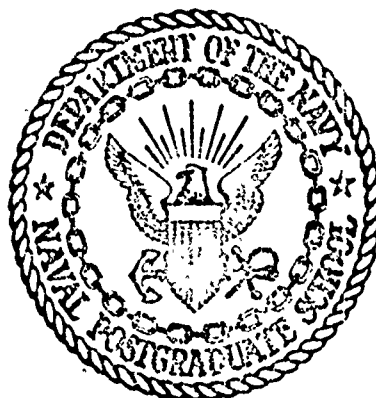


AD 728580

# United States Naval Postgraduate School



## THESIS

A SONAR DETECTION MODEL

by

Richard Charles Curley

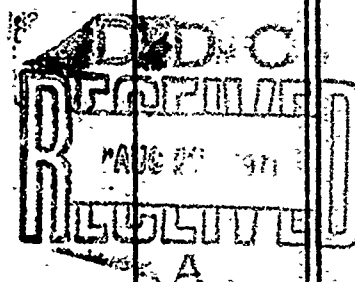
Thesis Advisor:

W. P. Cunningham

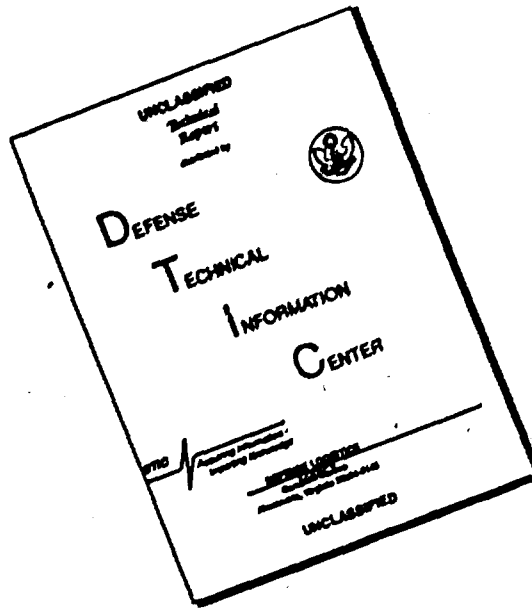
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A Sonar Detection Model

by

Richard Charles Curley  
Lieutenant, United States Navy  
B.S., United States Naval Academy, 1964

Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL  
March 1971

Author

Richard C. Curley

Approved by:

W. Peyton Cunningham

(Thesis Advisor)

P. W. Zelma for J. R. Berrington

Chairman, Department of Operations Analysis

Mr. H. C. ...

Academic Dean

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## ABSTRACT

This paper modifies an existing sonar range prediction model for the AN/SQS-23 in such a manner as to attain detection range data in consonance with exercises from which the original data was extracted. It also shows personnel a method for incorporating more than one ship in the model. This model will assist users in ascertaining the number of units required to perform a given antisubmarine task.

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## I. INTRODUCTION

Since early in World War II, and more predominantly since the early 1950's, there has been a continuing effort to attain a reliable method of accurately predicting the detection ranges of various sonars, along with the corresponding probabilities of detection, which are in consonance with the values obtained from the evaluation of fleet data. At present, the method which provides one of the better estimates of detection ranges and their corresponding probabilities is the model developed during Project Amos in 1951. This model employs a very simple concept, namely, an operator makes a detection only when the sum of his Figure of Merit plus the target strength are greater than or equal to the losses incurred during the two way propagation of the sound.

The author became acquainted with this model during an experience tour while attending the Naval Postgraduate School. The model was discussed in SAOTM69-3, an Anti-Submarine Warfare Systems Project Office study conducted in 1969. At that time, the model used average values for the Figure-of-Merit and also for the propagation losses. The target strengths employed are shown in Table I, and are the result of studies conducted by National Defense Research Committee in 1946, and the Planning Analysis Group, Office of Naval Operations, in 1963. The model assumes a semi-alert operator would predicate the use of a

semi-alert Figure-of-Merit throughout the running of the model. This model would ultimately produce the detection ranges expected by an operator under those particular circumstances. The author has undertaken the task of modifying the model in order to arrive at a model capable of providing results which more accurately predict the results obtained in fleet units. The author maintains a more realistic representation is one in which the operator gradually improves his Figure-of-Merit as a result of his having "seen" a target on the previous ping. This process continues until it finally culminates in a detection. The exact method employed in allowing the operator to attain a better value for his Figure-of-Merit will be more fully discussed in Section III. It was hoped that the alteration would enable the model to achieve results which were in consonance with those witnessed in a fleet exercise.

As the newer escort vessels join the fleet with their onboard computers, it becomes a rather simple task for a screen or unit commander to obtain the required information, namely detection ranges, which will enable him to achieve the optimal utilization of his screening forces so as to maximize the anti-submarine protection to the screened body, or area, through the use of this model.

The model as modified in this program consists only of straight line screens with a submarine closing the screening forces on a straight line course. This enables one to employ the geometry associated with right triangles, if it is desired to employ some more exotic type of screening force or to have the submarine travel in something

other than a straight line, then one needs only to rectify the geometry in use in the present edition of the model.

## II. STATEMENT OF THE PROBLEM

The problem attacked in this paper was two-fold. The first concern was to provide the individual fleet units with an easy to use method of determining the range at which they may expect to gain their initial detection of an opposing submarine. This is an area in which there is a paucity of information available to the fleet units, and they are normally forced to rely on remembered averages, i. e., they employ the range at which the personnel charged with determining the spacing of the units remember as the most common range at which ships concerned most commonly achieve detection. This method normally leads to an overly optimistic value and results in the screened force having less protection than desired. This use of optimistic detection ranges easily leads to the situation where the probability of penetration of an approaching submarine approaches an unacceptable limit. The use of screening stations as dictated by the various tactical publications is hardly much better. They fail to consider the fact that different personnel man different ships and the ship's detection ranges are not solely dependent upon the type sonar employed or the particular water conditions of the day. The system presently employed in the current publications provides a screen spacing based on the assured sonar range. This spacing is then used until the next time a bathythermograph reading is reported to the flagship, a time span which may cover four to eight

hours. The ships, if they were to travel at only 15 knots, will cover sixty to 120 nautical miles during this time frame and through a multitude of assured sonar ranges. Some of the newer screens presently employed in the fleet have no information available for the unit commanders to use in order to determine what spacing, or alternatively, how much area a particular ship is capable of covering effectively.

The absence of an ability to estimate ones own detection ranges, and their probabilities (or percentage of occurrences), places an increased burden on the operator, who must now attempt to estimate the best range scale on which to operate. By changing range scales, SAC Report 67-8 implies, it is possible to alter the amount of error in range prediction by up to one hundred per cent. This serves to point up the importance of having some idea as to which range scale to employ in a search.

The second facet of the problem deals with the ability to predict the probabilities associated with given detection ranges for a group of ships. This area requires renewed emphasis in order to be better able to employ our surface units in the protection of convoys or fast carrier attack forces. The availability of a model which would accurately predict the detection probabilities and ranges of a group of ships would be invaluable in assisting a researcher to ascertain the optimal spacing of a screen. This model would also provide the analyst with a means of comparing the relative merits of new screens and tactics as opposed to those already in use.

### III. METHODOLOGY

#### A. ASSUMPTIONS

The following list of assumptions were made in the model. For simplicity they have been divided into three categories.

1. Operational Assumptions (these may be easily varied to simulate different operational conditions).
  - a. The submarine is operating in the layer at 12 knots.
  - b. The escort is traveling at 15 knots in a straight line.
  - c. There is no form of interplay between the ships until a detection is made.
2. Environmental Characteristics (dependent on the weather, sea state, etc.)
  - a. The sea is in a state of two.
  - b. The layer depth is 150 feet.
3. General Assumptions
  - a. The submarine track is of infinite length, and the closest points of approach are uniformly distributed.
  - b. A run is concluded when a unit first makes a detection.
  - c. It is considered a missed detection whenever a submarine reaches the closest point of approach without having been previously detected.
  - d. The sonar operator is employing the 20 thousand yard range scale.

The last assumption is not a particularly valid one since the Figure of Merit employed in the model is taken from data resulting from an operator using the 10 thousand yard range scale. These data were then extrapolated in order to cover the range from zero to twenty thousand yards. This extrapolation will necessarily introduce some errors into the results obtained. It is felt this discrepancy will not result in any errors which are of greater degree than the errors resulting from the methods employed in obtaining the data, and arriving at the Figure of Merit used in the model.

#### B. PROCEDURES

The first step in calculating the Figure of Merit to be used was the recording of the minimum detectable echo level for various units participating in an exercise. This is obtained on board ship in the following manner: while the operator is operating on a ten thousand yard sonar range scale, the supervisor will go to the area on the equipment designated for this measurement and input a signal. The supervisor then increases the intensity of this signal until the operator makes a detection. This was done when the operator was in both a semi-alerted and fully-alerted state. For some units this information was also recorded when the operator was employing a twenty thousand yard range scale. The source levels for the participating ships was found to vary between 133dB and 137dB. The author opted to use 135dB as the mean source level to apply a variance of 2dB.

The form of the available data, taken from the SHAREM exercises, was such that the number of data points varied between ships and also between the ranges at which they were measured. The weighted averages for the minimum detectable echo level was found at three, five, and eight thousand yards for each ship. This was done for both the semi-alerted and fully-alerted states. The author's next step was to calculate the grand mean for all the ships and the associated variances for all the aforementioned ranges. These values were plotted on a graph, Figures 1 and 2 respectively, and a curve was constructed through the points. A third graph was plotted for the semi-alert operators using the twenty thousand yard range scale in Figure 3.

The curve was divided into three or more segments and a straight line approximation was fitted to these segments. The formulas used for the approximations were calculated to insure a resulting variation of less than two decibels.

The model was run as originally designed using the newly calculated Figure-of-Merit values, and the results were decidedly similar to the results of previous runs, i. e., the results produced a probability of detection of 1.0 at ranges from three to five thousand yards. This led the author to hypothesize the average fleet sonar operator is never really in an initial semi or fully-alerted state. It was further assumed the operator would always start in an unalerted state. He would remain in this state until he detected the first presentation on his scope. At this time the operator would become semi-alerted, and he would

remain in this state until the next presentation is depicted on the display. The operator now attains the fully-alerted condition and upon the occurrence of still further presentations the operator will ultimately achieve a detection. The question which arises at this time is how many presentations must occur while the operator is fully-alerted in order to arrive at a detection.

