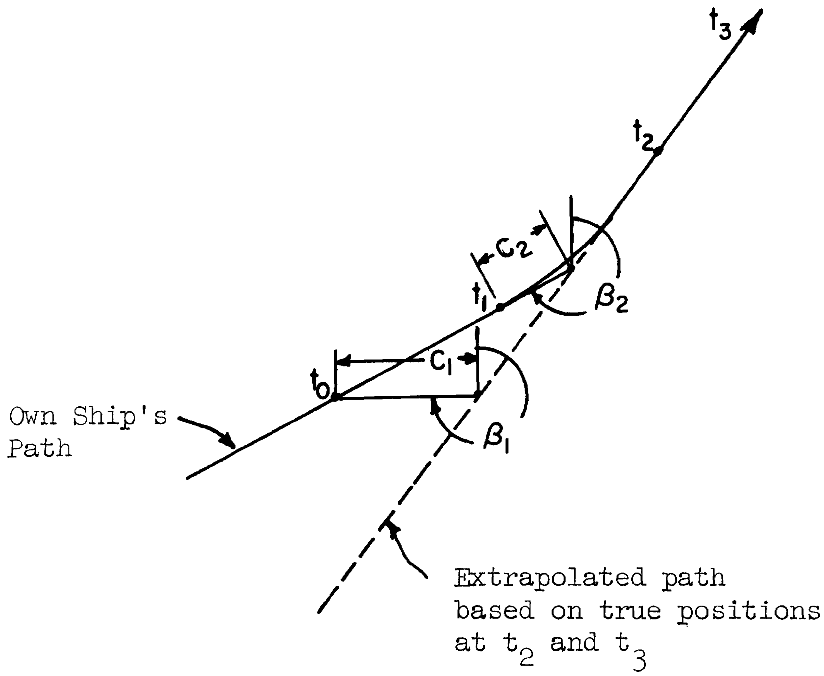
d) convert to radial coordinates

magnitude

$$C_i = \sqrt{[elat(t_{i-1})]^2 + [elong(t_{i-1})]^2} \qquad i = 1,\ 2$$

angle

$$\beta_i = \arctan\ [elong(t_{i-1}) \ /\ elat(t_{i-1})] \qquad i = 1,\ 2$$



C_i: Distance between the true position at t_0 and t_1 and position extrapolated from the positions at t_2, t_3.

β_i: Angle from extrapolated to true position.

Figure A-1

Evaluation of β_i and C_i From Own Ship's Position

Part II. Solution of triangles formed by intersecting extended bearings and own ship's position vector derived in Part I. See Figure A2.

a) evaluation of interior angles

$$\alpha_i = \Theta_3 - \Theta_{i-1}$$

$$\sigma_i = \beta_i - \pi - \Theta_3$$

since the sum of angles in a triangle is π

$$\begin{aligned}\delta_i &= \pi - \sigma_i - \alpha_i \\ &= \pi - (\beta_i - \pi - \Theta_3) - (\Theta_3 - \Theta_{i-1}) \\ &= 2\pi - \beta_i + \Theta_{i-1} \\ &= \Theta_{i-1} - \beta_i\end{aligned}$$

b) evaluation of B_i using law of sines

$$\frac{B_i}{\sin \delta_i} = \frac{C_i}{\sin \alpha_i} \quad \text{or} \quad B_i = \frac{C_i \sin (\Theta_{i-1} - \beta_i)}{\sin (\alpha_i)} \qquad i = 1, 2$$

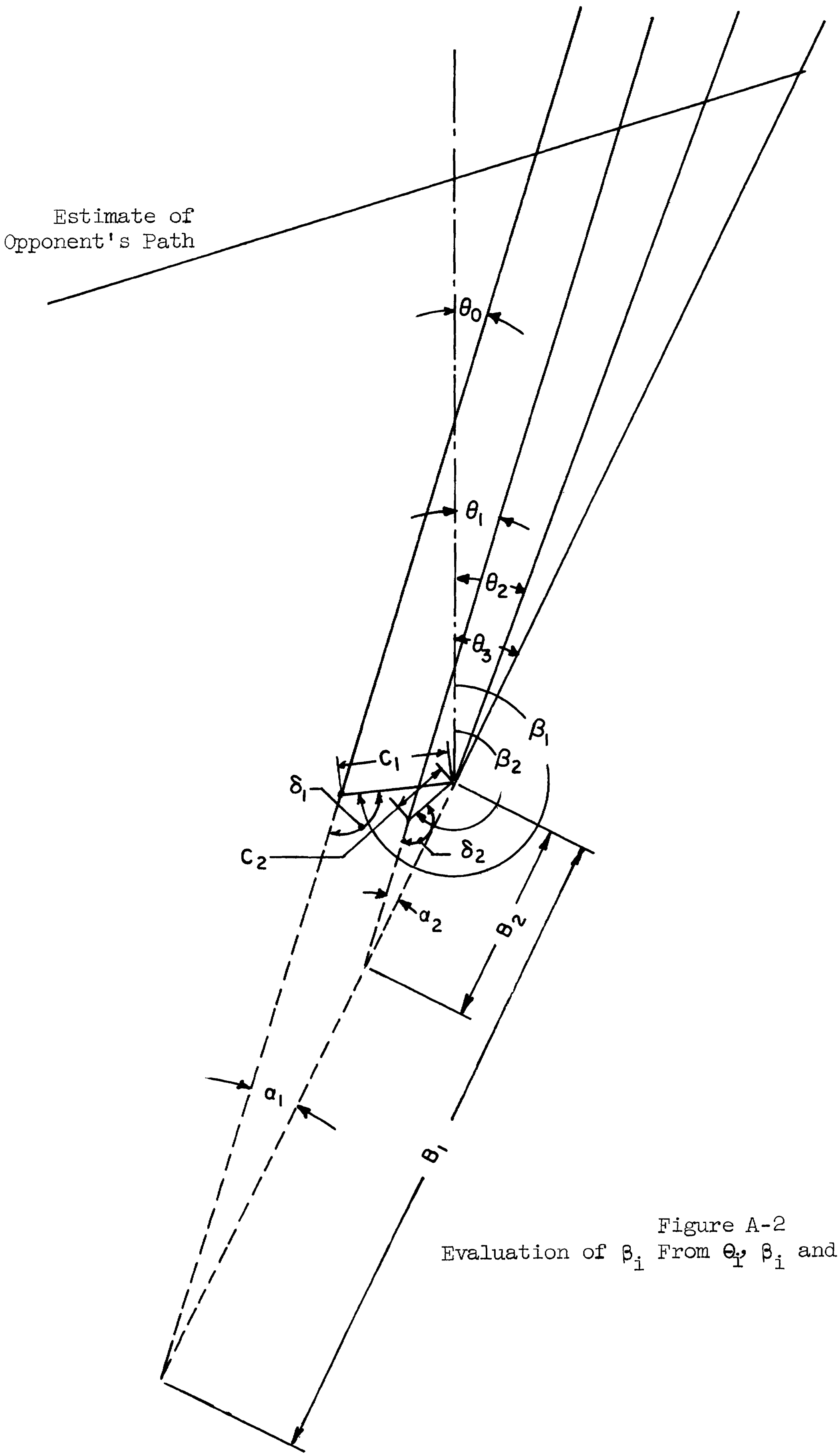


Figure A-2
Evaluation of β_i From θ_i, β_i and C_i

Part III. Evaluation of ϕ_R, the opponent's relative course. See Figure A3.

