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A HOMING TORPEDO
THE EFFECT OF THE TACTICAL SITUATION
AND THE TORPEDO PARAMETERS
ON THE TORPEDO EFFECTIVENESS.

Anders Mjelde

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

A HOMING TORPEDO.

THE EFFECT OF THE TACTICAL SITUATION AND THE
TORPEDO PARAMETERS ON THE TORPEDO EFFECTIVENESS

by

Anders Mjelde

September 1977

Thesis Advisor: A. R. Washburn

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PARAMETERS
ON THE TORPEDO EFFECTIVENESS

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the
NAVAL POSTGRADUATE SCHOOL
September 1977

ABSTRACT

When designing an active sonar homing torpedo, certain operational torpedo parameters such as speed, turn rate, etc. have to be decided upon. For a given homing torpedo, there must exist tactical guidelines of how to employ the torpedo, i.e. which firing position gives the best chance of a hit. This thesis attempts to gain some insight into the detection process during the torpedo run, as well as getting some indications of the relative importance of the different torpedo parameters and the tactical situations. A simulation model was used in order to generate the data base for analysis. The results stress the importance of a good firing position as well as show how it is possible to counter a bad firing position by a high speed torpedo. They also point to the importance of having only one detection as requirement for target acquisition.

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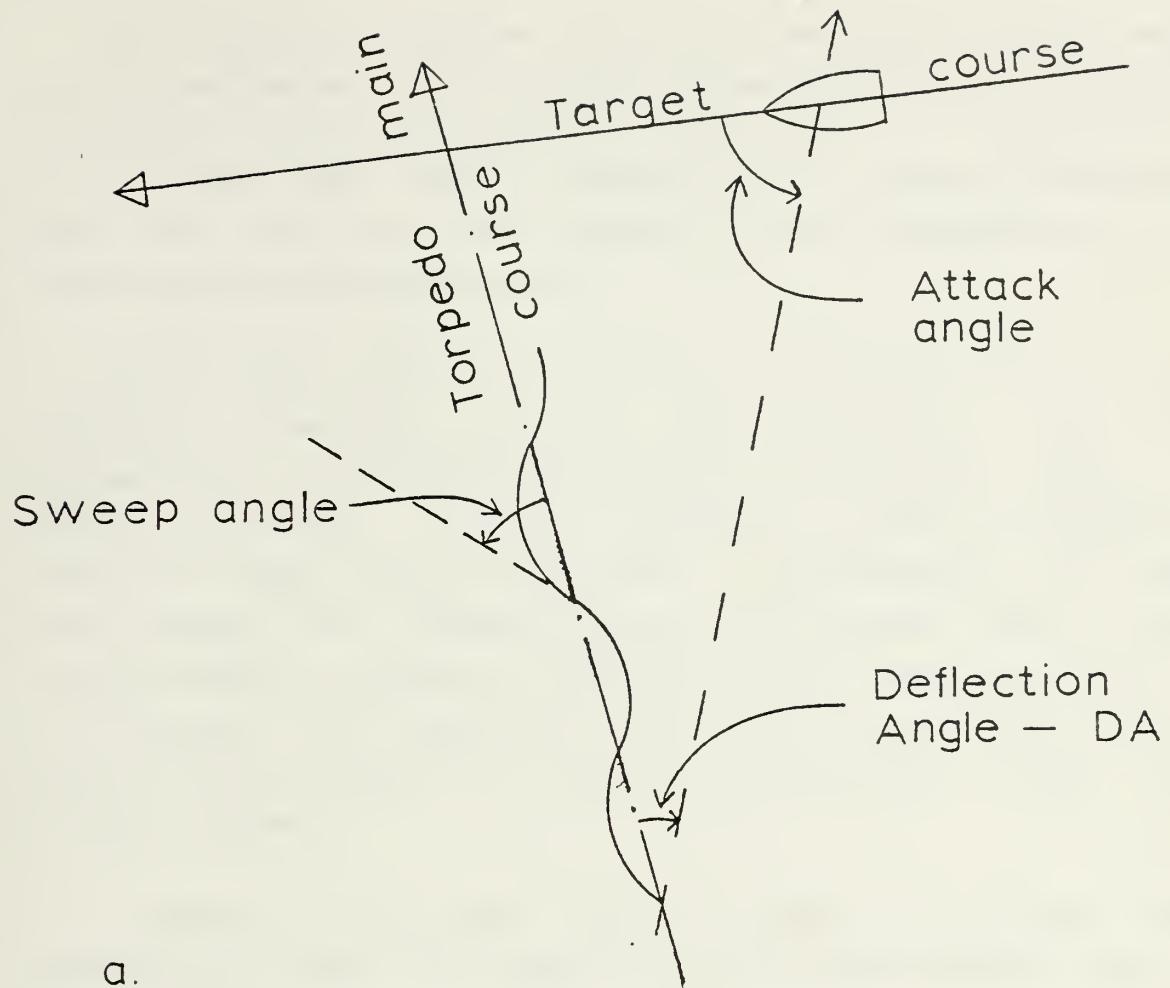
I. INTRODUCTION

The following analysis examines the performance of a homing torpedo against a surface ship. A homing torpedo is described as a torpedo which is searching/snaking on each side of its main course. It is searching for a target by transmitting with its sonar and listening for an echo. Ref. Fig. 1. Passive searching torpedoes and homing torpedoes going in circles are not investigated in this paper.

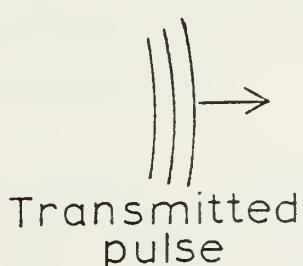
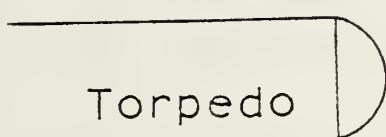
The torpedo's performance is a function of many variables. These variables are divided into two groups;

- technical variables; speed, max torpedo run, sweep angle, technical detection range, lobe characteristics and turn rate.
- tactical variables ; firing range, attack angle, target speed, type of target and tactical detection range (sonar conditions).

No attempt is made to analyze the first group of variables; instead, technical variables used are those of present technology. We are assuming a 'standard homing torpedo' based upon homing torpedoes in operational use today [8]. This 'standard torpedo' assumes conventional warhead and active sonar transmission for detection., and is unguided.



a.



b.

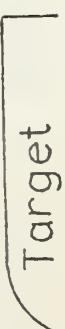


Figure 1 - A HOMING TORPEDO

The technical variables (torpedo parameters) are in many ways interrelated. For example, the maximum detection range will determine the transmission rate, since the transmitted energy must have time to traverse out to maximum detection range and return as an echo before the next transmission, at least during the search phase.

At the same time the torpedo is transmitting, it is searching (changing course) for a target. In each transmission, the transmitted energy is focused within a narrow beam(lobe). During reception, the echo is confined within the same narrow beam(lobe). Concurrently, in the time between two transmissions the turning rate of the torpedo must be limited to ensure that the receiving lobe is not outside the direction from where an echo may return. Thus turn rate should be a function of detection range and the lobe pattern.

In order to maintain torpedo speed, the number of degrees of sweep on each side of the main course must be small. If the sweepangle is small, however, the width of the possible detection lane will be small as well, and consequently the detection probability might be reduced during transit. Also, a high torpedo speed creates a great change in torpedo position between each transmission. In this way the torpedo may scan outside a target in the sweep lane. In other words, the coverage density of the lobe may be low as a result of the high movement rate.

As we recognize the relationship between torpedo parameters, tactical variables and torpedo performance, we know that frequently within the naval establishment decisions have to be made with regard to torpedo parameters and tactical doctrines. In localizing and defining these relationships this analysis may be a tool in this

decision process.

The measure of effectiveness by which different alternatives will be judged will be detection probability, by which is meant the probability that the torpedo's active sonar detects and begins to track the target. This probability will be measured by a digital computer simulation, construction of which was a major part of the author's effort in writing this thesis.

III. NATURE OF THE PROBLEM

A. DEFINITIONS

Lobe width is the number of degrees from the centerheading of the torpedo, until the first minimum in transmission intensity is reached. See Fig. 4.

Detection range is the range to the target when detection first occurs.

Technical detection range is the max detection range which is technically and reasonably possible considering power transmitted and lobewidth. It is the basis for determining the transmission rate.

Aspect is the angle measured from the positive direction of the longitudinal axis of the target to a line joining the centers of gravity of the target and the torpedo.

Attack angle is the aspect at the start of the torpedo run.

Sweep angle is the maximum number of degrees the torpedo will turn off the main course during search.

All dimensions are in meter, second, meter per second, degree, degree per second. Speed of the target and the torpedo are, however, always given in knots.

It is assumed that all firings are successful, and the torpedo will not deviate from its ordered/calculated course and speed.

All firings are made with a deflection angle; i.e. the torpedo is given a course to a predicted hitting point with the target.

B. ASSUMPTIONS

Not only in order to keep the problem tractable, but also because of modern torpedo development, only surface targets are considered. Previously within NATO, torpedo developments seemed to start as a development of an anti-submarine torpedo with later modifications in order to make the torpedo dual purpose. However, today there are some indications that the anti-surface ship requirement is coming into the development early in the planning process [7;8;9]. The entire problem is then kept in two dimensions. The vertical axis is not significant as we assume isovelocity condition, and we assume for simplicity that we have negligible surface effect.

Also, if the intensity of the echo is above detection threshold level, the target is detected with probability one. Probability of false contact is assumed to be zero.

The main purpose of a homing torpedo is to counter uncertainty in target data at firing and target maneuvering after firing.

For simplicity the following assumptions are made:

- the target remains on a steady course after firing.
- estimated target data is used in solving the deflection angle problem

- deflection angle (DA) is given by;

$$DA = \text{ARCSIN}((TAM \times \text{SIN}(ASP)) / TO) \quad (2.1)$$

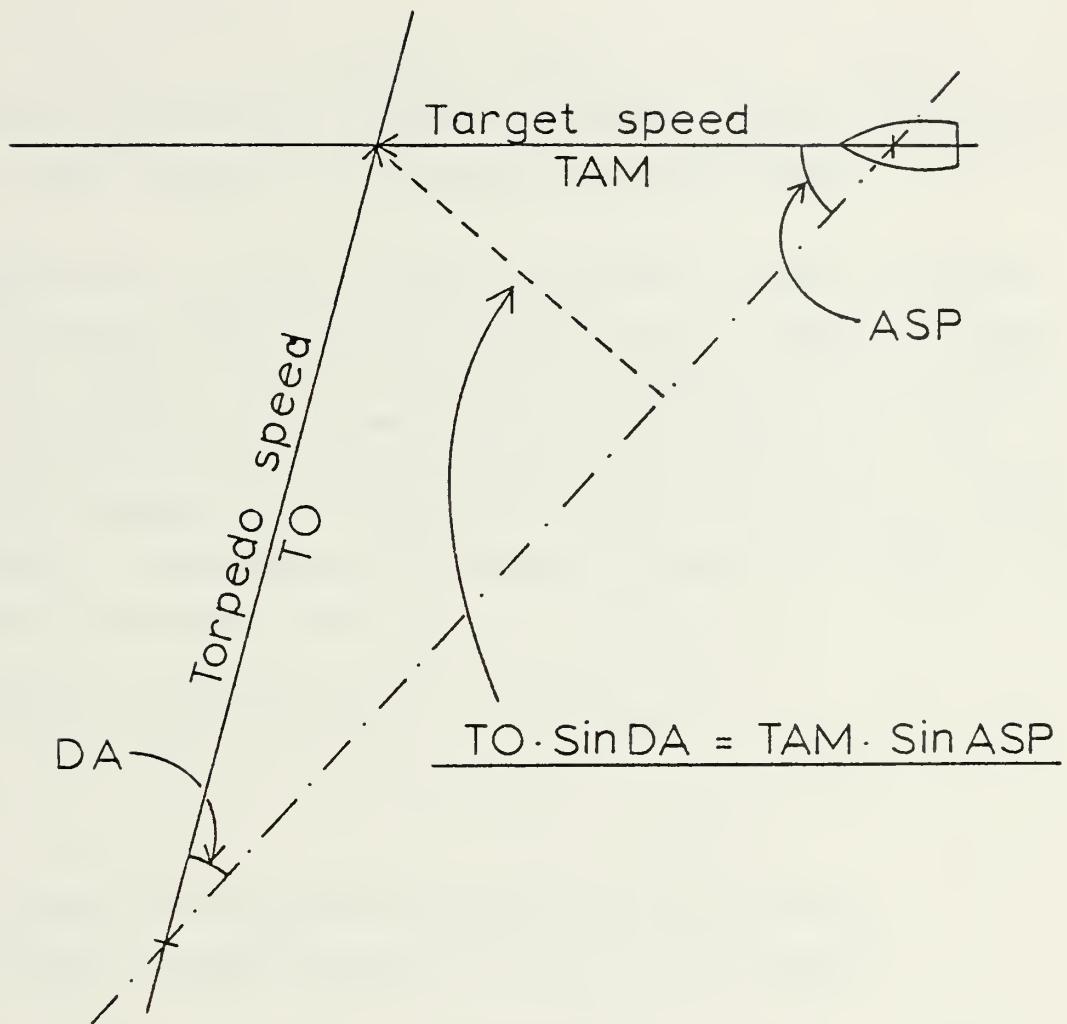
See Fig. 2.

The difference between the target data and the target estimated data are defined as errors in the target data. These errors are assumed to be random variates and are given as:

- target range error is uniformly distributed between - 15 % and + 15 % of actual target range
 - target course error is uniformly distributed between - 15 and + 15 degrees
 - target speed error is normally distributed with mean 0 and standard deviation 3 knots.

These errors are assumed to cover errors in the fire control solution at the time of firing as well as non-radical maneuvering of the target during the torpedo run.

As shown in Eq. 2.1, estimated range does not enter into the calculation. Estimated range would only be used for some more complicated tactical situations as angled torpedo firing off the firing course of the firing unit. These situations are not covered in this study.



ASP — Estimated Attack angle

DA — Deflection angle

Figure 2 - TORPEDO TRIANGLE

III. PROBLEM SOLVING APPROACH

At firing, the initial course of the torpedo is uniformly distributed between minimum course and maximum course (main course +/- a fraction of sweep angle).

Immediately after firing, the torpedo starts 'snaking'. During snaking, the torpedo is continuously changing course left or right out to the given sweepangle, then back past main course and out to sweepangle on the other side and so on. The torpedo is turning with the given turnrate. During the whole process, the torpedo is also transmitting and listening. Transmission interval(TTIME) is given by technical detection range as;

$$TTIME = 2 \times TEDEC/1500 \quad \text{seconds} \quad (3.1)$$

where

TEDEC = technical detection range in meters.

1500 = speed of sound in salt water, m/sec.

The torpedo run is conducted in steps. Every 0.5 seconds interval, all positions and courses are updated.

At each transmission; the relative bearing to target, and the target aspect are calculated in order to establish the intensity of the echo.

When a detection occurs, the following data is stored;

- detection range to the center of the target.

- detection range to the nearest part of the target.
- detection bearing (relative) to the center of the target.
- detection bearing(relative) to the nearest part of the target.
- target aspect.

In addition to the detection probability, the range at which the detection first occurs is also of interest. Therefore, we store these data at the first detection.

However, successive detections are also important. As part of the criterion for the decision of when to go from search-phase to attack-phase, the number of successive detections (with no non-detection between) may be employed. In real life there is always a positive probability of false detection. Even if we are not addressing the problem of false contact as such, we can cover the possibility by requiring the torpedo to have at least two successive detections before going into attack-phase. Accordingly, we store also the previously listed data at the second successive detection(two immediately following detections), at the third and so on, up to and including 5 successive detections. This listing of detections will give an indication of the decrease in detection probability if a large number of successive detections before going into attack-phase is required in order to decrease the probability of false contacts.

IV. MODEL

A. SEARCH

For simulating the torpedo search, a Fortran IV simulation program was developed.

The program was divided into;

- Main program, including generation of statistics and print out of summary after all the runs were completed.
- Subroutine PARMET for setting tactical situation and torpedo parameters.
- Subroutine FIRING which calculates estimated target data, and the deflection angle.
- Subroutine POSIS which calculates the torpedo course, and torpedo and target positions at each time step.
- Subroutine DETECT which checks if the target is detected and if so, store detection data.

See Fig. 3.

See Appendix A and Appendix B.

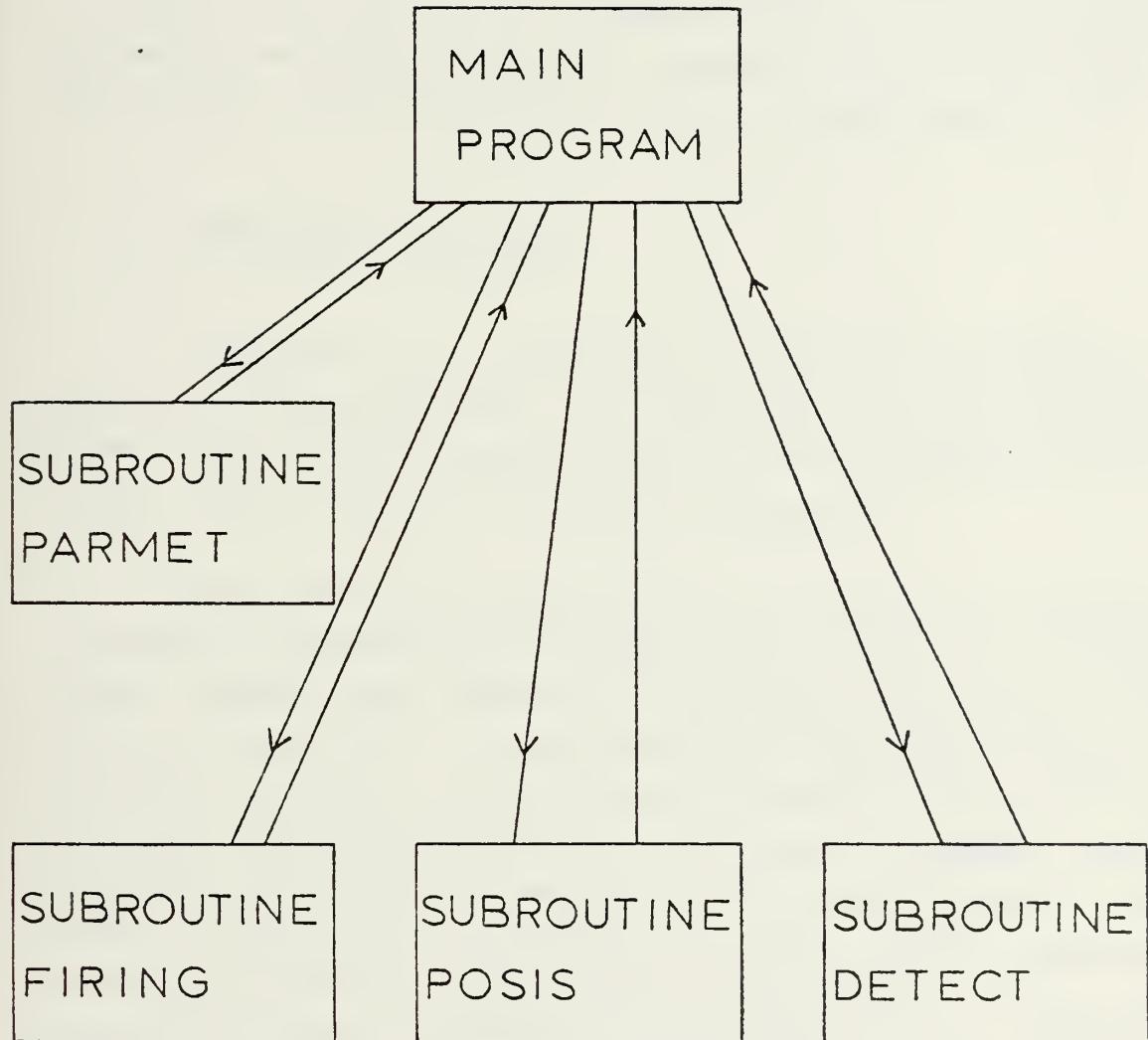


Figure 3 - STRUCTURE OF COMPUTER PROGRAM

B. DETECTION MODEL

A contact occurs when the acoustic energy-pulse generated at the transducer and reflected from the target as an echo, is at or above threshold level. In the following discussion we assume that the contact meets the tactical requirement, and accordingly we use the term detection.

