THE EFFECT OF FALSE CONTACTS ON THE PROBABILITY OF DETECTING A SUBMARINE

by

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THESIS

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ABSTRACT

A computer war game is developed to measure the effect of false contacts on the probability of detecting a submarine. The variables are the probability of correctly classifying a non-submarine contact, the probability of correctly classifying a submarine contact, and the false contact density. A scenario is developed to focus on the false contact problem while holding other ASW variables constant. It is concluded from the output of the game that the effect of false contacts is deeply embedded in the interrelationships between units.

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I. INTRODUCTION

Considerable study effort has been expended on the problem of determining the probability of detecting a submarine in various Anti-Submarine Warfare (ASW) environments and tactical situations. In the phase of search and detection, classification of sonar contacts has been recognized as a serious complication. This complication develops because there are many substances in the sea that reflect a sonar signal in much the same way as a submarine. Thus, a sonar contact that is in fact a submarine may be classified as non-submarine while a non-submarine or false contact may be classified as a submarine. In the first case the searching units continue looking for a submarine that has already been found while in the latter case the time available for the search is expended prosecuting a false contact.

Much has been done to improve the classification capability of ASW forces but the problem continues to be a serious one. In many ASW studies however, classification of sonar contacts is not considered. In Danskin's study [1] non-submarine contacts are not introduced into the problem and consequently it is neither necessary to revisit an area once it has been searched nor is time wasted prosecuting false contacts. Hammon [2] takes a typical war-gaming approach to the problem by assuming that for each helicopter a false contact is generated on any dip with a specified probability, and if a false contact is developed it is prosecuted by that one helicopter for a random period of time before it is correctly classified. It is implicitly assumed that this in no way influences the search for the submarine by the other helicopters.

The conclusions of both studies are valid if there exists a suitable degradation factor in the probability of detection that accounts for the effect of false contacts on the operational relationship among searching units. Unfortunately, the probabilities of correct classification are neither known with any degree of certainty nor are they static. In the Major Fleet Escort Study [3] it was assumed that a learning curve existed and that the probability of making an attack on a false contact, as a consequence of an incorrect classification, was a decreasing function of time.

The purpose of this thesis is to examine the effect of false contacts on the probability of detecting a submarine in order to develop the relationship between the interactions among units and the probabilities of correctly classifying sonar contacts. This thesis will develop probability of detection curves as a function of the probabilities of correct classification for all values between zero and one.

II. SCENARIO AND ASSUMPTIONS

In order to isolate the effect of false contacts a scenario was developed which held constant everything except those variables which bear on the classification problem. Although this creates a rather fictitious state of nature it does focus on the problem in its simpliest form much the same as a partial derivative represents the rate of change of a complicated function with respect to only one variable.

The scenario is initiated by a submarine being detected by an outside agent. Neither the type of initial detection nor the length of time that the submarine is tracked is important. The only assumption necessary is that the contacting agent is certain that the contact is a submarine and can determine the position of the contact accurately. The contacting agent calls for helicopter assistance and then loses contact establishing the location of the last known position of the submarine (DATUM). The submarine assumes helicopters have been called in; dives to its best depth to avoid helicopter sonar detection, and proceeds to clear DATUM at a constant, randomly selected, speed less than or equal to its maximum speed available. The helicopters arrive at DATUM at some time late and commence the search. They have a specified time on station available for the search and if the submarine is not found by that time the search is discontinued. It is assumed that the helicopters know the maximum speed available to the submarine, but they cannot deduce either speed or course intelligence from the tactical situation. They therefore commence a random dip search within the submarine's farthest-on circle allowing only a specified fraction of their detection range capability to overlap with any other unit's search area or the farthest-on circle. For its part the submarine can gain no intelligence from the active sonar transmissions of the helicopters and thus elects to take no evasive action. It is also assumed that the original contacting agent offers no further assistance to the helicopters.

The helicopters have a "cookie cutter sonar" which always detects a contact that is within range and never detects a contact that is not within range. When a helicopter detects a contact the classification process begins.

It is assumed that during the classification process there exists a constant probability that a valid contact will be correctly classified. There also exists a probability of correctly classifying a non-submarine contact however, in this case, it is assumed that the decision process in classifying a contact is influenced by previous classifications of the same contact. Thus it is assumed that a contact that has already been incorrectly classified is more likely to be incorrectly classified again than is a contact that is being classified for the first time. Alternatively the probability of generating a false contact prosecution is less than the probability of incorrectly classifying a contact given that it has already been incorrectly classified.

If the submarine is detected and correctly classified the search is successful. If the submarine is incorrectly classified the helicopter will continue searching for other contacts. If no others are found and if the helicopter has not reached the end of its dip cycle then the submarine contact will be re-evaluated.

If a false contact is detected and correctly classified it is marked, so that no other unit will subsequently consider it, and the search is continued for the submarine. If the false contact is incorrectly classified the helicopter goes into the track mode and immediately re-evaluates the contact. The effect of two successive classification opportunities is to raise the probability of correctly classifying the initial contact in line with the previous discussion. If the contact is again incorrectly classified then a false contact prosecution is generated.

If the number of helicopters prosecuting a false contact is less than a specified number and if another helicopter is available then it is called in to assist. When it arrives all units on the scene re-evaluate the contact. If the joint classification is correct the contact is scrubbed and all units return to the submarine search. Otherwise, all units continue to track the contact. Helicopters never lose contact on the false contact. This process is repeated incrementing the number of helicopters on the scene until either the contact is correctly classified or time on station is exceeded. The overall probability of detection is then computed as the number of times the search is successful divided by the number of times the scenario is run.

III. DESCRIPTION OF THE MODEL

A Monte Carlo event store computer war game, named "Helicopter DATUM Search" (HSDS), was developed to implement the scenario and assumptions. The principals of the game are the helicopters, submarine, and the false contacts. The helicopters have attributes of location and status while the submarine and and false contacts have attributes of location, velocity and status. HSDS can handle variations in tactics of either the submarine or helicopters. Up to 6 helicopters and up to 1000 false contacts can be introduced with any combination of time late, time on station, and probabilities of correct classification. This provides the capability within HSDS of varying the density of false contacts and the size of the initial area that the submarine can be in when the helicopters first arrive at DATUM.

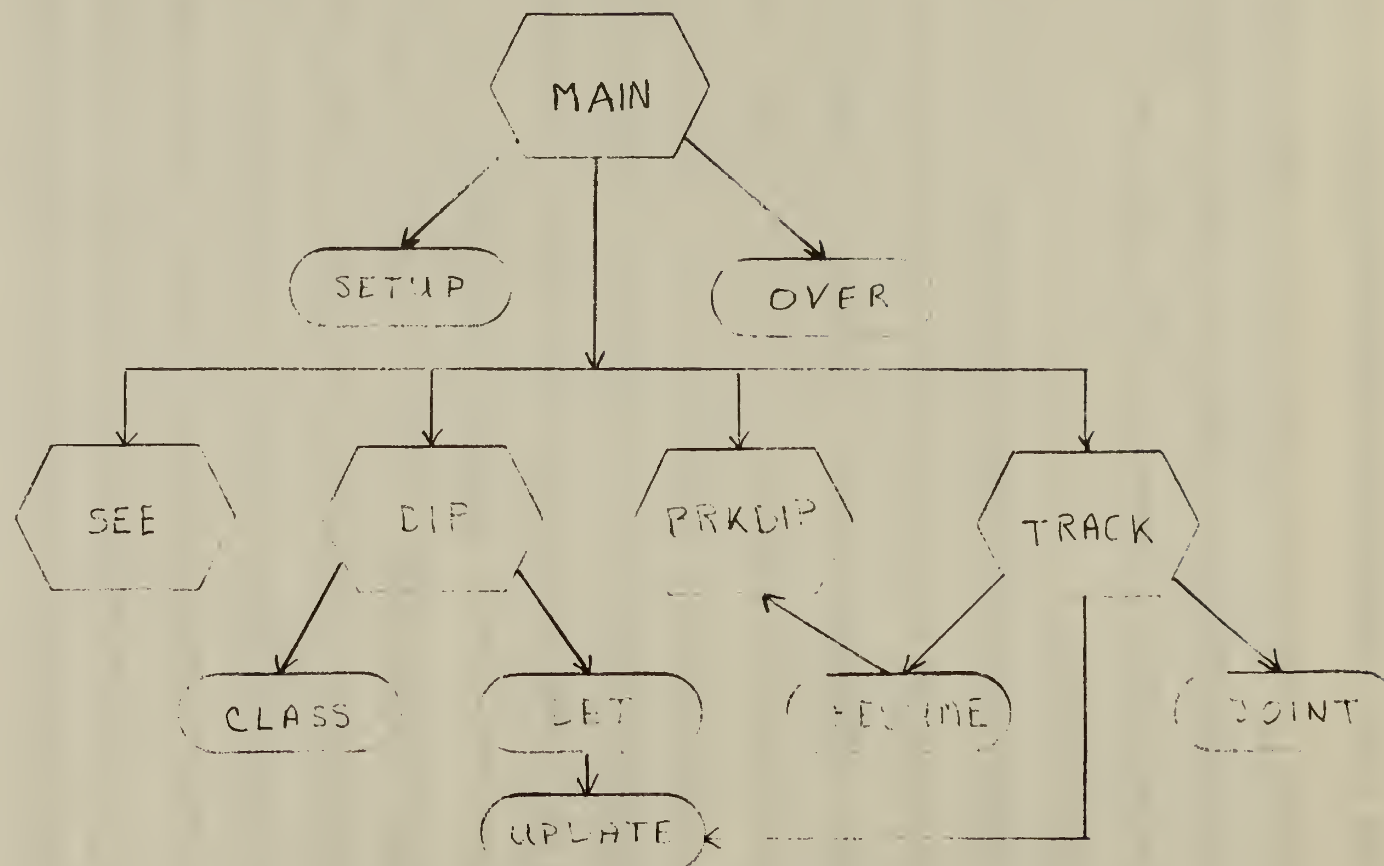
The logic of the game is written in FORTRAN IV for the IBM 360 computer and several support routines are written in OS/360 Assembler Language. The entire game is modularized with each function programmed as a separate subroutine to permit ease in modification for future study. The entire program requires less than 100K bytes of core storage and one run of 1000 replications with 4 helicopters and 250 false contacts requires slightly less than 5 minutes computing time.

A. EXECUTIVE ROUTINE

This section contains a description of the executive routine, or MAIN program, followed by the subroutines that support the MAIN program. These routines are written in FORTRAN IV and listed in Appendices B and D. A diagram of the flow between the MAIN program and the Events is contained in Figure 1.

The MAIN program first reads the input data. The salient parts of the input data are then printed and the run and first game are initialized. The helicopters start at DATUM. The submarine's speed is determined by a random number multiplied by the submarine's maximum speed. False contacts are distributed uniformly within an area bounded by the submarine's farthest-on circle at the end of time on station. A control loop is then entered taking the top event off the calendar and checking to see if time on station has been exceeded. If so, a branch is made to Subroutine OVER. Otherwise, the appropriate routine is called and upon normal return from that routine the program loops back to get another event from the calendar. Upon normal return from subroutine OVER the program loops back to initialize the next game. If this was the last replication of the run the results of the current run are printed and the MAIN program loops back to read another input card for the next run. If all cards have been read, and thus all runs are complete, the program terminates.

Subroutine OVER computes statistics for each game. The total number of replications of the game is divided into two groups. At the



GENERAL PROGRAM FLOW CHART

FIGURE 1

end of the first group of replications the random number generator is reset and the sign of the argument for the random number generator is changed. This causes the next stream of random numbers to be the compliment of the previous stream. The resulting statistics are assumed to have the Antithetic properties discussed in Hillier and Lieberman [4]. This is a technique which uses negative correlation between groups to produce a negative covariance thereby reducing the variance of the average of the groups. A special return to the MAIN program is made if the last replication of all groups has been played to indicate the end of the run.

Subroutine SETUP computes the time interval for each branch to the SEE event and schedules the SEE event on the calendar.

B. EVENTS

This section contains a description of the event routines followed by the subroutines that support the event routines. Each of these routines are written in FORTRAN IV and listed in Appendices B and D.

Event BRKDIP calculates the next dip position of a specified helicopter by using two random numbers to compute the X and Y coordinates of the new DIP station. If this position is within the farthest-on circle of the submarine and does not overlap another helicopter's search area by more than the specified amount, then a DIP event is scheduled for that position after calculating the time to station. Helicopters transit between DIP stations at 90 knots and require 3 minutes for lowering and raising the sonar dome. If either of the above tests fail a new position is calculated. Note that an infinite loop can be generated here if the sum of the helicopter's search areas is greater than the area within the submarine's farthest-on circle.

Event DIP handles the helicopter in the search phase. It first schedules a BRKDIP event and then branches to subroutine DET for detections. A normal return to the MAIN program is made if there were no detections. If a detection was made a branch is made to subroutine CLASS to determine the classification. If the submarine was the contact detected and it is correctly classified a special return is made to the MAIN program to indicate the search has been completed successfully. If the submarine was incorrectly classified a RELOOK event is scheduled. RELOOK is an entry point in the DIP routine just before the call to subroutine CLASS. If a non-submarine contact was detected and correctly classified the non-submarine's status is changed to inactive and a branch is made to subroutine DET to determine if any more detections are possible on this dip. If a non-submarine was detected and incorrectly classified a TRACK event is scheduled for the current game time.

Subroutine CLASS determines the classification of a contact, submarine or non-submarine, by comparing the input probability of correct classification with a random number.

Subroutine DET computes the index of the first contact that is within sonar range of the specified helicopter. Only active contacts are considered for detection. This routine gives a slight advantage to the helicopters since the submarine is always the first contact considered.

Subroutine UPDATE computes the position of all active contacts for the present game time.

Event SEE prints the position and status of all helicopters and contacts at the present game time.

Event TRACK handles the prosecution of false contacts. A branch is made to subroutine JOINT to determine the current classification. If this classification is correct, a branch is made to subroutine RESUME to discontinue prosecution of the contact. If the current classification is incorrect another TRACK event is scheduled and the number of helicopters on the scene is determined. If the number on the scene is less than the maximum number allowed and if there is another helicopter enroute to a new DIP station or in a DIP but not prosecuting a contact, that helicopter is sent to the scene. The position of all helicopters on the scene is then updated to the false contact's present position.

Subroutine JOINT determines the composite classification of the contact by all of the units on the scene prosecuting the false contact. The criterion for the classification is an average value computed as follows:

$$SUM = 1/NOS(K) \times \sum_{j=1}^{NOS(K)} X(j)$$

where $X(j)$ = 1 for $RN(IX) < PCNS$

$X(j)$ = 0 for $RN(IX) \geq PCNS$

NOS(K) = number of helicopters prosecuting contact K

PCNS = probability of correctly classifying a false contact

RN(IX) = random number from stream IX

The classification is correct if SUM is greater than PCNS and incorrect otherwise.

Subroutine RESUME calls BRKDIP for each helicopter that has been prosecuting a false contact and then sets the inactive code for that contact.

C. SUPPORT ROUTINES

The following routines, written in OS/360 Assembler Language, are general to any simulation and are not included in Appendices B and D.