In order to test this hypothesis it was necessary to obtain a curve for the unalerted operator's Figure-of-Merit. This curve was received from ASWSPO. As was done for the semi and fully-alerted curves, this curve was approximated by straight line segments and these approximations were applied to the model, Figure 4.

The next step required the running of the model. The model was now of the form:

$$\text{Signal Excess} = \text{Figure-of-Merit plus target strength} \\ \text{minus twice the one way propagation loss}$$

and was run under a variety of situations. These required the use of subroutines which employ Figure-of-Merit of varying degrees of alertness, from unalert, to semi-alert, etc. From previous work the author was able to ascertain if the model was run in any one state, i.e., an operator only semi-alerted, the result would yield 100% detection at a range of from three to five thousand yards, Figures 5 and 6. In an effort to adjust the results to more closely align with those attained by fleet units, the values of semi-alerted and fully-alerted operators were combined in one model. This same step was also taken

incorporating the two previously stated operator conditions with that of an unalerted operator. These two variations were run in such a manner as to require the operator to attain a "detection" in each of the states prior to attaining the next higher level of alertness. It was now possible to run the program utilizing the two different modes just discussed with varying closest points of approach. The reasoning behind the use of different CPA's was to be able to determine the probabilities of detection associated with these different CPA's at various ranges. This led to the attainment of an accurate probability of detection curve. These values were then plotted, for the three step model, in Figure 7, depicting a mean detection probability for a given range. The method of attaining the curve will be more fully discussed in the discussion of results.

Once the model was workable in the aforementioned configurations, the number of detections required of an operator upon attaining the fully-alerted state were varied in an effort to ascertain the actual number required.

The model was again reconstructed in order to demonstrate the feasibility of its operation when one employs more than one ship. The particular configuration chosen was an arbitrary one of four ships in a straight line with spacing of four thousand yards between ships. In its present form the multi-ship model provides an overly optimistic result, Figure 8, however, this result should become more in consonance with the fleet outcomes as the screen configurations are altered to more

closely approximate the fleet formations and mutual interference is considered.

Finally both the single ship and multi-ship models were run with the target strengths obtained from NAVWEPS Report 8989. These values were for an SSN target and were determined in 1963. The results for the single ship runs, each run consisting of three hundred iterations at each of eleven CPA's (.1, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0 thousand yards) were plotted in Figure 7. The multi-ship run, which required three hundred iterations also, was run at one purely arbitrary CPA and is plotted in Figure 8.

#### IV. DISCUSSION OF RESULTS

In order to achieve the values plotted as the cumulative detection probabilities, the following formula was employed:

$$P(r) = p_d [1 - P(r + \Delta r)] + P(r + \Delta r)$$

where:

$P(r)$  = probability of detection by range  $r$

$p_d$  = the ratio of the number of targets detected in the interval  $(r, r + \Delta r)$  to the number of targets undetected by  $r + \Delta r$ .

$P(r + r)$  = probability of detection by range  $r + \Delta r$ , where  $\Delta r$  was always equal to 1000 yards

This formula allowed the author to combine the values determined by the various runs and attain an overall detection probability curve.

The fact the CPA's were assumed to be uniformly distributed allowed the values to be equally weighted.

The resultant curves are not in agreement with the exercise curve at the tails. This can best be explained as a result of not conducting the runs with CPA's greater than ten thousand yards. This constraint tends to limit somewhat the number of observations in excess of ten thousand yards. The data obtained both by the author and in previous simulation (SAOTM 69-3) indicate a respectable number of detections will occur within one thousand yards of CPA as the range increases out to about fifteen thousand yards after which the number of detections would be small. In the results obtained by the author the number of

detections obtained within one thousand yards of CPA, when the CPA was ten thousand yards was approximately one-fourth, and for a nine thousand yard case it was about one third. These facts imply if the model were run with greater CPA's the probabilities of detection in the tail of the curve would be increased to more closely agree with the exercise data. These values were not obtained since the more important results were the values attained at shorter ranges. These values are considered more important since the detection probabilities are more acceptable, and the ranges more likely to be used in the fleet.

The results attained from using the one step model, always semi-alerted, etc., was in considerable disagreement with the exercise data as seen in Figures 5 and 6. The two step model resulted in very similar curves and hence was not plotted but quickly discarded in favor of the three step model.

The three step model, i. e., unalerted, semi-alerted, then fully alerted, produced a cumulative detection probability which was reasonably close to the exercise data, when employing the target strengths from NRDC, 1946. The maximum difference between the two curves, when only one detection was required while fully alerted was 26 percentage points. This value was at a range of five thousand yards and equal to a 37 percent error. The average error was found to be 11.2 percent.

When one considers the error between the use of a twenty thousand yard scale and a ten thousand yard scale as capable of producing a seven decibel difference, and the standard deviation is on the order of

five decibels then an error in detection prediction of thirty-seven percent can be accepted.

When the model, with the NRDC target strengths, was run requiring two detections in the fully alerted state the only change was the shifting of the curve to the left. Since the only problem with the first runs was the high discrepancies in detection probabilities in the four to six thousand yard range interval (from .21 at six thousand yards to maximum .26 at five thousand yards) a comparison was not made with the second run. It should be noted if one only intends to minimize the size of the error, or percent of error, between the exercise data and the model's results one can find a number,  $n$ , of required detections, once fully alerted to achieve this goal. This was not the author's goal and this was not therefore pursued.

Next the results were calculated from the running of the model with the NAVWEPS target strengths. These values were normally lower than those resulting from fleet exercises. The maximum error in this case occurs at zero range and is forty-four percentage points. This is an underestimation of fleet data of fifty-four percent. However, in the area of highest error under previous runnings the amount of errors was only eight to thirteen percentage points or approximately a twenty percent underestimation.

This led the author to the conclusion, the figure of merits, although not entirely accurate and contributing to some of the error, were not the greatest concern at present. The greatest single problem seems

to be the inability to accurately predict a target's echo strength. The importance of this cannot be overemphasized. The results attained by the two runs when the different target strengths were used varied by as much as thirty-five percentage points and between zero and eight thousand yards there was an average of thirty-three percentage points difference. These values result in a maximum of fifty-four percent difference and an average difference of forty-five percent. All this resulting from a change in target strength of, on the average, less than two decibels in the area from  $0^{\circ}$  to  $90^{\circ}$ , and this is the area of primary interest. This value is less than the smallest deviation used in calculating the figure of merit. These results serve to point up the need for an accurate measurement of the target strength of a submarine. It is felt the model is as accurate as possible for average values until there is more work done in determining target strengths of various submarines.

As for possible use by fleet units, providing they are able to determine accurate values for the figure of merit and recall the discrepancies in the five to six thousand yard range it is feasible to use this model, and results will give an indication of the ship's capabilities.

There was no attempt made to show anything other than a possible method of construction in the multi-ship model. Mutual sonar interference, and baffle areas were not considered. It is recommended as a follow on study to alter the multi-ship model in such a manner as to geometrically portray the screens presently in use. By using average

values for the figure of merit, one may determine the optimal spacing with prescribed limits to achieve the greatest protection to a force.

It is further recommended ships keep a record of each operator's figure of merit, in unalerted, semi-alerted and fully alerted states in much the same manner as radarmen presently measure ping time on a watch-to-watch basis.

TABLE I

Target Strengths

A. National Defense Research Committee

| Relative Bearing<br>(degrees) | Target Strength<br>(dB) | Relative Bearing<br>(degrees) | Target Strength<br>(dB) |
|-------------------------------|-------------------------|-------------------------------|-------------------------|
| 0-5                           | 8                       | 85-95                         | 24                      |
| 5-15                          | 11                      | 95-105                        | 20                      |
| 15-25                         | 17                      | 105-115                       | 16                      |
| 25-35                         | 16                      | 115-125                       | 15                      |
| 35-45                         | 15                      | 125-135                       | 15                      |
| 45-55                         | 15                      | 135-145                       | 16                      |
| 55-65                         | 15                      | 145-155                       | 16.5                    |
| 65-75                         | 16                      | 155-165                       | 17                      |
| 75-85                         | 20                      | 165-175                       | 14                      |

B. NAVWEPS Report 8989

| Relative Bearing<br>(degrees) | Target Strength<br>(dB) | Relative Bearing<br>(degrees) | Target Strength<br>(dB) |
|-------------------------------|-------------------------|-------------------------------|-------------------------|
| 0-10                          | 9                       | 90-100                        | 24                      |
| 10-20                         | 10.5                    | 100-110                       | 17.5                    |
| 20-30                         | 11                      | 110-120                       | 12.5                    |
| 30-40                         | 10.5                    | 120-130                       | 10.5                    |
| 40-50                         | 10                      | 130-140                       | 10                      |
| 50-60                         | 11                      | 140-150                       | 10                      |
| 60-70                         | 14                      | 150-160                       | 11                      |
| 70-80                         | 18                      | 160-170                       | 10                      |
| 80-90                         | 24                      | 170-180                       | 8                       |