1. Detection Threshold

Deciding if a detection occurs is a function of detection threshold(signal to noise ratio), the range to the target, the target strength and the relative bearing to the target, given a level of radiated intensity.

The detection threshold for a torpedo is a function of design and technological sophistication of the torpedo. Without making any assumption about these variables in the model, we start with a given technical detection range, a 'standard' target, and calculate intensity of echo at that range for target aspect equal to 90 degrees(maximum target strength) and relative bearing to the target equal to zero degrees. This echo intensity is then the detection threshold for every transmission during a run. If any echo intensity is above the detection threshold, it is detected; if below the detection threshold, it is not detected.

2. Echo Intensity

In calculating echo intensity we must separately investigate the important factors, which are transducer

gain, lobe characteristic, transmission loss and target strength. The model used is described below.

a. Lobe Characteristics

The transducer has a main lobe and many sidelobes as a function of the transducer's gain and relative bearing. Urick [6;51-57] discusses some of the different types of beam pattern (lobes), and the following mathematical model was developed and found to give an acceptable pattern;

$$G(\theta) = G_0 \left| \frac{\sin(x\pi)}{x\pi} \right| \cos(\theta/2) \quad (4.1)$$

where

$$x = \theta/\theta_0 \quad (4.2)$$

and

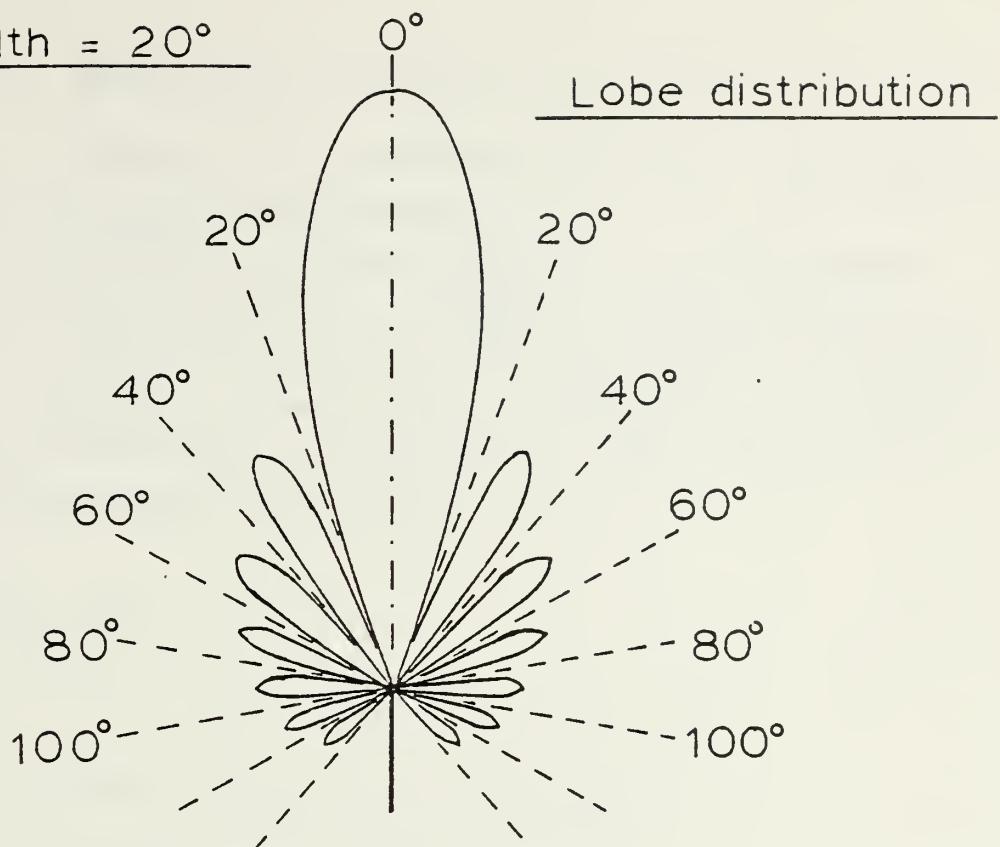
G_0 = maximum gain

θ = relative bearing

θ_0 = lobe width.

This model will produce the gain-pattern as shown in fig. 4.

Lobe width = 20°



Intensity distribution

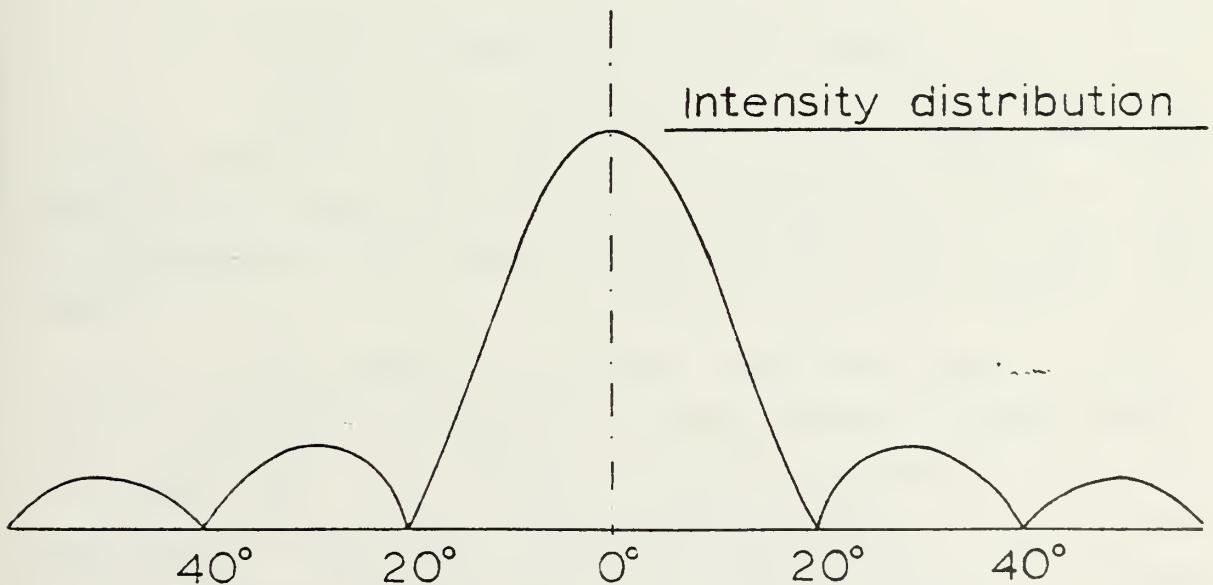


Figure 4 - DISTRIBUTION OF LOBES AND INTENSITY

b. Reduction in Intensity due to Range

Primarily, the reduction is due to two effects; spherical spreading and absorption.

Spherical spreading is a known function, but absorption is dependent upon transmission frequencies, water, salinity etc. In order to simplify the model and since spherical spreading has the greatest effect, only the spherical spreading for reduction in intensity is considered. This reduction in a one way propagation is given by;

$$I = I_0 / R^2 \quad (4.3)$$

where

I_0 = radiated intensity at one meter

I = intensity at range R .

R = range in meters.

c. Target Strength and Target Aspect

When the transmitted energy pulse hits the target, some of the energy is reflected back to the transducer. The echo intensity is a function of the shape and dimension of the target, type of reflective material and aspect.

It should be noted that the notion of target strength represents the ratio between target cross section and the surface of a sphere of radius 1 meter, or if in dB, 10 times the log of this ratio; base 10. In most references, the target strength or the target cross section is given abeam of the target, see [5;97],[6;274], without presenting the cross section as a function of the aspect. Urick [6;282,283] gives, however, as figures, an indication

of how the target strength(in dB) varies with the aspect. Cox[3;60] states that it will vary between 10 and 25 dB. All measurements in dB in the two references are relative to 1 yard as unit for range. Urick[6;283-286] indicates that his reference (as given in the figures) will not change in any considerable degree with changes in frequencies (20-60 KHz) or for different targets(submarines/surface ships).

Assuming a torpedo with transmitting frequency between 50 and 60 KHz, we get a wavelength varying between 2.5 and 3.0 cm(0.025 - 0.03 meters). As any reflection from a target is mostly determined by target form, size, aspect and wavelength, we may use a model from radar theory in our next step. The justification for this use is that in radar theory we are working in the same area of wavelength and target dimension as an active sonar for a homing torpedo.

Crispin and Siegel [4;86] give for target cross section a model for an ellipsoid where the incident angle(target aspect) is a variable. The relationship is as follows;

$$\sigma = \frac{\pi \cdot a^2 \cdot b^2 \cdot c^2}{(a^2 \cdot \sin^2 \theta \cdot \cos^2 \phi + b^2 \cdot \sin^2 \theta \cdot \sin^2 \phi + c^2 \cdot \cos^2 \theta)^2} \quad (4.4)$$

a, b, c being half axes of the ellipsoid.

Ref. Fig. 5.

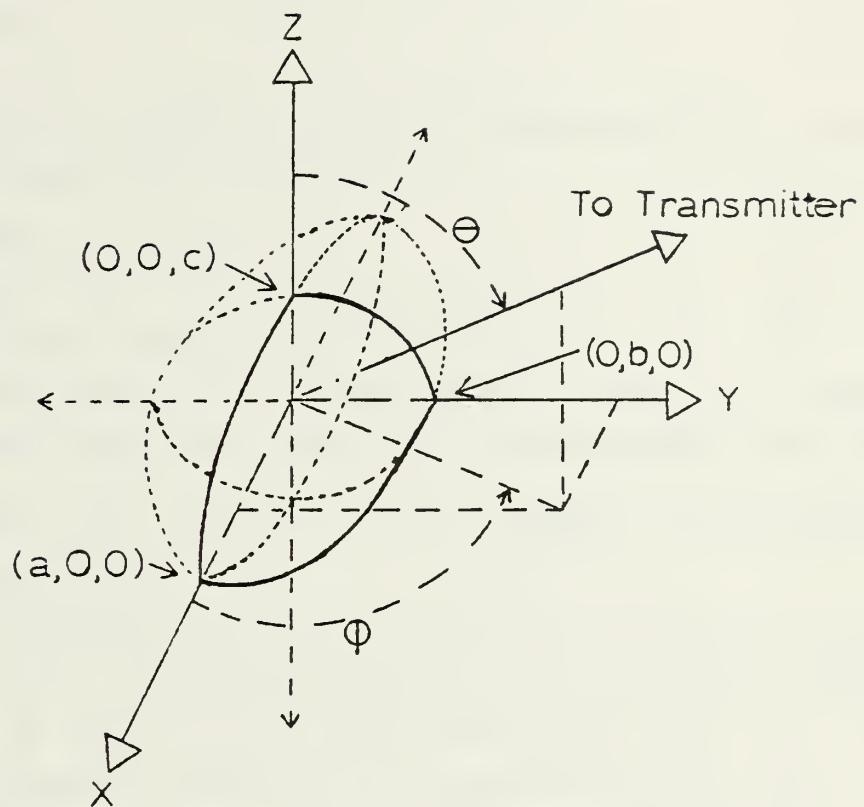


Figure 5 - MODEL OF TARGET AND TARGET ASPECT

As we assume that the transmitting pulse is always in the horizontal plane, θ is 90 degrees, which gives us;

$$\sigma = \frac{\pi \cdot a^2 \cdot b^2 \cdot c^2}{(a^2 \cdot \cos^2 \phi + b^2 \cdot \sin^2 \phi)^2} \quad (4.5)$$

ϕ = aspect.

Urick [6;275] gives for target section a model for abeam or ahead cases, which is;

$$t = \sigma / (4\pi) = (b \cdot c / 2 \cdot a)^2,$$

identical with Eq. 4.5. Note that Eq. 4.5 is an expression for the target cross section.

Haslett [5;139] gives for the target cross section a model for both ahead and abeam cases. His model equals Eq. 4.5 times a factor R^2 , where R is acoustic reflectivity coefficient (per cent) = 94.

The advantage of using Eq. 4.5 is that it gives the target cross area as a continuous function of the target aspect. For our model we will only use the lower part of the ellipsoid to simulate the ship hull below the water line.

Combining Eq. 4.5 and acoustic reflectivity coefficient we get the following model for the target cross section;

$$\sigma = \frac{\pi \cdot a^2 \cdot b^2 \cdot c^2 \cdot R^2}{(a^2 \cdot \cos^2 \phi + b^2 \cdot \sin^2 \phi)^2} \quad (4.6)$$

With reference to Urick's figures [6;283] where the pattern of the target strength is given as a function of

aspect in Fig. 9.13, and reproduced in this analysis as Fig. 6.a, we still have not obtained a model which gives the same type of pattern. By applying the following scaling factor to Eq. 4.6 we have approximated his information:

$$U = (0.251635 \cdot \phi^2 - 0.18555 \cdot \phi + 0.0365 \cdot \sin(3 \cdot (\phi + 0.17453))) \\ + 0.015 \cdot \phi^2 \cdot \sin(9 \cdot \phi/2))^{-1} \quad (4.7)$$

We then have as the target cross section in our model the following expression;

$$\underline{\sigma} = \sigma \times U \quad (4.8)$$

where σ and U are as previously shown.

Fig. 6.a and Fig 6.b shows an 'ideal' pattern and a model pattern. The figures given by Urick are for 1 yard as reference distance, but have been converted to 1 meter reference distance in Fig. 6. To go from dB(yard) to dB(meter), we subtract 0.78 dB. The dB as given in this analysis are all with 1 meter as reference distance.

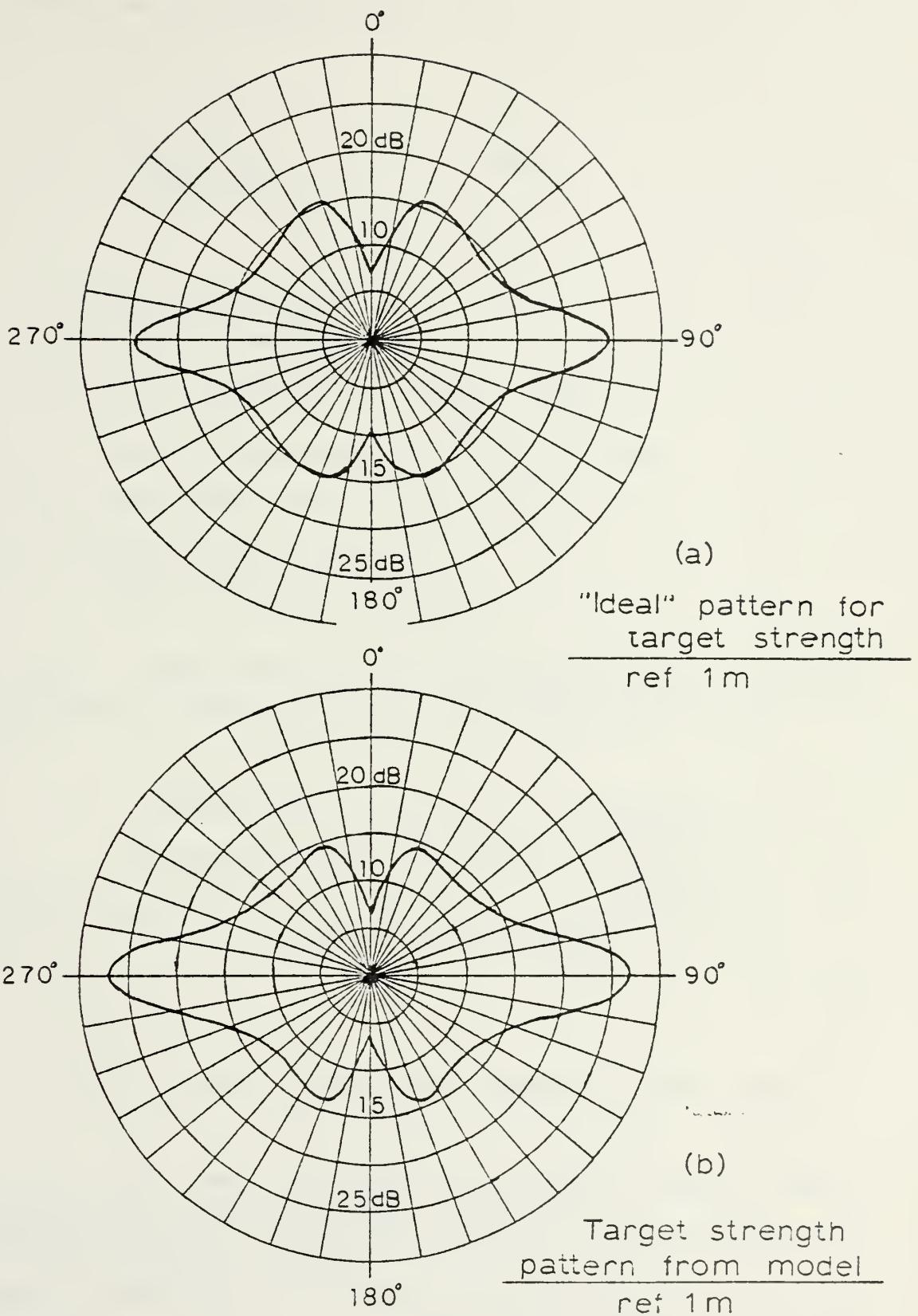


Figure 6 - TARGET STRENGTH

The active sonar equation is:

$$P = \frac{P_0 \cdot G_t \cdot \sigma \cdot G_r \cdot \lambda^2}{(4 \cdot \pi)^3 \cdot R^4} \quad \text{Watts} \quad (4.9)$$

P = power received

P_0 = power transmitted

G_t = gain transmitting, ref Eq. (4.1)

σ = target cross section, ref Eq. (4.8)

G_r = gain receiving, ref Eq. (4.1)

λ = wavelength in meters.

R = range to target in meters.

This may be rewritten into an expression of power received as a function of the variables of the different terms;

$$P = K \frac{\left| \frac{\sin(x_t \cdot \pi)}{x_t \cdot \pi} \right|^2 \cdot a^2 \cdot b^2 \cdot c^2 \cdot R^2 \left| \frac{\sin(x_r \cdot \pi)}{x_r \cdot \pi} \right|^2}{R^4 \cdot (a^2 \cdot \cos^2 \theta + b^2 \cdot \sin^2 \theta)} \quad (4.10)$$

K = the product of all the constants in the terms.

For more detailed discussion about gain, transmission loss and reflection (target cross section), see [1;110-111] and [6;29,94,263].

We can now calculate the minimum power level for detection by setting:

R_t = technical detection range

x_t = 0 degree

x_r = 0 degree

Φ = 90 degrees

and we get

$$P_{\min} = K \frac{a^2 \cdot b^2 \cdot c^2 \cdot R^2 \cdot U}{R_t^4 \cdot (b)^2} \quad (4.11)$$

and by substituting for U

$$P_{\min} = K \frac{a^2 \cdot b^2 \cdot c^2 \cdot R^2 \cdot 3.08657}{R_t^4 \cdot (b)^2} \quad (4.12)$$

a , b and c are the dimension of the target used in the model.

We assume a 'standard' target, length 100 meters, beam 15 meters and draught 4 meters, i.e.

$a = 100$

$b = 15$

$c = 4$.

There will be a detection if $P/P_{\min} > 1$. Note that P/P_{\min} does not depend on K , into which radiated power and transducer gains have been included. The technical detection range R_t is an operationally meaningful surrogate

for these parameters. The ratio P/P_{\min} will be called the "intensity fraction".

3. Detection Rule

Any intensity-fraction calculated during a transmission which is greater than 1 is a detection. However, to improve the model at close ranges, the following modification has been made for gain variation due to relative bearing.

At close ranges, the relative bearing to target can alter considerably from bow to stern. Therefore, the intensity in the pulse will differ along the target. To average this intensity both for the radiated pulse and for the echo, the model calculates relative bearing to the target bow, center and stern, calculates the corresponding gain factor for each bearing, and finds the arithmetic mean of these gain factors. These two average gainfactors (transmitting and receiving) are then used in the calculation of echo intensity.