RN is an additive random number generator which can produce a minimum of 16 unique random number streams. If the argument to the function is zero the generator is initialized and no number is returned. A positive argument produces a random number from the specified stream of numbers while a negative argument produces the compliment random number from the same stream. Two generators are used in HSDS; one for movement and position variables, and the other to determine classifications.

Subroutines INT, TNE, SNE, and REMOVE comprise the event calendar package. INT initializes the calendar and must be called before the calendar is used. TNE takes the top event off the calendar. SNE stores an event on the calendar in its proper time sequence. REMOVE nullifies all events on the calendar which have a specified value for a specified attribute. In HSDS events are removed from the calendar as they are invalidated rather than checking each event as it is returned by TNE.

Subroutine CALFUL, called when an error condition develops, terminates the program and produces a core dump.

Subroutine MOMENT calculates the mean and standard deviation of an input group of data.

IV. VALIDATION AND ANALYSIS

The first objective of this thesis was to measure the effect of the probability of correctly classifying a non-submarine on the overall probability of detection. Within the general scenario of Chapter II, a set of conditions, designed the base conditions, was chosen as follows:

Number of helicopters	4
Time late to DATUM	15 min.
Time on station	60 min.
Expected sonar range	3000 yards
Maximum submarine speed	20 kts.
Number of false contacts	250
Probability of correctly classifying a submarine contact	0.8

This corresponds to a false contact density of 0.1 contacts per square mile; a probability of detecting a false contact of 0.7 for any helicopter on any dip, and a probability of detecting the submarine on the first dip after reaching DATUM of 0.053 for any helicopter. This last probability is computed using time late plus the expected value of 4.5 minutes for the time from DATUM until the helicopter is in the first dip and searching for the submarine to determine the submarine's farthest-on circle. The probability of detection is then the area of the helicopter's sonar search divided by the area within the submarine's farthest-on circle. These conditions were chosen because other studies have considered the same or similar conditions.

A. RESULTS AND VALIDATION

Before a production run was made for each parameter, a pilot study was conducted to determine the number of runs that would produce statistics with an acceptable variance in the minimum amount of computing time. The number of runs described in the following sections are a result of such a pilot study.

The probability of correctly classifying a non-submarine contact (PCNS) was incremented from 1.0 to 0.0 and at each point 2000 replications of the game were run and the probability of detection calculated. The manner in which helicopters interacted was considered to be the maximum number of helicopters that would prosecute a contact (MAXNOS). As a result of these runs the probability of detection as a function of PCNS and MAXNOS is tabulated in Table 1. Additionally since a false contact must be incorrectly classified twice in succession to generate a false contact prosecution, PNFC is defined as the probability of NOT generating a false contact prosecution. PNFC is computed as:

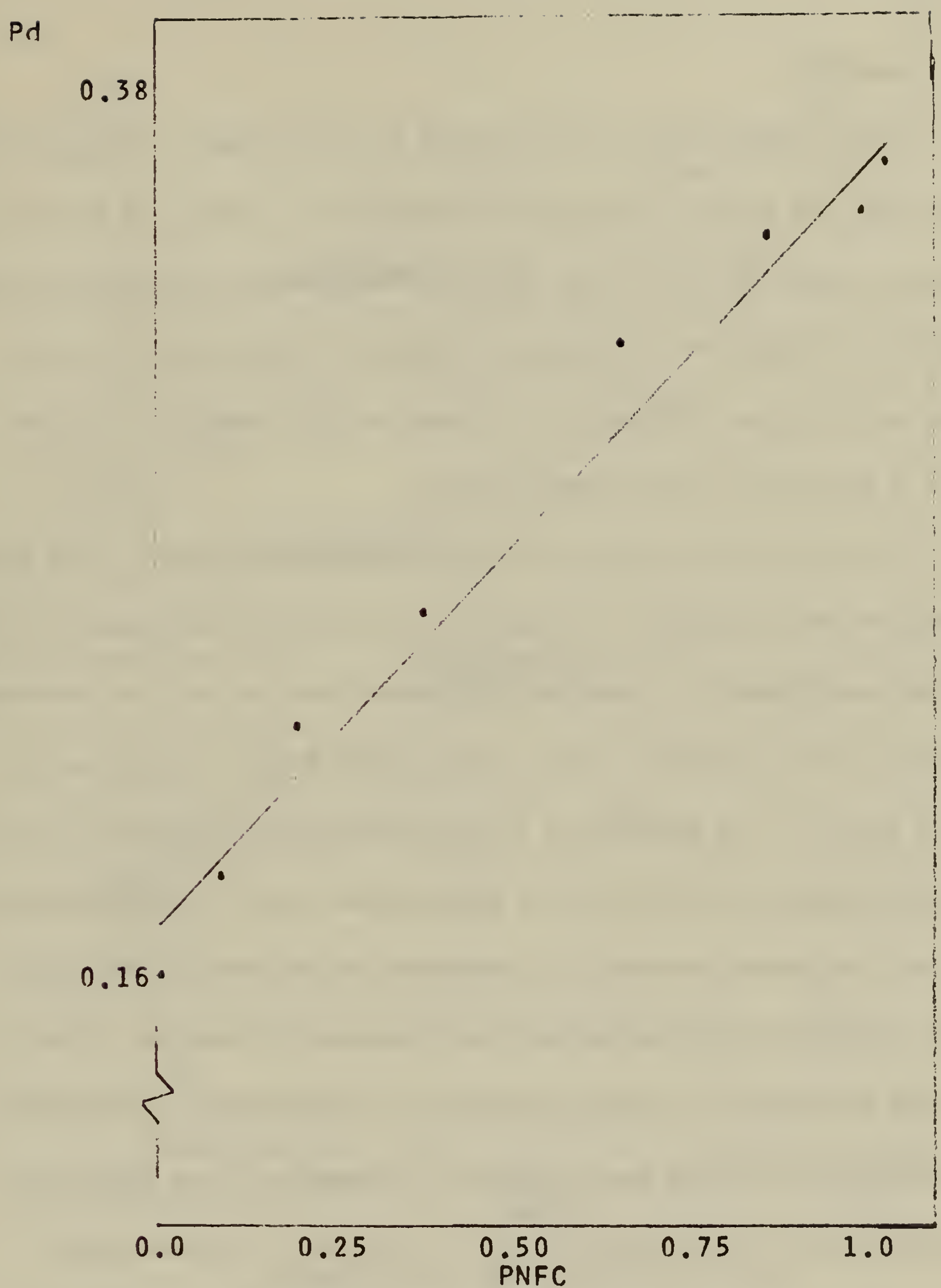
$$PNFC = 1.0 - (1.0 - PCNS)^2$$

		MAXNOS			
PCNS	PNFC	1	2	3	4
1.0	1.0	.371	.371	.371	.371
0.8	0.96	.394	.373	.372	.359
0.6	0.84	.390	.346	.348	.350
0.4	0.64	.371	.307	.315	.322
0.2	0.36	.342	.266	.259	.249
0.1	0.19	.316	.221	.211	.218
0.05	0.0975	.303	.196	.179	.173
0.0	0.0	.256	.162	.160	.149

The Probability of Detection

TABLE I

For each value of the maximum number of helicopters that will prosecute a submarine, the probability of detection is well approximated by a linear function in PNFC. A representative linear fit of the data is plotted in Figure 2. The linearity assumption between the probability of detection and PNFC appears reasonable since, with independent random dipping, the probability of detection should be degraded only by time lost in prosecuting false contacts. This is in contrast with a search plan where helicopters work together and the effectiveness of the search plan is dependent on the completion of a particular pattern. The probability of detection when PCNS is 1.0 is also reasonable. In LCDR Buck's study [5], which does not consider false contacts, the probability of detection for two helicopters against a closing submarine under the same conditions was computed to be 0.37. In the present analysis there are



PROBABILITY OF DETECTION (Pd)
vs
PROBABILITY OF NOT GENERATING
A FALSE CONTACT (PNFC)

FIGURE 2

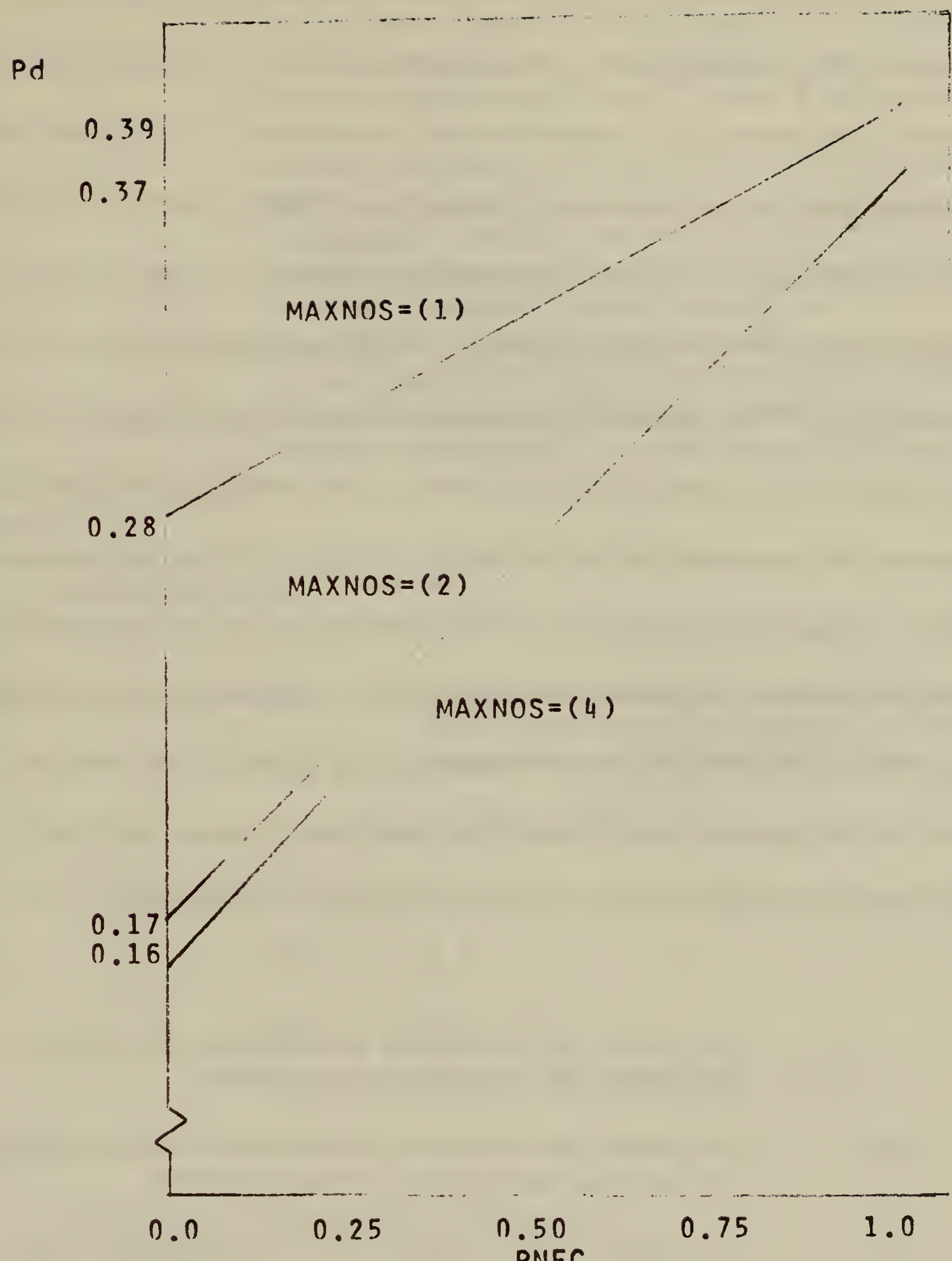
four helicopters searching for a submarine that can depart DATUM in any direction and the probabilities of detection are in close agreement.

B. ANALYSIS

The results of Table I demonstrate how the effect of false contacts varies with the extent of helicopter interaction. Figure 3 is a plot of the least square fit of the data taken of the probability of detection as a function of PNFC for the maximum number of helicopters that will prosecute a contact (MAXNOS). The gap at PNFC equals 1.0 is the result of the least square approximation.

Because of the simplicity of the scenario and tactics, it is possible to compute the probability of detection for all of the helicopters on the first dip analytically. Consider PNFC equal zero so that any helicopter detecting a false contact is lost to the search for the remaining time left on station. For MAXNOS of 1 the probability of detection for all of the helicopters on the first dip is equal to the sum of the probabilities that each helicopter detects the submarine on its first dip multiplied by the probability that the submarine is correctly classified. This is so since the actions of each helicopter are independent. If a false contact is detected and hence incorrectly classified by a helicopter, it is prosecuted by that one helicopter while the other helicopters continue the search unaffected. For the base conditions the overall probability of detection is approximately

$$4 \times 0.053 \times 0.8 = 0.17$$



PROBABILITY OF DETECTION (Pd)
vs
PROBABILITY OF NOT GENERATING
A FALSE CONTACT (PNFC)

FIGURE 3

When MAXNOS is greater than 1 the actions of each helicopter are no longer independent. The first helicopter to dip detects the submarine with probability 0.053 and detects a false contact and incorrectly classifies it as submarine with probability 0.7. If the first helicopter detects and incorrectly classifies a false contact the next helicopter comes to the first helicopter's assistance rather than continuing to its first dip station and thus never gets into the search for the submarine. The actions of each helicopter in turn depend on what has occurred to the previous helicopters. The overall probability of detecting the submarine for all of the helicopters is then the unconditioned probability of the sum of each conditional probability which is calculated below. In these calculations it is assumed that on the first dip the time required for a joint classification exceeds the time to station for subsequent helicopters and therefore no more than one helicopter can come to the assistance of another helicopter.