# Mean Semi-Alerted Figure of Merit With One Standard Deviation

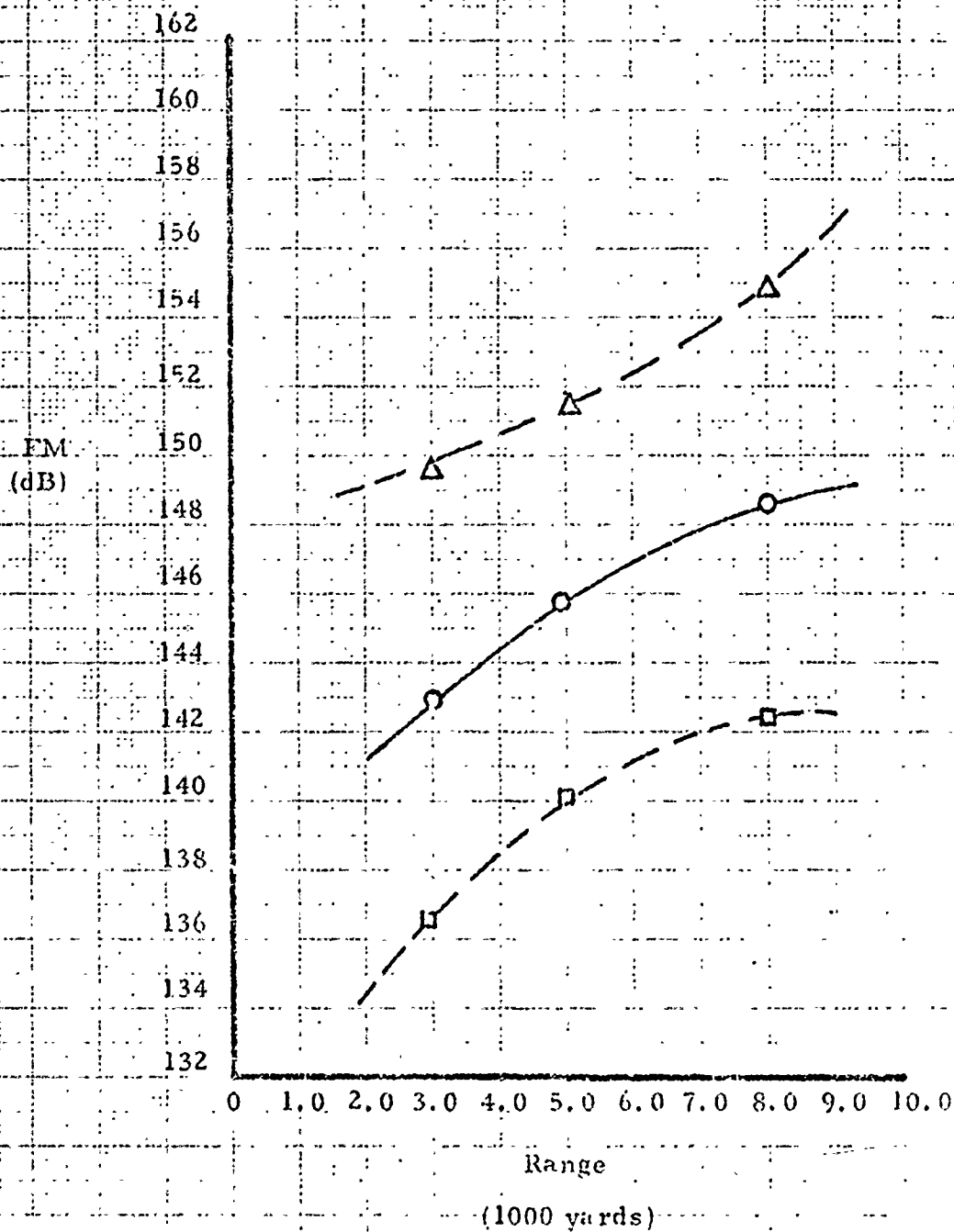


FIGURE I

# Mean Fully-Alerted Figure of Merit With One Standard Deviation

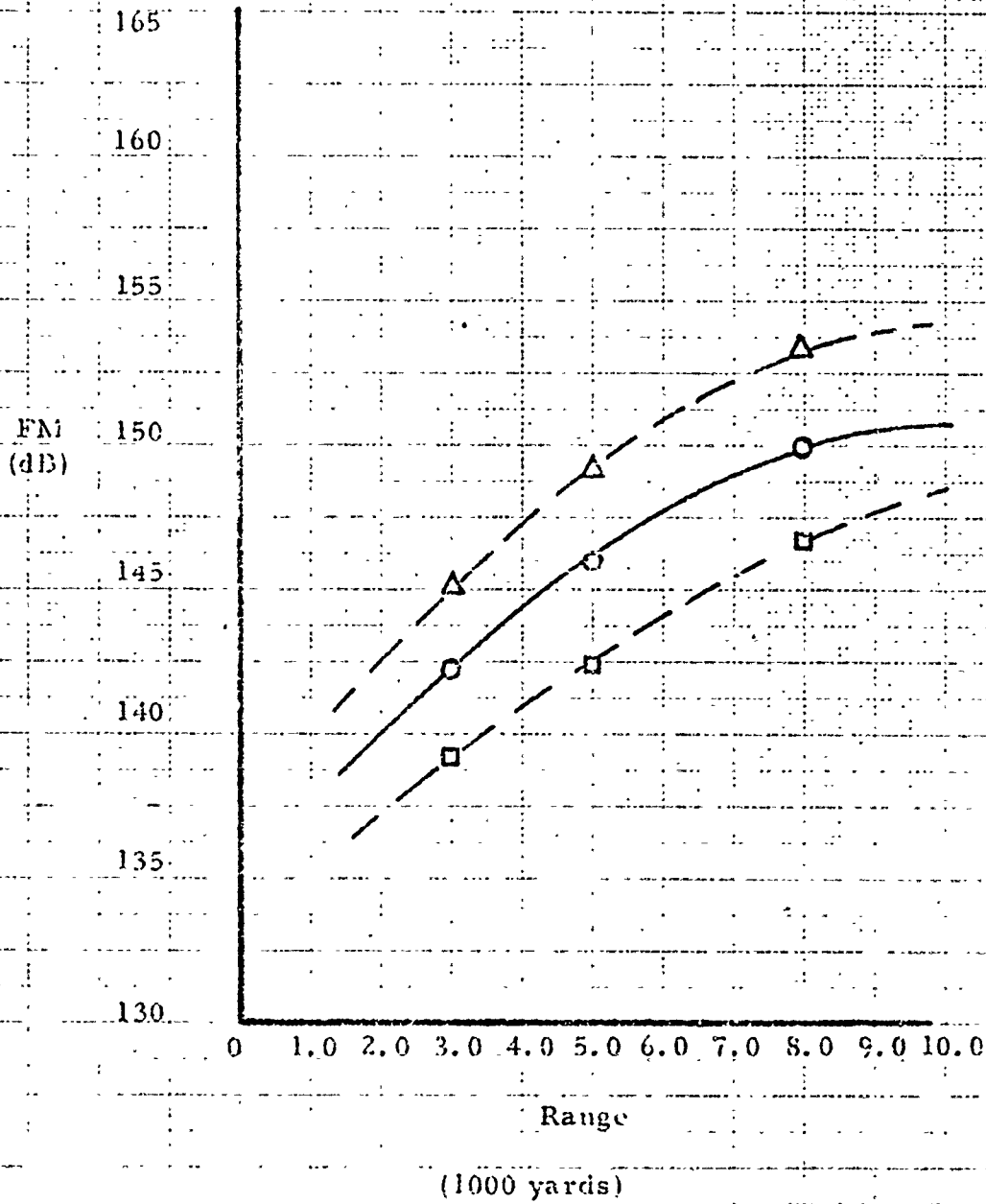
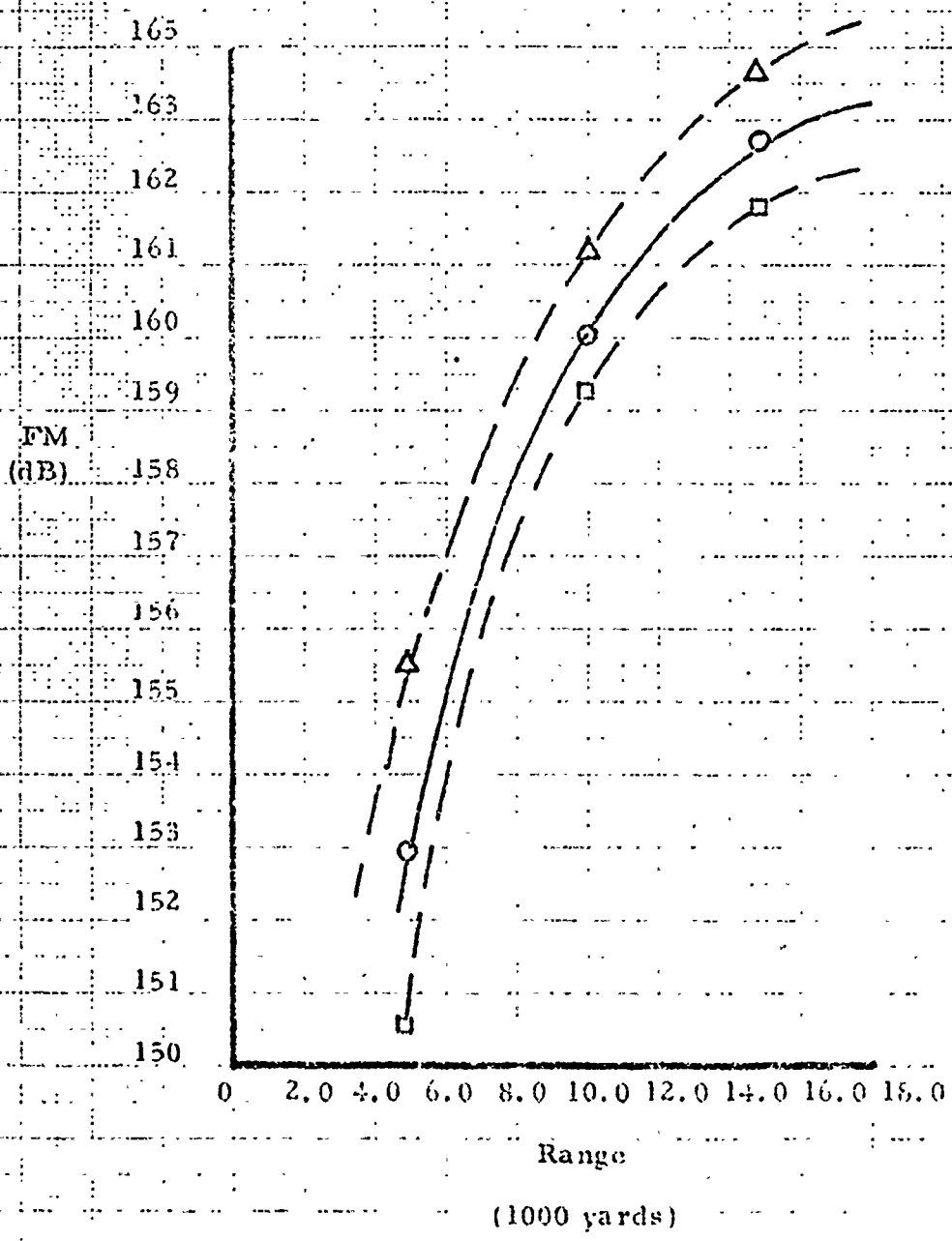


FIGURE 2

C  
C

10 X 10 TO THE CENTIMETER 46 1510  
MADE IN U.S.A.  
KLUFFEL & CO. INC.

# Mean Semi-Alerted Figure of Merit With One Standard Deviation



- a) 20,000 yard range scale
- b) 2 ships

FIG. 31.7

1/2 IN. 10 X 10 TO THE CENTIMETER 46 1510  
1/2 IN. 10 X 10 TO THE CENTIMETER 46 1510  
MADE IN U.S.A.  
KEUFFEL & ESSER CO.