The model does not recognize a detection unless the tactical situation makes it possible to maintain contact with the target for some time. To be precise, the following conditions must be present;

- torpedo turn rate higher than bearing rate
- closing speed must be positive.
- target must have 2 knots doppler.

V. PRESENTATION OF DATA

A. STOCHASTIC ELEMENTS

In the previous description of the model, the following input values are stochastic;

- error in target speed
- error in target course
- error in target range
- initial torpedo course (not main course).

The primary stochastic effects on the torpedo performance are identified as errors in target speed and course, since these two variables are the only stochastic ones used in computing the torpedo main course. The first problem to be solved was then how to design the run series in order to reduce variance in result at the same time as keeping the result unbiased.

It was found that instead of using a complete randomized design (random variates); we could deterministically section the probability range 0.0 - 1.0 for the two important random variables, using the inverse probability transformation to get variates, and then run the number of runs required to cover all combinations of variates.

Some preliminary simulation runs were done in three

versions; complete randomized and independent; with antithetic reduction technique (sectioning); and the previously described procedure. The number of runs needed in order to keep the variance low for the result was considerably higher for the first two versions. Accordingly, we selected the previously described procedure. It was found that a series of 150 runs was sufficient in order to give a reasonable accuracy in detection probability and at the same time keeping the total CPU time for a series of runs acceptably low. The 150 run series was established by dividing the range of probability of target speed errors into 15 equally spaced sections; and the range of probability of target course errors into 10 equally spaced sections. Each section boundary point was by inverse probability transformation converted into a variate. Bearing in mind that speed errors are normally distributed and course errors are uniformly distributed, all combinations of target data error are plotted in Fig. 7.

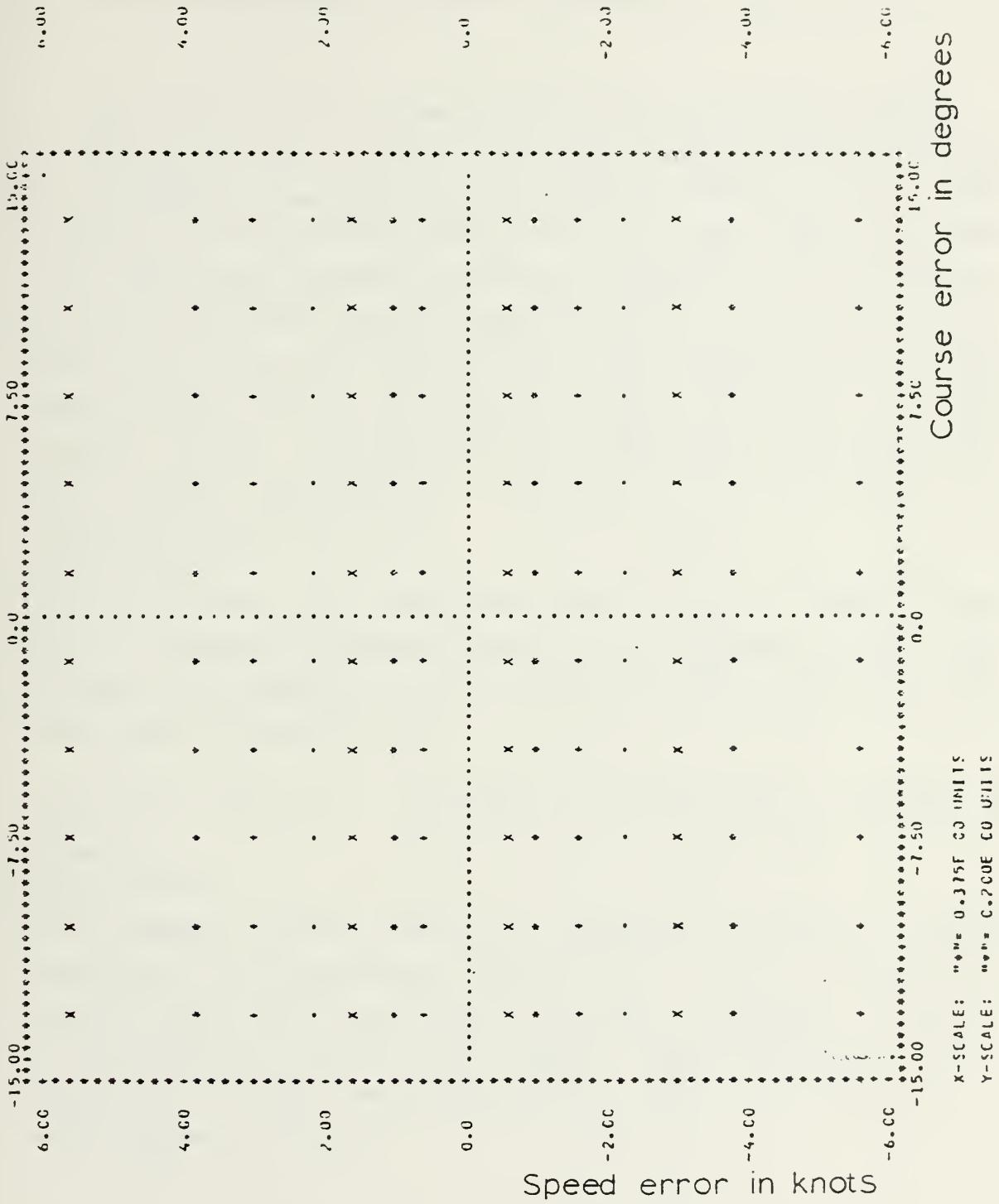


Figure 7 - DISTRIBUTION OF ERROR IN TARGET DATA

B. TYPE OF PRINTOUT OF DATA AND RESULT

Each series of 150 runs produces a printout as shown. The heading cf the printout gives the tactical situation and the torpedo parameters in the given run series. Also , the printout gives the sweep lane, which is the width of the lane where the torpedo has swept through by its sonar lobe. The coverage ratio gives an indication of the fraction of the lobe, which is covered twice; i.e. how much the lobe is being offset from its previous position by change in the torpedo course. The question of offsetting the sonar lobe, about which information is given in the printout, is discussed later in Ch. VI.

Ref. Fig. 8.

For each run, the following are output: target data, torpedo deflection angle, torpedo main course, target and torpedo grid position at end of run, duration of torpedo run and length of torpedo run.

After all runs in a series are completed, a summary is given.

Ref. Fig. 9.

The summary gives detection probability for a single detection, 2 successive detections, up to 5 successive detections. Also mean detection range, standard deviation of detection range, mean aspect, mean detection bearing relative to center bearing of sonar lobe and relative to main course are given.

Lastly, the detection range, the relative bearing to the center of the target and to the closest part of the target

TACTICAL SITUATION WHEN FIRING				TORPEDO PARAMETERS								
RANGE	ATTACK	TARGET	SPD	TEC. DET	TYPE	SWEEP	ANGLE	LORE	TURN	CROSS	CVERAGE	
SINGLE	Course	SPD	RANGE	SPD	RANGE	SPD	ANGLE	HLDTH	RTS	LATE	ATL	
3000.	-90.0	270.0	18.0		750.0	40.0	30.0	20.0	18.0	114.9	.1.550	
SCNR MAIN LOBE OFF-SET FROM CENTER BEARING 1.0 TIMES DEFLECTION ANGLE												
RUN	EST OF TARGET	TO RP	TORP M		TORP COORD		TARGET COORD		RUN	TORP		
NO	COUSE	SPD	DA	COURSE	X	Y	X	Y	STP	RUN		
1	256.5	12.4	3345.	-17.5	342.5		14037.	15061.	13488.	15000.	173	3360.
NO DETECTION MADE DURING THIS RUN												
2	256.5	14.2	2792.	-20.1	339.9		13825.	15199.	13394.	15000.	173	3570.
NO DETECTION MADE DURING THIS RUN												
3	256.5	15.1	2980.	-21.5	338.5		13755.	15177.	13394.	15000.	178	3570.
NO DETECTION MADE DURING THIS RUN												
4	256.5	15.4	2712.	-22.5	337.4		13695.	15149.	13394.	15000.	173	3570.
NO DETECTION MADE DURING THIS RUN												
5	256.5	16.4	3232.	-23.5	336.5		13634.	15122.	13394.	15000.	173	3570.
NO DETECTION MADE DURING THIS RUN												
6	256.5	17.0	3302.	-24.4	335.6		13597.	15106.	13394.	15000.	173	3570.
7	256.5	17.5	2922.	-25.2	334.8		13450.	15259.	13299.	15000.	189	3780.
8	256.5	18.0	3438.	-25.9	334.1		13434.	15251.	13299.	15000.	189	3780.
9	256.5	18.5	3312.	-26.7	333.3		13366.	15218.	13299.	15000.	189	3780.
10	256.5	19.0	2931.	-27.5	332.5		13342.	15206.	13299.	15000.	189	3780.
11	256.5	19.6	2948.	-28.4	331.6		13269.	15167.	13299.	15000.	189	3780.
12	256.5	20.2	3394.	-29.4	330.6		13241.	15151.	13299.	15000.	189	3780.
13	256.5	20.9	2897.	-30.5	329.5		13154.	15101.	13299.	15000.	189	3780.
NO DETECTION MADE DURING THIS RUN												
14	256.5	21.8	2813.	-32.1	327.9		12977.	15229.	13205.	15000.	199	3990.
NO DETECTION MADE DURING THIS RUN												
15	256.5	23.0	3230.	-35.0	325.0		12913.	15119.	13215.	15000.	199	3990.
NO DETECTION MADE DURING THIS RUN												
16	256.5	12.4	3430.	-17.7	342.3		14033.	15058.	13468.	15000.	163	3360.
NO DETECTION MADE DURING THIS RUN												
17	256.5	14.2	3277.	-20.4	339.6		13816.	15195.	13394.	15000.	173	3570.
NO DETECTION MADE DURING THIS RUN												
18	256.5	15.1	3353.	-21.8	338.2		13733.	15163.	13394.	15000.	173	3570.
NO DETECTION MADE DURING THIS RUN												
19	256.5	15.4	3363.	-22.9	337.1		13670.	15137.	13394.	15000.	173	3570.
NO DETECTION MADE DURING THIS RUN												
20	256.5	16.4	3282.	-23.8	336.2		13626.	15118.	13394.	15000.	173	3570.
21	256.5	17.0	2964.	-24.7	335.3		13581.	15098.	13394.	15000.	173	3570.
22	256.5	17.5	2791.	-25.5	334.5		13467.	15263.	13299.	15000.	189	3780.
23	256.5	18.0	2843.	-26.3	333.7		13389.	15229.	13299.	15000.	189	3780.
24	256.5	18.5	3260.	-27.1	332.9		13369.	15218.	13299.	15000.	189	3780.
25	256.5	19.0	2850.	-27.9	332.1		13325.	15196.	13299.	15000.	189	3780.
26	256.5	19.6	3338.	-28.3	331.2		13250.	15155.	13299.	15000.	189	3780.
27	256.5	20.2	2790.	-29.7	330.3		13198.	15127.	13299.	15000.	189	3780.
NO DETECTION MADE DURING THIS RUN												
28	256.5	20.9	3384.	-30.9	329.1		13132.	15088.	13299.	15000.	189	3780.
NO DETECTION MADE DURING THIS RUN												
29	256.5	21.8	2901.	-32.5	327.5		12953.	15212.	13205.	15000.	189	3990.

Figure 8 - EXAMPLE OF PRINTOUT HEADING

SUMMARY OF PERTINENT DATA FOR THIS RUN									
	14C	141	147	143	144	145	146	147	148
ONE SURFACE DEFLECTION	283.5	283.5	283.5	283.5	283.5	283.5	283.5	283.5	283.5
TWO SURFACE DEFLECTIONS	16.4	17.0	17.5	18.0	18.5	19.0	19.6	20.2	20.9
THREE SURFACE DEFLECTIONS	2951.	2891.	2978.	3231.	2908.	2985.	3321.	2915.	3379.
FOUR SURFACE DEFLECTIONS	-23.5	-24.4	-25.2	-25.9	-26.7	-27.5	-28.4	-29.4	-30.5
FIVE SURFACE DEFLECTIONS	336.5	335.6	334.8	334.1	333.3	332.5	331.6	330.6	329.5
AVERAGE DEFLECTION	15121.	15197.	15087.	1525C.	15366.	15218.	15180.	15138.	15117.
STD DEVIATION	13394.	15001.	13394.	15001.	13299.	15001.	13299.	13299.	13299.
AVERAGE DEVIATION	15000.	15000.	15000.	15000.	15000.	15000.	15000.	15000.	15000.
MAXIMUM DEVIATION	17H	35H	35H	37H	37H	37H	37H	37H	37H
MINIMUM DEVIATION	1570.	1570.	1570.	1570.	1570.	1570.	1570.	1570.	1570.

Figure 9 - EXAMPLE OF PRINTOUT SUMMARY

at detection (relative to present torpedo course), and the target aspect at detection are printed for each run for a single detection, 2 successive and 3 successive detections.

It also should be noted that it is possible to get a more detailed printout for each run by setting IPRINT = 0 in the main program (main program statement 035).

Ref. Appendix D. for example of detailed run printout.

From the printout data, it is possible to study different aspects of the detection process as well as to generate distributions of detection range, aspect, bearing etc.

VI. PARAMETRIC TORPEDO ANALYSIS

A. OBJECTIVES

The following approach was used:

The torpedo speed, the technical detection range and the lobe width were assumed to characterize a torpedo type. Within the type, it was possible to change the turn rate and the sweep angle.

A tactical situation was characterized by the attack angle, the target speed and the firing range.

The following questions were investigated:

- Can a torpedo be improved by offsetting its sonar lobe from the torpedo heading ?
Rephrased; it may be asked, is the sonar lobe searching in the right direction (most likely area) by pointing straight ahead along the torpedo course ?
- How do turn rate and sweep angle affect a torpedo's MOE ?
- How are the different torpedo types related to each other with regard to detection probability (MOE) ?

In the analysis, we started with a reasonable tactical situation; target speed 18 knots, range 3000 meters, technical detection range 750 meters. Initially, we changed the attack angles.

With regard to torpedoes, we started with three types of

torpedoes; 24 knots, 32 knots and 40 knots; all with 20 degree lobe width, 6 degree per second turn rate and 30 degree sweep angle.

B. OFFSETTING SONAR LOBE

The hypothesis was that when a torpedo is fired on a deflection angle course, the sonar lobe should be most effective if it scans across the bearing to the target. Or, the sonar lobe should be offset equal to deflection angle (DA). Ref. Fig. 10.

It was found that offsetting had a positive effect when attacking from ahead of target.

Ref. Fig. 11.a. and b.

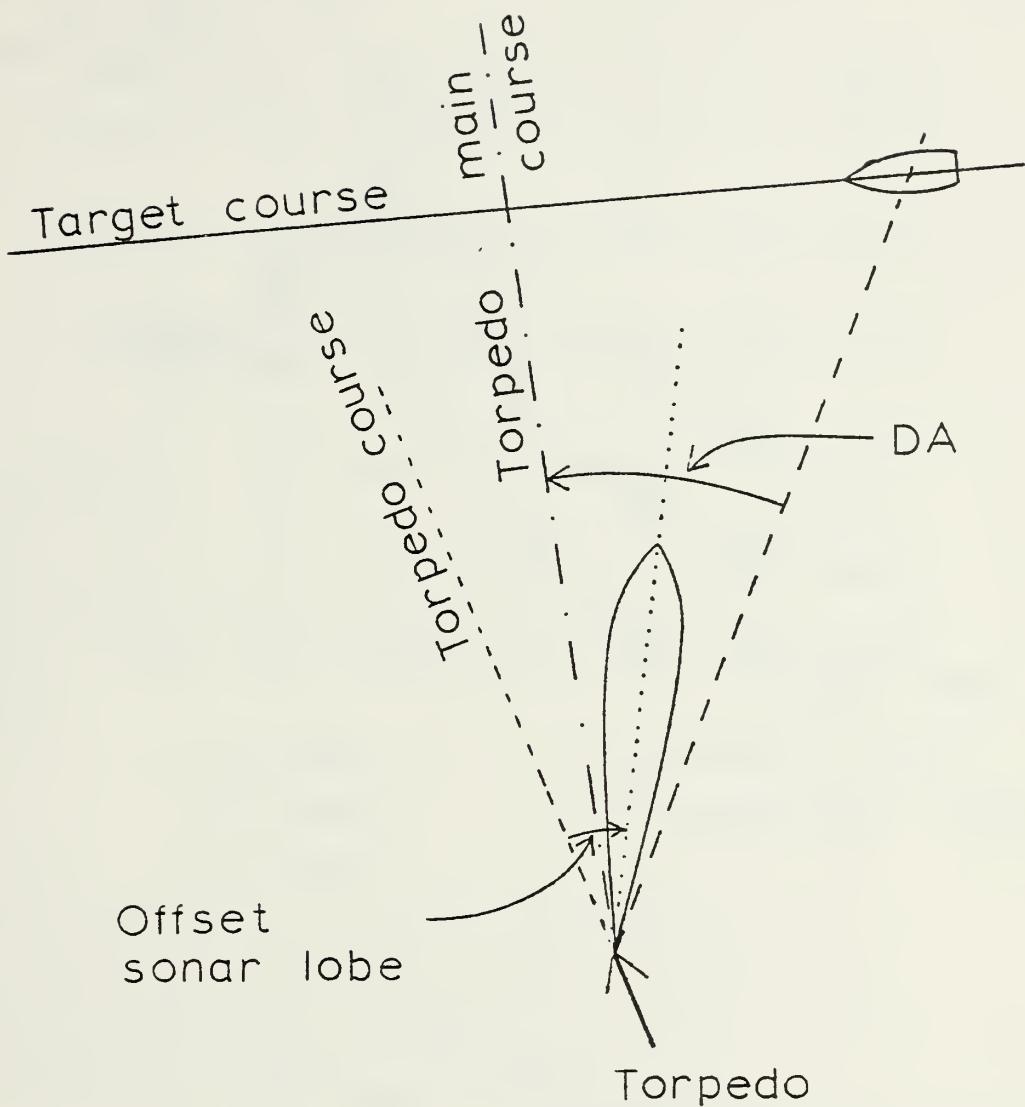
But from about 30 degree to about 110 degree attack angle the effect was negative. If more than 110 degree attack angle, there was no effect.

In analyzing the fraction of offsetting, we analyzed the case of 30 degree and 60 degree attack angle. There seemed to be no effect from 0.0 to $0.5 \times DA$; if more than $0.5 \times DA$ there was a decreasing efficiency.

This was found for 2 types of torpedoes (32 and 40 knots; 20 degree lobe width) at 2 different sets of turn rates and sweep angles.

This conclusion applies for both single detection and multiple successive detections; however, the magnitude of the effect is changing as we look on different number of successive detections. The conclusion was that there is

little to be gained by offsetting the sonar lobe, and the sonar lobe was therefore not offset in subsequent investigations.