Let:

A	=	The event the submarine is correctly classified given that the submarine is detected
B/j	=	The event the submarine is detected by helicopter j given that helicopter j is not diverted
C/1	=	The event that helicopter 1 is not diverted which always happens
C/2	=	The event that helicopter 2 is not diverted which happens only if helicopter 1 does not detect and incorrectly classifies a false contact

C/3 = The event that helicopter 3 is not diverted which happens only if:
1) helicopter 1 detects and incorrectly classifies a false contact thus diverting helicopter 2, or
2) neither helicopters 1 nor 2 detect a false contact

C/4 = The event helicopter 4 is not diverted which happens only if:
1) helicopter 1 detects and incorrectly classifies a false contact diverting helicopter 2 and helicopter 3 does not detect a false contact, or
2) helicopter 1 does not detect a false contact and helicopter 2 does detect and incorrectly classifies a false contact diverting helicopter 3, or
3) neither helicopters 1, 2, nor 3 detect a false contact

Then:

Probability of A = PCS
= 0.8

Probability of B/j = Probability of detection multiplied by the probability the submarine is not detected by a previous helicopter
= $0.053 \times 0.954^{j-1}$

Probability of C/1 = 1.0

C/2 = 0.3

C/3 = $0.7 + 0.3^2$

C/4 = $0.7 \times 0.3 + 0.3 \times 0.7 + 0.3^3$

And:

The overall probability of detection is:

$$\sum_{j=1}^{4} P(A) \times P(B/j) \times P(C/j)$$

$$= 0.101$$

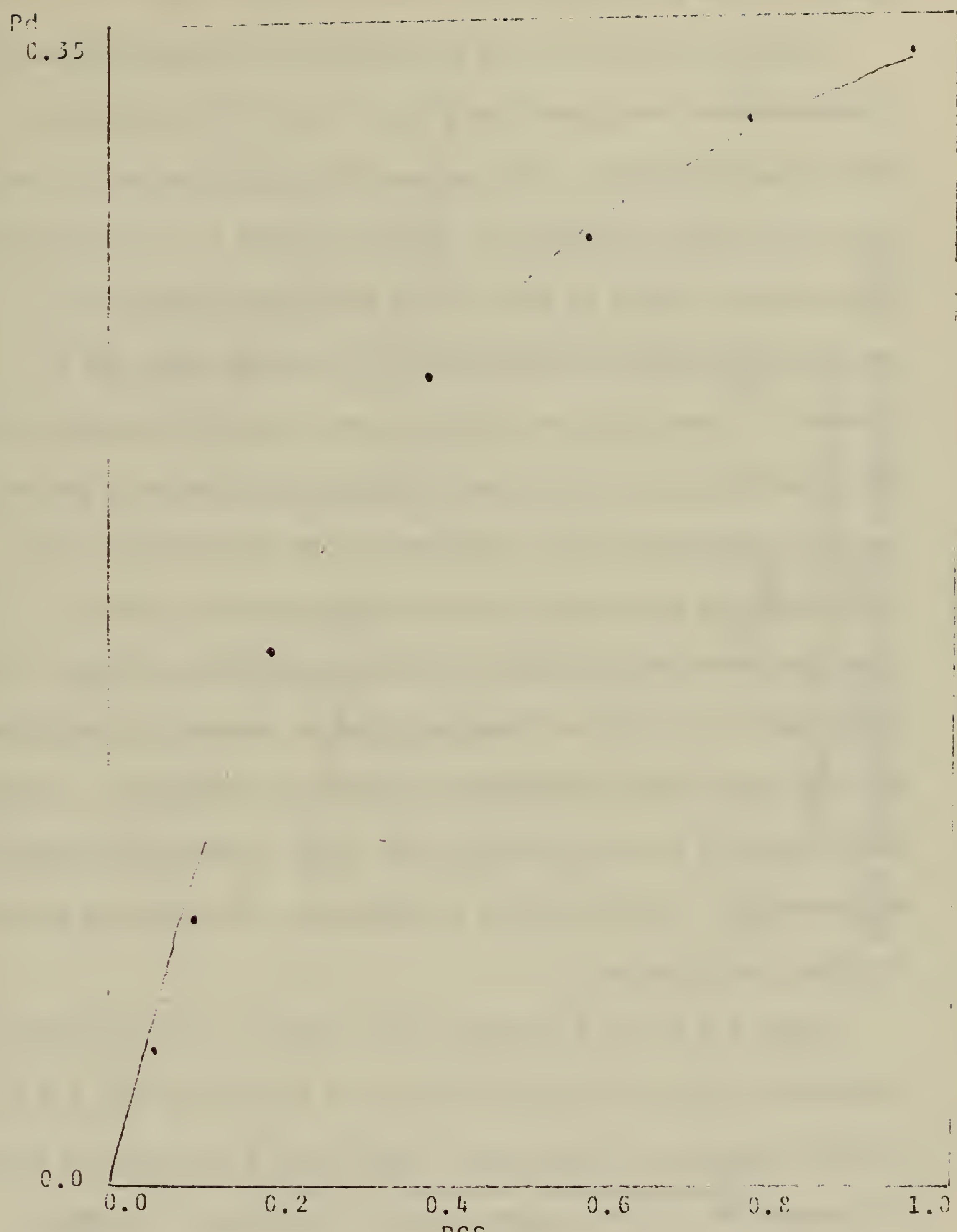
This is in comparison with the 0.17 probability of detection when there is no interaction between helicopters.

When PNFC is greater than zero the analysis is the same except that the conditional probabilities are further conditioned on the generation of a false contact prosecution given that a false contact has been detected by a previous helicopter. The difference in the probability of detection between MAXNOS of 1 and values greater than 1 approaches zero as PNFC approaches one.

The total probability of detection is of course greater than the probability of detection on the first dip but an analytic computation for subsequent dips becomes quite involved since the single dip probability of detection decreases as the square of the submarine's maximum speed. What the analytic computation for the first dip shows is that the disproportionate degradiations in the probability of detection for MAXNOS of 1, 2, and 4 is neither an accident nor a mistake. Thus even when the probability of detection is a simple linear function of the probability of prosecuting a false contact for any individual unit, the probability of detection for the group varies in a much more complicated manner.

C. EFFECT OF OTHER VARIABLES

Since the probability of detection is conditioned on the probability of correctly classifying a submarine contact (PCS) and the probability of detecting a false contact, or false contact density, it is necessary to determine how the probability of detection varies as a function of PCS and the false contact density. Although an argument can be made to the contrary, it is assumed here that these two phenomena are



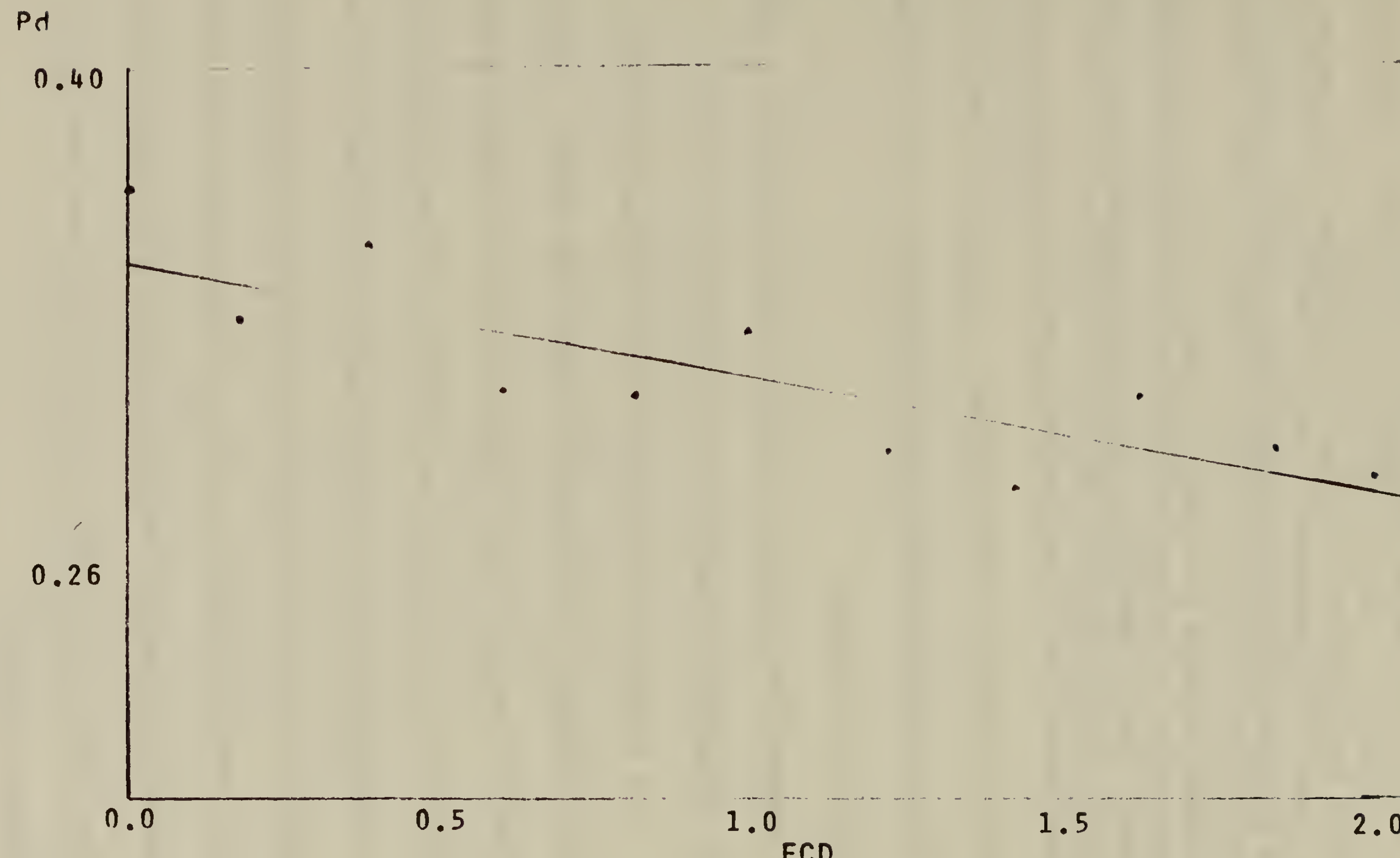
PROBABILITY OF DETECTION (Pd)
vs
PROBABILITY OF CORRECTLY CLASSIFYING
A SUBMARINE CONTACT (PCS)

FIGURE 4

independent and can be treated separately. No assumption is made that either PCNS and PCS or PCNS and the false contact density are independent.

PCNS was fixed at 0.4 and the probability of correctly classifying a submarine was incremented from 1.0 to 0.0 with 1000 replications made at each data point. The results are well approximated by a fourth degree least square polynomial as plotted in Figure 4. The significance of this curve is both in its effect on the conditional probability of detection as previously discussed and on the design trade-offs in hardware. In many cases an increase in the range of a detector, and thus an increase in the conditional probability of detection of the submarine, is accompanied by a degradation in the classification clues. Such is the case when going to lower frequency sonars. Under conditions where the probability of correct classification is high, say greater than 0.6, a greater degradiation can be accepted in classification clues, or classification capability, than when the probability of correct classification is low, say less than 0.4. This is because the slope of the probability of detection curve is decreasing with increasing probability of correct classification.

Figure 5 is a plot of the least square linear fit of the probability of detection as the false contact density was incremented from 0.0 to 0.2 false contacts per square mile. PCNS and PCS were set at 0.4 and 0.8 respectively and the maximum number of helicopters to prosecute a false contact was set at 4. Each data point is the result of 1000 replications of the game. Least square polynomials of higher degree were investigated but provided little additional information.



PROBABILITY OF DETECTION (Pd)
vs
FALSE CONTACT DENSITY PER SQUARE MILE (FCD)

FIGURE 5

V. CONCLUSIONS AND RECOMMENDATIONS

The analysis of Chapter IV indicates that the effect of false contacts is not obvious even under the simpliest of conditions. It is not unreasonable to assume that as the tactics become more involved the effect of false contacts becomes more deeply embedded in the interrelationships between units. This is particularly true when different types of units with different sensors and classification capabilities operate together. The analytic formulation of such a problem is formidable is not impossible. However, if the interrelationships can be well defined such a problem can be formulated as a game.

It is important to recognize that false contacts can play as large a part in the probability of detection of a submarine as any other parameter. It is therefore recommended that classification and the effect of false contacts be considered in future ASW studies. This could be accomplished by running a pilot study of the tactics under consideration in a simulation, such as the game in this thesis, in order to develop the appropriate degradation curves for those tactics and forces. It is further recommended that future ASW war games consider the interrelationships between units when developing the logic for false contact prosecutions. This is of particular importance where the game will be used to help in the evaluation of new equipments where trade-offs have been made in the classification capability.

There are several areas within this thesis which could be fruitful topics for further study. Current helicopter search plans could be implemented, by changing the BRKDIP routine, in order to study their sensitivity to classification errors. Subroutine JOINT could be modified to provide for the inclusion of different types of sensors to aid in the classification process when more than one unit is on the scene. Finally, a submarine maneuver event could be added to study the effect of submarine evasion.

APPENDIX A

LIST OF VARIABLES

A. INPUT VARIABLES

The following is a list of input variables in the order that they are read into the program:

IN	Input data set number
OUT	Output data set number
IRUN	Number of this run
NGRPS	Number of groups for each run
NREPS	Number of replications for each group
IX	Argument for the random number generator
NN	Number of intervals in the first game that the positions of all units will be printed
NHS	Number of helicopters
TL	Time late
DELT	Duration of each dip
TOS	Time on station
RS	Maximum sonar range
OVRLAP	Amount of overlap permitted between two HS sonar search areas
NUM	Number of false contacts (The program increments this number by 1 to include the SS in all calculations)
VMAX	Maximum speed of the SS
PCS	Probability of correctly classifying a submarine

PCNS	Probability of correctly classifying a non-submarine
MAXNOS	Maximum number of HS that will prosecute a false contact

B. INTERNAL VARIABLES

The following is a list of variables internal to the program as they appear in common:

XS(J)	X position of contact J
YS(J)	Y position of contact J
VXS(J)	X velocity component of contact J
VYS(J)	Y velocity component of contact J
ISTAT(J)	Status of contact J 0 => Active, 1 => Inactive
TS(J)	Time contact J was last updated
NOS(J)	Number of HS prosecuting contact J
MAX	Minimum of (NHS, MAXNOS)
XH(J)	X position of helicopter J
YH(J)	Y position of helicopter J
ICODE(J)	Status of helicopter J -1 => Airborne enroute to next dip 0 => In dip searching N > 0 => prosecuting contact N
TP	Current game time
IDUM	Dummy variable for arguments to SNE
NS	Number of times the submarine was detected in this group
TAVG(N)	Time to detection for detection N
NGAME	Counter for the number of games played

C. OUTPUT VARIABLES

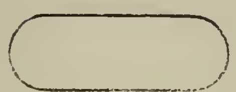
The following is a list of variables output by the program in the order that they are printed:

XBAR	Average probability of detection
SD	Standard deviation of the probability of detection
AVG(J)	Probability of detection for group J
TBAR	Average time to detection given that a detection was made
TSD	Standard deviation for time to detection
NC	Total number of times the submarine was detected

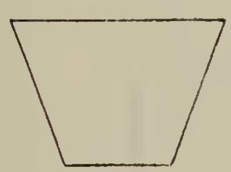
APPENDIX B

FLOW CHARTS

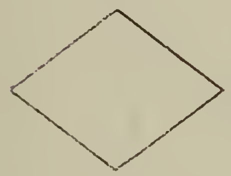
The following is a list of symbols and their meanings used in the flow charts of HSDS.