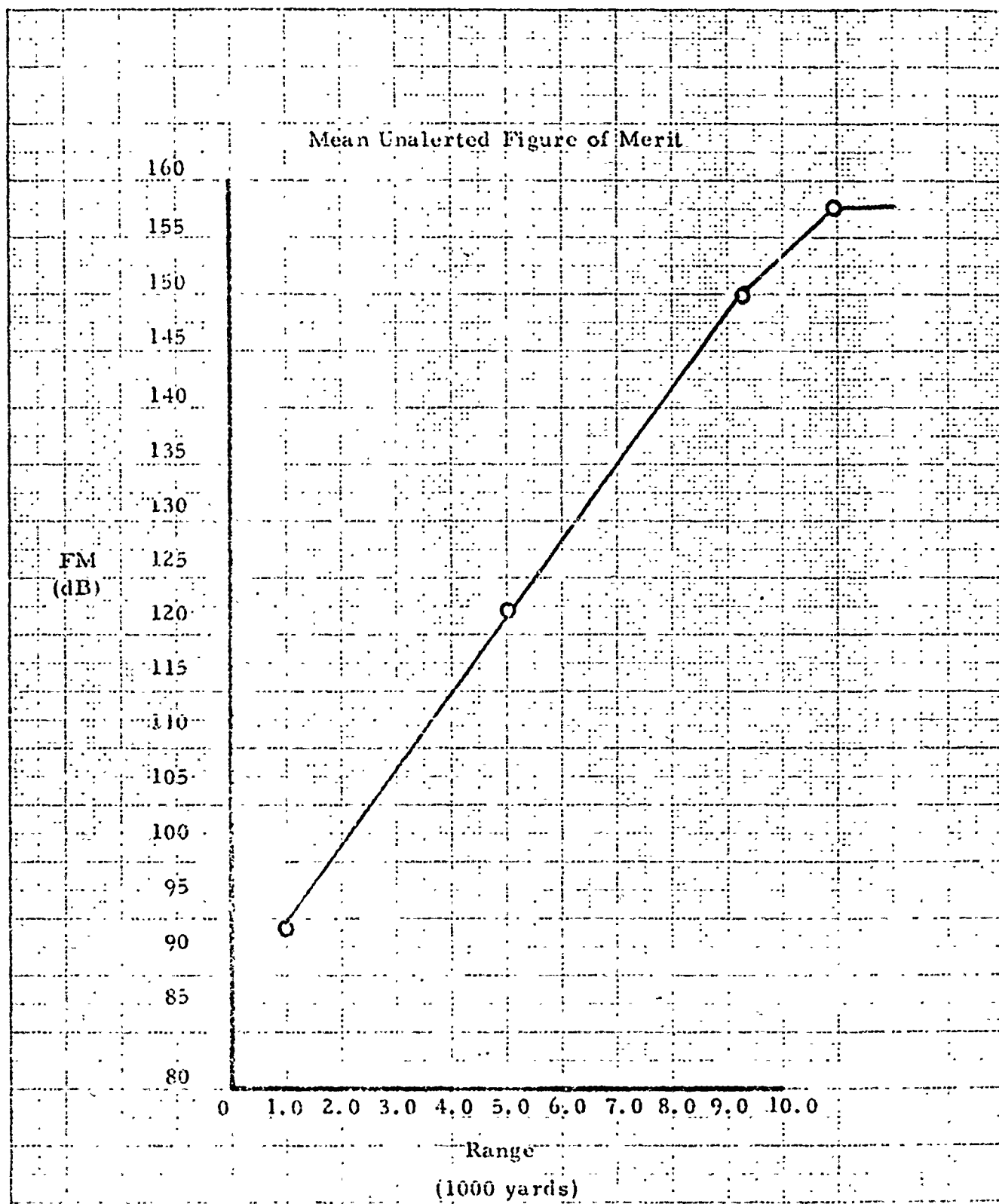


FIGURE 4

Cumulative Probability of Detection  
 Original Model (CPA = 500 yards)

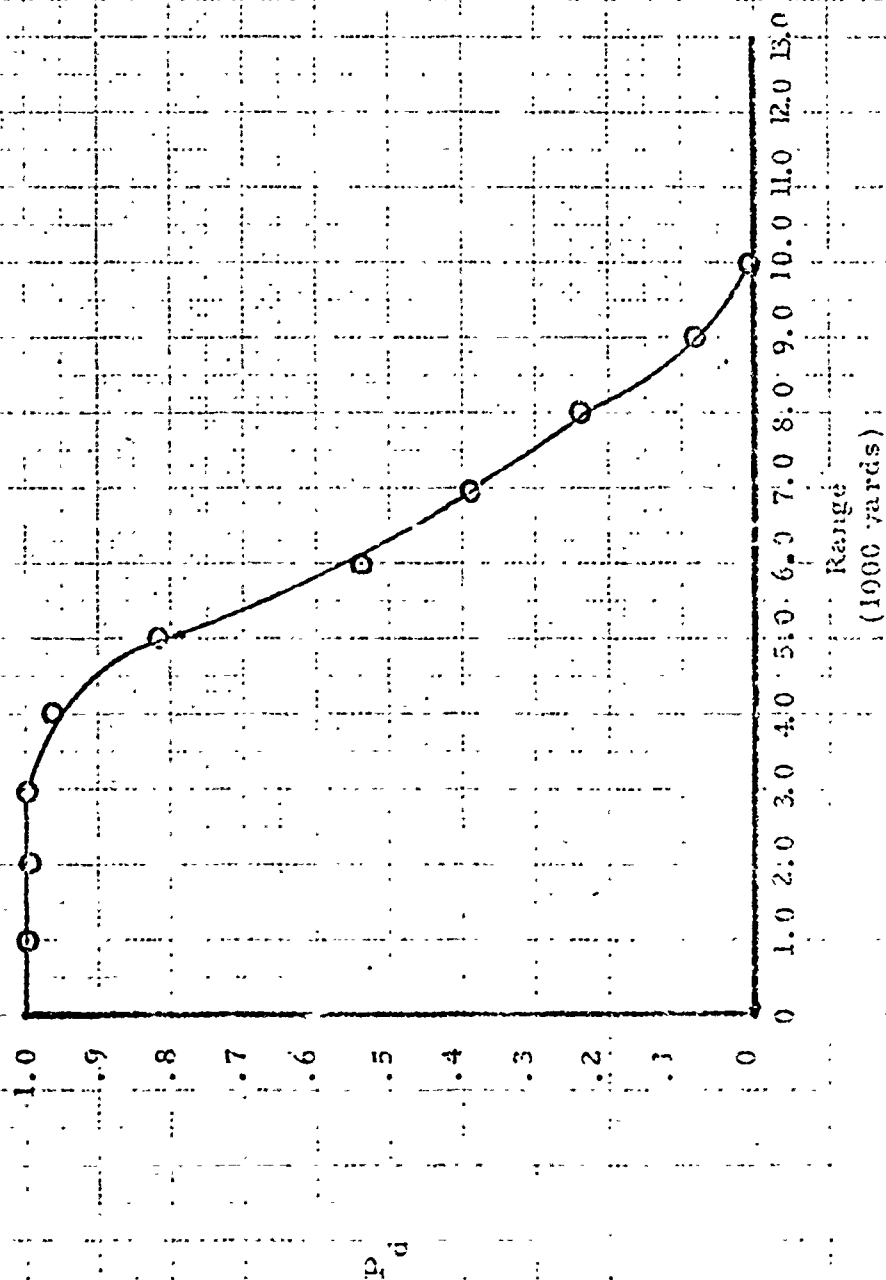


FIGURE 5

Cumulative Probability of Detection  
 Original Model (CPA = 2000 yards)