a) solve for interior angles of triangles formed by intersecting extended bearings.

$$\gamma_i = \pi + \theta_3 - \phi_R - \alpha_i \qquad i = 1, 3$$

b) V_R, the opponent's relative velocity, is constant; we can therefore write

$$A_i = V_R(t_3 - t_{i-1}) \qquad i = 1, 3$$

c) using the law of sines to solve for A_i in terms of α_i and γ_i we get

$$\text{(A1)} \quad \frac{A_i}{\sin \alpha_i} = \frac{R + B_i}{\sin \gamma_i} \qquad i = 1, 3 \text{ and } B_3 \equiv 0$$

making the substitutions indicated in a and b we get

$$\frac{V_R(t_3 - t_{i-1})}{\sin \alpha_i} = \frac{R + B_i}{\sin(\pi + \theta_3 - \phi_R - \alpha_i)} = \frac{R + B_i}{\sin(\phi_R + \alpha_i - \theta_3)} \qquad i = 1, 3$$

if $\sin \alpha_i \neq 0$ then

$$\text{(A2)} \quad V_R = \frac{(R + B_i) \sin \alpha_i}{(t_3 - t_{i-1}) \sin(\phi_R + \alpha_i - \theta_3)} \qquad i = 1, 3$$

d) Setting the equations for V_R for i = 1, 2 both equal to V_R for i = 3 we get

$$\frac{(R + B_i) \sin \alpha_i}{(t_3 - t_{i-1}) \sin(\phi_R + \alpha_i - \theta_3)} = \frac{R \sin \alpha_3}{(t_3 - t_2) \sin(\phi_R + \alpha_3 - \theta_3)}$$

$$i = 1, 2$$

grouping terms containing R and using cross multiplication to clear the denominators we get

$$\text{(A3)} \quad R[\sin \alpha_i (t_3 - t_2) \sin(\phi_R + \alpha_3 - \theta_3) - \sin \alpha_3 (t_3 - t_{i-1}) \sin(\phi_R + \alpha_i - \theta_3)] = - B_i \sin \alpha_i (t_3 - t_2) \sin(\phi_R + \alpha_3 - \theta_3) \qquad i = 1, 2$$

solving both equations for R we get

$$R = \frac{B_i \sin \alpha_i (t_3 - t_2) \sin (\phi_R + \alpha_3 - \theta_3)}{\sin \alpha_3 (t_3 - t_{i-1}) \sin (\phi_R + \alpha_i - \theta_3) - \sin \alpha_i (t_3 - t_2) \sin(\phi_R + \alpha_3 - \theta_3)} \qquad \text{(A4)}$$

$i = 1, 2$

elimination of range yields after cross multiplication

$$B_1 (t_3 - t_2) \sin \alpha_1 \sin (\phi_R + \alpha_3 + \theta_3) [(t_3 - t_1) \sin \alpha_3 \sin (\phi_R + \alpha_2 - \theta_3) - (t_3 - t_2) \sin \alpha_2 \sin (\phi_R + \alpha_3 - \theta_3)]$$

$$= B_2 (t_3 - t_2) \sin \alpha_2 \sin (\phi_R + \alpha_3 + \theta_3) [(t_3 - t_0) \sin \alpha_3 \sin (\phi_R + \alpha_1 - \theta_3) - (t_3 - t_2) \sin \alpha_1 \sin (\phi_R + \alpha_3 - \theta_3)]$$

dividing both sides by $\sin (\phi_R + \alpha_3 + \theta_3)(t_3 - t_2)$ we get

$$B_1 \sin \alpha_1 [(t_3 - t_1) \sin \alpha_3 \sin (\phi_R + \alpha_2 - \theta_3) - (t_3 - t_2) \sin \alpha_2 \sin (\phi_R + \alpha_3 - \theta_3)] =$$

$$B_2 \sin \alpha_2 [(t_3 - t_0) \sin \alpha_3 \sin (\phi_R + \alpha_1 - \theta_3) - (t_3 - t_2) \sin \alpha_1 \sin (\phi_R + \alpha_3 - \theta_3)]$$

there is only one unknown in this equation: ϕ_R

regrouping similar terms we get

$$(B_1 - B_2) \sin \alpha_1 \sin \alpha_2 (t_3 - t_2) \sin (\phi_R + \alpha_3 - \theta_3) - B_1 \sin \alpha_1 \sin \alpha_3 (t_3 - t_1) \sin (\phi_R - \theta_3 + \alpha_2) + B_2 \sin \alpha_2 \sin \alpha_3 (t_3 - t_0) \sin (\phi_R + \alpha_1 - \theta_3) = 0$$

making the substitution $\xi = \phi_R - \theta_3$ the equation becomes

$$(B_1 - B_2) \sin \alpha_1 \sin \alpha_2 (t_3 - t_2) \sin (\xi + \alpha_3) - B_1 \sin \alpha_1 \sin \alpha_3 (t_3 - t_1) \sin (\xi + \alpha_2) + B_2 \sin \alpha_2 \sin \alpha_3 (t_3 - t_0) \sin (\xi + \alpha_1) = 0$$

using the identity $\sin (A + B) = \sin A \cos B + \cos A \sin B$, we get

$$[(B_1 - B_2) \sin\alpha_1 \sin\alpha_2 (t_3 - t_2) \cos\alpha_3 + B_2 \sin\alpha_2 \sin\alpha_3 (t_3 - t_0) \cos\alpha_1 - B_1 \sin\alpha_1 \sin\alpha_3 (t_3 - t_1) \cos\alpha_2] \sin\xi =$$
$$- [(B_1 - B_2) \sin\alpha_1 \sin\alpha_2 (t_3 - t_2) \sin\alpha_3 + B_2 \sin\alpha_2 \sin\alpha_3 (t_3 - t_0) \sin\alpha_1 - B_1 \sin\alpha_1 \sin\alpha_3 (t_3 - t_1) \sin\alpha_2] \cos\xi$$

if $(\sin\alpha_i)$ $i = 1, 3$ are not zero then we can divide by $(\sin\alpha_1 \sin\alpha_2 \sin\alpha_3)$ and get

$$[(B_1 - B_2) (t_3 - t_2) \cot\alpha_3 + B_2 (t_3 - t_0) \cot\alpha_1 - B_1 (t_3 - t_1) \cot\alpha_2] \sin\xi = - \cos\xi [(B_1 - B_2) (t_3 - t_2) + B_2 (t_3 - t_0) - B_1 (t_3 - t_1)]$$

solving for $\tan\xi$ we get

$$\tan\xi = \frac{- [(B_1 - B_2) (t_3 - t_2) + B_2 (t_3 - t_0) - B_1 (t_3 - t_1)]}{(B_1 - B_2) (t_3 - t_2) \cot\alpha_3 + B_2 (t_3 - t_0) \cot\alpha_1 - B_1 (t_3 - t_1) \cot\alpha_2}$$

the solution for ϕ_R is therefore

$$\text{(A5)}\quad \phi_R = \operatorname{atan} \left\{ \frac{(B_2 - B_1) (t_3 - t_2) - B_2 (t_3 - t_0) + B_1 (t_3 - t_1)}{(B_1 - B_2) (t_3 - t_2) \cot\alpha_3 + B_2(t_3 - t_0) \cot\alpha_1 - B_1(t_3 - t_1) \cot\alpha_2} \right\} + \Theta_3$$

This solution is valid if certain conditions are met.