Entry or exit point

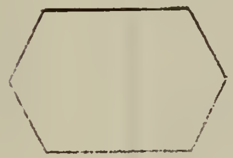


Input/Output operation



Decision point

Calculation or Instruction

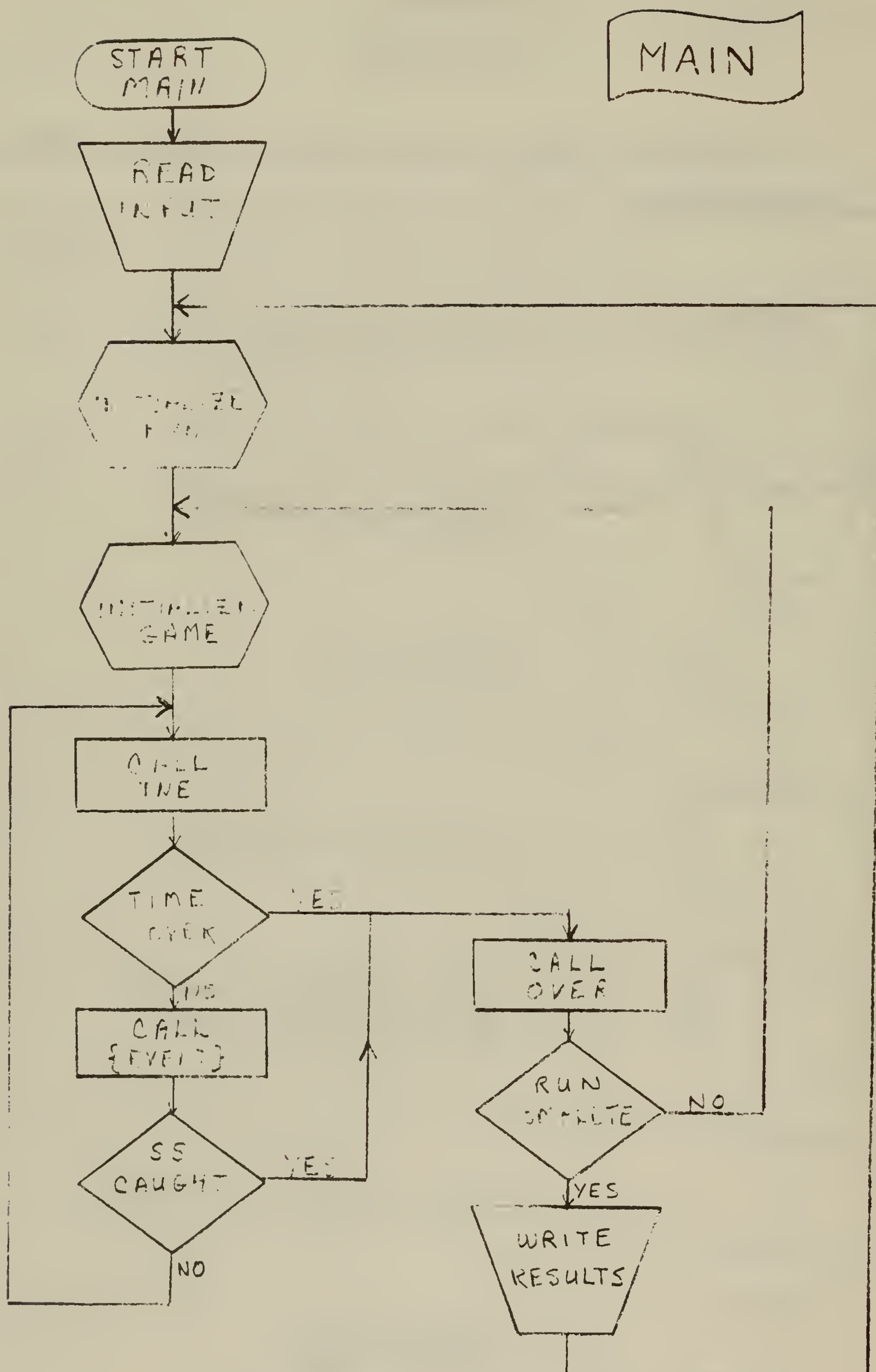


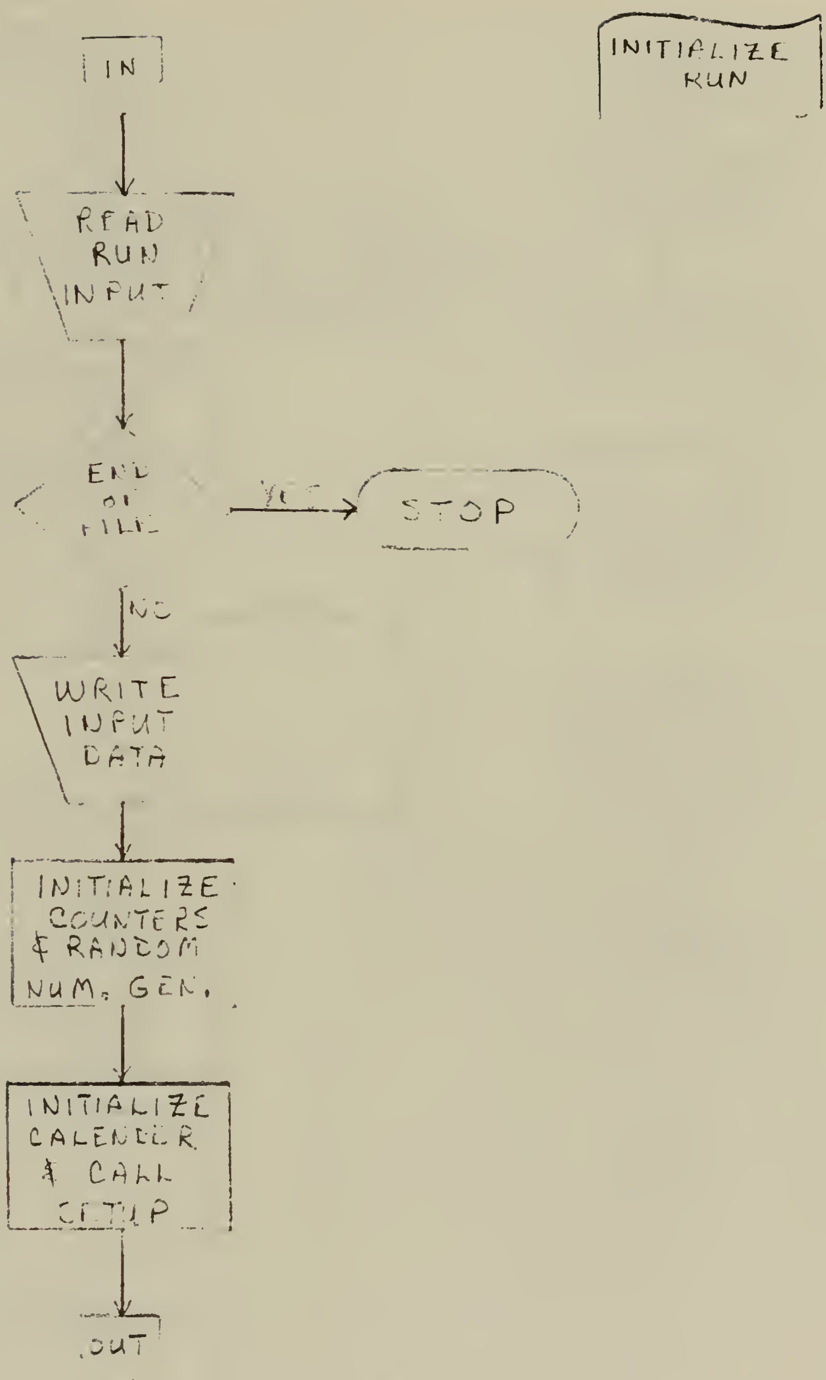
Set of calculations expanded
on a following flow chart