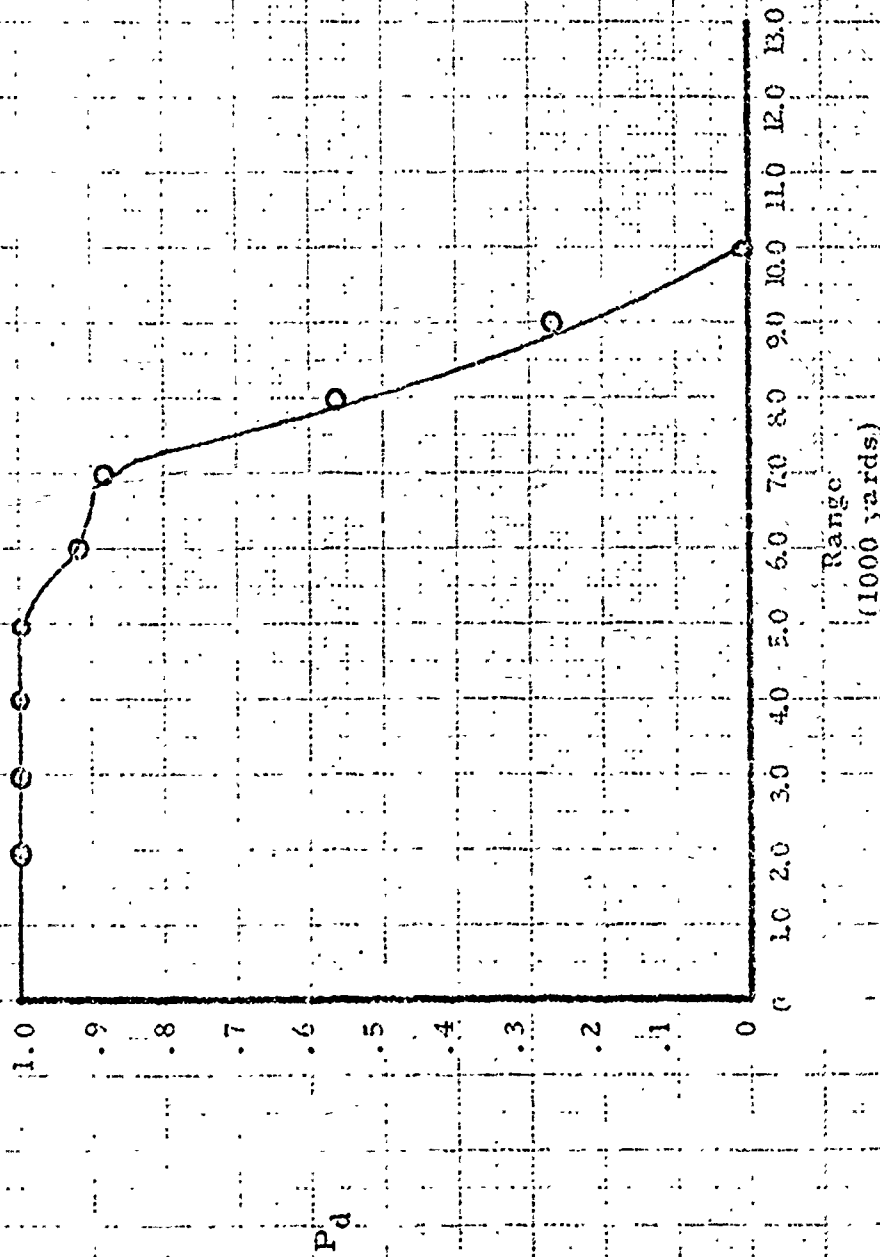


FIGURE 6

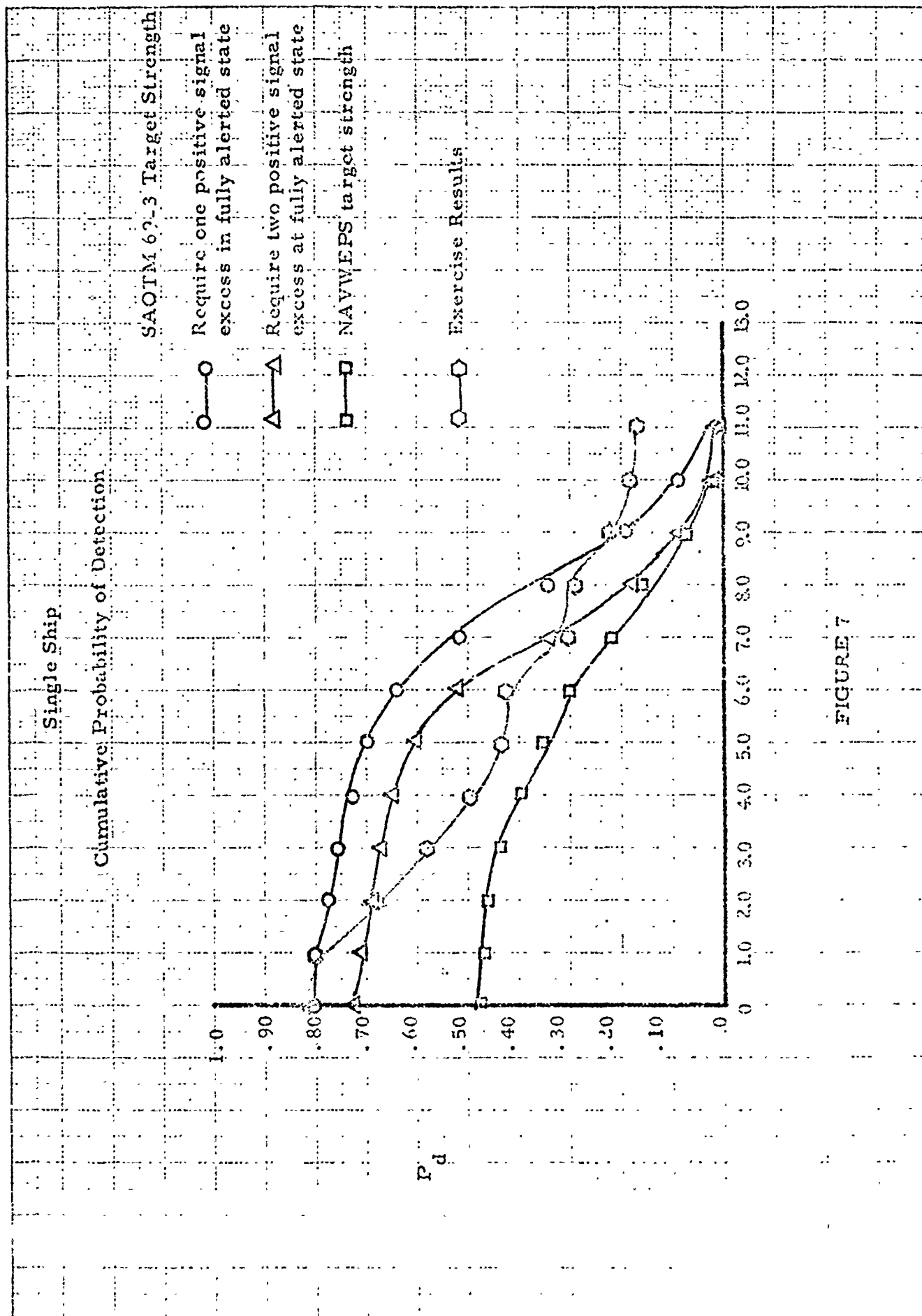


FIGURE 7

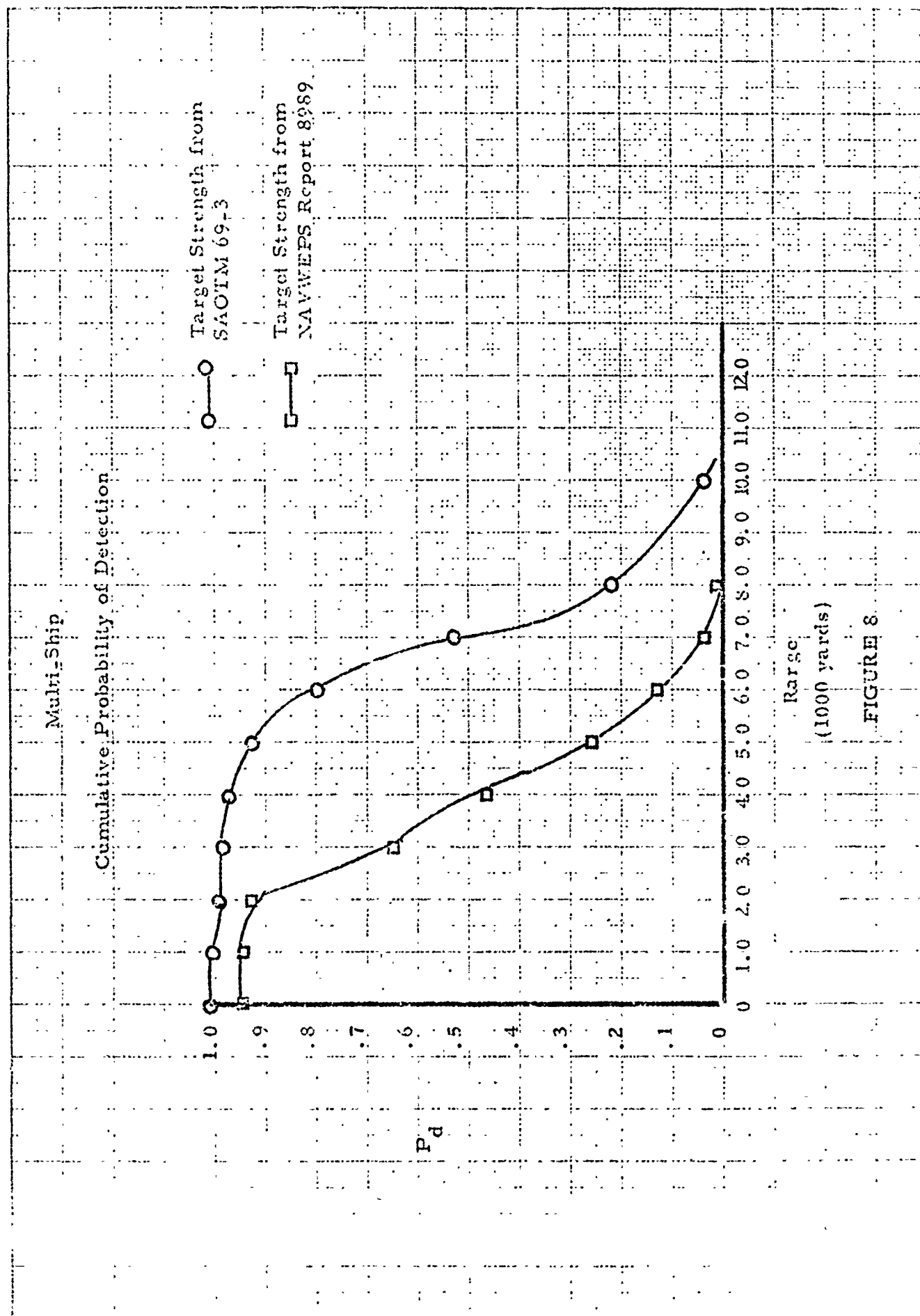


FIGURE 8

## COMPUTER PROGRAM SYMBOLS

All distances are in thousands of yards

- RO-     original range of submarine
- V-     relative velocity (yards/second)
- P-     ping interval (in seconds)
- W1-     indicator of above or below the layer  
         1=below layer  
         2=in layer
- S1-     standard deviation on figure of merit
- S2-     standard deviation on propagation loss
- S3-     standard deviation on target strength
- YO-     original distance from target to CPA on straight line track
- Y-     calculated distance from target to CPA on straight line track  
         as problem progresses
- R-     distance from ship to target
- B-     distance from "prime" ship to CPA (for multi-ship other ships  
         use a function of B)
- C-     bearing to target from beam (CPA)
- UFI-     unalerted figure of merit
- FM1-     figure of merit
- OWLI-   one way propagation loss
- TSI-     target strength
- E1-     unalerted signal excess
- E2-     semi-alerted signal excess
- E3-     fully-alerted signal excess