1. B_1 and B_2 are not both zero.

   This is equivalent to the assumption that the sensor ship must be maneuvering.

2. None of the α_i can be zero.

   This is equivalent to requiring that the bearings at times t_0, t_1 and t_2 not equal the bearing at t_3. This restriction also eliminates the possibility that $V_R = 0$, since $V_R = 0$ means the bearing is constant.

For further considerations of these conditions see Part VII of this appendix (page A12).

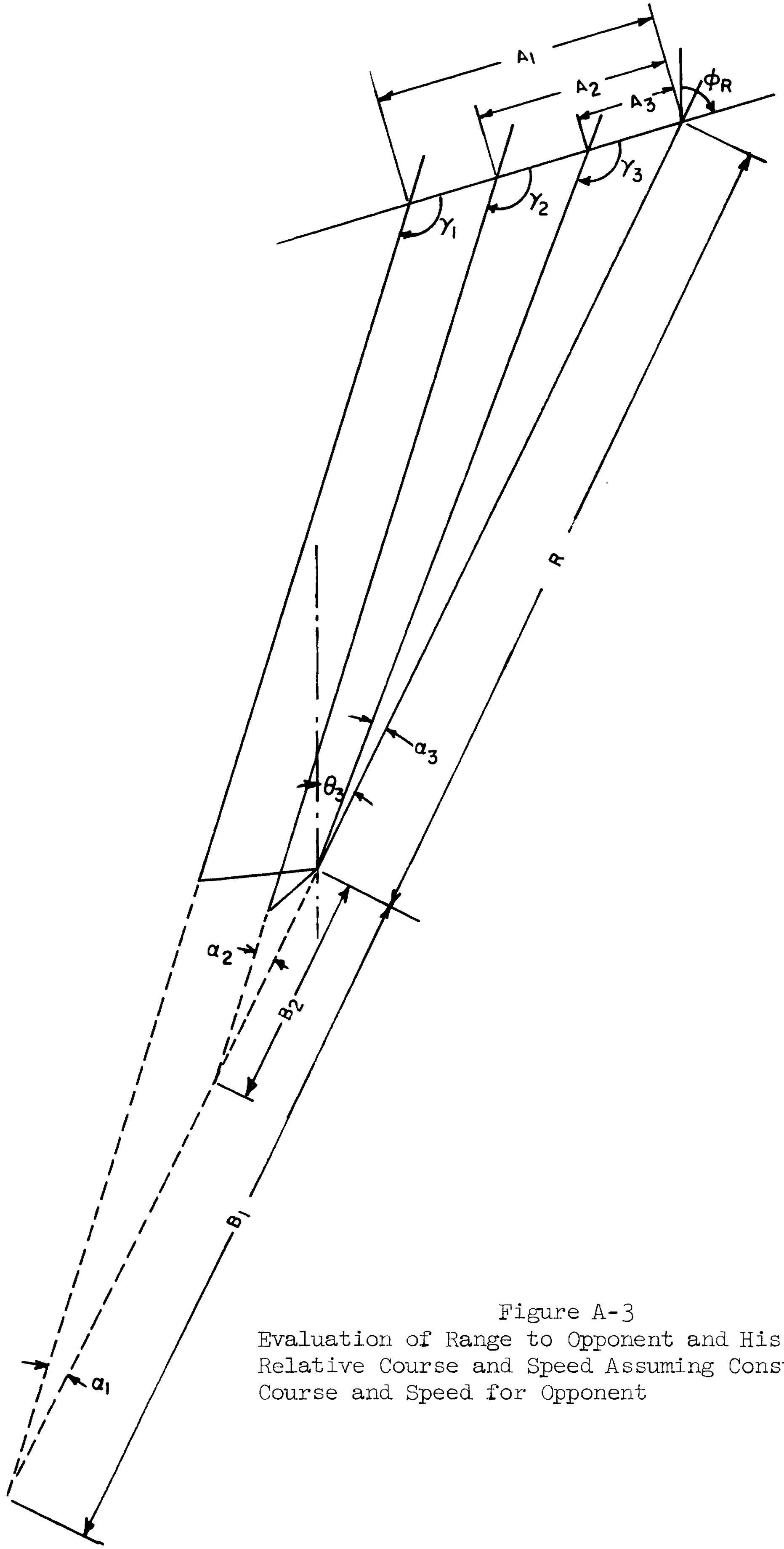


Figure A-3
Evaluation of Range to Opponent and His Relative Course and Speed Assuming Constant Course and Speed for Opponent

Part IV. Evaluation of Range at t_3 knowing ϕ_R

Now that ϕ_R is known, R can be determined directly from equations (A4) on page A7.

$$\text{(A4)} \qquad R = \frac{B_i \sin \alpha_i (t_3 - t_2) \sin(\phi_R + \alpha_3 - \Theta_3)}{\sin \alpha_3 (t_3 - t_{i-1}) \sin(\phi_R + \alpha_i - \Theta_3) - \sin \alpha_i (t_3 - t_2) \sin(\phi_R + \alpha_3 - \Theta_3)} \qquad i = 1, 2$$

To avoid problems with a B_i which is near zero, a combination of these two equations is used.

$$R = \frac{[B_1 \sin\alpha_1 + B_2 \sin\alpha_2] \sin(\phi_R + \alpha_3 - O_3)(t_3 - t_2)}{\sin \alpha_3 [(t_3 - t_0)\sin(\phi_R + \alpha_1 - O_3) + (t_3 - t_1)\sin(\phi_R + \alpha_2 - O_3)] - (t_3 - t_2)\sin(\phi_R + \alpha_3 - \Theta_3)[\sin\alpha_1 + \sin\alpha_2]}$$

or

$$R = \frac{B_1 \sin \alpha_1 + B_2 \sin \alpha_2}{\sin\alpha_3 \dfrac{(t_3 - t_0)\sin(\phi_R + \alpha_1 - \Theta_3) + (t_3 - t_1)\sin(\phi_R + \alpha_2 - \Theta_3)}{(t_3 - t_2)\sin(\phi_R + \alpha_3 - \Theta_3)} - \sin \alpha_1 - \sin \alpha_2}$$

Since both B_1 and B_2 cannot be zero, then this equation is always valid even if one B_i is zero.

Part V. Evaluation of Relative Speed, Knowing ϕ_R and R

Examination of equation (A2) on page A6 shows an easy way to get V_R.

$$\text{(A2)} \qquad V_R = \frac{(R + B_i) \sin \alpha_i}{(t_3 - t_{i-1}) \sin(\phi_R + \alpha_i - \Theta_3)} \qquad i = 1,3$$

for i = 3 we get

$$V_R = \frac{R \sin \alpha_3}{(t_3 - t_2) \sin(\phi_R + \alpha_3 - \Theta_3)}$$

This is well behaved so it can be used directly as soon as ϕ_R and R have been evaluated.