DA - Deflection angle

Figure 10 - OFFSET SONAR LOBE

Tactical Situation

Range 3000 m
 TA Speed 18 Knots
 Det. range 750 m

Torpedo Parameters

Sweep angle 30°
 Lobe width 20°
 Turn rate 6°/s

First detection

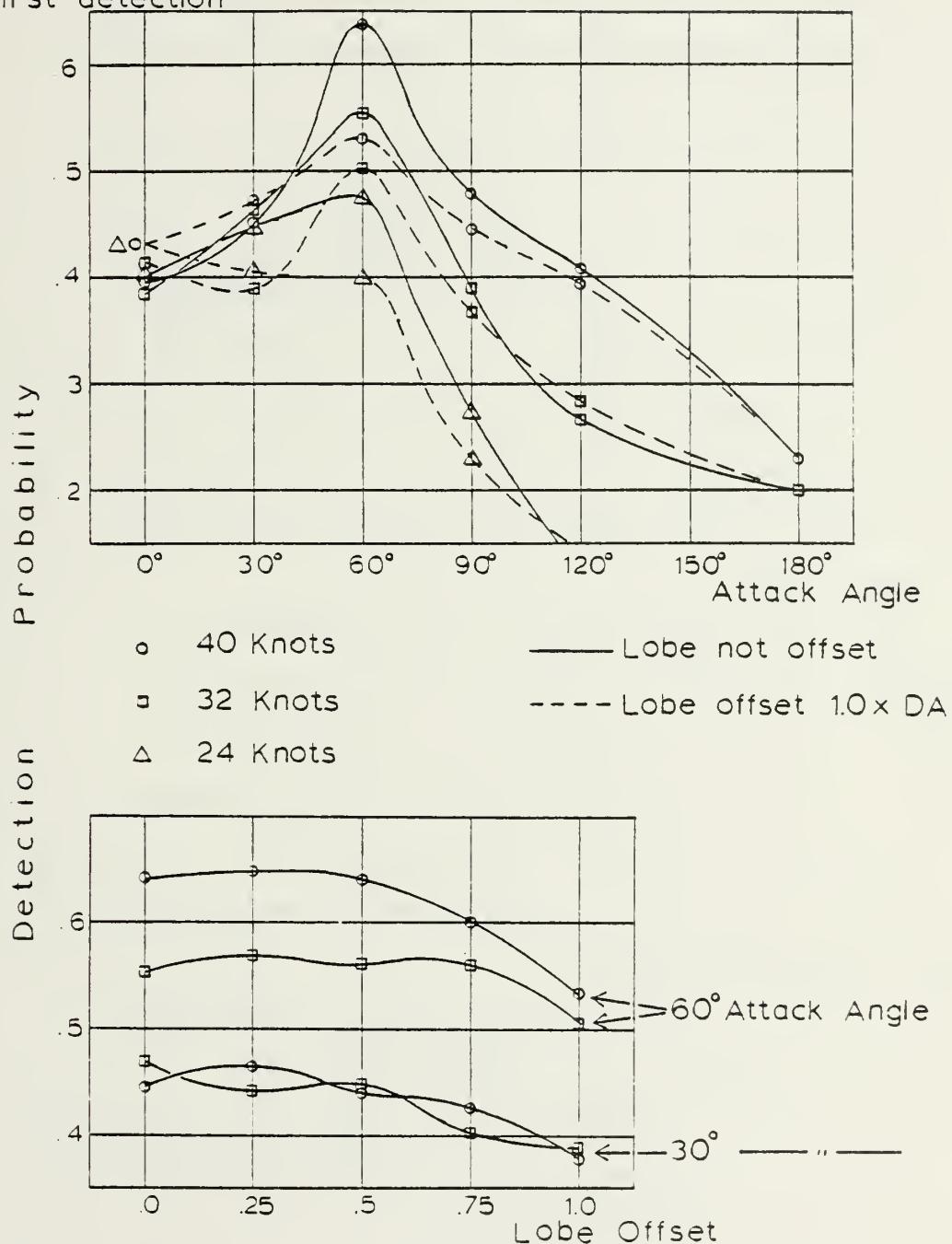


Figure 11 - EFFECT OF OFFSETTING SONAR LOBE

Tactical Situation

Range 3000 m
 TA Speed 18 Knots
 Det range 750 m

Torpedo Parameters

Sweep angle 30°
 Lobe width 20°
 Turn rate 6°/s

Two detections

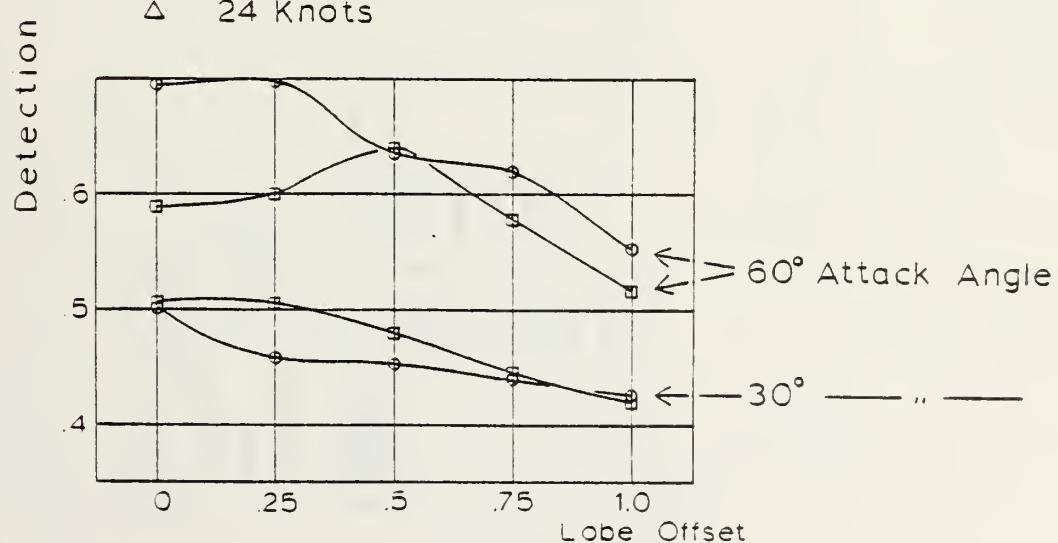
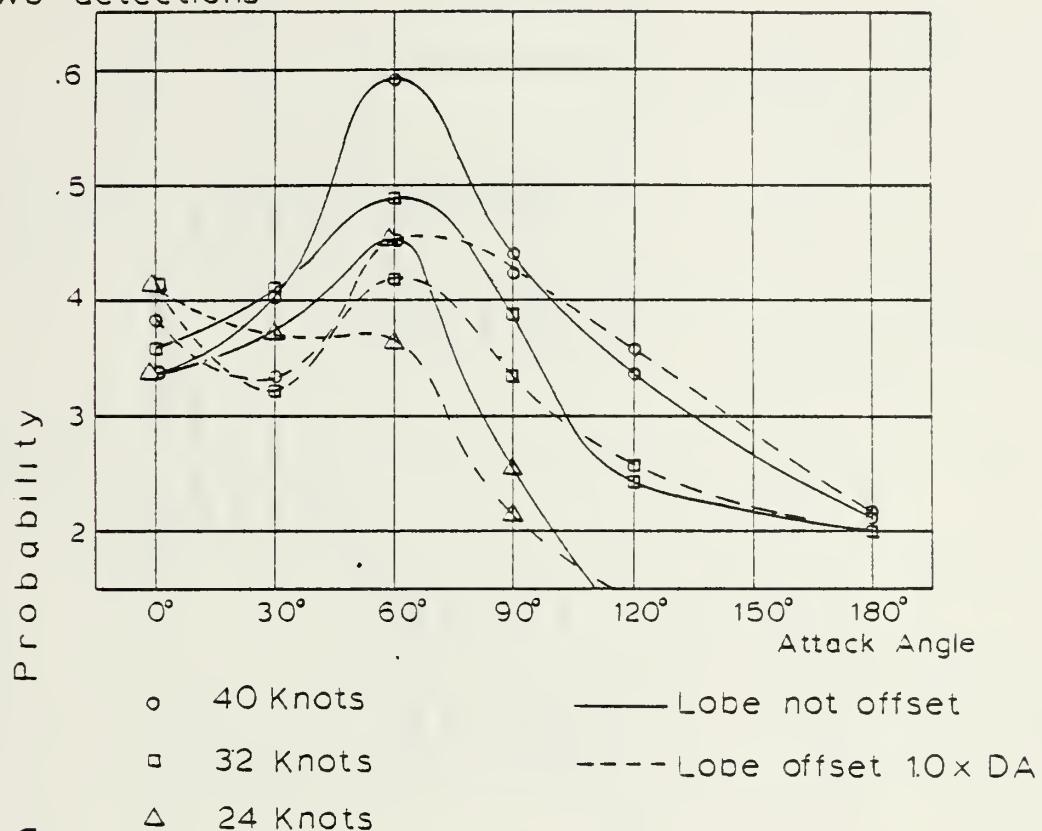


Figure 11.b. - EFFECT OF OFFSETTING SONAR LOBE

Tactical situation

Target speed	18 knots
Range	3000 m
Detection range	750 m

Torpedo parameters

	Torpedo speed	24 knots		
	Sweep angle	30 degrees		
	Lobe width	20 degrees		
	Turn rate	6 deg/sec		
Attack angle	0.0	1 detection	0.0	0.0
0	.4000	.4333	.3303	.4067
30	.4467	.4067	.3733	.3667
60	.4733	.4000	.4533	.3667
90	.2733	.2267	.2533	.2133
120	.1200	.1467	.1133	.1467
180	.0000		.0000	

	2 detections	3 detections	Offset lobe x DA
0	1.0	1.0	
30	.3303	.3133	.3400
60	.3733	.3200	.3133
90	.4533	.4267	.3333
120	.2533	.2400	.1867
180	.1133	.1133	.1200

Table I - VARIATION IN OFFSETTING SONAR LOBE

Tactical situation

Torpedo parameters

Target speed 18 knots
Range 3000 m
Detection range 750 m

Torpedo speed 32 knots
Sweep angle 30 degrees
Lobe width 20 degrees

Attack angle	1 detection		2 detections		3 detections		Offset lobe x DA						
	0.0	0.25	0.5	0.75	0.0	0.25	0.5	0.75	0.0	0.25	0.5	0.75	
0	.3867				.3600				.2800				
30	.4667	.4400	.4467	.4000	.4067	.4067	.3800	.3467	.3400	.3067	.2867	.2733	
60	.5533	.5667	.5600	.6600	.4867	.5000	.4800	.4800	.4333	.4600	.4333	.4133	
90	.3933				.3867				.3067				
120	.2667				.2400				.2133				
180	.2000				.2000				.2000				

Tactical situation

Torpedo parameters

Target speed 18 knots
Range 3000 m
Detection range 750 m

Torpedo speed 32 knots
Sweep angle 30 degrees
Lobe width 20 degrees

Attack angle	1 detection		2 detections		3 detections		Offset lobe x DA	
	1.0		1.0		1.0			
0	.4267				.4067			
30	.3867				.3200			
60	.5067				.4200			
90	.3667				.3267			
120	.2800				.2533			
180	.2000				.2000			

Table I.b. - VARIATION IN OFFSETTING SONAR LOBE

Tactical situation

Target speed 18 knots
 Range 3000 m
 Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots
 Sweep angle 30 degrees

Lobe width 20 degrees

Attack angle	1 detection			2 detections			3 detections			Offset lobe x DA
	0.0	0.25	0.5	0.75	0.0	0.25	0.5	0.75	0.0	
0	.3933				.3333				.2533	
30	.4467	.4667	.4400	.4267	.4000	.3533	.3400	.3533	.3200	.3067
60	.6400	.6467	.6400	.5867	.5933	.6000	.5333	.5200	.5400	.4733
90	.4733				.4400				.3933	.4200
120	.4067				.3400				.2800	
180	.2267				.2133				.2000	

Tactical situation

Torpedo parameters

Attack angle	1 detection			2 detections			3 detections			Offset lobe x DA
	1.0			1.0			1.0			
0	.4333				.3800				.2733	
30	.3733				.3267				.2733	
60	.5333				.4533				.4067	
90	.4467				.4200				.3600	
120	.3933				.3600				.3333	
180	.2333				.2200				.2000	

Table I.c. - VARIATION IN OFFSETTING SONAR LOBE

C. EFFECT OF TURN RATE

The effect of turn rate was investigated in the range 3 to 21 degrees per second in steps of 3. For both types of torpedoes the model showed an increase in MOE as turn rate was increased. The MOE leveled off as turn rate was approaching 15 - 20 degrees per second.

The reason may be due to the 1 second transmission interval and the 20 degree lobe width, which indicates that the torpedo should be turned at a turn rate equal to lobe width divided by transmission interval for maximum MOE. However, as the number of successive detections required is increased, we get maximum MOE at lower turn rates.

Fig. 12 shows the change in MOE with turn rate for 30 and 60 degrees attack angles.

From Fig. 15 where different combinations of turn rates and sweep angles are plotted versus MOE, we see that the effect is negligible from about 60-80 degrees to 180 degrees attack angle.

A 6 degrees per second turn rate is compared with what may be termed an 'optimal' turn rate in Fig. 13. The 'optimal' turn rates were established by the general trend from Fig. 12 and Table II.a and II.b.

The following turn rates were identified as 'optimal':

- 15 degrees per second for the 32 knots torpedo
- 18 degrees per second for the 40 knots torpedo.

Tactical Situation

Range

3000 m

TA Speed

18 Knots

Det. range

750 m

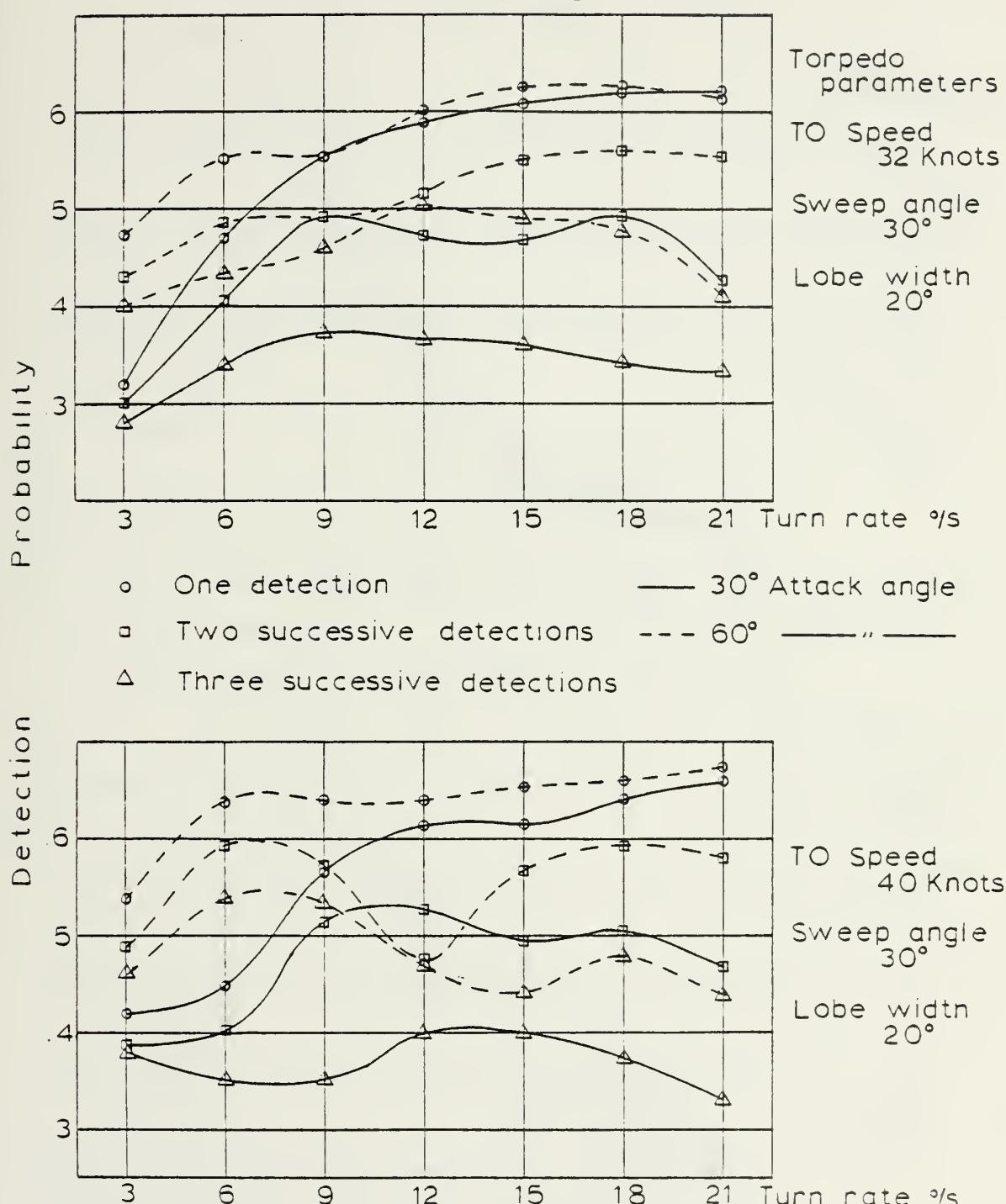


Figure 12 - EFFECT OF TURN RATE

Tactical Situation:

Range	3000 m
TA Speed	18 Knots
Det. range	750 m

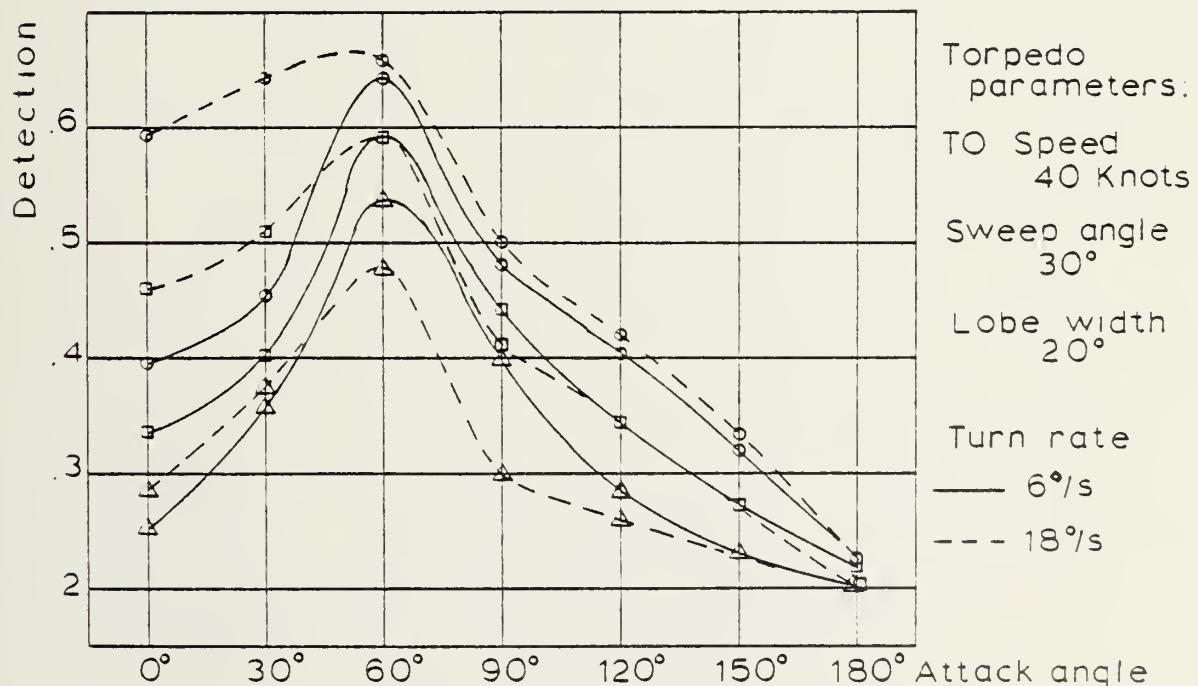
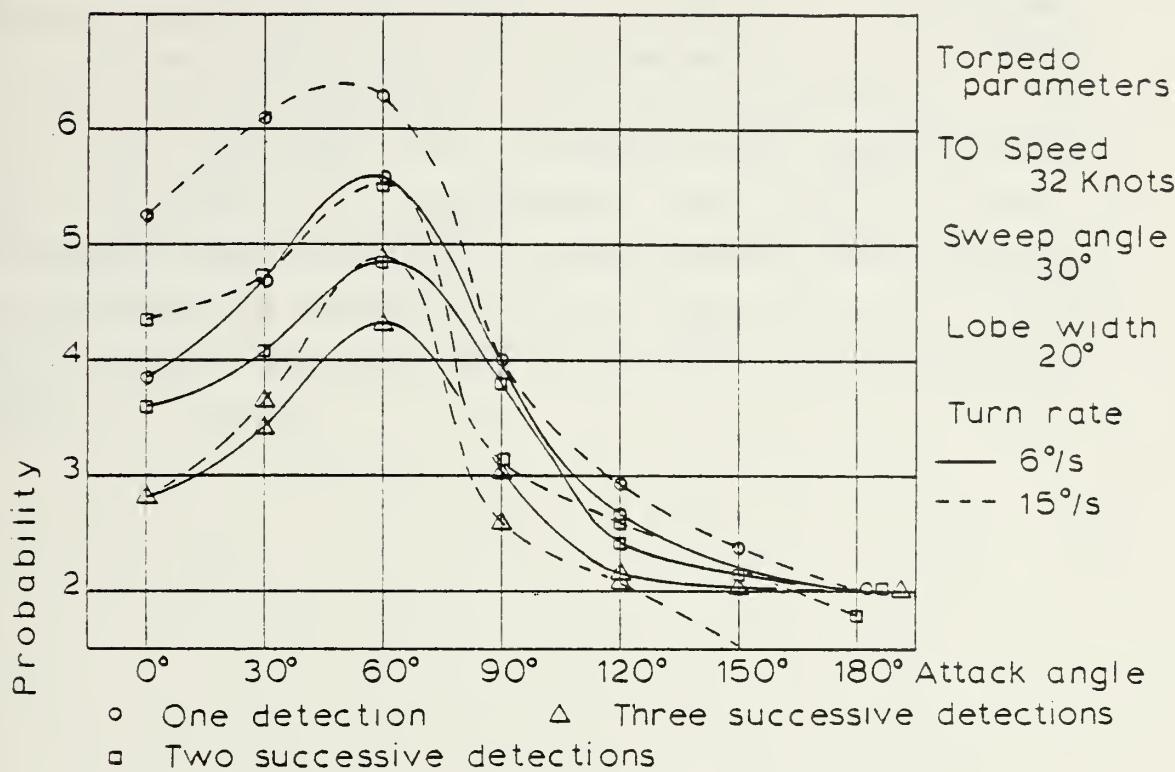


Figure 13 - COMPARISON OF TORPEDOES WITH DIFFERENT TURN RATES

We see here in Fig. 13 a considerable increase in MOE with increase in turn rate for attack angles less than 60 - 80 degrees for single detection; an consistent improvement for 2 successive detections in the same area; but no change or a slight detoriation for 3 successive detections.