# SINGLE SHIP MODEL

```

CALL URN(0)
COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
DIMENSION Q(3)
DO 2000 L=1,11
  READ(5,724)B
  FORMAT(F4.2)
  DO 1000 M=1,300
    S=M
    U=0
    D=V*P
    YC=SORT(RO**2-B**2)
    Y=0
    DI=URN(1)
    Y=YC-(V*P*DI)
    Y=Y-D
    U=U+1
    R=SQRT(Y**2+B**2)
    IF(R.GT.20.0) GO TO 160
    C=57.3*ATAN(Y/B)
    IF(R.LE.1.0) GO TO 200
    IF(R.LE.12.00) GO TO 210
    IF(R.LE.9.00) GO TO 220
    UFL=148.6+3.00*(R-9.00)
    GO TO 420
    UFL=80.0
    GO TO 420
    UFL=158.0
    GO TO 420
    UFL=93.4+7.00*(R-1.00)
    IF(W1.EQ.1) GO TO 510
    IF(R.LE.3.0) GO TO 470
    IF(R.GT.10.0) GO TO 490
    AL1=(.434294*39.0*ALOG(R))+51.0
    GO TO 580
    AL1=(.434294*20.0*ALOG(R))+60.0
    GO TO 580
    AL1=(.43294*51.0*ALOG(R))+39.0
    GO TO 580
    IF(R.LE.3.0) GO TO 550
    IF(R.GT.5.0) GO TO 570
    AL1=(.434294*48.8*ALOG(R))+55.7
    GO TO 580
    AL1=(.434294*32.8*ALOG(R))+63.0

```

724

160

200

210

220  
420

470

490

510

550

```

570 GO TO 580
580 AL1=(-.434294*72.0*ALOG(R))+40.0
      K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      SI=5.5
      GO TO 660
630 SI=6.0
      GO TO 660
650 SI=4.5
      DO 205 J=1,3
660 X=URN(1)
      A=SQRT((-2*ALOG(0.5*(1-ABS(1-2*X))))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+ (.001303*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
      Q(J)=Z
      CONTINUE
      FWL1=U*1+SI*Q(1)
      QWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E1=FN1+TS1-2.0*QWL1
      IF (Y.LE.-1.5) GO TO 801
      IF (E1.LE.0.0) GO TO 160
      YM=Y
      CALL SEMI(YM,YO,D,Y1,Y2,Y3)
      Y=YM
      R=SQRT(Y**2+B**2)
      C=57.3*ATAN(Y/B)
      WRITE(6,751)R,C
      FORMAT(751,F10.2,2X,F10.2)
1000 CONTINUE
2000 STOP
      END

SUBROUTINE SEMI (YM,YO,D,Y1,Y2,Y3)
COMMON/UNAL/T(18),RO,V,P,WI,S2,S3,B
DIMENSION Q(3)
Y=YM
Y=Y-D
U=U+1
R=SQRT(Y**2+B**2)
IF(R.GT.20.0) GO TO 160
C=57.3*ATAN(Y/B)

```

```

390 IF(R.LE.8.0) GO TO 390
410 IF(R.GT.15.0) GO TO 410
420 F1=(1.2*R)+139.4
      GO TO 420
      F1=(5.4*R)+105.8
      GO TO 420
      F1=157.4
      IF(MI.CQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434254*39.0*ALOG(R))+51.0
      GO TO 580
      AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
      AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
      IF(R.LE.3.0) GO TO 550
      IF(R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
      AL1=(.434294*32.0*ALOG(R))+63.0
      GO TO 580
      AL1=(.434294*72.0*ALOG(R))+40.0
      KE=((90-C)/10)+1.0
      IF(R.LE.3.0) GO TO 630
      IF(R.GT.15.0) GO TO 650
      S1=5.5
      GO TO 660
      S1=6.0
      GO TO 660
      S1=4.5
      GO TO 660
      DO 200 J=1,3
      X=URN(1)
      A=SQR(1-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF(X.GT.0.5) GO TO 770
      Z=-Z
      Q(J)=Z
      CONTINUE
      FM1=F1+S1*Q(1)
      ONL1=FM1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      IF(TS1-2.0*OWL1 801
      IF(Y.LE.-1.5) GO TO 160
      IF(E2.LE.0.0) GO TO 160
      YN=Y

```

```

801 CALL FULL (YM,YO,D,Y1,Y2,Y3)
RETURN
END

SUBROUTINE FULL (YM,YO,D,Y1,Y2,Y3)
COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,3
DIMENSION Q(3)
N=0.0
Y=YM
Y=Y-D
U=U+1
R=SQRT(Y**2+B**2)
C=57.3*ATAN(Y/B)
IF (R-LE.4.00) GO TO 245
IF (R-GT.6.50) GO TO 255
IF (R-GT.8.00) GO TO 265
FI=138.0+2.2*R
GO TO 420
FI=135.0+2.2*R
GO TO 420
FI=142.0+0.9*R
GO TO 420
FI=149.0+C.1*R
IF (W1-EQ.1) GO TO 510
IF (R-LE.3.0) GO TO 470
IF (R-GT.10.0) GO TO 490
AL1=(.434294*39.0*ALOG(R))+51.0
GO TO 580
AL1=(.434294*20.0*ALOG(R))+60.0
GO TO 580
AL1=(.434294*51.0*ALOG(R))+39.0
GO TO 580
IF (R-LE.3.0) GO TO 550
IF (R-GT.5.0) GO TO 570
AL1=(.434294*48.8*ALOG(R))+55.7
GO TO 580
AL1=(.434294*32.8*ALOG(R))+63.0
GO TO 580
AL1=(.434294*72.0*ALOG(R))+40.0
K=(90-C)/10+1.0
IF (R-LE.4.00) GO TO 625
IF (R-GT.6.50) GO TO 630
IF (R-GT.8.00) GO TO 650
SI=3.5
SI=3.1
GO TO 660
SI=3.1
GO TO 660

```

```

630 S1=3.4
GO TO 660
650 S1=3.0
660 DO 200 J=1,3
X=URN(1)
A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
A1=(A*(.013028*A+.802853))+2.515517
A2=1+A*(1.423788+A*(.189269+(.001308*A)))
Z=A-A1/A2
IF (X.GT.0.5) GO TO 770
Z=-Z
770 Q(J)=Z
CONTINUE
200 FMI=F1+S1*Q(1)
FMI1=F1+S2*Q(2)
FMI2=F1+S3*Q(3)
T31=T(K)+T31-2.0*OWL1
E3=FMI1+T31-1.5) GO TO 824
IF (Y.LE.-1.5) GO TO 160
YM=Y
824 RETURN
END

BLOCK DATA
COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
DATA T,RO,V,P,W1,S2,S3/9.,10.5,11.,10.5,11.,10.5,10.,11.,14.,18.,24.,24.,17
1.5,12.5,10.5,10.,10.,11.,10.,8.,20.,0.015,24.,2.,3.5,2.0/
END

```

# MULTI-SHIP MODEL

```

CALL URN(0)
COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
DIMENSION Q(3)
DO 1000 M=1,300
S=M
U=0
D=V*P
Y0=SQRT(RO**2-B**2)
Y=0
D1=URN(1)
Y=Y0-(V*P*D1)
Y=Y-D
U=U+1
R=SQRT(Y**2+B**2)
IF(R.GT.20.0) GO TO 160
C=57.3*ATAN(Y/B)
IF(R.LE.1.0) GO TO 200
IF(R.GE.12.00) GO TO 210
IF(R.LE.9.00) GO TO 220
UF1=148.6+3.00*(R-9.00)
GO TO 420
UF1=80.0
GO TO 420
UF1=158.0
GO TO 420
UF1=93.4+7.00*(R-1.00)
IF(W1.EQ.1) GO TO 510
IF(R.LE.3.0) GO TO 470
IF(R.GT.10.0) GO TO 490
AL1=(.434294*39.0*ALOG(R))+51.0
GO TO 580
AL1=(.434294*20.0*ALOG(R))+60.0
GO TO 580
AL1=(.43294*51.0*ALOG(R))+39.0
GO TO 580
IF(R.LE.3.0) GO TO 550
IF(R.GT.5.0) GO TO 570
AL1=(.434294*48.8*ALOG(R))+55.7
GO TO 580
AL1=(.434294*32.8*ALOG(R))+53.0
GO TO 580
AL1=(.434294*72.0*ALOG(R))+40.0
K=((90-C)/10)+1.0

```

160

200

210

220

420

470

490

510

550

570

580



```

1HIP, M RANGE',2X,'SHIP 1 RANGE',2X,'SHIP 2 RANGE ',2X,'SHIP 3 RAN
2GE')
WRITE (6,750)S,U,R,C,YM,Y1,Y2,Y3
750 FORMAT(15,F10.2,2X,F10.2,2X,F10.2,2X,F10.2,2X,F10.2,2X,F10.2,5X,F1
1000 30.2,2X,F10.2)
STOP
CONTINUE
END

```

```

SUBROUTINE SEMI (YM,YO,D,Y1,Y2,Y3)
COMMON/UNAL/T(18),RO,V,P,WI,S2,S3,B
DIMENSION Q(3)
Y=YM
Y=Y-D

```

```

160 U=U+1
R=SQRT(Y*2+B*2)
IF(R.GT.20.0) GO TO 160
C=57.3*ATAN(Y/8)
IF(R.LE.8.0) GO TO 390
IF(R.GT.15.0) GO TO 410
FI=(1.2*R)+139.4
GO TO 420
FI=(5.4*R)+105.8
GO TO 420
FI=157.4
IF(WI.EQ.1) GO TO 510
IF(R.LE.3.0) GO TO 470
IF(R.GT.10.0) GO TO 490
AL1=(.434294*39.0*ALOG(R))+51.0
GO TO 580
AL1=(.434294*20.0*ALOG(R))+60.0
GO TO 580
AL1=(.434294*51.0*ALOG(R))+39.0
GO TO 580
IF(R.LE.3.0) GO TO 550
IF(R.GT.5.0) GO TO 570
AL1=(.434294*48.8*ALOG(R))+55.7
GO TO 580
AL1=(.434294*32.8*ALOG(R))+63.0
GO TO 580
AL1=(.434294*72.0*ALOG(R))+40.0
K=((90-C)/10)+1
IF(R.LE.3.0) GO TO 630
IF(R.GT.15.0) GO TO 650
SI=5.5
GO TO 660
SI=6.0
GO TO 660
630