Part VI. Opponent's True Course and Speed

The opponent's estimated true course and speed can now be computed using simple vector addition.

$$\bar{V}_{TRUE} = \bar{V}_{OWN} + \bar{V}_R$$

or

$$V_{TRUE} \angle \phi_{TRUE} = V_{OWN} \angle \phi_{OWN} + V_R \angle \phi_R$$

Since the own ship's velocity is known (V_{OWN} at course ϕ_{OWN}) and V_R and ϕ_R have just been computed, then V_{TRUE} and ϕ_{TRUE} are calculated as follows:

$$\phi_{TRUE} = \text{atan} \left[\frac{V_{OWN} \sin \phi_{OWN} + V_R \sin \phi_R}{V_{OWN} \cos \phi_{OWN} + V_R \cos \phi_R} \right]$$

$$V_{TRUE} = \left[(V_{OWN} \sin \phi_{OWN} + V_R \sin \phi_R)^2 + (V_{OWN} \cos \phi_{OWN} + V_R \cos \phi_R)^2 \right]^{\frac{1}{2}}$$

This completes the analysis of the opponent's estimated course and speed for normal circumstances. Some consideration follows of areas where assumptions were necessary for easy calculation.

Part VII. Special Cases

It was noted that both B_i cannot be zero. An examination of the results of one B_i zero and the other non-zero shows that it is not necessary to use this as a special case.

Equation (A3) on page A6 is

$$\text{(A3)} \quad R[\sin \alpha_1(t_3-t_2) \sin (\phi_R + \alpha_3 - \theta_3) - \sin \alpha_3 (t_3-t_{i-1}) \sin (\phi_R + \alpha_i - \theta_3)]$$

$$= -B_i \sin \alpha_i(t_3-t_2) \sin (\phi_R + \alpha_3 - \theta_3) \text{ for } i = 1, 2$$

If $B_i = 0$ then this becomes considerably simplified. If range is assumed non-zero then we get the equation:

$$\text{(A6)} \quad \sin \alpha_1(t_3-t_2) \sin (\phi_R + \alpha_3 - \theta_3) - \sin \alpha_3(t_3-t_{i-1}) \sin (\phi_R + \alpha_i - \theta_3) = 0$$

The only unknown in equation (A6) is ϕ_R. It can be reduced by using the same trig identity as before $[\sin(A + B) = \sin A \cos B + \cos A \sin B]$ and by letting $\xi = \phi_R - \theta_3$. This yields

$$[\sin \alpha_3 \cos \alpha_i(t_3-t_{i-1}) - \sin \alpha_i \cos \alpha_3(t_3-t_2)] \sin \xi =$$

$$- \cos \xi [\sin \alpha_3 \sin \alpha_i(t_3-t_{i-1}) - \sin \alpha_i \sin \alpha_3(t_3-t_2)]$$

Assuming $\sin \alpha_3 \sin \alpha_i$ is non-zero as previously done, and dividing we get

$$[\cot \alpha_i(t_3-t_{i-1}) - \cot \alpha_3(t_3-t_2)] \sin \xi = -\cos \xi [(t_3-t_{i-1}) - (t_3-t_2)]$$

or

$$\tan \xi = - \frac{(t_3-t_{i-1}) - (t_3-t_2)}{\cot \alpha_i(t_3-t_{i-1}) - \cot \alpha_3(t_3-t_2)}$$

or

$$\phi_R = \operatorname{atan} \left[\frac{(t_3-t_{i-1}) - (t_3-t_2)}{\cot \alpha_i(t_3-t_{i-1}) - \cot \alpha_3(t_3-t_2)} \right] + \theta_3$$

This is exactly the equation that results from setting a B_i to zero in the full equation (A5) (on page A8) and then cancelling the other B_i. Thus one non-zero B_i is sufficient to allow solution for ϕ_R using (A5).

APPENDIX B

INTERCEPTION CALCULATIONS

When a player is ready to fire a weapon, he knows his own position, the characteristics of the weapon he is firing, and has an estimate of the present position, course and speed of his opponent. Given this information, he needs to know if an interception is possible and if so, the course the weapon should be fired on for the earliest possible interception. The player would also like to know the position and time at which the weapon will intercept the enemy ship.

There are two basic types of weapons with which we are dealing. The first type (e.g. ASROC) travels through two media at two distinct velocities. They are characterized by the fact that they always travel a fixed distance (e.g. 1500 yards) at the second velocity. For example, if the interception position is calculated to be 5 miles away from you, then the ASROC would be in the air for (5 miles-1500 yards) and would travel the last 1500 yards in the water.

The other type of weapon (e.g. torpedos and hedgehogs) can be considered to be a specific case of the first. This is a weapon which travels only through one medium and at a fixed speed. This assumes that the fixed distance travelled in the second medium is zero.

Assume that your present position is (x_1,y_1), the estimated position of your opponent is (x_2,y_2) and the interception position will be (x_3,y_3).

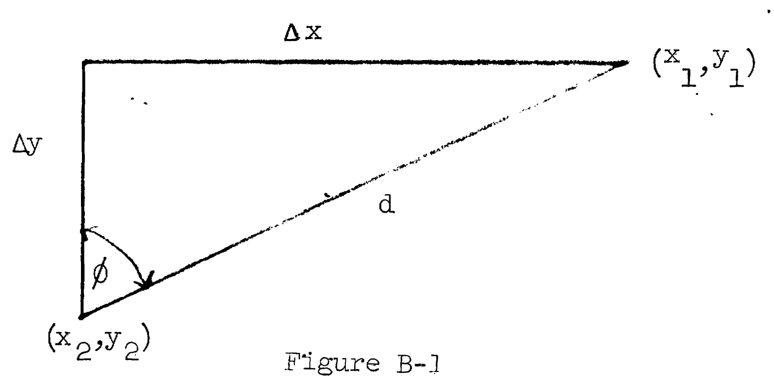


Figure B-1
Terminology

The following terminology is introduced here and will be used throughout the following derivations (see Fig. 1).

Δlongitude = $x_2 - x_1 = \Delta x$

Δlatitude = $y_2 - y_1 = \Delta y$

middle latitude = $(y_1 + y_2)/2$

distanced = d $=((\text{departure})^2 + (\Delta y)^2)^{\frac{1}{2}}$

departure = Δlongitude(cos(middle latitude))

$\phi = \tan^{-1}$ (departure/Δlatitude)

To compute the time and position of interception, the diagram of Fig. 2 is needed. The component sides of the triangle are 1) the distance between the two ships at the time the weapon is fired, 2) the distance travelled by the enemy ship to the interception point and 3) the distance travelled by the enemy ship to the interception point.

Consider the multispeed type of weapon. Define the following terms:

v_i: first velocity of interceptor (weapon)