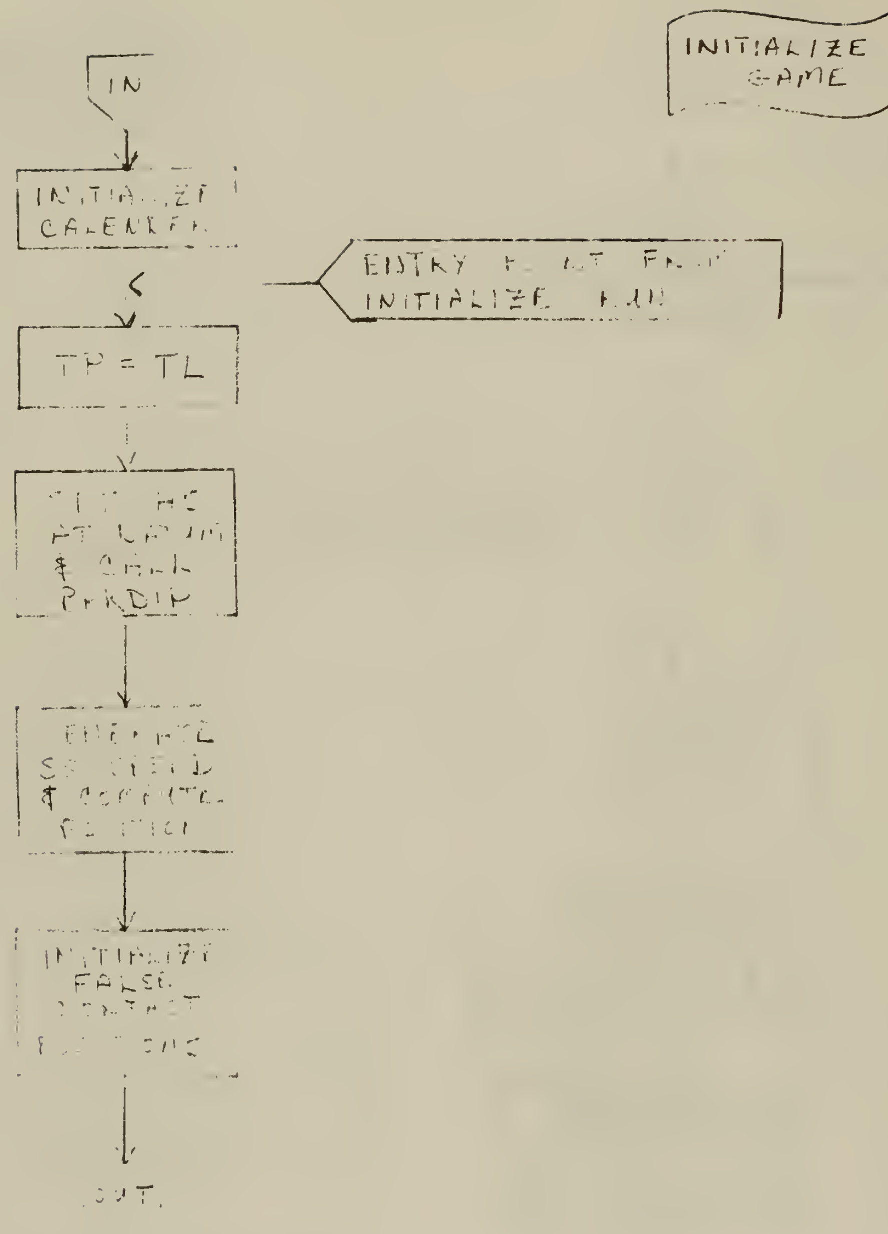
Store an event on the calendar

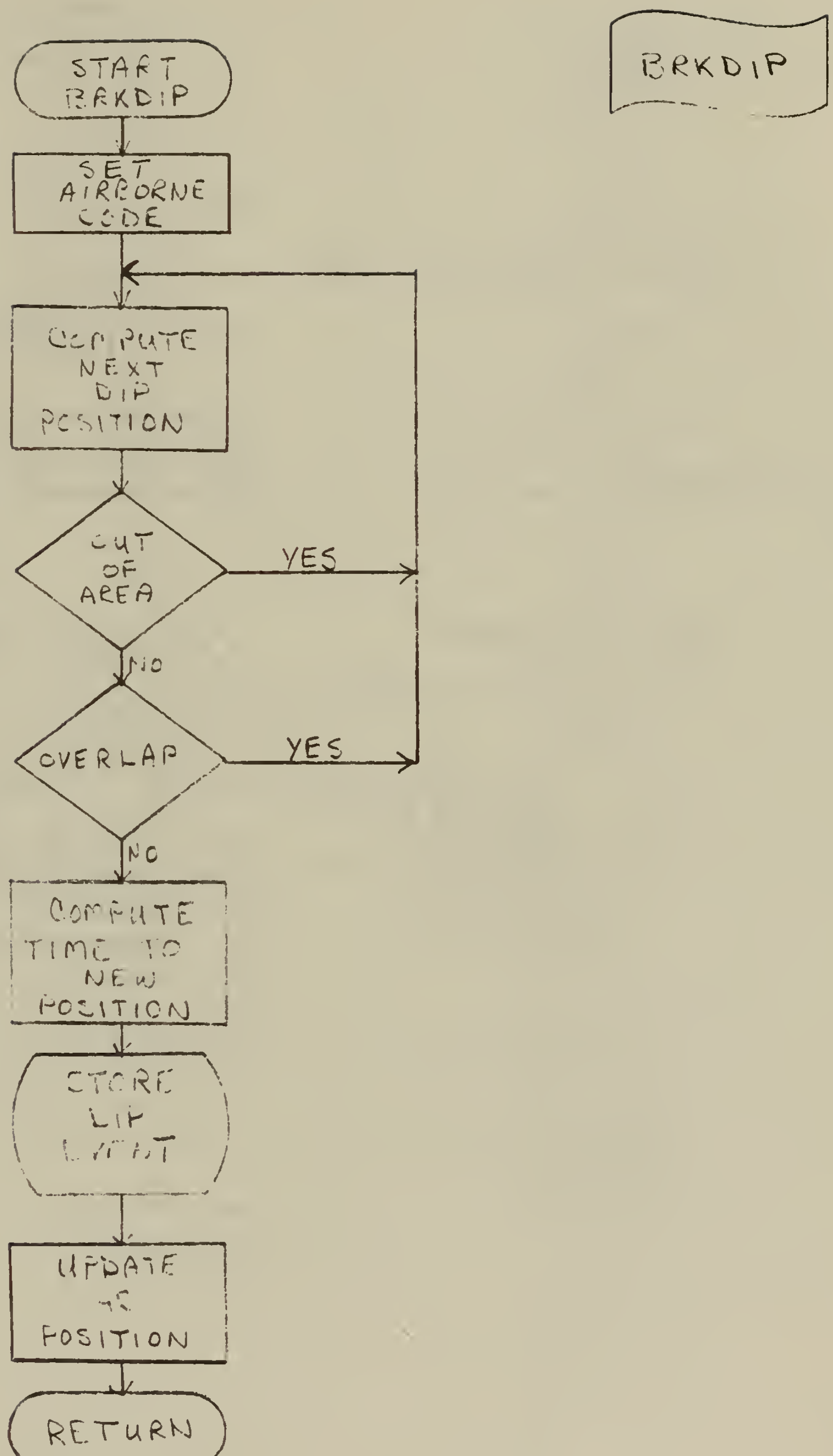
Multiple branch
Computer GOTO

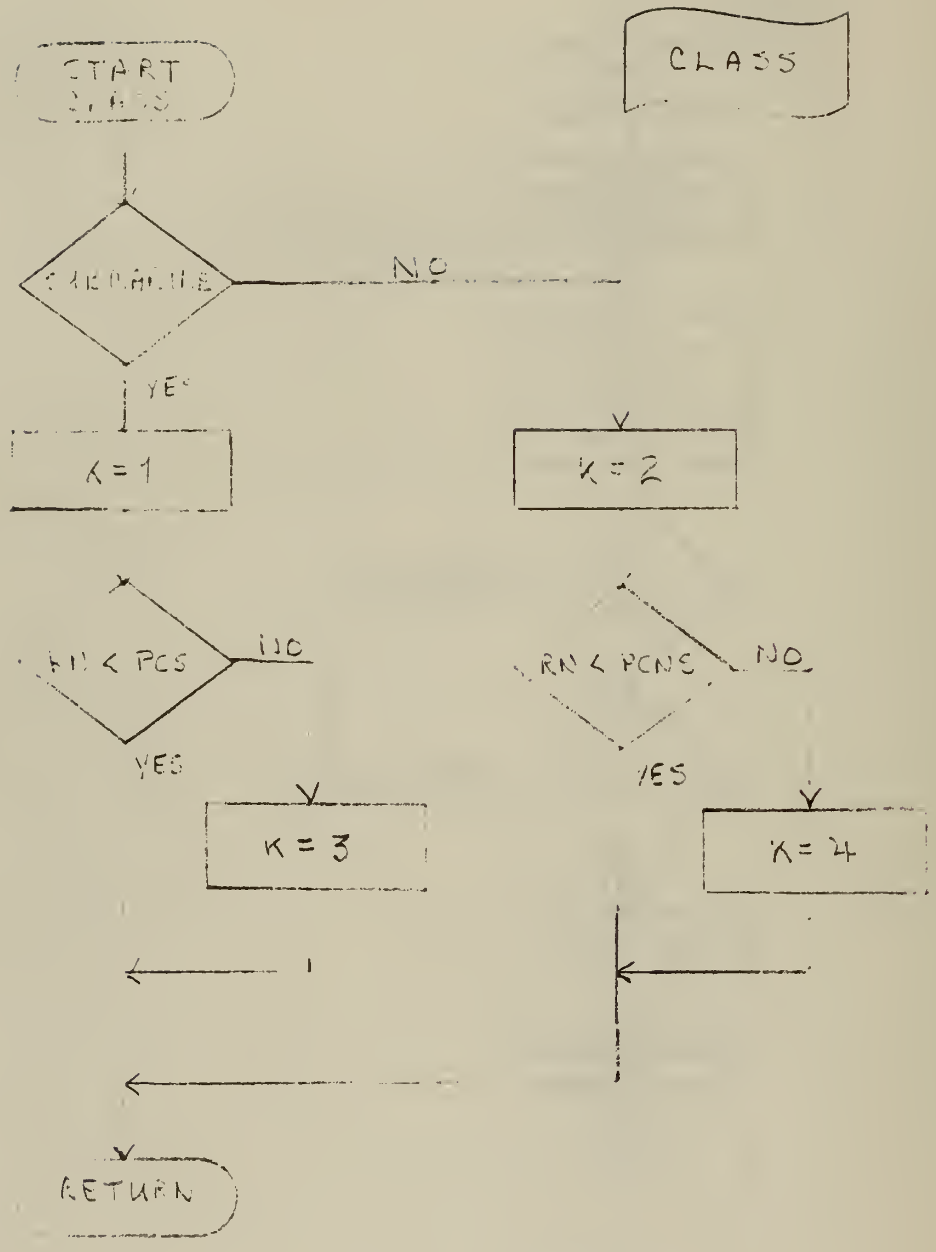
Off-page connector

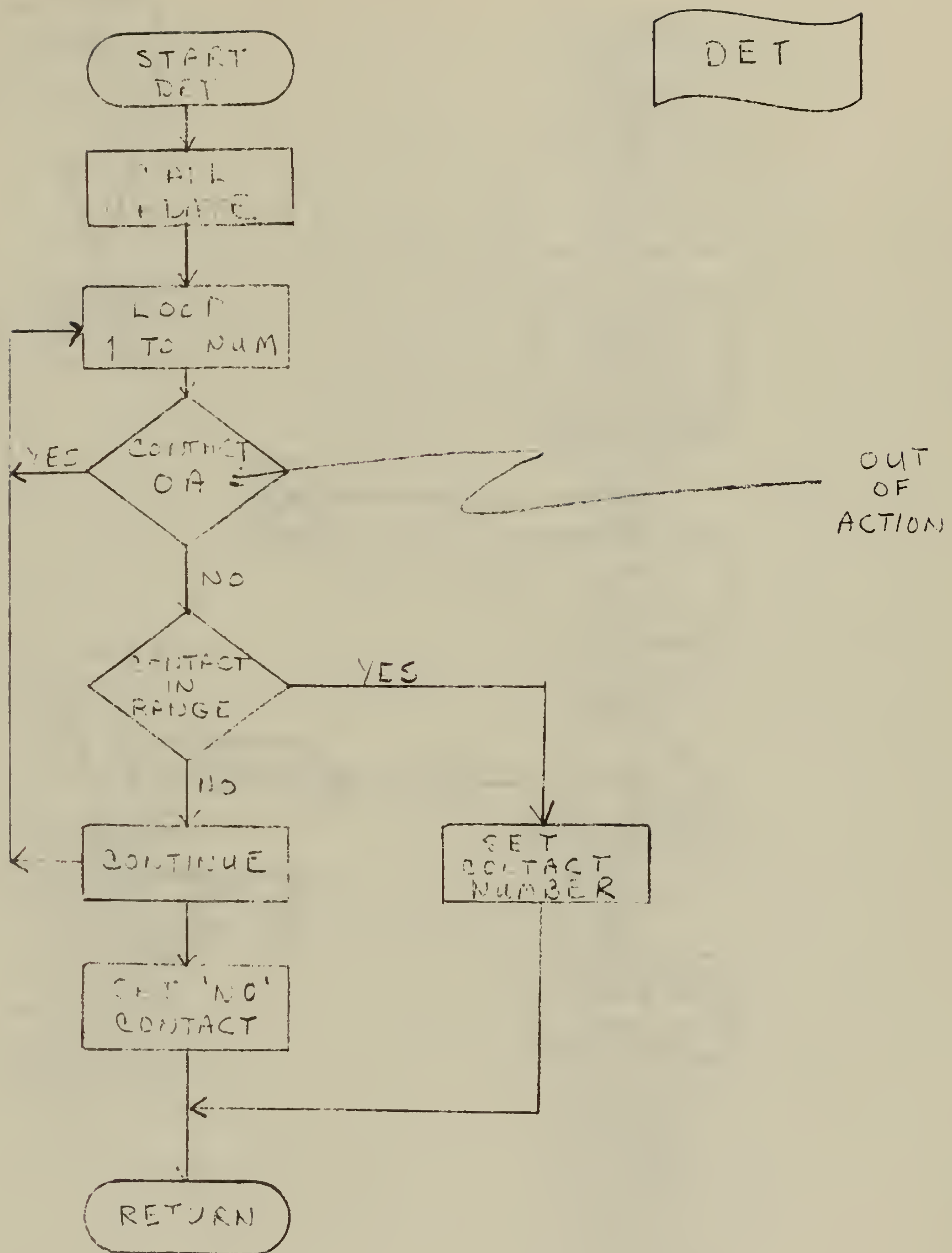

MAIN
START
READ
GAME
TIME
YES
CALL
OVER
RUN
NO
SS
CAUGHT
YES
NO
WRITE
RESULTS

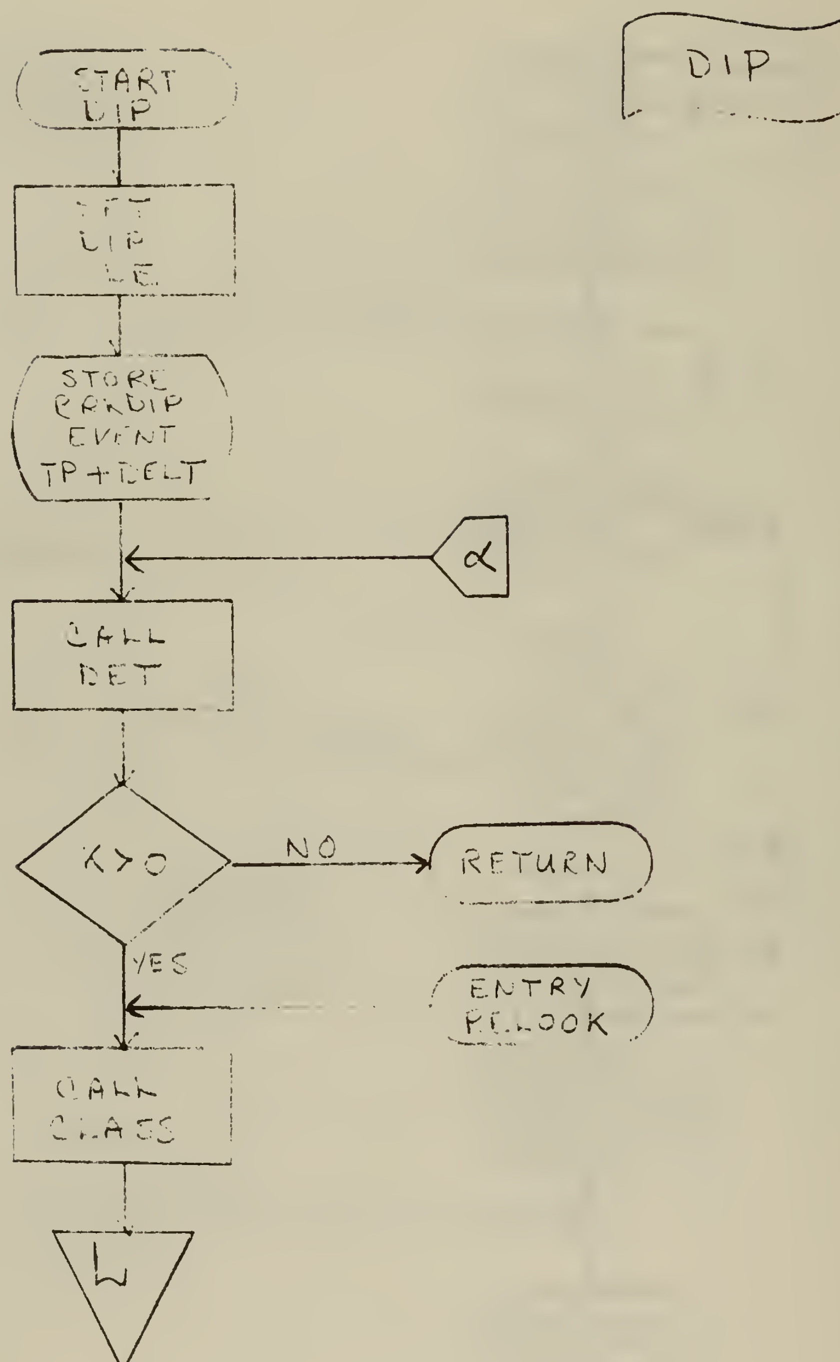

INITIALIZE RUN
IN
READ RUN INPUT
STOP
WRITE INPUT DATA
INITIALIZE COUNTERS & RANDOM NUM. GEN.
INITIALIZE CALENDER & CALL
OUT