It is quite obvious that a torpedo which requires only a single detection as requirement for attack has a considerably better MOE, and a considerably higher potential for improvement by changes in turn rate, than a torpedo which requires more successive detections for classifying a contact as a target.

Tactical situation

Target speed 18 knots
 Range 3000 m
 Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots
 Sweep angle 30 degrees
 Lobe width 20 degrees

Attack angle	1 detection			2 detections			3 detections			Turn rate deg/sec	
	3	6	9	12	3	6	9	12	3		
0	.3933	.5733	.5733	.5733	.3333	.4000	.4600	.5267	.5933	.2533	.2667
30	.4200	.4467	.5667	.6133	.3867	.5133	.5800	.5267	.5533	.3533	.4000
60	.5333	.6400	.6400	.6400	.4867	.5933	.4667	.4667	.5333	.4667	
90		.6400	.6400	.4067	.4733	.4400	.3400	.3400	.3933	.2800	.3600
120		.4067	.2267							.2000	
180											

Tactical situation

Torpedo parameters

Attack angle	1 detection			2 detections			3 detections			Turn rate deg/sec		
	12	15	18	21	12	15	18	21	12	15	18	21
0	.5733	.5933	.5933	.6600	.4600	.4933	.4600	.5067	.4667	.2667	.2867	
30	.6133	.6133	.6400	.6600	.5267	.4933	.4667	.4667	.4000	.4000	.3733	.3300
60	.6400	.6533	.6600	.6733	.4667	.5667	.5933	.5933	.4400	.4400	.4800	.4400
90	.4733		.4933	.4200	.4400	.4067	.3467	.3467	.3600	.3600	.2933	
120											.2600	
180											.2000	

Table II.b. - VARIATION IN TORPEDO TURN RATE

D. EFFECT OF SWEEP ANGLE

From preliminary simulation runs, it was found that from 90 degrees (inclusive) to 180 degrees attack angle the effect of the sweep angle was negligible. The analysis was therefore done from 20 to 50 degrees sweep angle only for 30 and 60 degrees attack angle for both the 32 and the 40 knots torpedo.

The result is shown in Fig. 14.

For the 32 knot torpedo we get an increase from 30 to 40 degrees for both attack angles. From 40 to 50 degrees, MOE either levels off or decrease slowly. As a conclusion, we established 40 degrees sweep angle as the 'optimal' value. For the 40 knot torpedo, the MOE was fairly steady over the whole range for 30 degrees attack angle. For 60 degrees attack angle, there was a peak at 30 degrees sweep angle, which indicated that 30 degrees was the optimal value.

The reason for the different sweep angles for the two torpedo types (Note; both have 6 degrees per second turn rate) may be due to the time it takes to reach the target. The shorter time, the less area on each side of the main course is needed to be covered in order to detect a target; i.e. a 40 knot torpedo needs only a 30 degree sweep angle, a 32 knot torpedo needs 40 degree sweep angle.

Tactical Situation.	Range	3000 m
	TA Speed	18 Knots
	Det. range	750 m
Torpedo Parameters:	Lobe width	20°
	Turn rate	6°/s

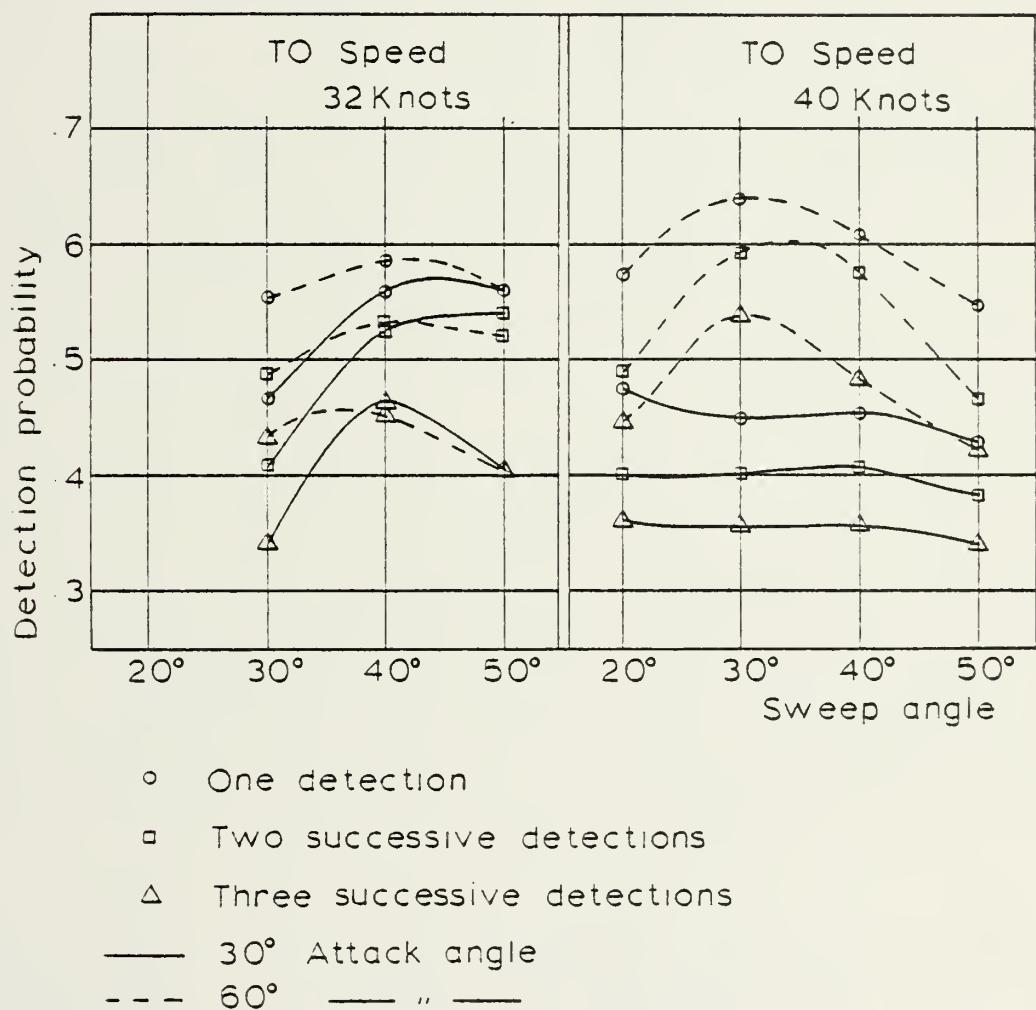


Figure 14 - EFFECT OF SWEEP ANGLE

The reason why we get a peak and then a reduction in MOE as we increase sweep angle is supposedly due to a sharp decrease in speed along the main course as sweep angle is approaching 60 degrees.

As example, for a 40 knots torpedo the model gave 35 knots along main course for 50 degrees sweep angle as compared with 38.6 knots for 20 degrees sweep angle. For a slower torpedo, the effect on MOE may be considerable due to less speed advantage relative to the target.

Tactical situation

Target speed 18 knots
 Range 3000 m
 Detection range 750 m

Torpedo parameters

Torpedo speed 32 knots
 Lobe width 20 degrees
 Turn rate 6 deg/sec

Attack angle	20	1 detection			2 detections			3 detections			Sweep angle degree
		30	40	50	30	40	50	30	40	50	
0	.3867	.3933			.3600	.3267		.2800	.2600		
30	.4667	.5600	.5600		.4067	.5267	.5400	.3400	.4600	.4067	
60	.5533	.5867	.5600		.4867	.5333	.5200	.4333	.4533	.4067	
90	.3933	.3733			.3867	.3733		.3067	.3400		
120	.2667	.2800			.2400	.2667		.2133	.2333		
180	.2000	.2000			.2000	.2000		.2000	.1867		

Tactical situation

Target speed 18 knots
 Range 3000 m
 Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots
 Lobe width 20 degrees
 Turn rate 6 deg/sec

Attack angle	20	1 detection			2 detections			3 detections			Sweep angle degree
		30	40	50	30	40	50	30	40	50	
0	.3933				.3333			.2533			
30	.4467	.4533	.4267	.4000	.4067	.3800	.3600	.3533	.3533	.3400	
60	.5733	.6400	.6067	.5467	.5933	.5733	.4667	.4467	.5400	.4800	.4200
90	.4733				.4400			.3933			
120	.4067				.3900			.2800			
180	.2267				.2133			.2000			

Table III - VARIATION IN SWEEP ANGLE

E. EFFECT OF BOTH SWEEP ANGLE AND TURN RATE

In the previous discussion we changed either sweep angle or turn rate for both types of torpedo while we kept the other variables constant.

In plotting MOE for initial torpedo (32 knots) value, optimal value for sweep angle, optimal value for turn rate and the 'optimal' torpedo (having both the 'optimal' turn rate and sweep angle), we get Fig. 15. Observe how the MOE changes as we apply the individual 'optimal' values, and the MOE obtained by applying both the 'optimal' values.

At this stage, no trials were made in order to further increase MOE by changing sweep angle or turn rate from these values.

One essential feature is that virtually none of the variables so far have had any effect on MOE for larger attack angles than 60-90 degrees.

The relative difference in MOE between the 32 and the 40 knots torpedo types is shown in Fig. 16. Both torpedoes are optimal in the sense that the best values for turn rate and sweep angle have been chosen for that specific speed.

Tactical Situation
 Range 3000 m
 TA Speed 18 Knots
 Det. range 750 m

Torpedo parameters
 TO Speed 32 Knots
 Lobe width 20°

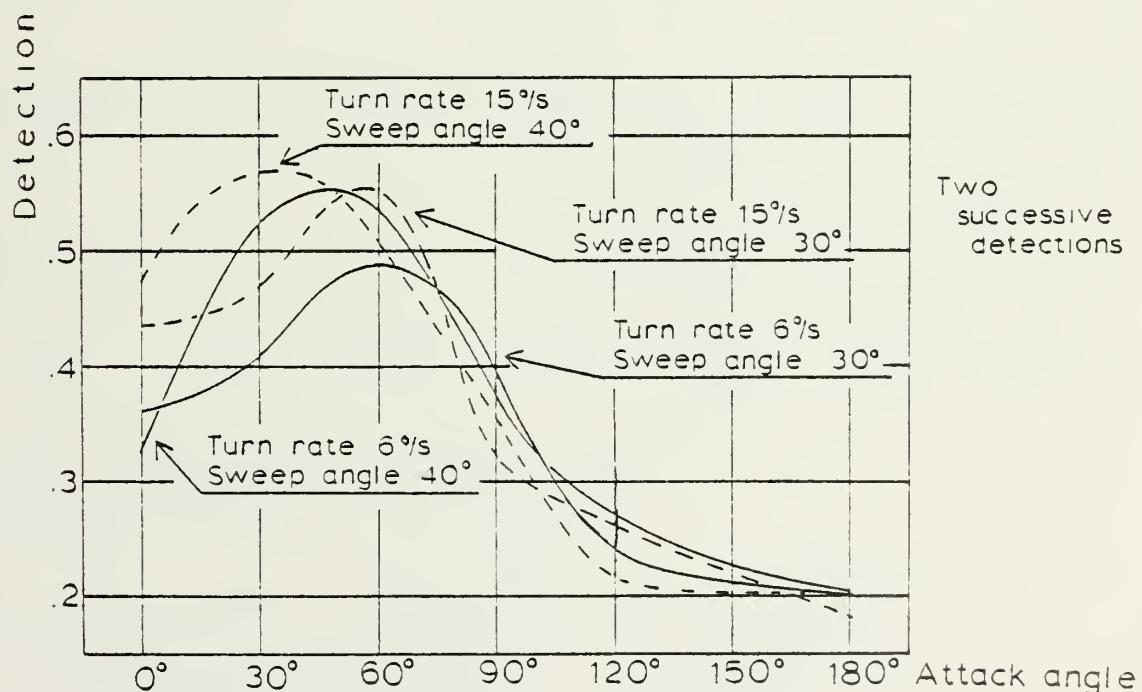
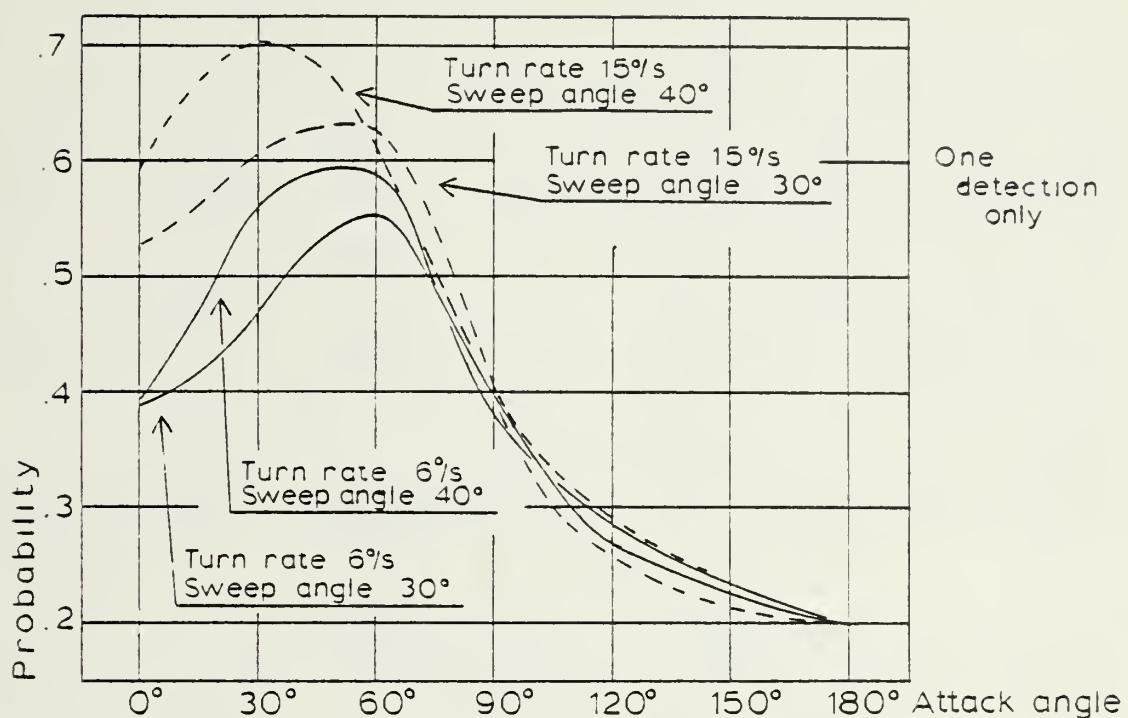


Figure 15 - COMPARISON OF DIFFERENT MODIFICATION OF A TORPEDO

Tactical Situation: Range 3000 m
 TA Speed 18 Knots
 Det. range 750 m

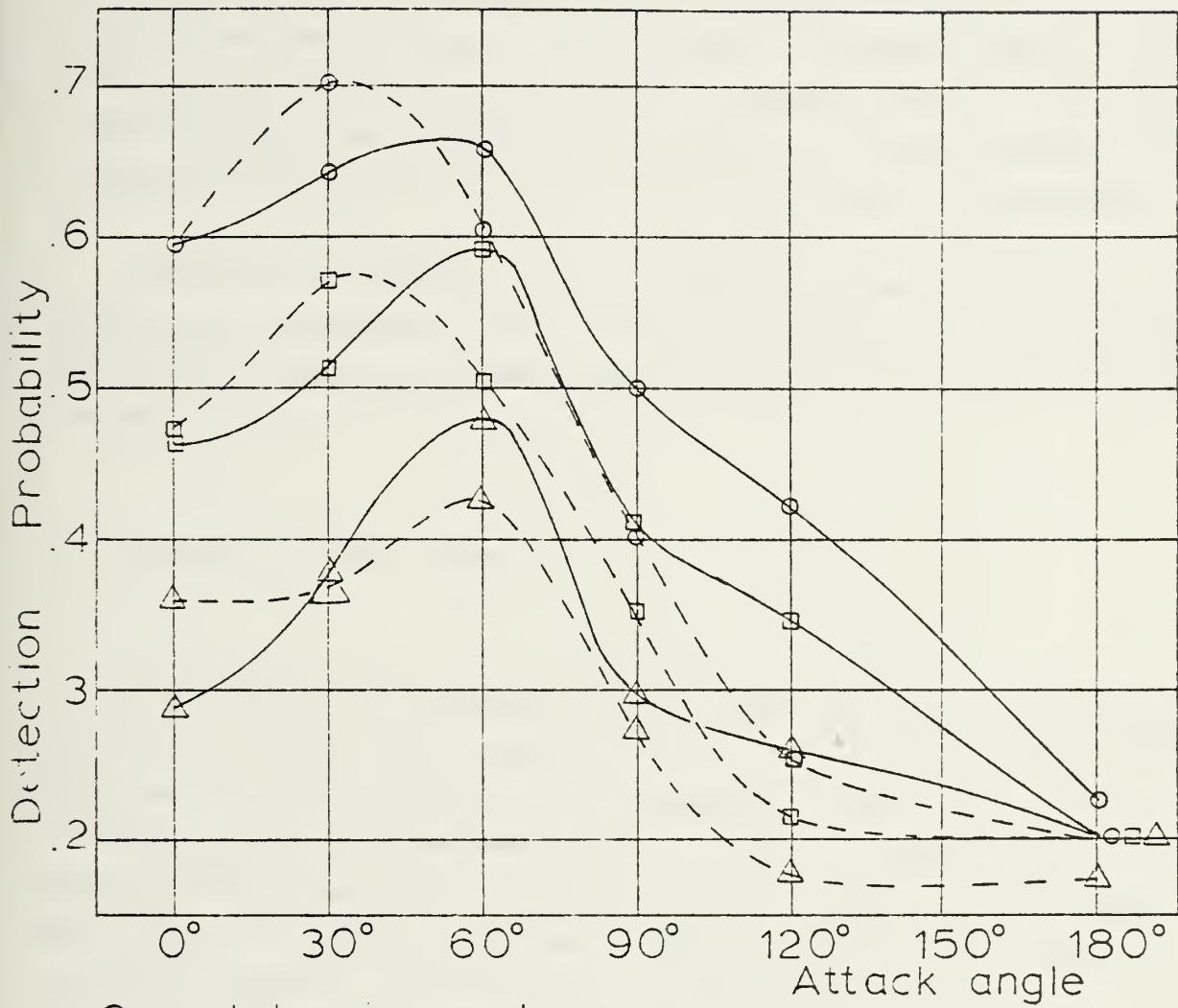


Figure 16 - COMPARISON OF TWO DIFFERENT TORPEDOES

It is obvious that the main differences are for large attack angles; more than 60-80 degrees.