d_1: fixed distance traversed by weapon in second medium

t_1: time needed for weapon to traverse first medium

t_2: elapsed time between firing and interception

Δt: time taken to traverse second medium $(t_2 - t_1)$

v_t: velocity of target ship

d: distance between both ships at time of firing

$\Delta x, \Delta y, \phi$: as defined in Fig. 1

α : course of target ship

θ : interior angle of triangle = $\phi - \alpha$

β: course that weapon is fired on

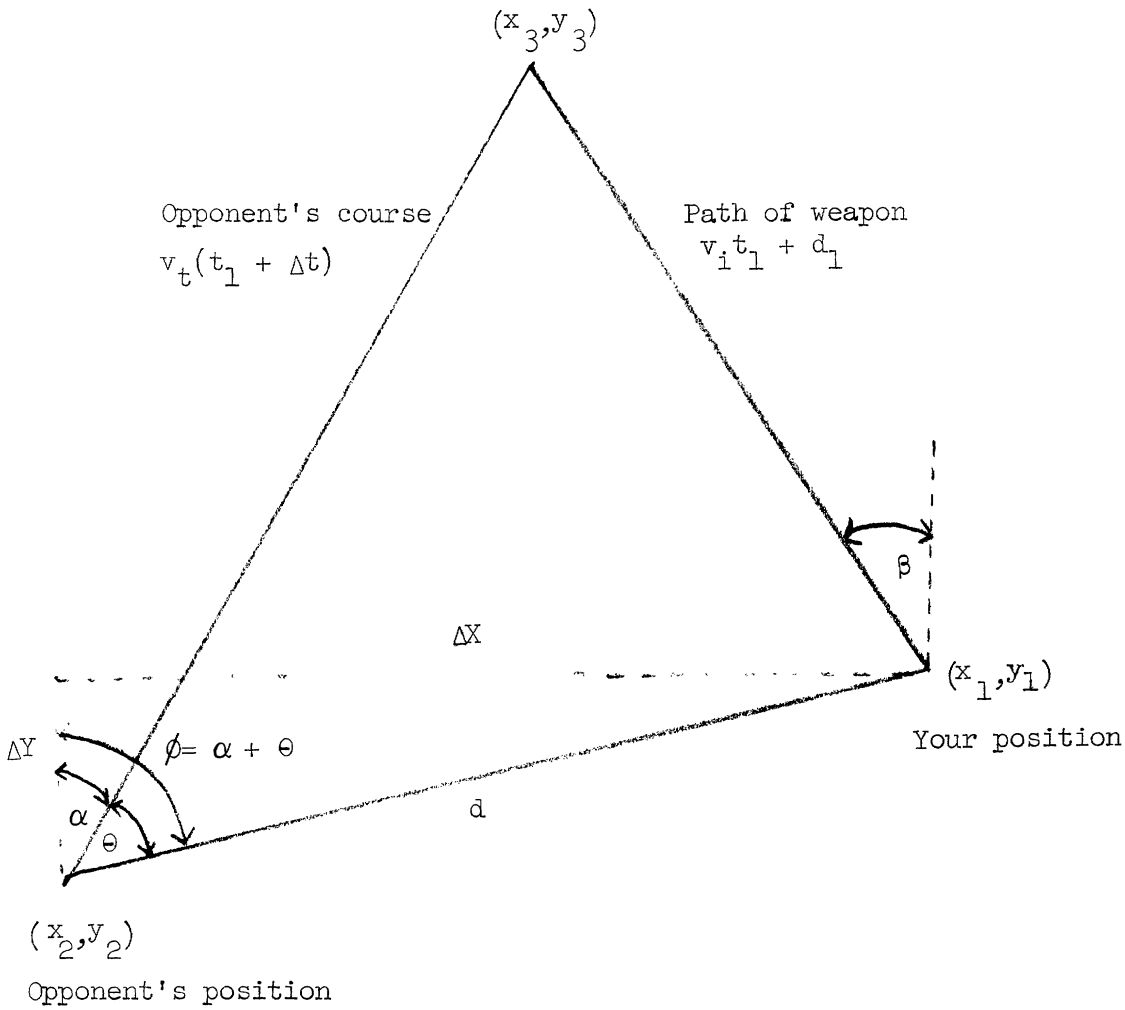


Figure B-2
Interception with a Multi-Speed Weapon

From these definitions we can represent side 1 of the triangle by "d"; side 2 by "$v_t t_2$" or "$v_t(t_1+\Delta t)$"; and side 3 by "$v_i t_1+d_1$".

If we examine the triangle we see that every quantity is known except for t_1. Therefore, if we solve for t_1, this will give the distance travelled by the weapon and the target and will provide a means for computing the interception point and the weapon course.

Applying the law of cosines to the triangle:

$$(v_i t_1+d_1)^2 = (v_t(t_1+\Delta t))^2 + d^2 - 2dv_t(t_1+\Delta t)\cos\Theta$$

expanding:

$$v_i t_1^2 + 2v_i t_1 d_1 + d_1^2 = v_t^2 t_1^2 + 2v_t^2 t_1\Delta t + v_t^2\Delta t^2 + d^2 - 2dv_t t_1\cos\Theta - 2dv_t\Delta t\cos\Theta$$

group by powers of t_1:

$$t_1^2(v_i^2-v_t^2) + t_1(2v_i d_1-2v_t^2\Delta t+2dv_t\cos\Theta) + (d_1^2-v_t^2\Delta t^2-d^2+2dv_t\Delta t\cos\Theta) = 0$$

solve for t_1 using quadratic formula:

$$t_1 = \frac{-2(v_i d_1-v_t^2\Delta t+dv_t\cos\Theta)}{2(v_i^2-v_t^2)} \pm \sqrt{\frac{4(v_i d_1-v_t^2\Delta t + dv_t\cos\Theta)^2 - 4(v_i^2-v_t^2)(d_1^2-v_t^2\Delta t^2-d^2+2dv_t\Delta t\cos\Theta)}{2(v_i^2-v_t^2)}}$$

or:

$$t_1 = \frac{(v_i d_1-v_t^2\Delta t+dv_t\cos\Theta)}{(v_t^2-v_i^2)} \mp \sqrt{\frac{(v_i d_1-v_t^2\Delta t+dv_t\cos\Theta)^2 + (v_t^2-v_1^2)(d_1^2-v_t^2\Delta t^2-d^2+2dv_t\Delta t\cos\Theta)}{(v_t^2-v_i^2)}}$$

and since $t_1+\Delta t = t_2$ we have computed the total elapsed time between the time of firing and the time of interception.

In the case of the single speed weapon, we have $\Delta t = d_1 = 0$ and if we let $t_1 = t_2 = t$, we can see from Fig. 3 that the law

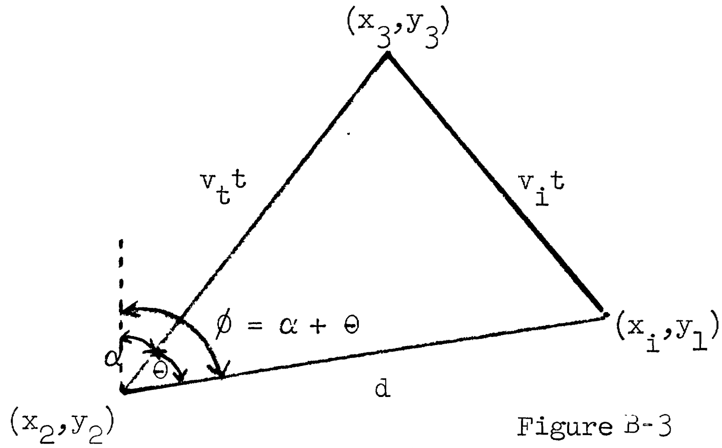


Figure B-3
Interception with a Single Speed Weapon

of cosines simplifies to:

$$(v_i t)^2 = (v_t t)^2 + d^2 - 2dv_t t \cos \theta$$

or:

$$t^2(v_i^2-v_t^2) + t(2v_t d \cos \theta) - d^2 = 0$$

therefore:

$$t = \frac{-2v_t d \cos \theta}{2(v_i^2-v_t^2)} \pm \frac{\sqrt{4v_t^2 d^2 \cos^2\theta + 4d^2(v_i^2-v_t^2)}}{2(v_i^2-v_t^2)}$$

If we substitute $(1-\sin^2\theta)$ for $\cos^2\theta$ and divide the 2d out of the radical we get a simplified equation for t:

$$t = -v_t \cos \theta \pm \sqrt{(v_1^2-v_t^2\sin^2\theta\ )}\ (d/(v_1^2-v_t^2)$$

Two problems may arise which prevent the solution from being solved for t_1 (or t) in this form:

1) Discriminant < 0

Conceptually, the only way we will not be able to solve for an interception time is if the target is moving at a speed and an angle such that the interceptor can never catch up.