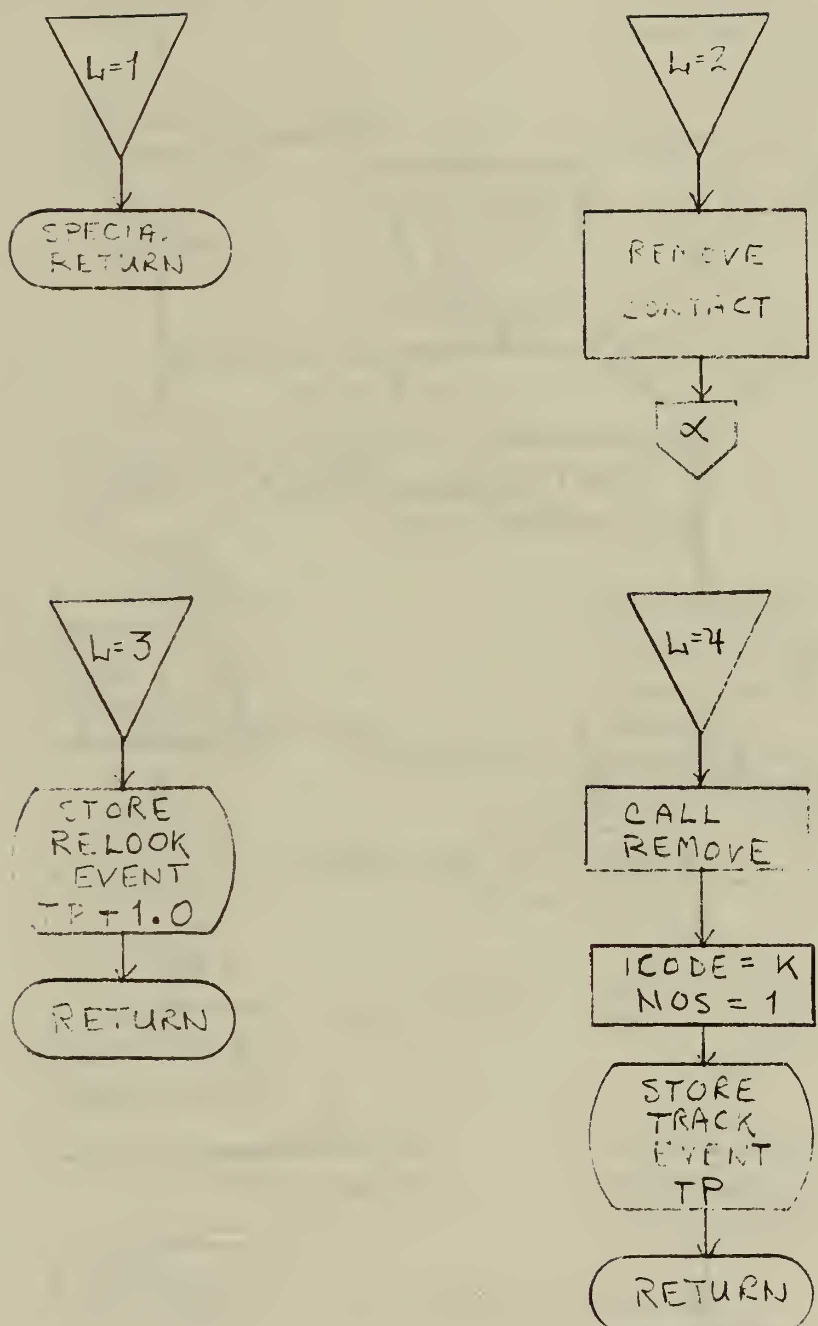

INITIALIZE GAME
IN
TP = TL

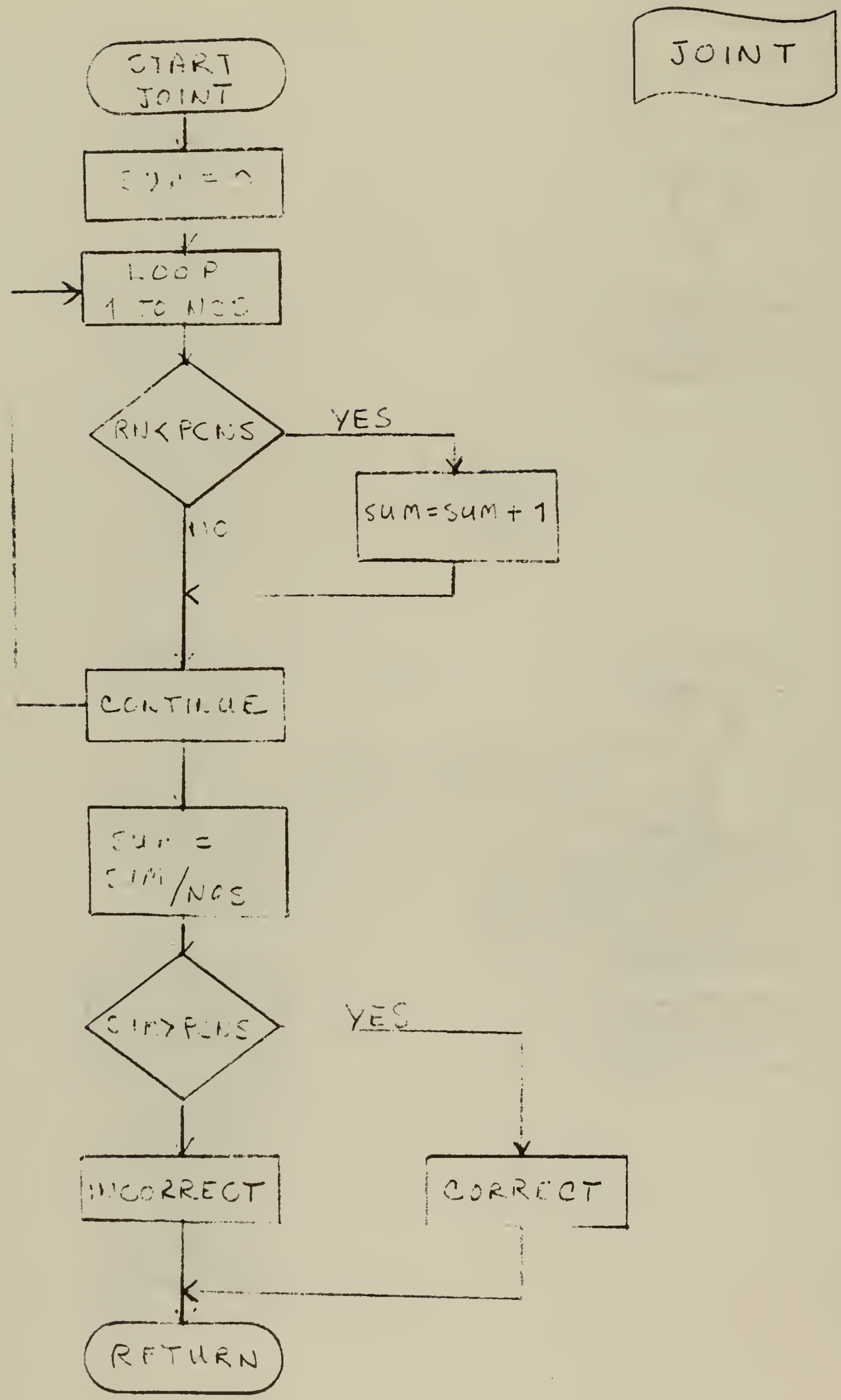

START BRKDIP
SET AIRBORNE CODE
COMPUTE NEXT DIP POSITION
OUT OF AREA
YES
NO
OVERLAP
YES
NO
COMPUTE TIME TO NEW POSITION
STORE
UPDATE
POSITION
RETURN
BRKDIP

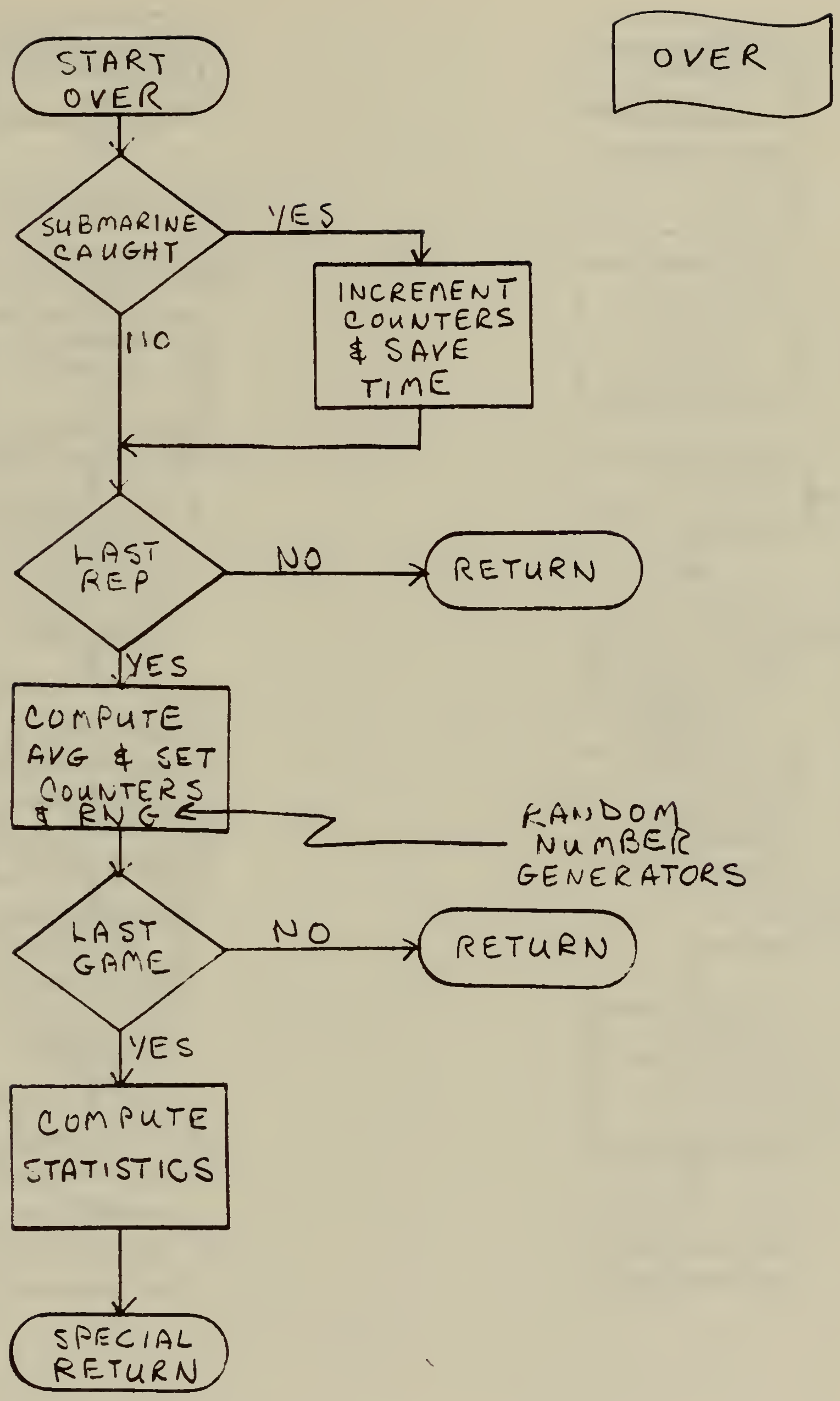

START
CLASS
NO
YES
K = 1
K = 2
RN < PCS
NO
YES
RN < PCNS
NO
YES
K = 3
K = 4
RETURN


DET
START
DET
LOOP
1 TO NUM
CONTACT
OA
YES
OUT
OF
ACTION
NO
CONTACT
IN
RANGE
YES
NO
CONTINUE
SET
CONTACT
NUMBER
CONTACT
RETURN

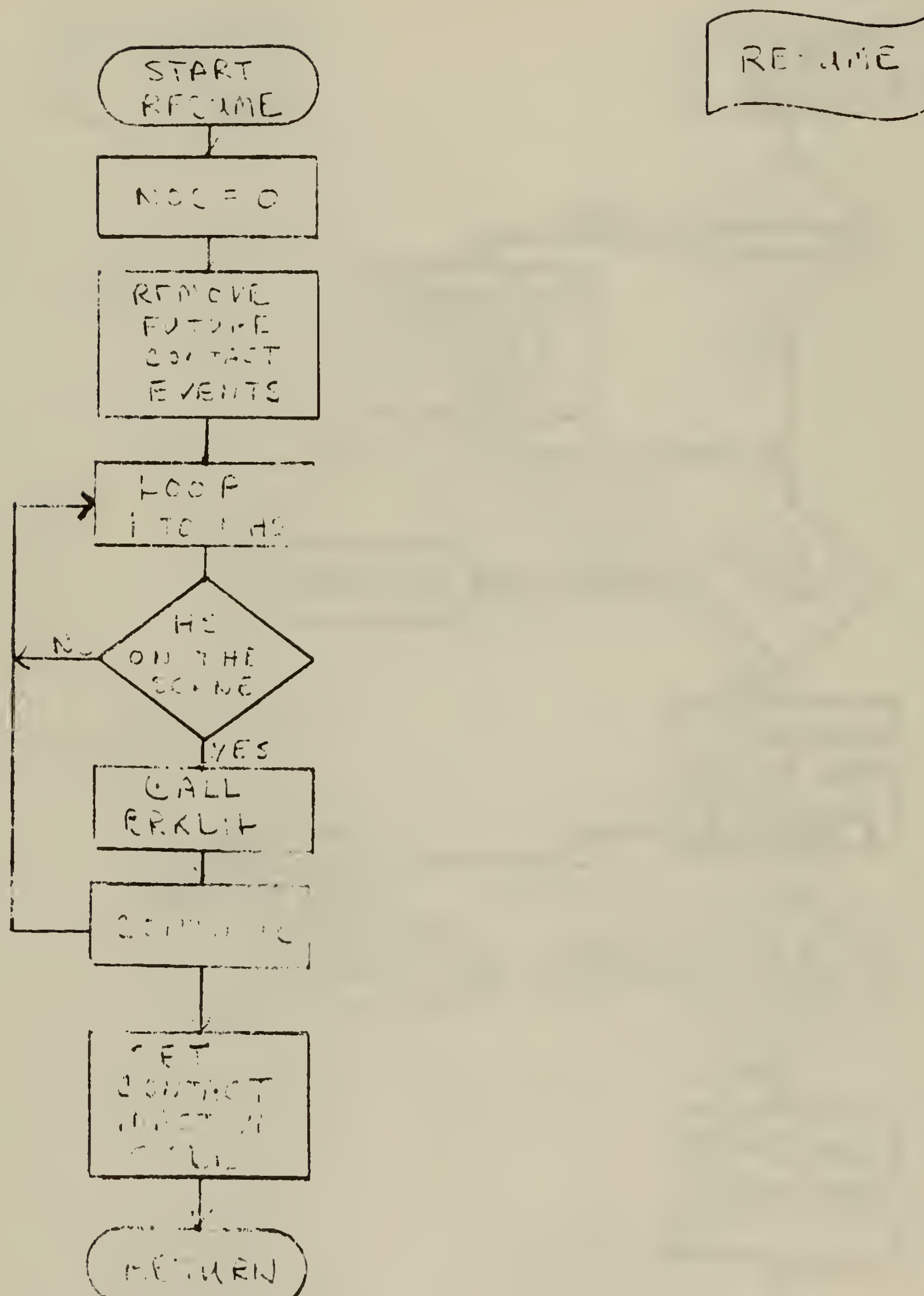

DIP
START DIP
STORE
EVENT
TP+DELT
α
CALL DET
K>0
NO
RETURN
YES
ENTRY RELOOK
CALL CLASS
L

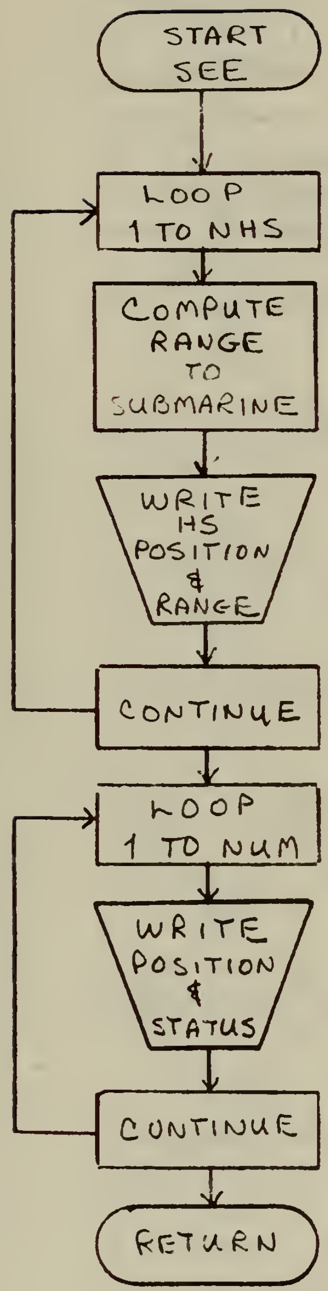

L=1
SPECIAL RETURN
L=2
REMOVE CONTACT
α
L=3
STORE RELOOK EVENT TP+1.0
RETURN
L=4
CALL REMOVE
ICODE = K
NOS = 1
STORE TRACK EVENT TP
RETURN