```

```

650      GO TO 660
660      S1=4.5      J=1,3
        DO 200 J=1,3
        X=URN(1)
        A=SQRT((-2*ALOG(0.5*(1-ABS(1-2*X))))))
        A1=(A*(.013028*A+.802853)))+2.515517
        A2=1+A*(1.423788+A*(.189269+ (.001308*A)))
        Z=A-A1/A2
        IF (X.GT.0.5) GO TO 770
        Z=-Z
        C(J)=Z
        CONTINUE
        FM1=FI+S1*Q(1)
        DM1=AL1+S2*Q(2)
        TS1=FM1+TS1-2.0*QWL1
        IF (Y.LE.-1.5) GO TO 801
        IF (E2.LE.0.0) GO TO 160
        YM=Y
        CALL FULL (YM,YO,D,Y1,Y2,Y3)
        RETURN
        END

770
200

801      SUBROUTINE FULL (YM,YO,D,Y1,Y2,Y3)
        COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
        DIMENSION Q(3)
        N=0.0
        Y=YM
        Y=Y-D
        U=U+1
        R=SQRT(Y**2+B**2)
        C=57.3*ATAN(Y/B)
        IF (R.LE.4.00) GO TO 245
        IF (R.GT.6.50) GO TO 255
        IF (R.GT.8.00) GO TO 265
        F1=138.0+2.2*R
        GO TO 420 + 2.2*R
        F1=135.420
        GO TO 420 + 0.9*R
        F1=142.0
        GO TO 420 + 0.1*R
        F1=149.0
        IF (W1.EQ.1) GO TO 510
        IF (R.LE.3.0) GO TO 470
        IF (R.GT.10.0) GO TO 490
        AL1=(.434254*39.0*ALOG(R))+51.0
        GO TO 580

```

```

470 AL1=(-.434294*20.0*ALOG(R))+60.0
GO TO 580
490 AL1=(-.43294*51.0*ALOG(R))+39.0
GO TO 580
510 IF (R.LE.3.0) GO TO 550
IF (R.GT.5.0) GO TO 570
AL1=(-.434294*48.8*ALOG(R))+55.7
GO TO 580
550 AL1=(-.434294*32.8*ALOG(R))+63.0
GO TO 580
570 AL1=(-.434294*72.0*ALOG(R))+40.0
K=((90-C)/10)+1.0
IF (R.LE.4.00) GO TO 625
IF (R.GT.6.50) GO TO 630
IF (R.GT.8.00) GO TO 650
S1=3.5
GO TO 660
625 S1=3.1
GO TO 660
630 S1=3.4
GO TO 660
650 S1=3.0
DO 200 J=1,3
X=URN(1)
A=SQRT((-2*ALOG(0.5*(1-ABS(1-2*X))))
A1=(A*(.013028*A+.802853))+2.515517
A2=1+A*(1.423788+A*(.189269+(-.001308*A)))
Z=A-A1/A2
IF (X.GT.0.5) GO TO 770
Z=-Z
Q(J)=Z
CONTINUE
FM1=FM1+S1*Q(1)
QWL1=AL1+S2*Q(2)
TS1=T(K)+S3*Q(3)
E3=FM1+TS1-2.0*QWL1
IF (Y.LE.-1.5) GO TO 824
IF (E3.LE.0.0) GO TO 160
YM=Y
824 CALL SHIP1(Y,Y0,D,Y1,Y2,Y3)
925 RETURN
END

```

```

SUBROUTINE SHIP1(Y,YO,D,Y1,Y2,Y3)
COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,3
DIMENSION Q(3)
D1=URN(1)
U=O.C
Y=YC-V*P*D1
Y=Y-D
U=U+1
R=SQR(T(Y**2+(B+8.0)**2)
C=57.3*ATAN(Y/(B+8.0))
IF (R.LE.1.0) GO TO 200
IF (R.GE.12.00) GO TO 210
IF (R.LE.9.00) GO TO 220
UF1=148.6+3.00*(R-9.00)
GO TO 420
UF1=80.0
GO TO 420
UF1=158.0
GO TO 420
UF1=93.4+7.00*(R-1.00)
IF (W1.EQ.1) GO TO 510
IF (R.LE.3.0) GO TO 470
IF (R.GT.10.0) GO TO 490
AL1=(.434294*39.0*ALOG(R))+51.0
GO TO 580
AL1=(.434294*20.0*ALOG(R))+60.0
GO TO 580
AL1=(.43294*51.0*ALOG(R))+39.0
GO TO 580
IF (R.LE.3.0) GO TO 550
IF (R.GT.5.0) GO TO 570
AL1=(.434294*48.8*ALOG(R))+55.7
GO TO 580
AL1=(.434294*32.8*ALOG(R))+63.0
GO TO 580
AL1=(.434294*72.0*ALOG(R))+40.0
K=((90-C)/10)+1.0
IF (R.LE.3.0) GO TO 630
IF (R.GT.15.0) GO TO 650
S1=5.5
GO TO 660
S1=6.0
GO TO 660
S1=4.5
GO TO 660
DO 205 J=1,3
X=URN(1)
A=SQR(T(-2*ALOG(0.5*(1-ABS(1-2*X))))
AL1=A*(.013028*A+.802853))+2.515517

```

160

200

210

220

420

470

490

510

550

570

580

630

650

660

```

A2=1+A*(1.423788+A*(.189269+(.001308*A)))
Z=A-A1/A2
IF (X.GT.0.5) GO TO 770
Z=-Z
Q(J)=Z
CONTINUE
FMI=UFI+S1*Q(1)
QWL1=AL1+S2*Q(2)
TSI=T(K)+S3*Q(3)
EI=FMI+TSI-2.0*QWL1
IF (Y.LE.-1.5) GO TO 801
IF (EI.LE.0.0) GO TO 160
Y1=Y
CALL SEM11 (Y,YO,D,Y1,Y2,Y3)
801 RETURN
END

```

```

SUBROUTINE SEM11(Y,YO,D,Y1,Y2,Y3)
COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
DIMENSION Q(3)
Y=Y1

```

```

160 Y=Y-D
161 U=U+1
R=SQR(T(Y**2+(B+8.0)**2))
IF (R.GT.20.0) GO TO 160
C=57.3*ATAN(Y/(B+8.0))
IF (R.LE.8.0) GO TO 390
IF (R.GT.15.0) GO TO 410
F1=(1.2*R)+139.4
GO TO 420
390 F1=(5.4*R)+105.8
GO TO 420
410 F1=157.4
GO TO 510
420 IF (W1.EQ.1) GO TO 510
IF (R.LE.3.0) GO TO 470
IF (R.GT.10.0) GO TO 490
AL1=(-.434294*39.0*ALOG(R))+51.0
GO TO 580
470 AL1=(-.434294*20.0*ALOG(R))+60.0
GO TO 580
490 AL1=(-.434294*51.0*ALOG(R))+39.0
GO TO 580
510 IF (R.LE.3.0) GO TO 550
IF (R.GT.5.0) GO TO 570
AL1=(-.434294*48.8*ALOG(R))+55.7
GO TO 580
550 AL1=(-.434294*32.8*ALOG(R))+63.0

```

```

570 GO TO 580
580 AL1=((.434294*72.0*ALOG(R))+40.0
      K=((90-C)/10)+1.0
      IF (P.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
      SI=5.5
      GO TO 660
630 SI=6.0
      GO TO 660
650 SI=4.5
      GO TO 660
660 DC=URN(1) J=1,3
      X=SQRT((-2*ALOG(0.5*(1-ABS(1-2*X))))).
      A1=(A+(-.013028*A+.802853))*2.51551.
      A2=1+A*(1.423788+A*(.139269*(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770 C(J)=Z
      CONTINUE
      UWL1=FI+S1*Q(1)
      YSI=AL1+S2*Q(2)
      TS1=T(X)+S3*Q(3)
      E2=FM1+TS1-2.0*OWL1
      IF (E2.LE.0.0) GO TO 160
      YI=Y
      CALL FULL1 (Y,YO,D,Y1,Y2,Y3)
      RETURN
      END

160 SUBROUTINE FULL1(Y,YO,D,Y1,Y2,Y3)
COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
DIMENSION Q(3)
N=0.0
Y=Y1
Y=Y-D
U=U+1
R=SQRT(Y**2+(B+8.0)**2)
IF (R.GT.20.0) GO TO 160
C=57.3*ATAN(Y/(B+8.0))
IF (R.LE.4.00) GO TO 245
IF (R.GT.6.50) GO TO 255
IF (R.GT.8.00) GO TO 265
FI=138.0+2.2*R
GO TO 420
FI=135.0+2.2*R
245

```





```

650 S1=4.5 J=1,3
660 DO 205 J=1,3
X=UPN(1)
A1=SQRT((-2*ALOG(0.5*(1-ABS(1-2*X))))))
A2=1+A*(-0.13028*A+.802853)))+2.515517
Z=A-A1/A2
IF (X.GT.0.5) GO TO 770
Z=-Z
C(J)=Z
CONTINUE
QW1=UPN1+S1*Q(1)
TS1=T(K1+S3*Q(3))
IF (Y.LE.-1.5) GO TO 801
IF (Y.LE.0.0) GO TO 160
Y2=Y
CALL SEMI2 (Y,Y0,D,Y1,Y2,Y3)
RETURN
END

```

```

SUBROUTINE SEMI2(Y,Y0,D,Y1,Y2,Y3)
COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
DIMENSION Q(3)
Y=Y2
Y=Y-D
U=U+1
R=SQRT(Y**2+(4.0-B)**2)
IF (R.GT.20.0) GO TO 160
C=57.3*ATAN(Y/(4.0-B))
IF (R.LE.8.0) GO TO 390
IF (R.GT.15.0) GO TO 410
FI=(1.2*R)+139.4
GO TO 420
FI=(5.4*R)+105.8
GO TO 420
FI=157.4
IF (W1.EQ.1) GO TO 510
IF (R.LE.3.0) GO TO 470
IF (R.GT.10.0) GO TO 480
AL1=(-4.34274*39.0*ALOG(R))+51.0
GO TO 580
AL1=(-4.24294*20.0*ALOG(R))+60.0
GO TO 580
AL1=(-4.32794*51.0*ALOG(R))+39.0
GO TO 580