If the first case, the discriminant less than zero means:

$$(v_i d_1 - v_t^2 \Delta t + d v_t \cos \Theta)^2 < (v_t^2 - v_i^2)(d_1^2 - v_t^2 \Delta t^2 - d^2 + 2 d v_t \Delta t \cos \Theta)$$

To visualize what this means take the case of the torpedo. We have already solved this equation and know that the discriminant is $(v_i^2 - v_t^2 \sin^2 \Theta)$.

Then if the discriminant is less than zero:

$$v_i^2 - v_t^2 \sin^2 \Theta < 0$$

$$v_i^2 < v_t^2 \sin^2 \Theta$$

$$v_i < v_t \sin \Theta$$

Therefore there will be no solution if the target is moving away faster than the weapon can catch up. If this is the case then the player is notified that "No hit is possible".

2) $V_i = V_t$

If $v_i = v_t$ then the denominator, $(v_i^2 - v_t^2)$, is zero and the fraction blows up. As an example, consider the case of the torpedo, when $v_i = v_t$. We have an isosoles triangle:

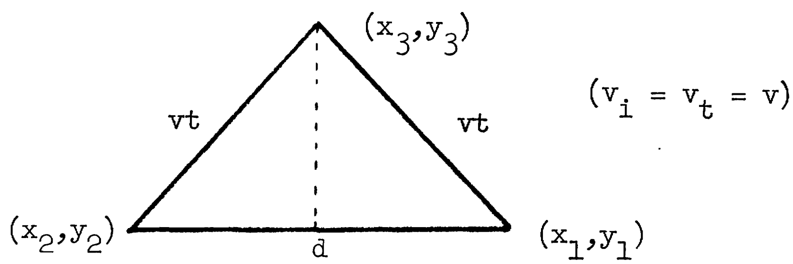


Figure B-4 Velocity of Weapon is the Same as that of Target Ship

From Fig. 4 we see that $\cos \Theta = (d/2)/(vt)$. Therefore $t = d/(2v\cos \Theta)$, and we have a simplified solution.

After we have solved for the time that it will take for the weapon to reach the calculated interception point we still need to know the course on which to fire the weapon and we would like to know when the interception will take place. To determine the position consider the following triangle; where α is the course of the target ship.

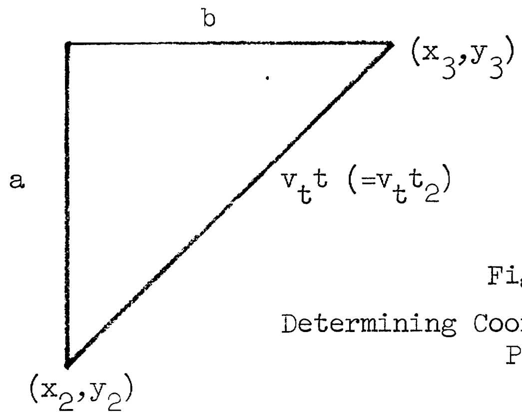


Figure B-5
Determining Coordinates of Interception Point

From Fig. 5 we see that $\cos(\alpha) = a/(v_t t)$. Therefore $v_t t\cos(\alpha) = a = \Delta y = \Delta$Latitude which means that $y_3 = y_2+\Delta y$. To find the longitude we need the middle latitude where Middle latitude = (latitude of target ship + Δlatitude)/2. Also, from Fig. 5 we have:

$\sin(\alpha) = b/(v_t t)$. Therefore $v_t t\sin(\alpha) = b =$ Departure

and Δlongitude = departure/cos(mid. lat.) = $v_t t\sin(\alpha)/(\cos(\text{mid.lat.}) = \Delta x$ which means that $x_3 = x_2+\Delta x$.

Once we know the latitude and longitude of interception determining the weapon course requires only drawing a straight line between (x_1,y_1) and (x_3,y_3).

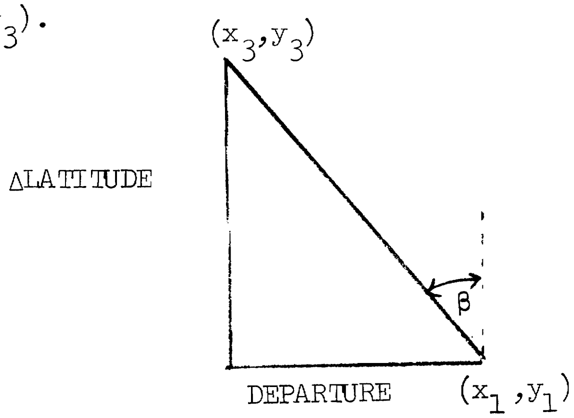


Figure B-6
Determining Interception Course

From Fig. 6 we can see that the course β, that the weapon will be fired on is:

$$\beta = \tan^{-1} \frac{\text{DEPARTURE}}{\Delta\text{LATITUDE}}$$

where ΔLatitude = $y_3 - y_1$

and the departure is $(x_3 - x_1) \cos \frac{(y_3 + y_1)}{2}$

APPENDIX C

DESCRIPTION OF GAME FUNCTIONS

This appendix contains information concerning the use of all player or referee functions as they currently exist. Additional examples can be found in Chapter 6 which contains a sample game.

The following table gives general information which applies to the numerical parameters of all programs except as noted for a particular function.

Parameter Type	Units
time	4 digits: left 2 specify hour (00-23); right 2 digits specify minute (00-59)
duration	minutes
speed	knots
course	degrees (0-359)
depth	feet

The presence of parenthesis around a parameter indicate that a substitution is to be made. Normally it can be either a number or one of a group of words.

IDENTIFICATION: INTCL: INiTialize CLock - A referee function

PURPOSE: Full and exclusive control of the game clock

USAGE & ACTIONS FORMAT		No previous INTCL		Was a Previous INTCL	
		Present time	Scale	Present time	Scale
1	INTCL INTCL/START	real time	1	as calculated from previous INTCL	unchanged
2	INTCL/(time)	specified time	1	specified times	unchanged
3	INTCL//(scale) INTCL/START/(scale)	real time	specified scale	as calculated from previous INTCL	as specified
4	INTCL/(time)/(scale)	specified time	specified scale	specified time	specified scale
5	INTCL/STOP	---	---	as calculated from previous INTCL	unchanged

RESTRICTION: Must be executed before any other function at the start of the game. Use is restricted to the referee.

IDENTIFICATION: INTLZ, INiTiaLiZe the game - A referee function

PURPOSE: To create the player's OWN records

USAGE: INTLZ

RESTRICTION: This must be executed before each game. Execution must precede any use of START.

IDENTIFICATION: START, Set Initial position at START of game - A referee function

PURPOSE: Set initial position of a ship

USAGE: START/(player's identification)/(initial latitude)/(initial longitude)

Both the initial latitude and longitude are specified in degrees. E latitude and N longitude are positive; W latitude and S longitude are negative.

RESTRICTION: Must be executed for each player at the start of each game.