Especially if the acquisition requirement is one detection only, however, a 32 knots torpedo is slightly better up to 60 degrees attack angle. This improved MOE for the slower torpedo may be explained by a better balance between the time to the target and the total relative speed. A too high relative speed may prohibit the torpedo from getting the target within its sonar lobe before the target is passed.

Generally, however, the higher speed torpedo is superior, especially for larger attack angles (120 degrees and more); this can be explained by the shorter time to the target.

F. EFFECT OF LOBE WIDTH

The effect of changing lobe width while maintaining detection range is shown in Fig. 17. It should be noted that we initially started the simulation with an 'optimal' torpedo with 20 degrees lobe width. When we ran the simulation series for 10 degrees and 30 degrees lobe width, we did not change the other torpedo parameters in order to make the torpedo 'optimal' for the new lobe width. If we had carried through this optimization process, we might have expected an increase in the result for 10 and 30 degrees lobe width. The torpedo parameter in question would most likely be turn rate, ref discussion previously on page 61.

The interesting points from Fig. 17 are;

- a 10 degrees lobe width torpedo with a one-detection-only acquisition requirement is as good

as a 20 degrees lobe width torpedo with a two-successive-detection requirement. This should indicate what we have to pay in additional power transmitted when acquisition requirement is high. Or, where to invest research resources; in transducer or in echo filtering.

- the equally shaped curves for increasing lobe width. However, we also observe an increasing difference in MOE between the curves as attack angle is decreasing.
- the importance of the correct balance between turn rate and lobe width for successive detections. We observe for a small aspect target how MOE decreases drastically when we reduce lobe width from 20 degrees to 10 degrees and maintain turn rate and require two successive detections.

Tactical Situation

TA Speed 18 knots
 Det range 750 m
 Range 3000 m

Torpedo Parameter

TO Speed 40 Knots
 Sweep angle 30°
 Turn rate 18 °/s

Δ 10° Lobe width

\square 20° " "

\circ 30° " "

— One detection only

- - - - Two successive detections

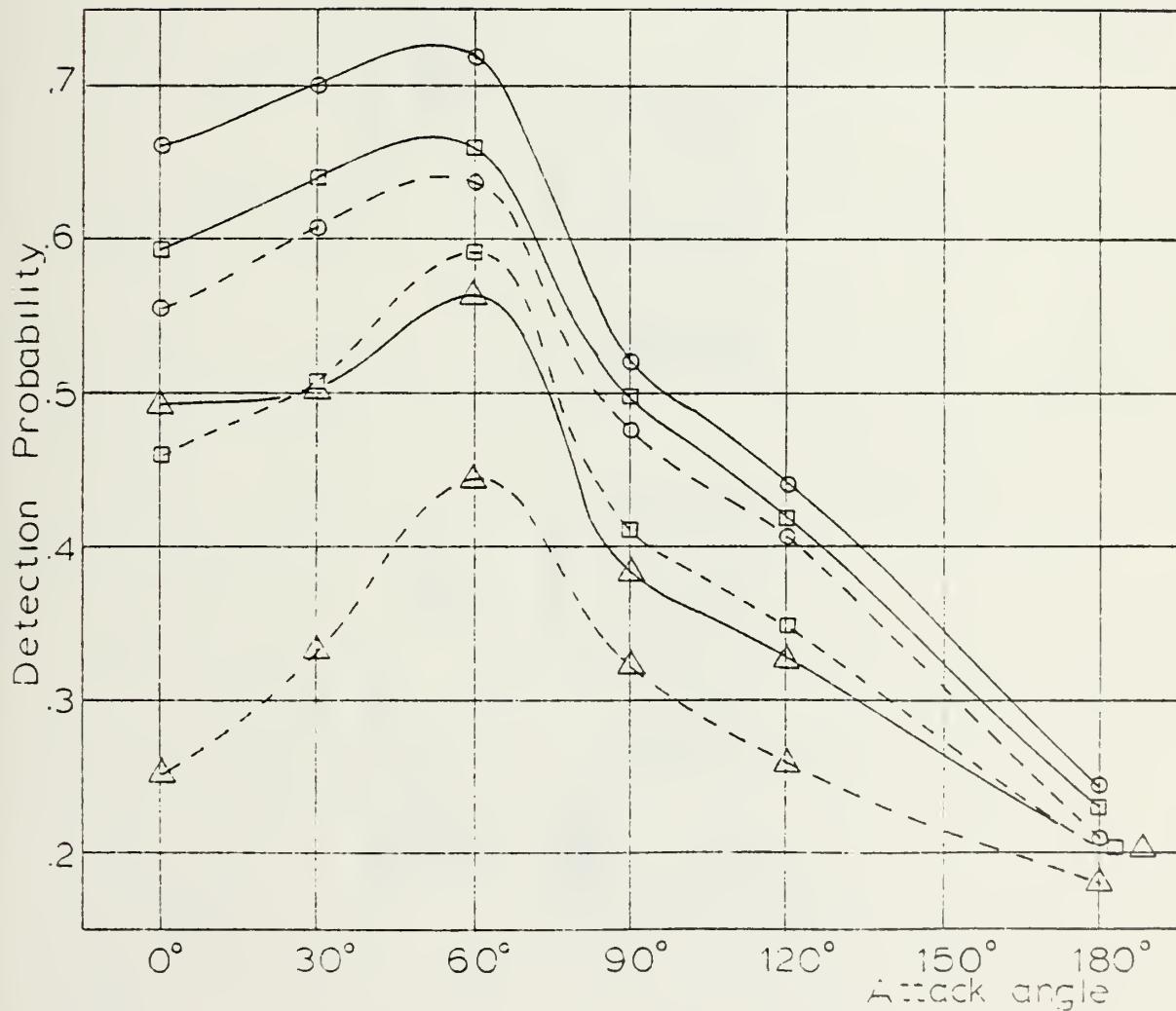


Figure 17 - EFFECT OF LOBE WIDTH

Tactical situation

Target speed	18 knots
Det. range	750 m
Range	3000 m

Torpedo parameters

Torpedo speed	10 knots
Sweep angle	30 degrees
Turn rate	18 deg/s

Attack angle	1 detection			2 detections			3 detections			Lobe width degrees
	10	20	30	10	20	30	10	20	30	
0	.1933	.5933	.6667	.2167	.4600	.5533	.1133	.2867	.4200	
30	.5000	.6100	.7000	.3267	.5067	.6067	.2333	.3733	.4800	
60	.5667	.6600	.7200	.4167	.5933	.6400	.3067	.4800	.5167	
90	.3800	.4933	.5133	.3200	.4067	.4733	.2267	.2933	.4000	
120	.3267	.4200	.4400	.2600	.3467	.4067	.1800	.2600	.3267	
180	.2000	.2267	.2400	.1800	.2000	.2067	.0867	.2100	.2000	

Table IV - VARIATION IN LOBE WIDTH

G. EFFECT OF DETECTION RANGE

The detection range is a function of the design of the active sonar in the torpedo as well as sonar condition at the time of the torpedo firing. The detection range as a function of the design of the active sonar is termed technical detection range. The detection range as a function of both the design and the sonar conditions is termed tactical detection range, or just detection range. In analyzing the detection probability as a function of detection range, we assumed optimal sonar conditions by equal technical detection range with detection range.

Detection range was varied in discrete steps: 375 - 750 - 1125 - 1500 meters.

Figs. 18.a. and b. indicate that detection probability is a linear function of the detection range up to a detection probability of 0.8 - 0.9 for one detection. From the model, it may be justifiable to approximate the detection probability as a linear function from 375 m to 1125 m detection range.

From the model and the given assumptions, there is little usefulness in a homing torpedo with less than 300 m detection range.

The same situation is shown in Figs. 19.a. and b. in another cut of the response surface. We see here how consistently the MOE has decreased over the whole range of attack angles when going from 1500 m to 375 m detection range.

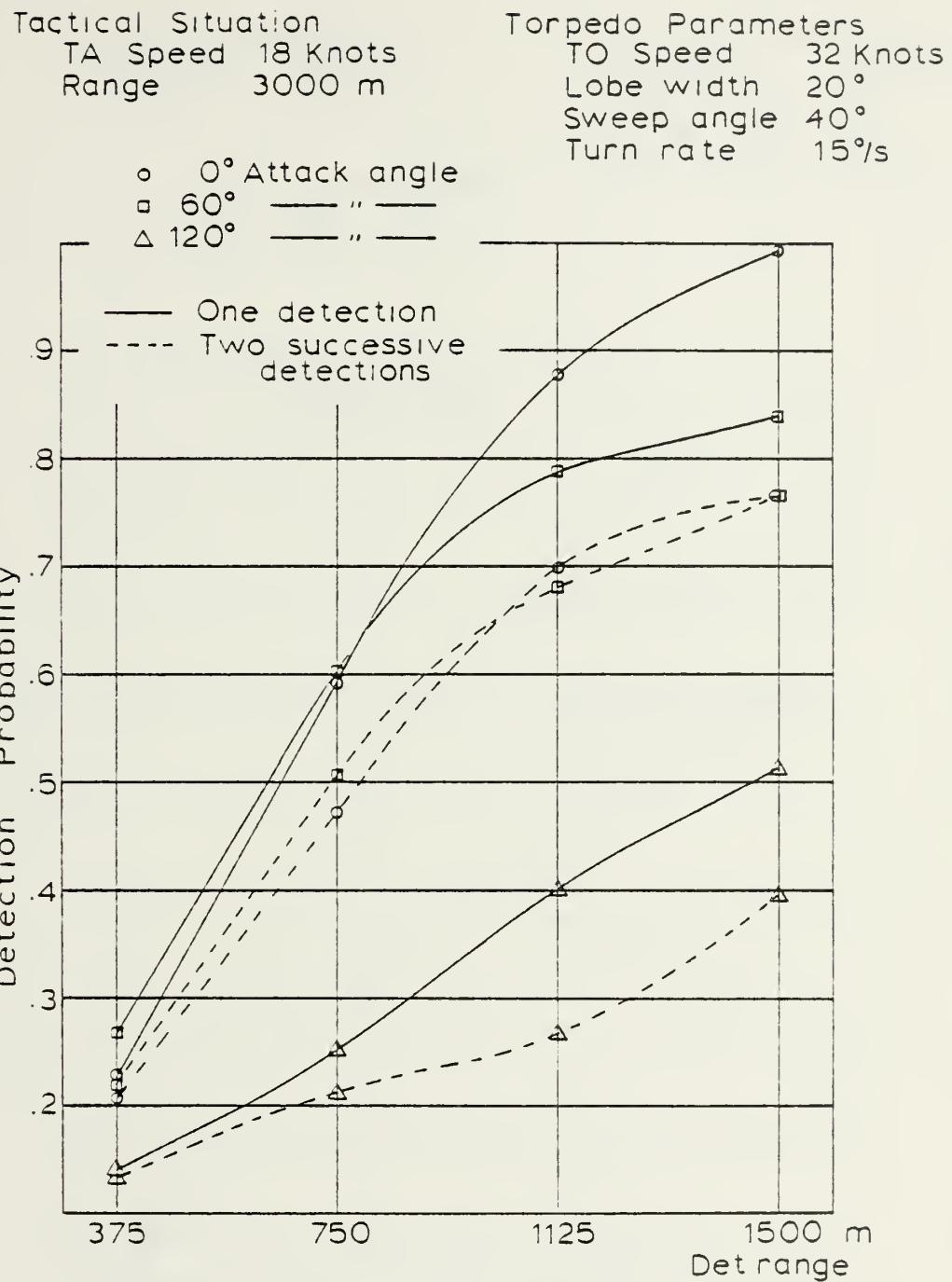


Figure 18 - EFFECT OF DETECTION RANGE

Tactical Situation:
TA Speed 18 Knots
Range 3000 m

Torpedo Parameters:
TO Speed 40 Knots
Lobe width 20°
Sweep angle 30°
Turn rate 18°/s

- 0° Attack angle
- 60° " "
- △ 120° " "

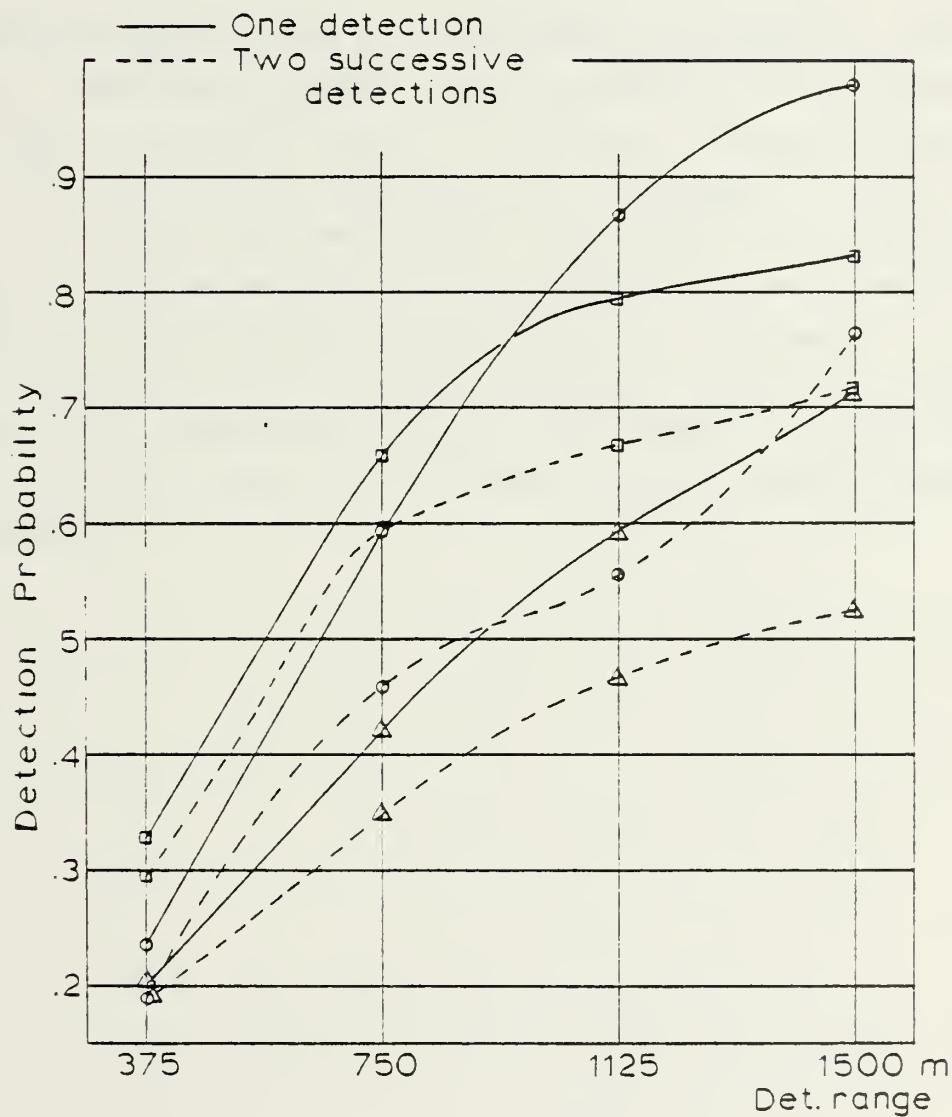


Figure 18.b. - EFFECT OF DETECTION RANGE

Otherwise the picture in Figs. 19.a. and b. is as in previous similar figures; a marked decrease in MOE with attack angles more than 60 - 90 degrees, and with the faster torpedo superior over most of the range. It should, however, be noted that for longer detection ranges we get maximum MOE at 0 degree attack angle for both torpedo types. This effect is reduced when we require two successive detections for acquisition.

We also experienced a considerable decrease in MOE for longer detection ranges when requiring two successive detections instead of one. It seems obvious that this reduction is due to a larger lateral movement at the extreme range. As noted previously, we increase the transmission interval (increase interval in order to allow time for echo to return) when the detection range is increased. Keeping the same turn rate, the sonar lobe will turn a larger angle between each transmission, which can have a deteriorating effect on MOE for more than a one-detection-only acquisition requirement.

Torpedo Parameters.

TO Speed 32 40 Knots
 Lobe width 20 20 °
 Sweep angle 40 30 °
 Turn rate 15 18 °/s

Tactical Situation.

TA Speed 18 Knots
 Range 3000 m

→ ----- One detection

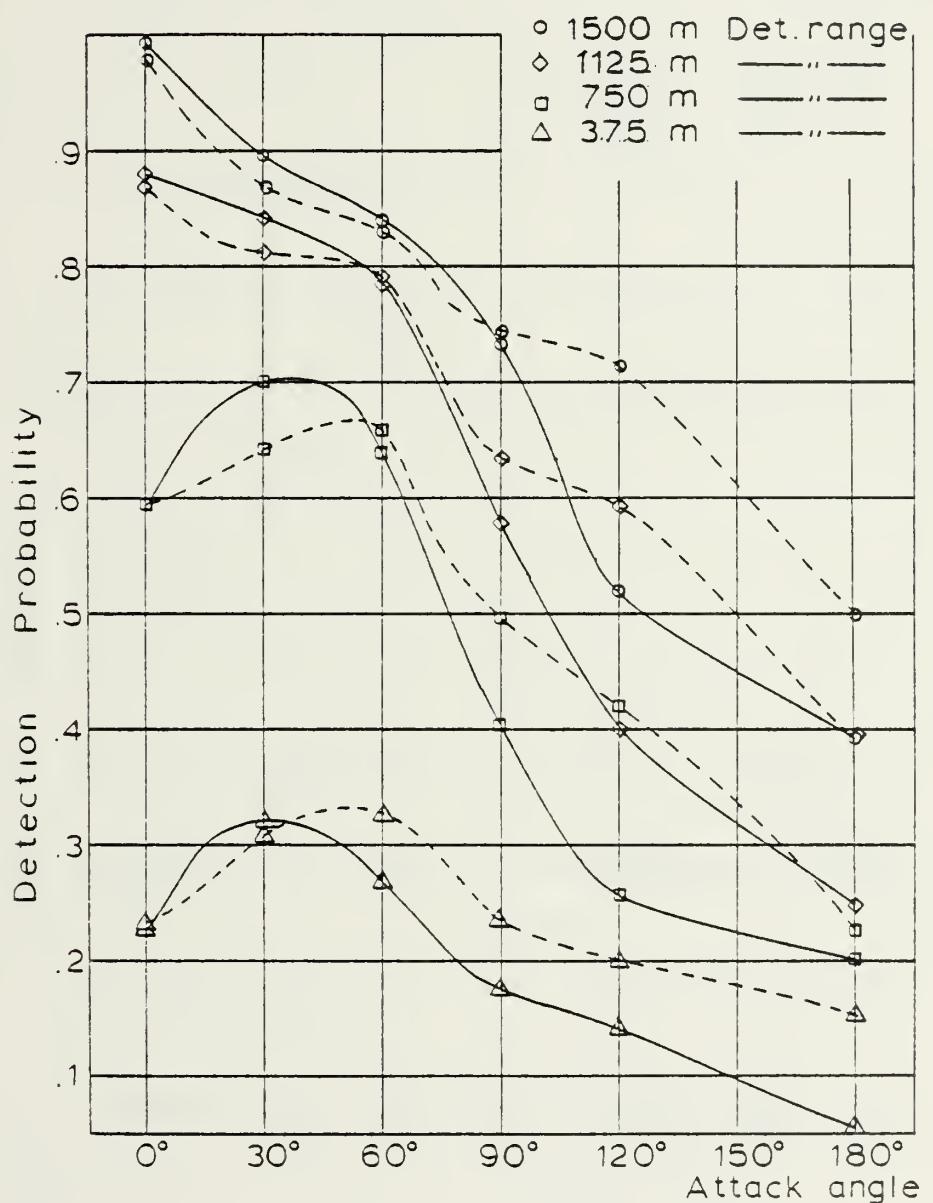


Figure 19 - COMPARISON OF TWO TORPEDOES WITH CHANGE IN DETECTION RANGE

Torpedo Parameters:
 TO Speed 32 40 Knots TA Speed 18 Knots
 Lobe width 20 20 ° Range 3000 m
 Sweep angle 40 30 °
 Turn rate 15 18 °/s