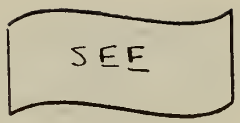

JOINT
START JOINT
LOOP
YES
sum=sum+1
CONTINUE
YES
INCORRECT
CORRECT
RETURN

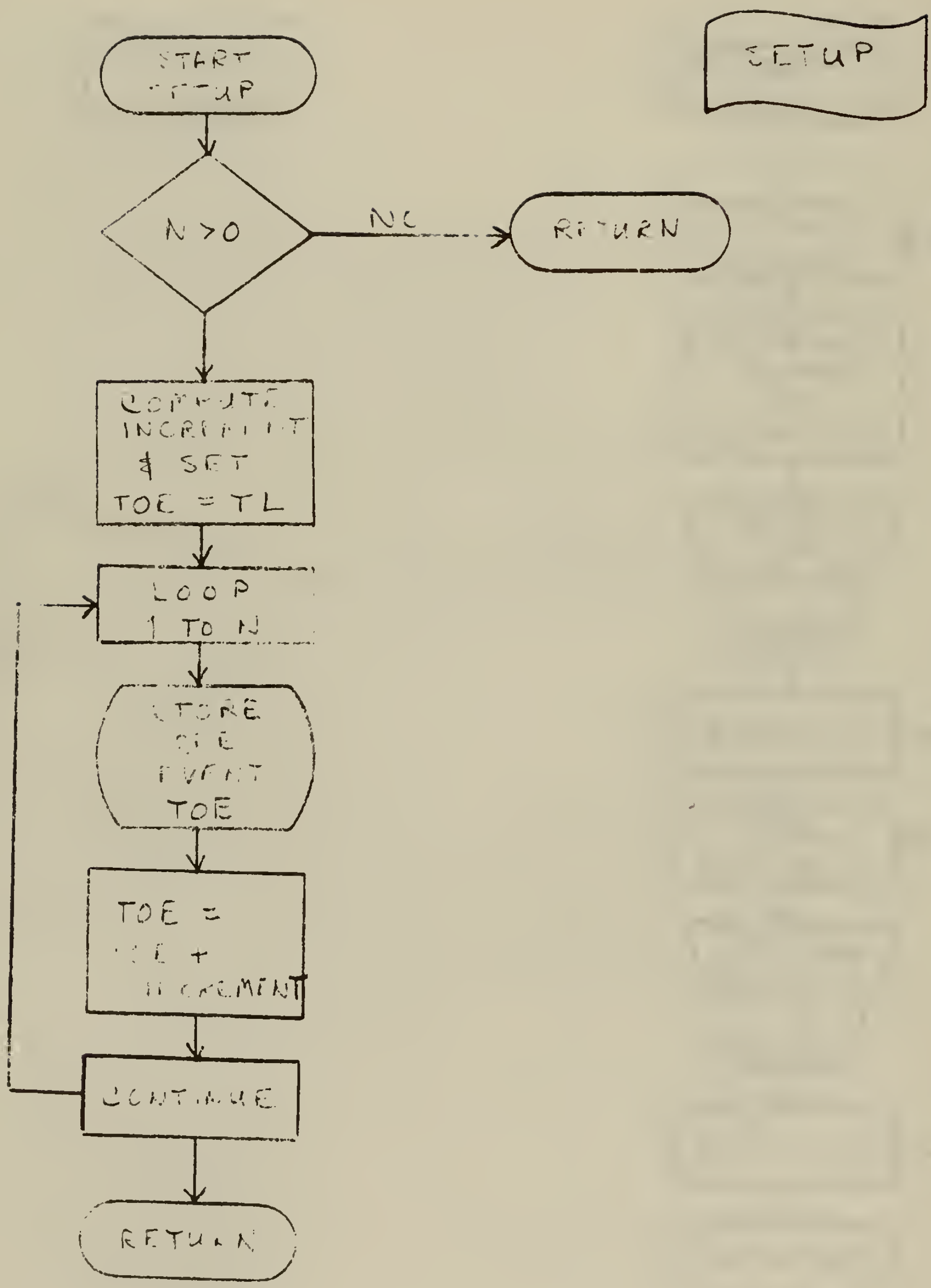


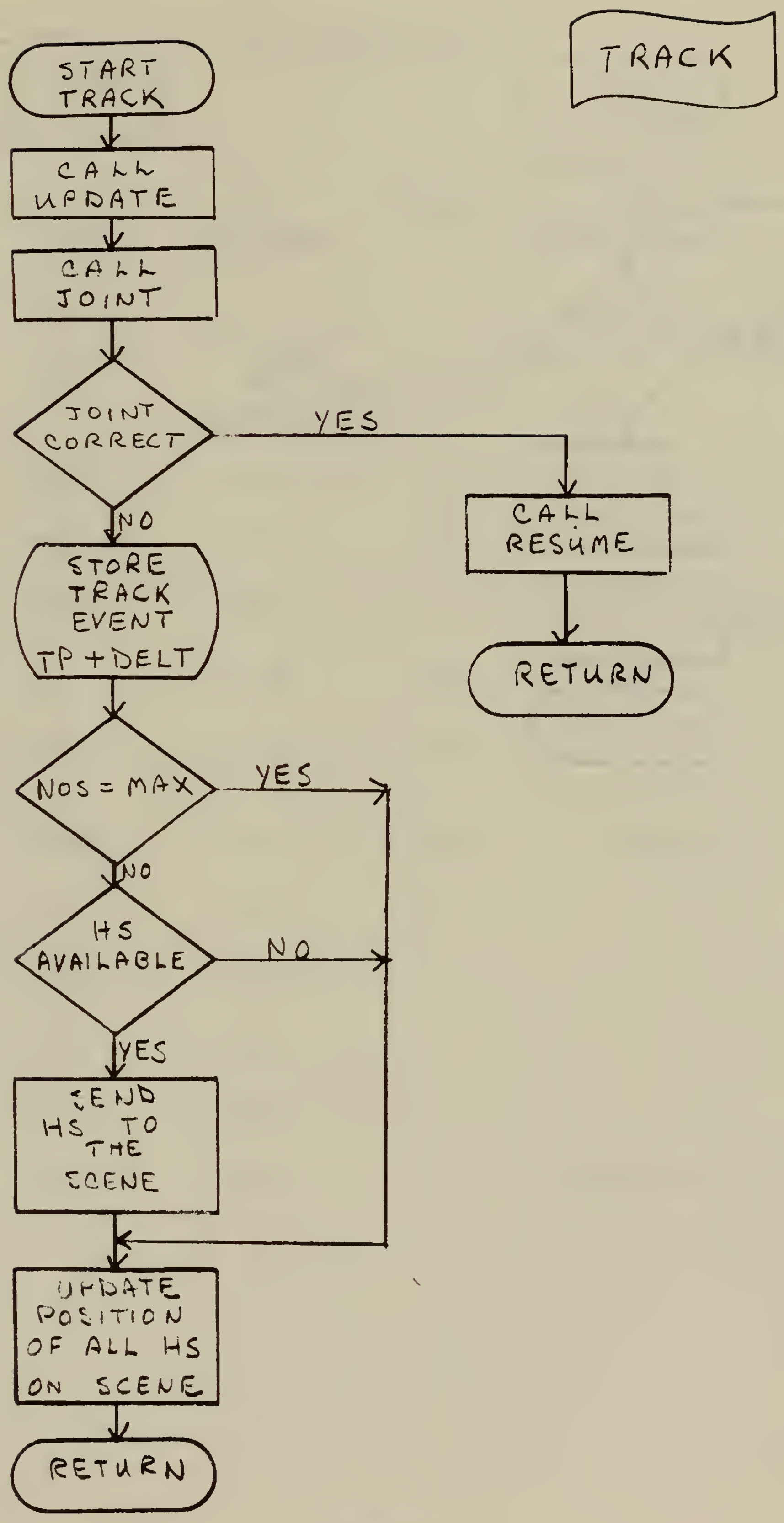
START OVER
OVER
SUBMARINE CAUGHT
YES
INCREMENT COUNTERS & SAVE TIME
NO
LAST REP
NO
RETURN
YES
COMPUTE AVG & SET COUNTERS & RNG
RANDOM NUMBER GENERATORS
LAST GAME
NO
RETURN
YES
COMPUTE STATISTICS
SPECIAL RETURN

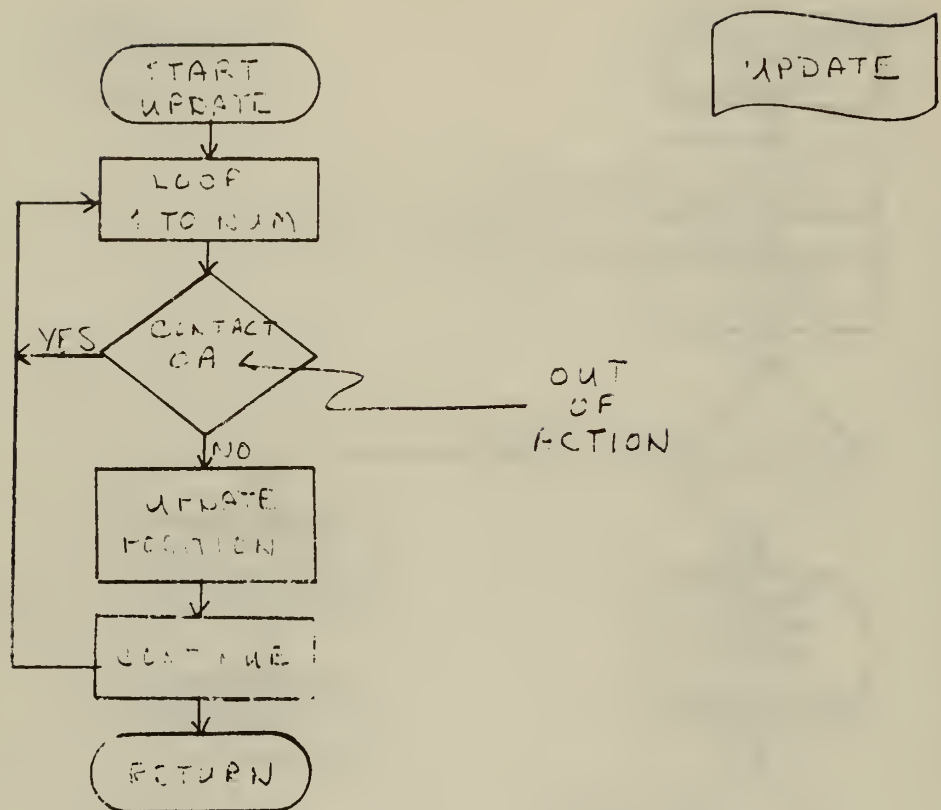

START
EVENTS
YES
CALL


START
SEE
LOOP
1 TO NHS
COMPUTE
RANGE
TO
SUBMARINE
WRITE
HS
POSITION
&
RANGE
CONTINUE
LOOP
1 TO NUM
WRITE
POSITION
&
STATUS
CONTINUE
RETURN


SEE


SETUP
N>0
RETURN
TOE = TL
LOOP
1 TO N
TOE
TOE =
RETURN


TRACK
START TRACK
CALL UPDATE
CALL JOINT
JOINT CORRECT
YES
CALL RESUME
RETURN
NO
STORE TRACK EVENT TP + DELT
NOS = MAX
YES
NO
HS AVAILABLE
NO
YES
SEND HS TO THE SCENE
UPDATE POSITION OF ALL HS ON SCENE
RETURN


UPDATE
START
UPDATE
LOOP
YES
NO
OUT
OF
ACTION

APPENDIX C

INPUT AND OUTPUT

A. INPUT FORMAT

CARD NO.	VARIABLE NAME	CARD COLUMN	FORMAT	RANGE	UNITS
1	IN	1	I1		
1	OUT	2	I1		
2	IRUN	1-5	I5		
2	NGRPS	6-10	I5	NGRPS $\geq$ 2	
2	NREPS	11-15	I5	NREPS $\leq$ 99999	
2	IX	16-20	I5	1 $\leq$ IX $\leq$ 16	
2	NN	21-25	I5		
3	NHS	1-10	I10	1 $\leq$ NHS $\leq$ 6	
3	TL	11-20	F		minutes
3	DELT	21-30	F		minutes
3	TOS	31-40	F		minutes
3	RS	41-50	F		yards
3	OVRLAP	51-60	F	1.0 $\leq$ OVRLAP $\leq$ 2.0	

CARD NO.	VARIABLE NAME	CARD COLUMN	FORMAT	RANGE	UNITS
4	NUM	1-10	I10	$0 \leq NUM \leq 999$	
4	VMAX	1-20	F		knots
4	PCS	21-30	F	$0.0 \leq PCS \leq 1.0$	
4	PCNS	31-40	F	$0.0 \leq PCNS \leq 1.0$	
4	MAXNOS	41-45	I5	$MAXNOS > 0$	

NOTE: F denotes a real variable requiring 10 card columns and a decimal point.

Ixx denotes an integer variable right-justified in xx card columns.

B. SAMPLE OUTPUT

```
          HS DATUM SEARCH *** RUN NUMBER  103
          THE INPUT PARAMETERS FOR THIS RUN ARE:
NREPS =  1000      THE RANDOM NUMBER SEQUENCE IS  1
THERE ARE  4 HELICOPTERS WITH A TIME LATE OF 15.00 MINUTES
AND A TIME ON STATION OF  60.0 MINUTES
EXPECTED SONAR RANGE = 3000.00 YARDS

THE MAXIMUM SUBMARINE SPEED IS 20.0 KNOTS
THERE ARE 250 FALSE CONTACTS
THE PROBABILITY OF CORRECTLY CLASSIFING A SUBMARINE CONTACT IS 0.80
THE PROBABILITY OF CORRECTLY CLASSIFING A NON-SUBMARINE CONTACT IS 0.40
AT MOST 1 HELICOPTERS WILL PROSECUTE A CONTACT


         RESULTS OF THIS RUN
THE PROBABILITY OF DETECTION WAS 0.37100
WITH ONE STANDARD DEVIATION OF 0.02546

THE PROBABILITIES BY GROUP WERE 0.38900 AND 0.35300

THE AVERAGE TIME TO DETECTION WAS   9.04021
WITH ONE STANDARD DEVIATION OF   4.18291
BASED ON A SAMPLE SIZE OF 742
```