SAMPLE: START/RED&OWN/=-30.02/=-40

Set the initial position of RED to 30.02°S, 40°W

IDENTIFICATION: SETSP, SET Sailing Plan, A player function

PURPOSE: Control of the maneuvers of a player's ship

USAGE: A. for surface vessels

1. SETSP/(future time specification)/($speed_1$)/($course_1$)/($duration_1$)/($speed_2$)/($course_2$)/($duration_2$)/.../($speed_n$)/($course_n$)
2. SETSP/($speed_1$)/($course_1$)/...

B. for submarines

1. SETSP/(future time specification)/($speed_1$)/($course_1$)/($depth_1$)/($duration_1$)/.../($speed_n$)/($course_n$)/($depth_n$)
2. SETSP/($speed_1$)/($course_1$)/($depth_1$)/...

There are two basic ways of specifying a future time of execution. In both cases the first word is TIME. If a particular time is chosen then follow TIME with the specified time (e.g. TIME/1215). If the second parameter is PLUS then the time is the present value plus the number of minutes specified in the third parameter (e.g. TIME/PLUS/5). If no time specification is given, the present time is used.

A speed specification can be either a number or any of the following words: SLOW (about 1/3 full), STANDARD (about 2/3 full), FULL, FLANK (about 10% above full) and SAME. If STOP is specified then the speed is set to 0 and the course and depth set to present value; STOP is followed by a duration since it is a full specification in itself.

Courses can be given either as an absolute course (a number between 0 and 360), by the word SAME, or as a relative course. Relative courses are given by a direction word (RIGHT or LEFT) followed by the amount of the turn (between 0 and 180).

SETSP continued:

Depths are given either as a depth in feet, the words SAME or SURFACE or as a relative depth change. Relative depths are given as UP or DOWN followed by the change in feet.

If a speed, course or depth is skipped by typing a '/' instead of one of the above then the word SAME is substituted.

All durations are in minutes.

SAMPLES: For a submarine

SETSP/TIME/1215/SLOW/RIGHT/70/100

at 1215 begin a 70° right turn at slow speed and 100 feet

SETSP/FULL/300/UP/100

begin a turn to 300° at full speed and go up 100 feet

For a surface vessel

SETSP/TIME/PLUS/5/FULL/LEFT/50/4/STANDARD/RIGHT/60

in 5 minutes begin a left turn of 50° at full speed.

Four minutes later make a 60° right turn at standard speed.

IDENTIFICATION: USESN, USE SeNsor - A player function

PURPOSE: Control of the simulated sonar sensors

USAGE: 1) USESN/(Player's color)& {ACTIVE | PASSIVE} /CONTN/(time interval)

used to start taking continuous sonar readings

2) USESN/(Player's color)& {ACTIVE | PASSIVE} /STOP

used to stop taking continuous sonar readings

3) USESN/(Player's color)& {ACTIVE | PASSIVE} /(number of readings)/(time interval)

used to take a specified number of readings

The time interval in minutes is optional; if unspecified then .25 minutes is assumed.

The active and passive sonars are completely independent. A single USESN can control either one but not both.

SAMPLE: USESN/RED&PASSIVE/CONTN

Start making continuous passive sonar reading for player RED (assumed separation .25 minutes).

IDENTIFICATION: LAYER, Set LAYER depth - A referee function

PURPOSE: The referee may set a layer depth. If this function is not used, it is assumed that there is no thermal layer.

USAGE: LAYER/number of feet

LAYER/NONE

The parameter NONE eliminates the thermal layer.

IDENTIFICATION: ESTPS, ESTimate Passive Sonar

PURPOSE: Estimate position, course and speed of opponent's vessel using available passive sonar readings.

USAGE: ESTPS/(time of last reading)/(ESTO record name)

Both parameters are optional.

Parameter Number	Parameter Type	Meaning Assumed if missing	Notes
1	time of last reading	present time	format [hr hr min min]
2	ESTO Record name	generate name internally	

An ESTO record is created only when reliability is satisfactory.

RESTRICTIONS: Player should be signed in as either RED or WHITE.

IDENTIFICATION: ESTAC, ESTimate ACtive sonar, A player function

PURPOSE: Estimate position, course and speed of opponent's vessel using available active sonar readings.

USAGE: ESTAC/(number of readings)/(time of last reading)/(ESTO record name)

All parameters are optional.

Parameter Number	Parameter Type	Assumed Value	Specification Notes
1	Number of readings	4	$1 \leq n \leq 12$
2	Time of last reading	present time	format (hr hr min min)
3	ESTO record name	generate automatically	

An ESTO record is created whenever 2 or more readings are available.

RESTRICTION: Player should be signed in as either RED or WHITE.

IDENTIFICATION: ASCOM, Active Sonar COMpare - A player function

PURPOSE: Compare active sonar readings with an estimate to determine when a new estimate is needed.

USAGE: ASCOM/(estimate description)/(parameter 1)/.../(parameter n)

The estimate descriptions are one of

1. Estimate Name

2a. LASTA — Last Active estimate

b. LASTP — Last Passive estimate

c. LAST — Last estimate

3a. CONTINUE — Continue with the estimate used on the previous call.

If the ESTO described is the same as the name of the last ESTO examined by ASCOM, then CONTINUE is substituted, providing no ESTO description is equivalent to CONTINUE. If a CONTINUE is attempted when the estimate already failed then the description LASTA is tried to see if a newer estimate has been created.

The parameter list consists of two distinct parameter classes:

1. A single word non-positional parameter which can appear anywhere in the parameter list.
2. Parameters which can be set to a value by single words in sequence. If any of the sequence are to be skipped then the description of the next parameter to be set is inserted and the sequence jumps to the specified parameter. The first null parameter stops the processing of the list.

Parameter Description

CLASS I

1. DESCRIBE — Print a description of the parameters and their current values
2. LIST — Print the current values of the parameters

ASCOM continued:

3a.	MAX	Maximum output level
b.	NORMAL	Normal print output level
c.	FULL	Slightly edited output
d.	MIN	Minimum output level
e.	EDIT	Reduce the printing one level
f.	NOEDIT	Increase printing one level
4.	SET	Make the parameters for this run the new assumed parameters for this user.

CLASS II

The following parameters can be set by supplying a number at the proper point in the sequence. OFF and ON are also valid and have the obvious effect. All parameters in this list are saved when SET is typed.

	Keyword	Parameter Description
1	M	See 3, 4, 5 below
2	N	" "
3	D	Reject ESTO when M out of last N points exceed D
4	D1	Reject when M/N points exceed D1 (component of D parallel to estimate - SPEED sensitive) in the same direction
5	D2	Reject when M/N points exceed D2 (component of D perpendicular to estimate - COURSE sensitive) in the same direction
6	AVGD	Reject when the average D exceeds this value
7	RMSD	Reject when the RMS average D exceeds this value
8	SUMD1	Reject when the signed sum of D1 exceeds this value
9	SUMD2	Reject when the signed sum of D2 exceeds this value

ASCOM continued:

	Keyword	Parameter Description
10	AGE	Modifier of LASTA, LAST, LASTP: maximum age of estimate
11	RELIB	Modifier of LASTA, LAST, LASTP: minimum reliability of estimate
12	ASSEL	Time span to be used for automatic ASSEL execution
13	ESTAC	Time span of readings used for automatic ESTAC execution

SAMPLES:

This is the statement which is assumed before any parameters are typed.

1. ASCOM/LASTA/3/5/.1/.15/.10/.05/OFF/OFF/OFF/OFF/OFF/OFF/1.5

   This statement sets the values for M, N, D1, D2, AVGD, RMSD, SUMD1, SUMD2, AGE, RELIB, ASSEL and ESTAC respectively.