Two successive detections

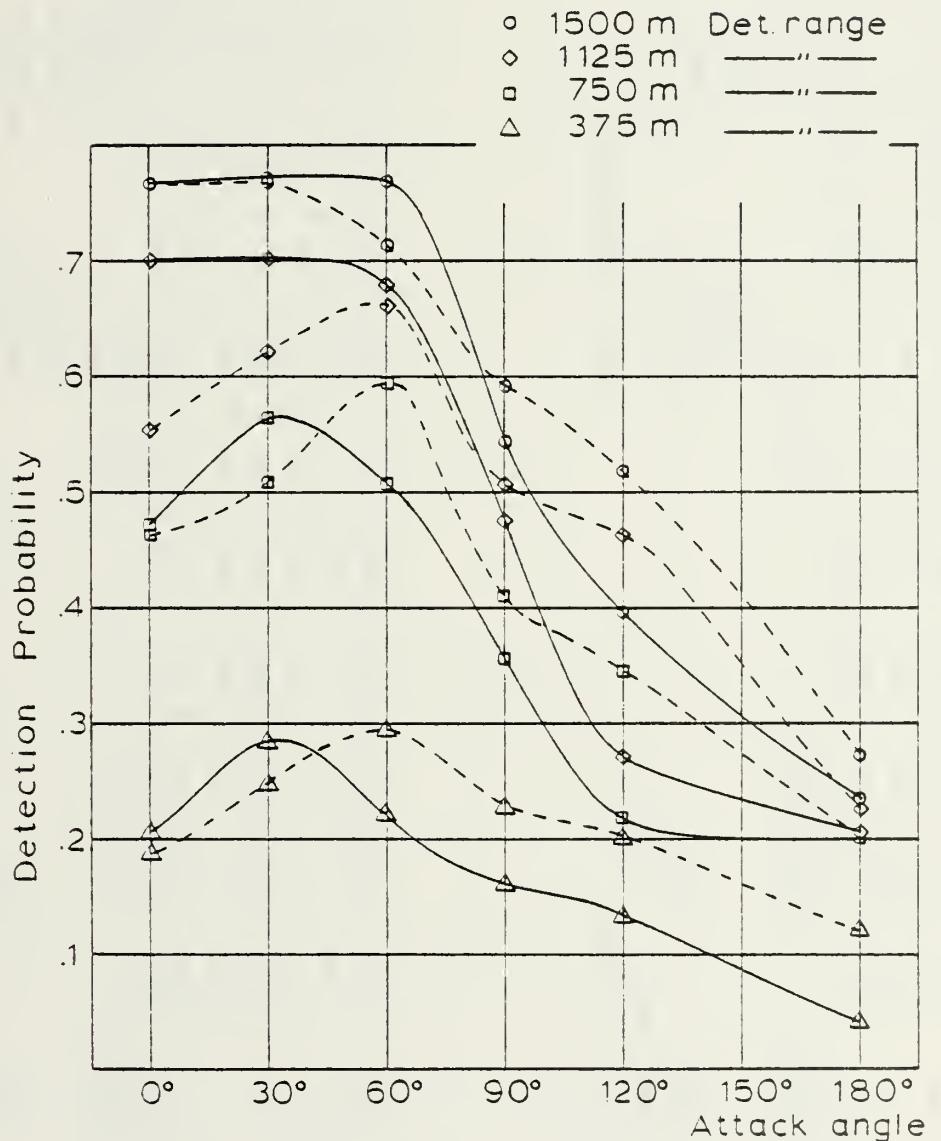


Figure 19.b. - COMPARISON OF TWO TORPEDOES
 WITH CHANGE IN DETECTION RANGE

Tactical situation

Target speed 18 knots
Range 3000 m

Torpedo parameters

Torpedo speed 32 knots
Sweep angle 40 degrees
Lobe width 20 degrees

Attack angle	375	1 detection			2 detections			Turn rate			Detection range m
		750	1125	1500	375	750	1125	1500	375	750	
0	.2267	.5933	.8800	.9933	.2067	.4733	.7000	.7667	.1667	.3600	.4800
30	.3200	.7000	.8333	.8933	.2867	.5667	.7000	.7667	.2600	.3667	.5267
60	.2667	.6067	.7867	.8400	.2200	.5067	.6800	.7667	.1933	.4267	.5600
90	.1733	.4000	.5800	.7333	.1600	.3533	.4733	.5467	.1400	.2733	.3667
120	.1400	.2533	.4000	.5133	.1333	.2133	.2667	.3933	.1200	.1733	.1867
180	.0533	.2000	.2467	.3933	.0400	.2000	.2067	.2333	.0267	.1733	.1933
											.2000

Tactical situation

Target speed 18 knots
Range 3000 m

Torpedo parameters

Torpedo speed 40 knots
Sweep angle 30 degrees
Lobe width 20 degrees

Attack angle	375	1 detection			2 detections			Turn rate			Detection range m
		750	1125	1500	375	750	1125	1500	375	750	
0	.2333	.5933	.8667	.9800	.1867	.4600	.5533	.7667	.1267	.2867	.3533
30	.3067	.6400	.8133	.8667	.2467	.5067	.6200	.7667	.1933	.3733	.4133
60	.3267	.6600	.7933	.8333	.2933	.5933	.6667	.7133	.2200	.4800	.5000
90	.2333	.4933	.6333	.7400	.2267	.4067	.5067	.5933	.1733	.2933	.3133
120	.2000	.4200	.5933	.7133	.2000	.3467	.4667	.5267	.1733	.2600	.3133
180	.1533	.2267	.3867	.5000	.1200	.2000	.2267	.2733	.0867	.2000	.2200

Table V - VARIATION IN DETECTION RANGE

H. COMBINED EFFECT OF LOBE WIDTH AND DETECTION RANGE

The following approximate relationships exist between lobe width, detection range and sonar power:

$$P = \frac{P_0 \cdot G_t \cdot \sigma \cdot G_r \cdot \lambda^2}{(4\pi)^3 \cdot R} \quad \text{Watts} \quad (4.9)$$

where

$$G_t = G_r = (4\pi / w) \quad (6.1)$$

$$w = L^2$$

$L = 2 \times \text{lobe width.}$

Ref [1;49].

w is defined as solid angle. The given equation is valid for small lobe width only. For larger lobe width the exact relationship is;

$$w = 2\pi \cdot (1 - \cos l) \quad (6.2)$$

$l = \text{lobe width.}$

The approximate relationship is close enough up to 60 degrees lobe width.

By substituting the approximate relationship into Eq. 4.9, we get a reduction of L^4 in receiving echo due to change in lobe width,
or

$$(L \cdot R)^4 = \text{constant}, \quad (6.3)$$

which combine range and lobe width, and implies that detection range is inverse proportional to lobe width for constant power transmitted.

It is therefore possible to plot this function for constant power transmitted, and use this as a prediction of how MOE may change with change in these two torpedo parameters (lobe width and detection range).

This is done in Fig. 20; and indicated by the dashed line going through 20 degrees lobe width and 750 m detection range.

We then ran some simulation series in order to generate data points from the model. The data points gave the MOE, and by fitting curves we were able to get some indication of the relationship between the lobe width and the detection range as given by the model.

The application could be as follows;

For a given torpedo with lobe width 20 degrees and a detection range of 750 m, we ask the question, can MOE be increased without increasing power transmitted?

The dashed curve through the point(20 degrees, 750 m) is a constant power curve, and by following the curve we observe how MOE is changing.

From the figure, it is obvious that a narrower lobe and a longer detection range gives a better result. But we also observe the assymptotical feature of the curves. We reach a point where the constant power curve and the constant MOE curve are parallel.

However, it should be born in mind that the theoretical relationship between lobe width and detection range is an approximation which does not account for absorption-effect or surface-effect. This implies that the constant power

curve in real life will be lowered. Only a more detailed analysis can say how much.

Tactical Situation
 TA Speed 18 Knots
 Range 3000 m

Torpedo Parameter
 TO Speed 40 Knots
 Sweep angle 30 °
 Turn rate 18 %/s

One detection only

— Constant detection probability
 - - - Constant power transmitted

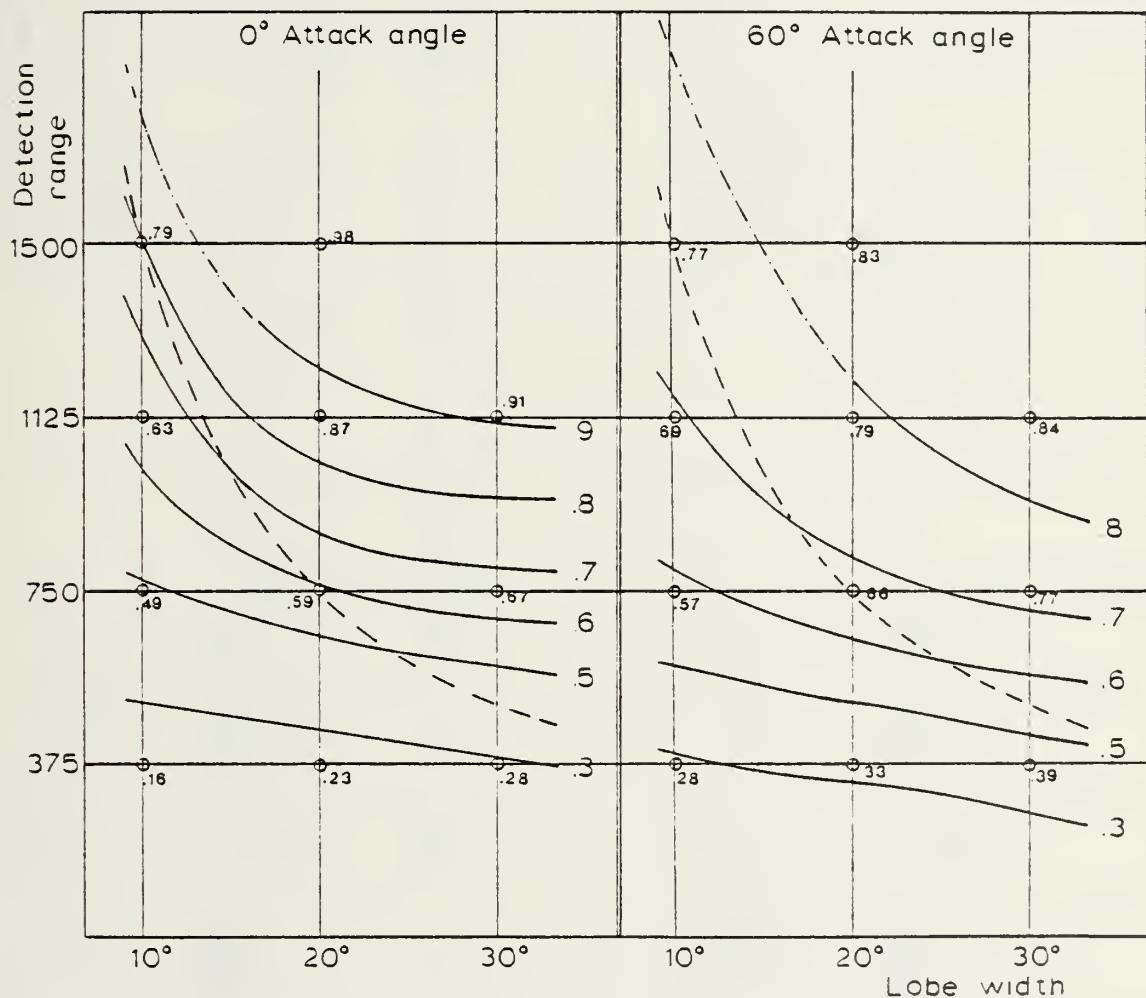


Figure 20 - VARIATION IN EFFECTIVENESS AS A FUNCTION OF LOBE WIDTH AND DETECTION RANGE

Tactical situation

Torpedo parameters

Target speed Range	18 knots 3000 m
-----------------------	--------------------

Attack angle	1 detection			2 detections			3 detections			Detection range, m		
	375	750	1125	1500	375	750	1125	1500	375	750	1125	1500
0°	.1600	.4933	.6267	.7867	.1267	.2167	.3600	.4600	.1200	.1133	.1800	.1600
60°	.2800	.5667	.6933	.7733	.1667	.3167	.5400	.5533	.0867	.3067	.3667	.3667
0°	.2333	.5933	.8667	.9800	.1867	.4600	.5533	.7667	.1267	.2867	.3533	.4060
60°	.3267	.6600	.7933	.8333	.2933	.5933	.6667	.7133	.2200	.4800	.5000	.6267

Tactical situation

Torpedo parameters

Target speed Range	18 knots 3000 m
-----------------------	--------------------

Attack angle	1 detection			2 detections			3 detections			Detection range, m		
	375	750	1125	1500	375	750	1125	1500	375	750	1125	1500
0°	.2800	.6667	.9133	.8400	.2333	.5533	.6733	.7333	.1867	.4200	.4867	.4067
60°	.3867	.7200			.3733	.6100	.7333		.3333	.5167	.6067	.3067

Table VI - VARIATION IN BOTH LOBE WIDTH AND DETECTION RANGE

I. EFFECT OF FIRING RANGE

The most important factor in achieving high detection probability is the difference between estimated target position and actual target position at the time when the torpedo is in position to detect. The effect on the detection probability is mainly due to the time the torpedo takes to reach within detection range of target and the speed/course errors in target data.

As we increased the firing range, we experienced as anticipated a degradation in MOE. This degradation was experienced for both the 32 and the 40 knots torpedo. The variation in firing ranges were at the following values: 1500 - 3000 - 5000 - 7000 meters.

Fig. 21.a. and b. shows consistently the importance of short firing ranges. This applies to both one detection and two successive detections.

Fig. 22.a. and b. shows an additional advantage with short firing ranges; a considerable improvement at firing with small aspect (attack angle), less than 30 degrees. Again this applies for both types of torpedoes.

Also, we get an indication that at short ranges, about 1500 meters, there is no significant difference in MOE of the two types of torpedoes up to an attack angle of 90 degrees.

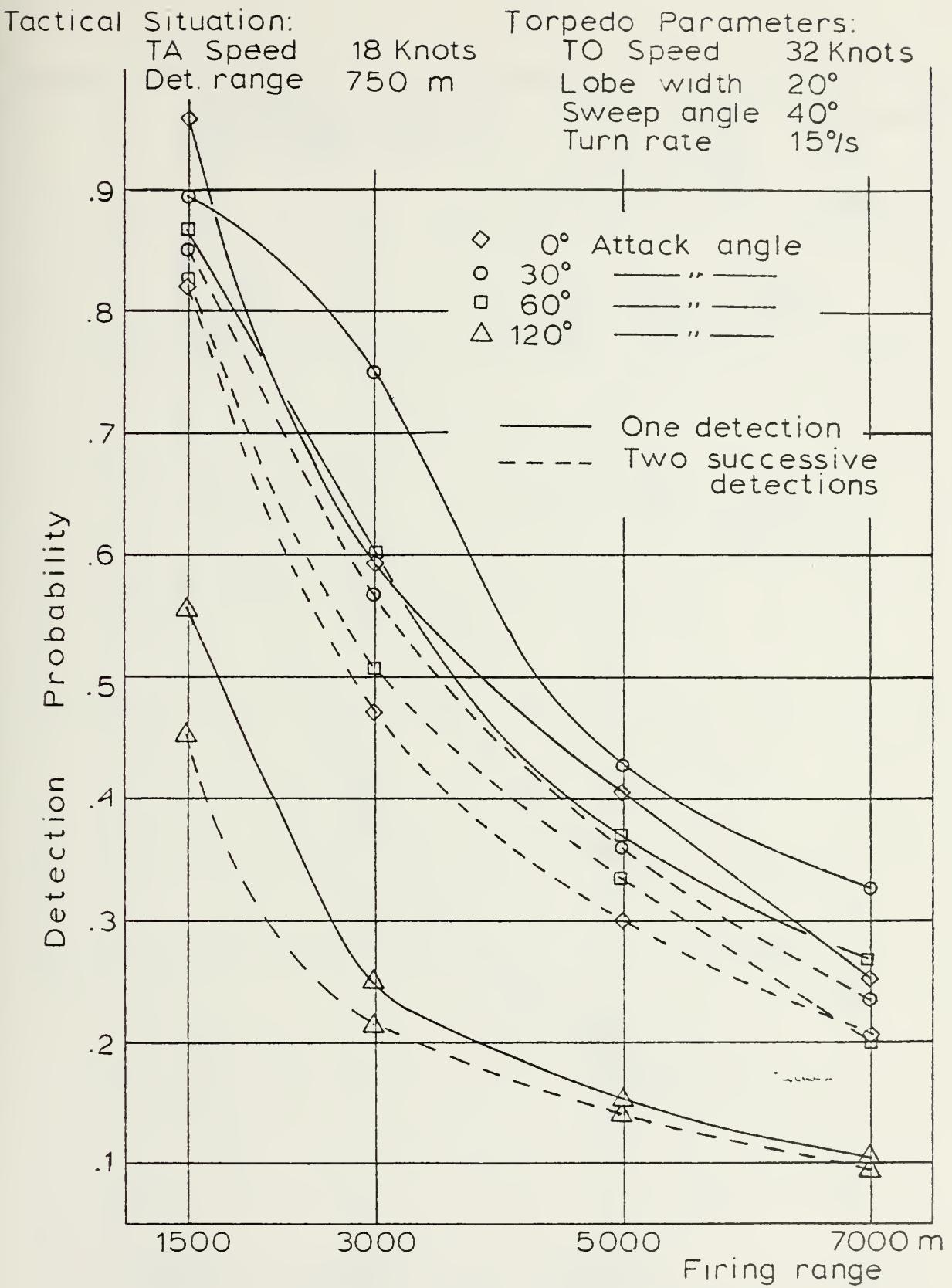


Figure 21 - EFFECT OF FIRING RANGE

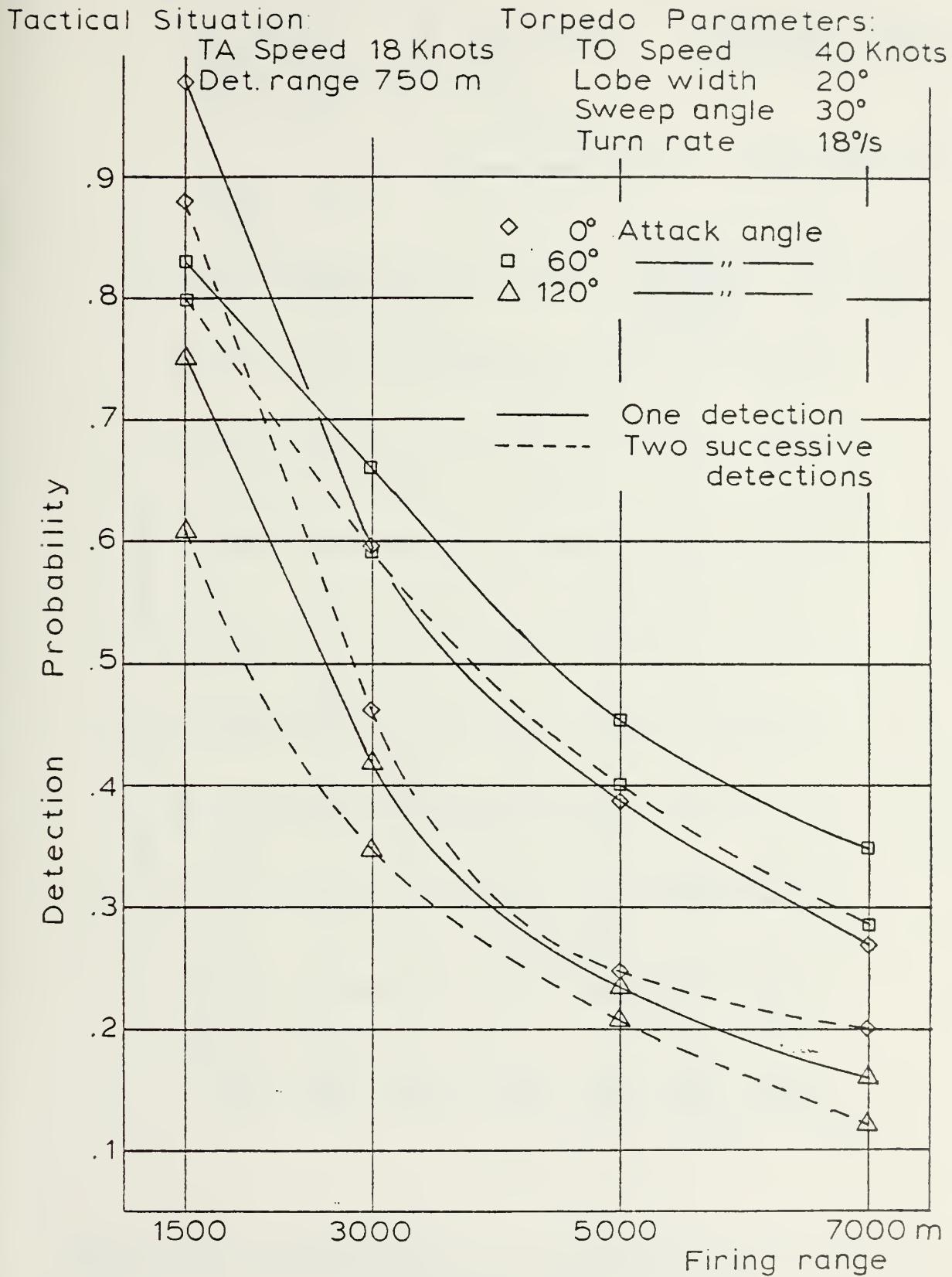


Figure 21.b. - EFFECT OF FIRING RANGE

Torpedo Parameters

TO Speed	32	40	Knots
Lobe width	20	20	$^{\circ}$
Sweep angle	40	30	$^{\circ}$
Turn rate	15	18	$^{\circ}/s$