APPENDIX D

PROGRAM LISTING

```
      COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
     *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
C
      COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TOS
C
      COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
     *NC,TBAR,TSD,NGAME,NREPS,NGRPS,IOUT,OVRLAP,XBAR,SD
C
C     READ INPUT DATA
C     ---- ----- ----
C
      READ(4,199)IN,IOUT
      READ(IN,100)IRUN,NGRPS,NREPS,IX,NN
      READ(IN,101)NHS,TL,DELT,TOS,RS,OVRLAP
      RS=RS/2000.0
  700 READ(IN,102,END=900)NUM,VMAX,PCS,PCNS,MAXNOS
      MAX=MINO(MAXNOS,NHS)
C
C     WRITE INPUT PARAMETERS FOR THIS RUN
C     ----- ----- ---------- --- ---- ---
C
      WRITE(IOUT,200)IRUN
      IRUN=IRUN+1
      RRS=RS*2000.0
      WRITE(IOUT,201)NREPS,IX,NHS,TL,TOS,RRS
      WRITE(IOUT,202)VMAX,NUM,PCS,PCNS,MAX
C
C     INITIALIZE THIS RUN
C     ---------- ---- ---
C
      NMAX=NREPS*NGRPS
      NGAME=1
      NUM=NUM+1
      IDUM=-9999999
      NC=0
      SUM=RN1(0)
      SUM=RN2(0)
      NS=0
      CALL INT
      CALL SETUP(NN)
      GOTO 501
C
C     INITIALIZE THIS GAME
C     ---------- ---- ----
C
  500 CALL INT
  501 TP=TL
C
C     SET HS STARTING DIP STATIONS
C     --- -- -------- --- --------
C
      DO 301 I=1,NHS
      XH(I)=0.0
      YH(I)=0.0
  301 CONTINUE
      DO 302 I=1,NHS
      CALL BRKDIP(I)
  302 CONTINUE
C
C     SET SS COURSE SPEED & STATUS
C     --- -- ------ ----- - ------
C
      VXS(1)=RN1(IX)*VMAX
      VYS(1)=0.0
      XS(1)=VXS(1)*TL/60.0
      YS(1)=0.0
```

```
      TS(1)=TL
      ISTAT(1)=0
C
C     INITIALIZE FALSE CONTACTS
C     ---------- ----- --------
C
      IF (NUM-1) 401,401,400
  400 R=TOS*VMAX/60.0
      DO 303 I=2,NUM
      XS(I)=RN1(IX)*2.0*R-R
      YS(I)=RN1(IX)*2.0*R-R
      VXS(I)=0.0
      VYS(I)=0.0
      NCS(I)=0
      ISTAT(I)=0
      TS(I)=TL
  303 CONTINUE
C
C     TAKE NEXT EVENT AND CHECK TIME
C     ---- ---- ----- --- ----- ----
C
  401 CALL TNE(TTP,ISUB,IUNIT,IVAL,&999)
      IF (TTP-TP) 701,702,702
  701 CALL CALFUL(15)
  702 TP=TTP
      IF (TP+TL-TOS) 402,402,403
C
C     GO TO PROPER EVENT ROUTINE, EXECUTE EVENT
C     -- -- ------ ----- -------  ------- -----
C
C     THEN RETURN FOR NEXT EVENT
C     ---- ------ --- ---- -----
C
  402 GOTO (601,602,603,604,605,606,607,608),ISUB
  601 CALL BRKDIP(IUNIT)
      GOTO 401
  602 CALL DIP(IUNIT,&403)
      GOTO 401
  603 CALL DET(IUNIT,IVAL)
      GOTO 401
  604 CALL TRACK(IVAL)
      GOTO 401
  605 CALL RELOOK(IUNIT,IVAL,&403)
      GOTO 401
  606 CALL SEF
      GOTO 401
  607 GOTO 401
  608 GOTO 401
C
C     THIS GAME IS COMPLETE
C     ---- ---- -- --------
C
  403 CALL OVER(&404)
      NGAME=NGAME+1
      GOTO 500
C
C     THIS RUN IS COMPLETE
C     ---- --- -- --------
C
C     WRITE RESULTS AND GO BACK FOR ANOTHER RUN
C     ----- ------- --- -- ---- --- ------- ---
C
  404 WRITE(IOUT,203)XBAR,SD
      WRITE(IOUT,204)(AVG(I),I=1,NGRPS)
      WRITE(IOUT,205)TBAR,TSD,NC
      GOTO 700
C
C     ALL RUNS COMPLETE
C     --- ---- --------
C
  900 STOP
  999 CALL CALFUL(10)
```

```
199 FORMAT(2I1)
100 FORMAT(5I5)
101 FORMAT(I10,5F10.0)
102 FORMAT(I10,3F10.0,I5)
200 FORMAT(///1H1,20X,30HHS DATUM SEARCH *** RUN NUMBER,
   *I5)
201 FORMAT(1H0,20X,34HTHE INPUT PARAMETERS FOR THIS RUN ,
   *4HARE:,//10X,8HNREPS = ,I5,5X,
   *30HTHE RANDOM NUMBER SEQUENCE IS ,I2,//10X,9HTHERE ARE
   *,I3,32H HELICOPTERS WITH A TIME LATE OF,F6.2,8H MINUTE
   *,//10X,
   *24HAND A TIME ON STATION OF,F6.1,8H MINUTES,//10X,
   *22HEXPECTED SONAR RANGE =,F8.2,6H YARDS,/)
202 FORMAT(/10X,30HTHE MAXIMUM SUBMARINE SPEED IS,F5.1,
   *6H KNOTS,//10X,10HTHERE ARE ,I3,15H FALSE CONTACTS,//
   *10X,42HTHE PROBABILITY OF CORRECTLY CLASSIFING A ,
   *20HSUBMARINE CONTACT IS,F5.2,//10X,16HTHE PROBABILITY
   *50HOF CORRECTLY CLASSIFING A NON-SUBMARINE CONTACT IS,
   *F5.2,//10X,7HAT MOST,I2,27H HELICOPTERS WILL PROSECUTE
   *10H A CONTACT)
203 FORMAT(///20X,19HRESULTS OF THIS RUN,//10X,
   *32HTHE PROBABILITY OF DETECTION WAS,F8.5,//10X,
   *30HWITH ONE STANDARD DEVIATION OF,F8.5/)
204 FORMAT(/10X,31HTHE PROBABILITIES BY GROUP WERE,F8.5,
   *4H AND,F8.5/)
205 FORMAT(/10X,33HTHE AVERAGE TIME TO DETECTION WAS,F10.5
   *//10X,30HWITH ONE STANDARD DEVIATION OF,F10.5,//10X,
   *25HBASED ON A SAMPLE SIZE OF,I4)
    END

    SUBROUTINE BRKDIP(N)
C
    COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
   *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
    COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TOS
    COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
   *NC,TBAR,TSD,NGAME,NREPS,NGRPS,ICUT,CVRLAP,XBAR,SD
C
C   CANCEL ALL FUTURE EVENTS AND SET AIRBORNE CODE
C   ------ --- ------ ------ --- --- -------- ----
C
    CALL REMOVE(2,N)
    ICODE(N)=-1
C
C   COMPUTE AND TEST NEXT DIP STATION
C   ------- --- ---- ---- --- -------
C
    R=VMAX*TP/60.0
500 X=RN1(IX)*2.0*R-R
    Y=RN1(IX)*2.0*R-R
    IF ((X*X+Y*Y)-(R-RS)**2) 400,400,500
400 DO 300 I=1,NHS
    R1=(X-XH(N))**2+(Y-YH(N))**2
    IF (SQRT(R1) - CVRLAP*RS) 500,500,300
300 CONTINUE
C
C   COMPUTE TIME TO STATION & STORE DIP EVENT
C   ------- ---- -- ------- - ----- --- -----
C
    TCE=TP+SQRT((X-XH(N))**2+(Y-YH(N))**2)*0.667+3.0
    CALL SNE(TCE,2,N,IDUM,&999)
    XH(N)=X
    YH(N)=Y
    RETURN
999 CALL CALFUL(1)
    END
```

```
      SUBROUTINE CLASS(J,K)
C
      COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
     *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
      COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TCS
      COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
     *NC,TBAR,TSD,NGAME,NREPS,NGRPS,ICUT,CVRLAP,XBAR,SD
C
C     J IS THE SUBSCRIPT OF THE CONTACT
C
C     K IS THE CLASSIFICATION CODE
C
      IF (J-1) 402,400,402
  400 K=1
      IF (RN2(IX)-PCS) 500,500,401
  401 K=3
      GOTO 500
  402 K=2
      IF (RN2(IX)-PCNS) 500,500,403
  403 K=4
  500 RETURN
      END


      SUBROUTINE DET(J,K)
C
      COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
     *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
      COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TCS
      COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
     *NC,TBAR,TSD,NGAME,NREPS,NGRPS,ICUT,CVRLAP,XBAR,SD
      CALL UPDATE
C
C     SET K = THE SUBSCRIPT OF THE FIRST CONTACT WITHIN
C     RANGE OR = 0 IF NO CONTACT IS WITHIN RANGE
C
      DO 300 I=1,NUM
      IF (ISTAT(I)-1) 400,300,400
  400 TEMP=(XH(J)-XS(I))**2+(YH(J)-YS(I))**2
      IF (TEMP-RS*RS) 401,401,300
  401 K=I
      GOTO 500
  300 CONTINUE
      K=0
  500 RETURN
      END


      SUBROUTINE DIP(N,*)
C
      COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
     *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
      COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TCS
      COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
     *NC,TBAR,TSD,NGAME,NREPS,NGRPS,ICUT,CVRLAP,XBAR,SD
C
C     SET DIP CODE, STORE NEXT BRKDIP EVENT
C     & CHECK FOR DETECTIONS
C
      ICODE(N)=0
      TC=TP+DELT
      CALL SNE(TC,1,N,IDUM,&999)
  500 CALL DET(N,K)
      IF (K) 402,402,400
      ENTRY RELOCK(N,K,*)
C
C     CLASSIFY CONTACT
C
```

```
  400 CALL CLASS(K,L)
      GOTO(600,601,602,603),L
C
C     THE SS HAS BEEN DETECTED & CORRECTLY CLASSIFIED
C
  600 ISTAT(1)=1
      RETURN 1
C
C     THE FALSE CONTACT HAS BEEN CORRECTLY CLASSIFIED.
C     DELETE IT & CHECK FOR MORE CONTACTS
C
  601 ISTAT(K)=1
      GOTO 500
C
C     THE SS HAS BEEN INCORRECTLY CLASSIFIED.
C     SCHEDULE A RELOCK EVENT
C
  602 TCE=TP+1.0
      CALL SNE(TCE,5,N,1,&999)
      GOTO 402
C
C     THE FALSE CONTACT HAS BEEN INCORRECTLY CLASSIFIED.
C     SCHEDULE A TRACK EVENT FOR THE CURRENT GAME TIME
C
  603 NOS(K)=1
      ICODE(N)=K
      CALL REMOVE(2,N)
      CALL SNE(TP,4,IDUM,K,&999)
  402 RETURN
  999 CALL CALFUL(2)
      END


      SUBROUTINE JOINT(K,L)
C
      COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
     *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
      COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TOS
      COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
     *NC,TBAR,TSD,NGAME,NREPS,NGRPS,ICUT,OVRLAP,XBAR,SD
C
C     COMPUTE THE AVERAGE NUMBER OF UNITS CORRECTLY
C     CLASSIFING THE CONTACT
C
      SUM=0.0
      M=NOS(K)
      DO 300 I=1,M
      IF (RN2(IX)-PCNS) 401,401,300
  401 SUM=SUM+1.0
  300 CONTINUE
      SUM=SUM/M
      L=0
C
C     IF THE AVERAGE IS GREATER THAN THE INPUT
C     PROBABILITY THE CLASSIFICATION IS CORRECT
C
      IF (SUM-PCNS) 403,403,402
  402 L=1
  403 RETURN
      END


      SUBROUTINE OVER(*)
C
      COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
     *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
      COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TOS
      COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
     *NC,TBAR,TSD,NGAME,NREPS,NGRPS,ICUT,OVRLAP,XBAR,SD
      IF (ISTAT(1)) 401,401,400
C
C     IF THE SS WAS DETECTED INCREMENT
```

```
C       THE COUNTERS & STORE THE TIME
C
  400   NS=NS+1
        NC=NC+1
        TAVG(NC)=TP-TL
C
C       IF THIS WAS THE LAST REPLICATION COMPUTE
C       THE AVERAGE NUMBER OF DETECTIONS & RESET
C       THE COUNTERS & RANDOM NUMBER GENERATORS
C
  401   IF (NGAME/NREPS*NREPS-NGAME) 500,402,500
  402   IND=NGAME/NREPS
        AVG(IND)=FLOAT(NS)/NREPS
        DUMMY=RN1(0)
        DUMMY=RN2(0)
        IX=-IX
        NS=0
C
C       IF THIS WAS THE LAST GAME COMPUTE
C       STATISTICS & SIGNAL OUTPUT
C
        IF (NGAME-NREPS*NGRPS) 500,403,403
  403   CALL MOMENT(AVG,NGRPS,XBAR,SD)
        IF (NC) 404,404,405
  404   TBAR=0.0
        TSD=0.0
        GOTO 406
  405   CALL MOMENT(TAVG,NC,TBAR,TSD)
  406   RETURN 1
  500   RETURN
        END


        SUBROUTINE RESUME(K)
C
        COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
       *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
        COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TCS
        COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
       *NC,TBAR,TSD,NGAME,NREPS,NGRPS,IOUT,OVRLAP,XBAR,SD
C
C       SET NUMBER ON THE SCENE TO 0 AND CANCEL
C       ANY STORED EVENTS FOR THIS CONTACT
C
        NOS(K)=0
        CALL REMOVE(3,K)
        DO 300 I=1,NHS
C
C       CALL BRKDIP FOR ALL UNITS ON THE SCENE
C
        IF (ICODE(I)-K) 300,401,300
  401   CALL BRKDIP(I)
  300   CONTINUE
C
C       DELETE THE FALSE CONTACT
C
        ISTAT(K)=1
        RETURN
        END


        SUBROUTINE SEE
C
        COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
       *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
        COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TCS
        COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
       *NC,TBAR,TSD,NGAME,NREPS,NGRPS,IOUT,OVRLAP,XBAR,SD
        WRITE(IOUT,200)TP
C
C       PRINT EACH HS POSITION & RANGE TO THE SS
C
```

```
      DO 300 I=1,NHS
      R=SQRT((XH(I)-XS(1))**2+(YH(I)-YS(1))**2)*2000.0
      WRITE(IOUT,202)I,XH(I),YH(I),ICODE(I),R
  300 CONTINUE
      WRITE(IOUT,201)
C
C     PRINT EACH FALSE CONTACT POSITION & CODE
C
      DO 301 I=1,NUM
      WRITE(IOUT,202)I,XS(I),YS(I),ISTAT(I)
  301 CONTINUE
      RETURN
  200 FORMAT(///10X,14HSTATUS AT TIME,F8.3,//20X,9HHS STATUS
     *//)
  201 FORMAT(1H0,20X,14HCONTACT STATUS)
  202 FORMAT(1H0,I12,2F30.4,I12,F11.2)
      END


      SUBROUTINE SETUP(N)
C
      COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
     *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
      COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TOS
      COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
     *NC,TBAR,TSD,NGAME,NREPS,NGRPS,IOUT,OVRLAP,XBAR,SD
      IF (N) 401,401,400
C
C     IF N > 0 COMPUTE TIME INCREMENT FOR
C     EACH CALL TO SEE & STORE THE EVENT
C
  400 TINC=(TOS-TL)/N
      TOE=TL
      DO 300 I=1,N
      CALL SNE(TOE,6,IDUM,IDUM,&999)
      TOE=TOE+TINC
  300 CONTINUE
  401 RETURN
  999 CALL CALFUL(9)
      END


      SUBROUTINE TRACK(K)
C
      COMMON /SS/ XS(1000),YS(1000),VXS(1000),VYS(1000),
     *ISTAT(1000),TS(1000),VMAX,NOS(1000),NUM,MAX
      COMMON /HS/ XH(6),YH(6),ICODE(6),RS,DELT,NHS,TL,TOS
      COMMON /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
     *NC,TBAR,TSD,NGAME,NREPS,NGRPS,IOUT,OVRLAP,XBAR,SD
      CALL UPDATE
C
C     GET JOINT CLASSIFICATION
C
      CALL JOINT(K,L)
      IF (L) 401,401,400
C
C     CONTACT HAS BEEN CORRECTLY CLASSIFIED
C
  400 CALL RESUME(K)
      GOTO 503
C
C     CONTACT HAS NOT BEEN CORRECTLY CLASSIFIED
C     STORE THE NEXT TRACK EVENT & CHECK THE NUMBER
C     ON THE SCENE
C
  401 CALL SNE(TP+DELT,4,IDUM,K,&999)
      IF (NOS(K)-MAX) 403,502,502
C
C     IF A HS IS AVAILABLE SEND HIM TO THE SCENE
C
  403 DO 300 I=1,NHS
      IF (ICODE(I)) 500,300,300
```

```
  3CC CCNTINUE
      DC 301 I=1,NHS
      IF (ICODE(I)) 3C1,5C0,3C1
  3C1 CCNTINUF
      GCTO 502
  5CC CALL REMOVE(2,I)
  5C1 ICCDE(I)=K
      NCS(K)=NCS(K)+1
C
C     UPDATE THE POSITICN CF ALL HS ON THE SCENE
C
  5C2 DC 302 I=1,NHS
      IF (ICODE(I)-K) 3C2,4C2,3C2
  402 XH(I)=XS(K)
      YH(I)=YS(K)
  3C2 CCNTINUE
  503 RETURN
  999 CALL CALFUL(4)
      END


      SUBROUTINE UPDATE
C
      CCMMCN /SS/ XS(1000),YS(1000),VXS(1C00),VYS(1C00),
     *ISTAT(100C),TS(1000),VMAX,NOS(1000),NUM,MAX
      CCMMCN /HS/ XH(6),YH(6),ICCDE(6),RS,DELT,NHS,TL,TCS
      CCMMCN /UTIL/TP,IX,PCS,PCNS,IDUM,NS,AVG(2),TAVG(1000),
     *NC,TBAR,TSD,NGAME,NREPS,NGRPS,ICUT,CVRLAP,XBAR,SD
      DC 3CC I=1,NUM
C
C     IF THE CCNTACT IS ACTIVE UPDATE ITS PCSITICN
C
      IF (ISTAT(I)-1) 400,30C,400
  4CC XS(I)=XS(I)+VXS(I)*(TP-TS(I))/6C.0
      YS(I)=YS(I)+VYS(I)*(TP-TS(I))/6C.0
      TS(I)=TP
  3CC CCNTINUE
      RETURN
      END
```

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13. ABSTRACT

A computer war game is developed to measure the effect of false contacts on the probability of detecting a submarine. The variables are the probability of correctly classifying a non-submarine contact, the probability of correctly classifying a submarine contact, and the false contact density. A scenario is developed to focus on the false contact problem while holding other ASW variables constant. It is concluded from the output of the game that the effect of false contacts is deeply embedded in the interrelationships between units.

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