```

```

160
161
390
410
420
470
490

```

```

510 IF (R.LE.3.0) GO TO 550
    IF (R.GT.5.0) GO TO 570
    AL1=(.434294*48.8*ALOG(R))+55.7
    GO TO 580
550 AL1=(.434294*32.8*ALOG(R))+63.0
    GO TO 580
570 AL1=(.434294*72.0*ALOG(R))+40.0
580 K=(90-C)/10+1.0
    IF (R.LE.3.0) GO TO 630
    IF (R.GT.15.0) GO TO 650
    S1=5.5
    GO TO 660
630 S1=6.0
    GO TO 660
650 S1=4.5
660 DO 200 J=1,3
    X=URN(1)
    A=SQR((-2*ALOG(0.5*(1-ABS(1-2*X))))))
    A1=(A*(.013028*A+.802853))+2.515517
    A2=A1+A*(1.423788+A*(-.189269+((.001308*A))))
    Z=A-A1/A2
    IF (X.GT.0.5) GO TO 770
    Z=-Z
    Q(J)=Z
    CONTINUE
200 FMI=F1+S1*Q(1)
    OWL1=AL1+S2*Q(2)
    IS1=OWL1+K+S3*Q(3)
    F2=FMI+IS1-2.0*OWL1
    IF (Y.LE.-1.5) GO TO 801
    IF (E2.LE.0.0) GO TO 160
    Y2=Y
    CALL FULL2 (Y,YQ,D,Y1,Y2,Y3)
    RETURN
801 END

SUBROUTINE FULL2(X,YQ,D,Y1,Y2,Y3)
COMMON/UNAL/T(I8),RO,V,P,WI,S2,S3,B
DIMENSION Q(3)
N=0.0
Y=Y2
Y=Y-D
U=U+1
R=SQR(1+(Y**2+(4.0-B)**2))
IF (R.GT.20.0) GO TO 160
C=57.3*ATAN(Y/(4.0-B))
IF (R.LE.4.00) GO TO 245

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245 IF (R.GT.6.50) GO TO 255
    IF (R.GT.8.00) GO TO 265
    F1=138.0+2.2*R
    GO TO 420
255 F1=135.0+2.2*R
    GO TO 420
265 F1=142.0+0.9*R
    GO TO 420
420 F1=149.0+0.1*R
    IF (M1.EQ.1) GO TO 510
    IF (R.LE.3.0) GO TO 470
    IF (R.GT.10.0) GO TO 490
    AL1=(-.434294*39.0*ALOG(R))+51.0
    GO TO 580
470 AL1=(-.434294*20.0*ALOG(R))+60.0
    GO TO 580
490 AL1=(-.43294*51.0*ALOG(R))+39.0
    GO TO 580
510 IF (R.LE.3.0) GO TO 550
    IF (R.GT.5.0) GO TO 570
    AL1=(-.434294*48.8*ALOG(R))+55.7
    GO TO 580
550 AL1=(-.434294*32.8*ALOG(R))+63.0
    GO TO 580
570 AL1=(-.434294*72.0*ALOG(R))+40.0
    K=((90-C)/10)+1.0
    IF (R.LE.4.00) GO TO 625
    IF (R.GT.6.50) GO TO 630
    IF (R.GT.8.00) GO TO 650
    S1=3.5
    GO TO 660
625 S1=3.1
    GO TO 660
630 S1=3.4
    GO TO 660
650 S1=3.0
    DO 200 J=1,3
    X=URN(J)
    A=SQRT((-2*ALOG(0.5*(1-ABS(1-2*X))))
    A1=(A*(-.013028*A+.802853))+2.515517
    A2=1+A*(1.423783+A*(.189269+(-.001308*A)))
    Z=A-A1/A2
    IF (X.GT.0.5) GO TO 770
    Z=-Z
770 Q(J)=Z
200 CONTINUE
    FMI=F1+S1*Q(1)
    OWLI=AL1+S2*Q(2)

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824 TS1=T(K)+S3*Q(3)
      E3=FM1+TS1-2.0*OWL1
      IF (E3.LE.0.0) GO TO 160
825 Y2=Y
      CALL SHIP3(Y,YO,D,Y1,Y2,Y3)
      RETURN
      END

      SUBROUTINE SHIP3(Y,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      U=0.0
      D1=URN(1)
      Y=Y0-V*P*D1
      Y=Y-D
      U=U+1
      R=SQRT(Y**2+(B+4.0)**2)
      C=57.3*ATAN(Y/(B+4.0))
      IF (R.LE.1.0) GO TO 200
      IF (R.GE.12.00) GO TO 210
      IF (R.LE.9.00) GO TO 220
      UF1=148.6+3.00*(R-9.00)
      GO TO 420
      UF1=80.0
      GO TO 420
      UF1=158.0
      GO TO 420
      UF1=93.4+7.00*(R-1.00)
      IF (M1.EQ.1) GO TO 510
      IF (R.LE.3.0) GO TO 470
      IF (R.GT.10.0) GO TO 490
      AL1=(-.434294*39.0*ALOG(R))+51.0
      GO TO 580
      AL1=(-.434294*20.0*ALOG(R))+60.0
      GO TO 580
      AL1=(-.43294*51.0*ALOG(R))+39.0
      GO TO 580
      IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(-.434294*48.8*ALOG(R))+55.7
      GO TO 580
      AL1=(-.434294*32.8*ALOG(R))+63.0
      GO TO 580
      AL1=(-.434294*72.0*ALOG(R))+40.0
      K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650

```

```

630 S1=5.5
GO TO 660
650 S1=6.0
GO TO 660
660 S1=4.5
DO 205 J=1,3
X=URN(1)
A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
A1=(A*(.013028*A+.802853))+2.515517
A2=1+A*(1.423788+A*(.189269*(.001308*A)))
Z=A-A1/A2
IF (X.GT.0.5) GO TO 770
Z=-Z
Q(J)=Z
CONTINUE
FMI=UFI+S1*Q(1)
QWLI=ALI+S2*Q(2)
TSI=T(K)+S3*Q(3)
EI=FMI+TSI-2.0*QWLI
IF (Y.LE.-1.5) GO TO 801
IF (EI.LE.0.0) GO TO 160
Y3=Y
CALL SEMI3 (Y,Y0,D,Y1,Y2,Y3)
801 RETURN
END

```

```

160 SUBROUTINE SEMI3(Y,Y0,D,Y1,Y2,Y3)
COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
DIMENSION Q(3)
Y=Y3
U=Y-D
U=U+1
R=SQRT(Y**2+(B+4.0)**2)
IF (R.GT.20.0) GO TO 160
C=57.3*ATAN(Y/(B+4.0))
IF (R.LE.8.0) GO TO 390
IF (R.GT.15.0) GO TO 410
FI=(1.2*R)+139.4
GO TO 420
FI=(5.4*R)+105.8
GO TO 420
FI=157.4
IF (W1.EQ.1) GO TO 510
IF (R.LE.3.0) GO TO 470
IF (R.GT.10.0) GO TO 490
ALI=(.434294*39.0*ALOG(R))+51.0
GO TO 580
390
410
420
510
580

```

```

470 AL1=(.434294*20.0*ALOG(R))+60.0
GO TO 580
490 AL1=(.43294*51.0*ALOG(R))+39.0
GO TO 580
510 IF (R.LE.3.0) GO TO 550
IF (R.GT.5.0) GO TO 570
AL1=(.434294*48.8*ALOG(R))+55.7
GO TO 580
550 AL1=(.434294*32.8*ALOG(R))+63.0
GO TO 580
570 AL1=(.434294*72.0*ALOG(R))+40.0
580 K=((90-C)/10)+1.0
IF (R.LE.3.0) GO TO 630
IF (R.GT.15.0) GO TO 650
S1=5.5
GO TO 660
630 S1=6.0
GO TO 660
650 S1=4.5
GO TO 660
660 DO 200 J=1,3
X=URN(1)
A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
AL1=(A*(.013028*A+.802853))+2.515517
A2=1+A*(1.423788+A*(-.189269+(-.001308*A)))
Z=A-A1/A2
IF (X.GT.0.5) GO TO 770
Z=-Z
Q(J)=Z
CONTINUE
FM1=FM1+S1*Q(1)
QWL1=AL1+S2*Q(2)
TS1=T(K)+S3*Q(3)
E2=FM1+TS1-2.0*QWL1
IF (Y.LE.-1.5) GO TO 801
IF (E2.LE.0.0) GO TO 160
Y3=Y
801 CALL FULL3 (Y,Y0,D,Y1,Y2,Y3)
RETURN
END

SUBROUTINE FULL3(Y,Y0,D,Y1,Y2,Y3)
COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
DIMENSION Q(3)
N=0.0
Y=Y3
160 Y=Y-G
161 R=SQRT(Y**2+(B+4.0)**2)

```

```

U=U+1
IF(R.GT.20.0) GO TO 160
C=57.3*ATAN(Y/(8+4.0))
IF(R.LE.4.00) GO TO 245
IF(R.GT.6.50) GO TO 255
IF(R.GT.8.00) GO TO 265
F1=138.0+2.2*R
GO TO 420
F1=135. + 2.2*R
GO TO 420
F1=142.0 + 0.9*R
GO TO 420
F1=149.0+0.1*R
GO TO 510
IF(WI.EQ.1) GO TO 510
IF(R.LE.3.0) GO TO 470
IF(R.GT.10.0) GO TO 490
AL1=(.434294*39.0*ALOG(R))+51.0
GO TO 580
AL1=(.434294*20.0*ALOG(R))+60.0
GO TO 580
AL1=(.43294*51.0*ALOG(R))+39.0
GO TO 580
IF(R.LE.3.0) GO TO 550
IF(R.GT.5.0) GO TO 570
AL1=(.434294*48.8*ALOG(R))+55.7
GO TO 580
AL1=(.434294*32.8*ALOG(R))+63.0
GO TO 580
AL1=(.434294*72.0*ALOG(R))+40.0
K=((90-C)/10)+1.0
IF(R.LE.4.00) GO TO 625
IF(R.GT.6.50) GO TO 630
S1=3.560
GO TO 660
S1=3.1660
GO TO 660
S1=3.4660
GO TO 660
S1=3.0
DO 200 J=1,3
X=URNC(I)-2*ALOG(0.5*(1-ABS(1-2*X)))
A1=(A*(.013028*A*.802853))+2.515517
A2=1+A*(1.423788*A*(.189269*(.001308*A)))
Z=A-A1/A2
IF(X.GT.0.5) GO TO 770
Z=-Z

```

245  
255  
265  
420  
470  
490  
510  
550  
570  
580  
625  
630  
650  
660



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