2. ASCOM/MAX/AVGD/.06

   Set print level to max.

   Change AVGD from .05 to .06.

   These changes are effective for one run only.

3. ASCOM/NORMAL/RMSD/.055/SET

   Set print level to NORMAL

   Set RMSD to .055 and turn it on.

   These changes are effective until changed again.

4. ASCOM

   Continue with the estimate used in the previous call and with the parameters as they were last set.

IDENTIFICATION: OPHIS, OPponent HIStory - A player or referee function

PURPOSE: Display sonar readings, estimates of opponent and/or one's own sailing history.

USAGE: 1) OPHIS/(any number of estimates and/or OWN history)/(options to be used)/INCL/first time/final time

2) OPHIS/(sonar record)/(options to be used)/BKSTEP/(time of last readings)/(number of readings to be displayed)

SAMPLES: OPHIS/WHITE&OWN/ALL/INCL/=2050/=2110

display WHITE's true position during the interval 2050 to 2110.

OPHIS/WHITE&OWN ∨ WA001/STD/INCL/=2030/=2120

display both WHITE's true position and WHITE's estimate of RED called WA001 for period 2030 to 2120.

OPHIS/WHITE&ACTIVE&SONAR/ALL/BKSTEP/=2130/=20

display 20 active sonar readings ending at 2130 as received by WHITE.

IDENTIFICATION: ELISA, Estimate LISt Active - A player function

PURPOSE: Estimate position, course and speed of the opponent's vessel using specified active sonar readings.

USAGE: ELISA/$(t_1),(t_2),(t_3),\ldots,(t_n)$/(ESTO name)

The times are specified in descending order - most recent times first. The times are specified in six digit format. The first two are hours, second two for minutes and third pair for seconds.

This function is normally used only with the display, which generates the request automatically.

The ESTO name is optional (see ESTAC).

RESTRICTIONS: The player should be signed in as RED or WHITE.

SAMPLE: ELISA/=121531,=121546,=121601

Make an active estimate using the three specified readings.

IDENTIFICATION: INTER, Find INTERception Course - A player function

PURPOSE: to find an interception course to an estimate of the opponent at a specified speed.

USAGE: INTER/(ESTO name)/(speed of own vessel desired)

SAMPLE: INTER/RP004/=10

This requests an interception course with RED's estimate of WHITE called RP004 at a speed for RED of 10 knots.

IDENTIFICATION: OPINT, Find OPponent's INTerception course - A player function

PURPOSE: To enable a player to calculate what course the opponent should use if the opponent is trying to intercept assuming a speed of the opponent.

USAGE: OPINT/(ESTO name)/(speed of opponent's vessel)

SAMPLE: OPINT/RP004/=10

This requests that a calculation be made of the course the opponent should follow if its position is as given by RP004 and if he travels at 10 knots.

IDENTIFICATION: RANGE, RANGE between positions - A player and referee function.

PURPOSE: To calculate and print the range and true bearing between the positions of two objects at specified times. The objects can be vessels, estimates of vessels or weapons.

USAGE: RANGE/(first record)/(second record)/(first time)/(time interval)/(number of times)

If the first time is not supplied then the program assumes the present time. If either the time interval or number of times is unspecified then only one time is considered.

SAMPLES: 1) RANGE/RED&OWN/RP003/=1215/=1/=10

This supplies the range and bearing from the estimate RP003 to the OWN position of RED for times from 1215 to 1224 separated by 1 minute.

2) RANGE/RED&OWN/RP003

This provides the present range and bearing.

IDENTIFICATION: POS, POSition - A player or referee function

PURPOSE: To print the position, speed, course and depth of a vessel at specified times. It can also be used on estimates of a ship or on a weapon's path.

USAGE: POS/(record description)/t_1/t_2/t_3/.../t_n

where t_i is a four digit number; first two for hour and second two for minute.

SAMPLES: 1) POS/RED&OWN/=1215/=1220/=1225

This supplies the position, speed, course and depth of the true position of RED at 1215, 1220 and 1225.

2) POS/WP004/=1830

This supplies the information as obtained from the ESTO record WP004.

3) POS/RED&TORP2/=0900/=0905

This gives the data for RED's torpedo 2.

IDENTIFICATION: WEAPO, fire a WEAPOn - A player function

PURPOSE: To fire weapon. The weapons available include ASROC torpedoes and hedgehogs.

USAGE: WEAPO/(type of weapon)/(ESTO item description or bearing)/(number of weapons to be fired)/(speed between weapons)/(vertical angle for ASROC expressed as distance from your ship where it will splash down)/(NOFIRE OPTION)/(NUMBER OF SPREADS)

All parameters are optional. The value which is assumed if a parameter is unspecified can be obtained from the following table:

Type of Ship	Assumed Weapon Type	ESTO Description	Number in Spread	Degrees Between Weapons	Vertical Angle for ASROC	Number of Spreads
Submarine	Torpedo	Last active	1	2	NA	1
Destroyer	ASROC	Last active	1	2	3 miles	1

SAMPLES: 1) WEAPO/TORPEDO/LASTA

Fire a torpedo using the last active estimate to calculate interception position.

2) WEAPO/ASROC/=84.3/=2/=1.5/=5.0

Fire a spread of two asrocs with 1.5 degrees between them using a center bearing of 84.3 degrees. Compute the vertical angle of launch using assumption that asroc is to hit water 5 miles from point of firing.

3) WEAPO/TORPEDO/NEWA////NOFIRE

Make a new active estimate and give me all the interception information but don't fire the weapon.

IDENTIFICATION: WEPST, WEaPon STatus - A player or referee function

PURPOSE: To inform the player of the number of weapons remaining

USAGE: WEPST/(list of types of weapons)

If a list of weapon types is not supplied, then all weapons are individually considered.

SAMPLES: 1) WEPST/ALL

This supplies a count of all remaining torpedoes if the player making the request is a sub and supplies a count of asrocs, torpedoes and hedgehogs if the DD makes the request.

2) WEPST/TORPEDO'AND'ASROC

This supplies a count of all remaining asrocs and torpedoes to the DD commander.

IDENTIFICATION: CNFRM, CoNFiRM a hit or miss - A player or referee function

PURPOSE: To determine the results of the firing of a weapon.

USAGE: CNFRM/NAME OF WEAPON

or

CNFRM/LAST/(TYPE OF WEAPON)

or

CNFRM/ALL/(TYPE OF WEAPON)

Type of weapon is optional.

The weapon names are automatically generated and printed by WEAPO.

RESTRICTIONS: Confirmations are calculated up to present time. If it is too early, a message to that effect is printed.

SAMPLES: 1) CNFRM/TORP4

The results of the firing of torpedo 4 are computed and printed.

2) CNFRM/LAST/ASROC

Confirms last asroc fired.

3) CNFRM/LAST

Confirms last weapon fired.

4) CNFRM/ALL

Confirms all unconfirmed weapons.

IDENTIFICATION: WPARM, set Weapon PARaMeters - A player function

PURPOSE: To set decision parameters necessary to fire weapons

USAGE: WPARM/sequential list of parameter values separated by slashes or a list of parameter name/value/parameter name/value

SAMPLES: WPARM/WEP8/YES/EST6/=.005

WPARM/YES/NO/=.01/YES/=3.0

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