Tactical Situation

TA Speed	18 Knots
Det range	750 m

→ ----- One detection

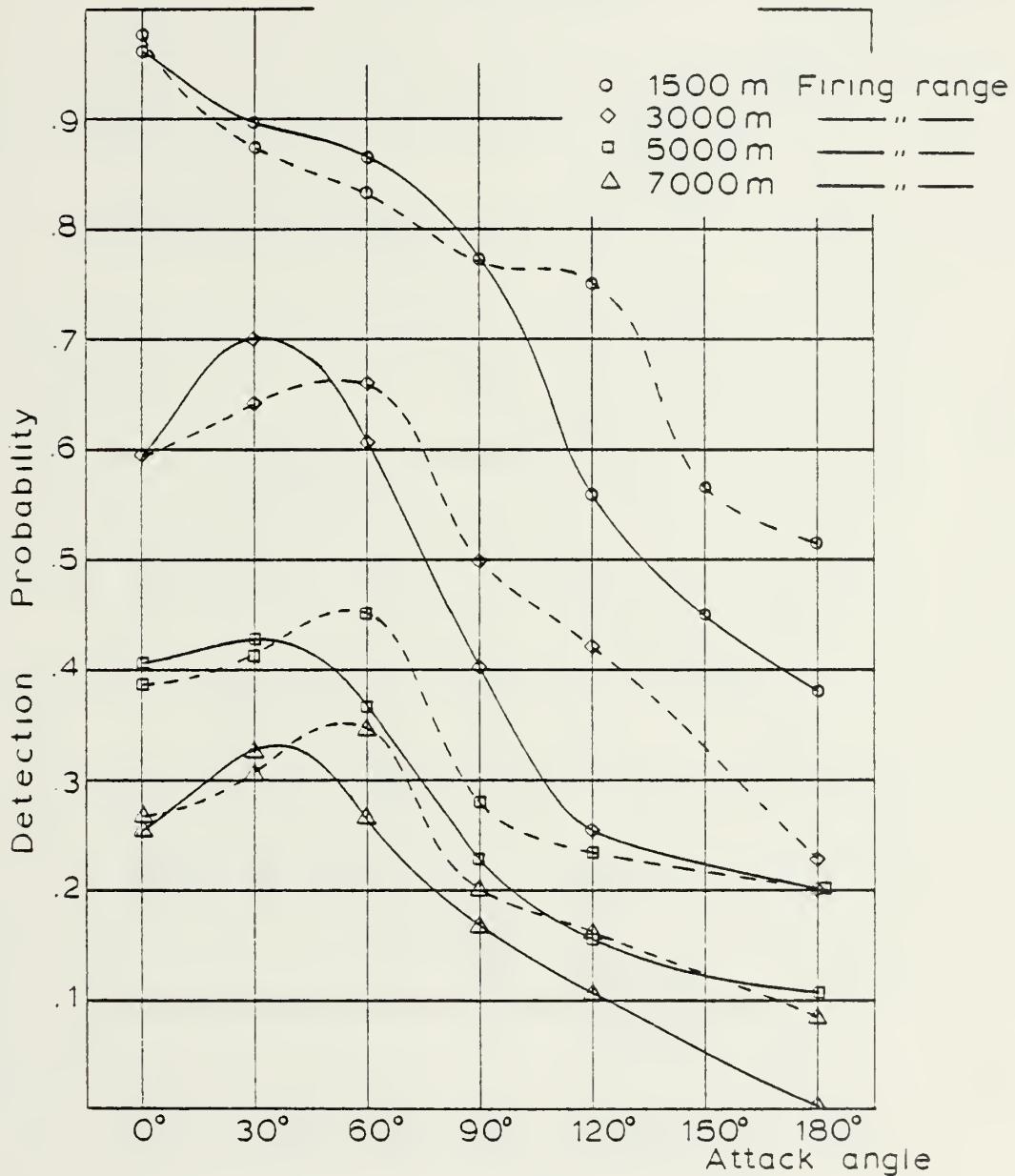


Figure 22 - COMPARISON OF TWO TORPEDOES WITH CHANGE IN FIRING RANGE

Torpedo Parameters

TO Speed	32	40 Knots
Lobe width	20	20 °
Sweep angle	40	30 °
Turn rate	15	18 °/s

Tactical Situation.

TA Speed 18 Knots
Det. range 750 m

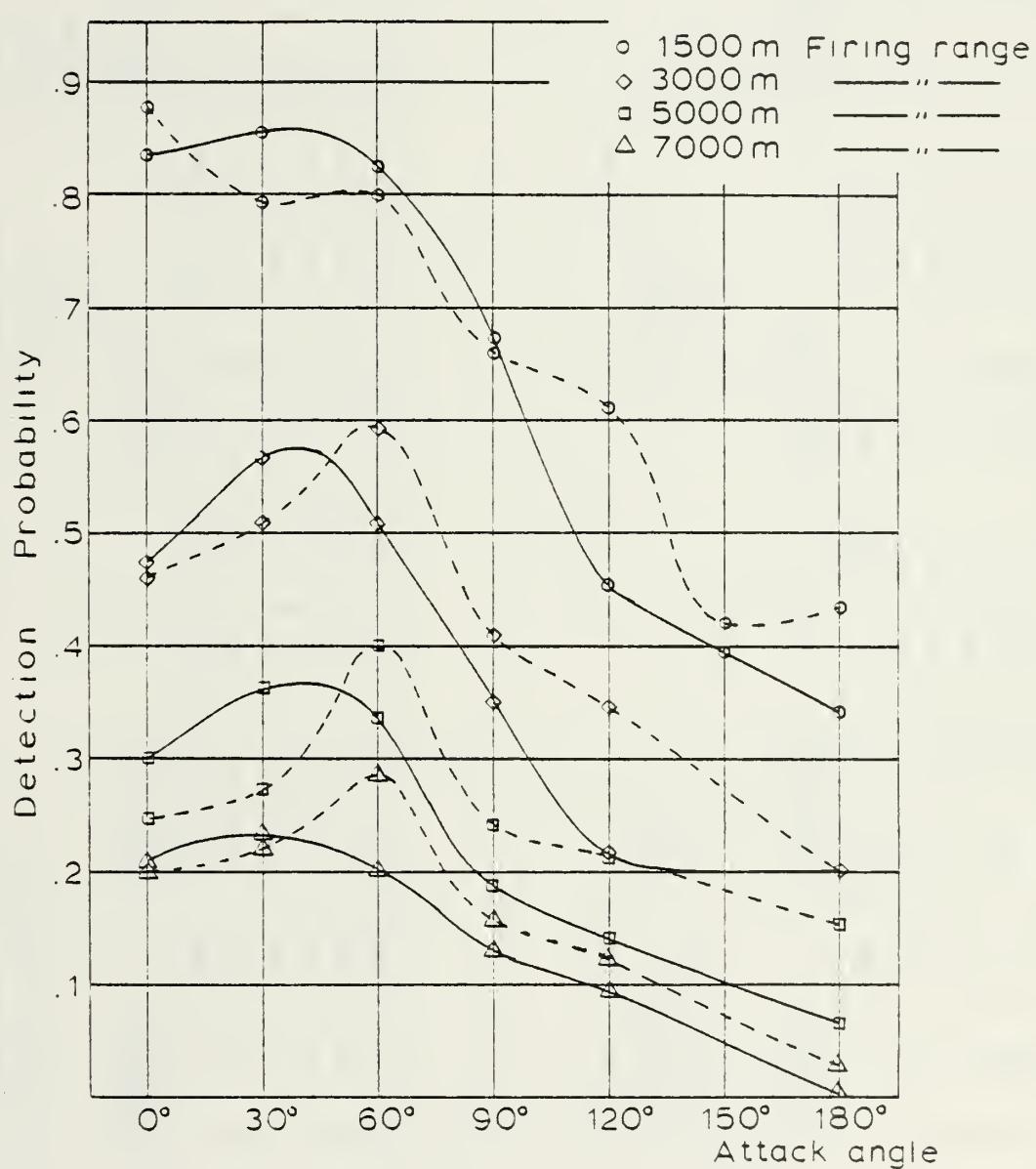


Figure 22.b. - COMPARISION OF TWO TORPEDOES WITH CHANGE
IN FIRING RANGE

Tactical situation

Target speed 18 knots
Detection range 750 m

Torpedo parameters

Torpedo speed 32 knots
Sweep angle 40 degrees

Attack angle	1 detection		2 detections		3 detections		Range m
	1500	3000	7000	1500	3000	7000	
0	.9600	.5933	.4067	.2533	.8333	.4733	.1000
30	.8933	.7000	.4267	.3267	.8533	.5667	.1000
60	.8667	.6067	.3667	.2667	.8267	.5067	.1800
90	.7733	.4000	.2267	.1667	.6733	.3533	.1867
120	.5600	.2533	.1067	.4533	.2133	.1400	.1200
180	.3800	.2000	.1067	.3400	.0000	.0667	.0533

Tactical situation

Target speed 18 knots
Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots
Sweep angle 30 degrees

Attack angle	1 detection		2 detections		3 detections		Range m
	1500	3000	7000	1500	3000	7000	
0	.9800	.5933	.3867	.2667	.8800	.4600	.1000
30	.8733	.6400	.4133	.3067	.7933	.5067	.1000
60	.8333	.6600	.4533	.3467	.8000	.5933	.1000
90	.7667	.4933	.2800	.2000	.6600	.4067	.1000
120	.7533	.4200	.2333	.1600	.6133	.3467	.1000
180	.5133	.2267	.2000	.0867	.4333	.2000	.0000

Table VII - VARIATION IN FIRING RANGE

J. EFFECT OF TARGET SPEED

Generally, we anticipated a degradation in MOE as the target speed was increased. And overall, this was confirmed.

The simulations were carried through at 12, 18, 24, 30 knots target speed.

However, fig. 23.a and b shows some interesting patterns regarding optimal attack angle for different target speeds. For a 32 knots torpedo, at 60 degrees attack angle, the torpedo is equally good for any type of target speed for one detection only. For two successive detections, the torpedo is equally good between 30 and 90 degrees for 12 and 18 knots target. A 24 knots target gives a consistently lower MOE over the whole range of attack angles, and the 2 simulation runs with a 30 knots target confirmed that trend for the 32 knots torpedo.

We may form the conclusion that for one detection only 60 degrees attack angle is an optimal attack angle for the range of target speeds. For two successive detections, 30 to 90 degrees attack angle gives equally good MOE between target speed of 12 and 18 knots.

One interesting point is that it seems that if the target speed is less than 0.4 of the torpedo speed the optimal attack angle shifts forward to 0 degree. This also applies to two successive detections.

Tactical Situation:
Range 3000 m
Det. range 750 m

Torpedo Parameters:
TO Speed 32 Knots
Lobe width 20°
Sweep angle 40°
Turn rate 15 °/s

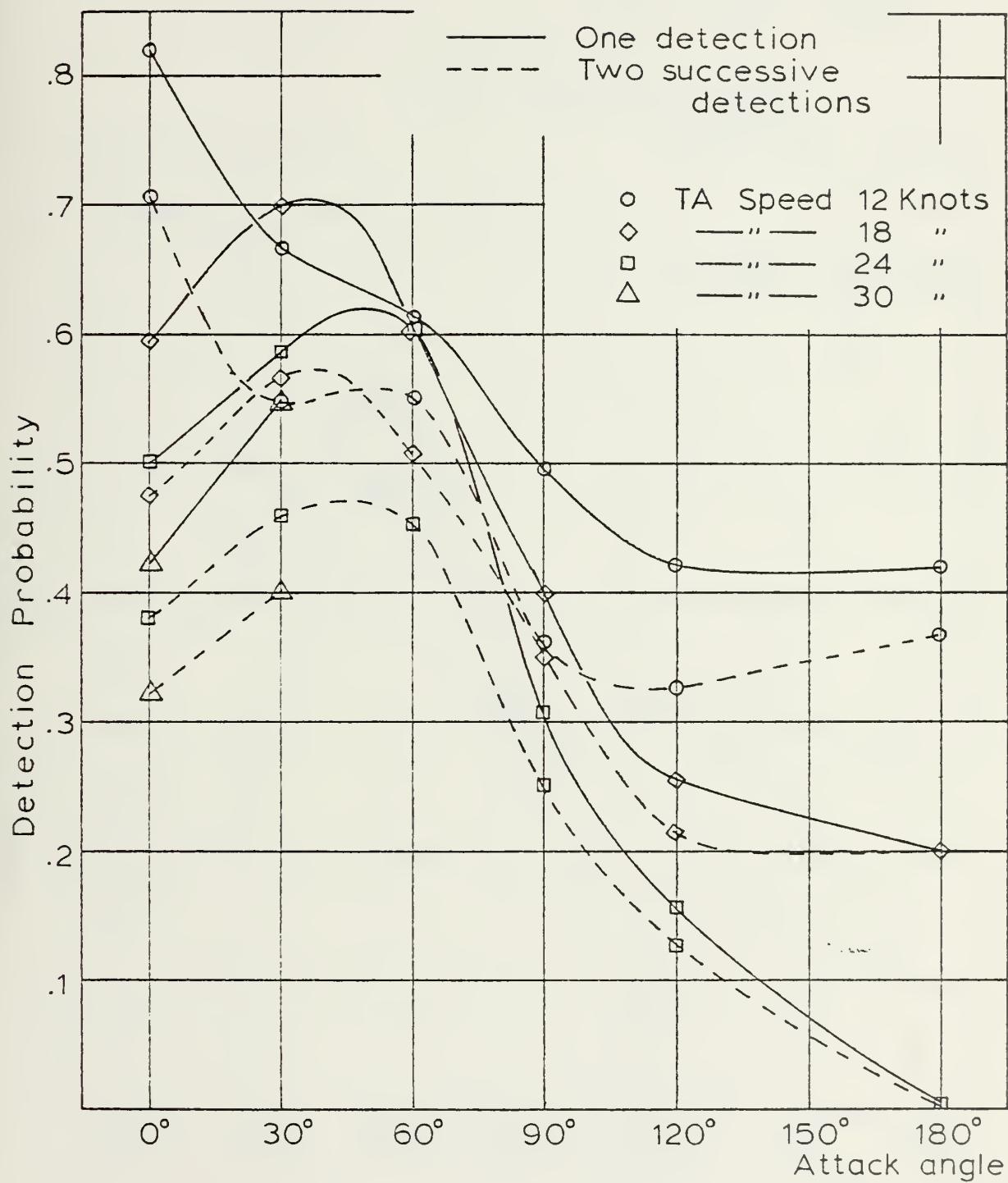


Figure 23 - EFFECT OF TARGET SPEED

Tactical Situation:
 Range 3000 m
 Det. range 750 m

Torpedo Parameters:
 TO Speed 40 Knots
 Lobe width 20°
 Sweep angle 30°
 Turn rate 18°/s

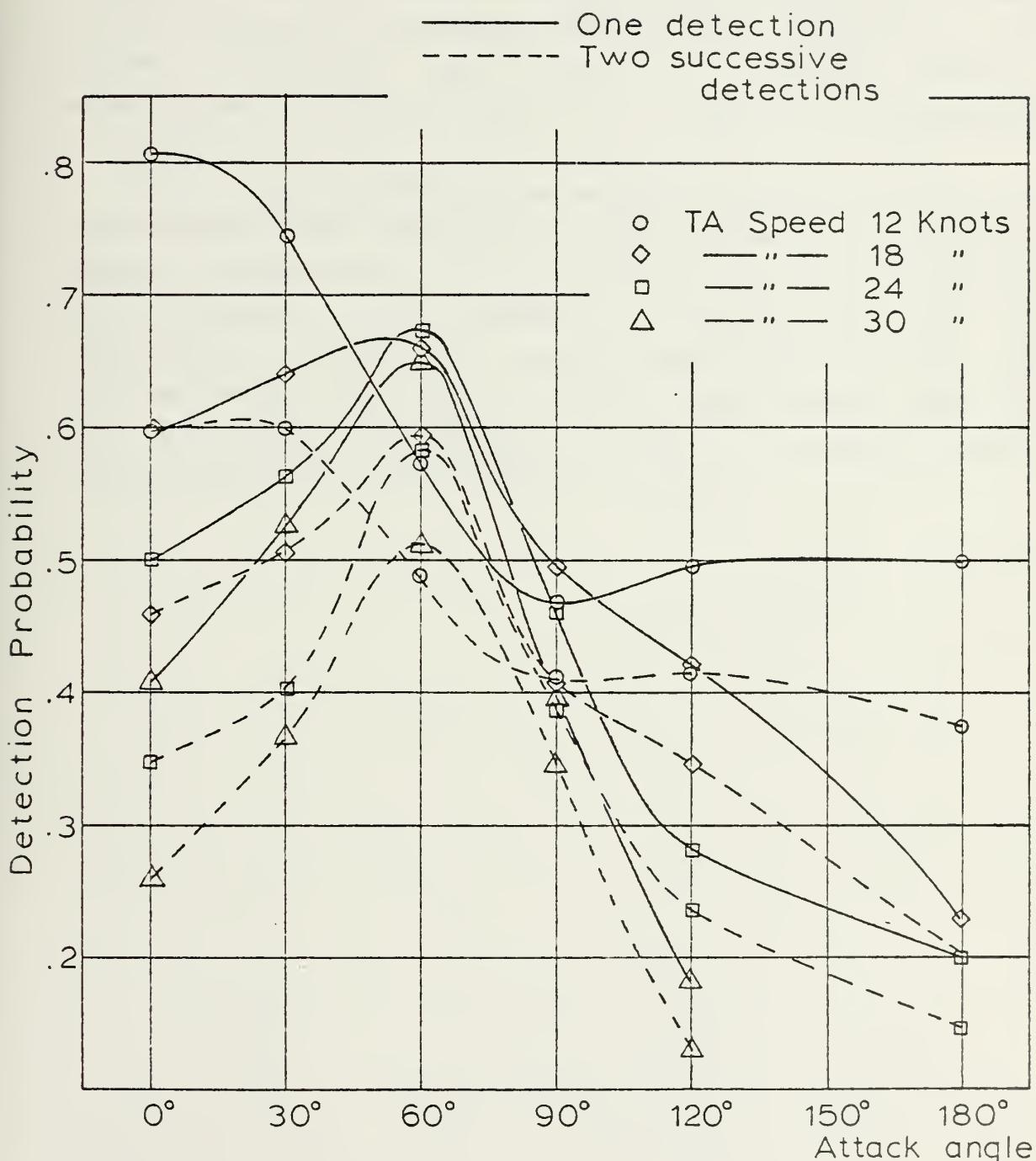
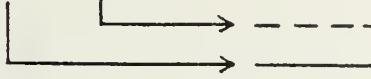


Figure 23.b. - EFFECT OF TARGET SPEED

For a 40 knot torpedo, in addition to the point of optimal attack angle at 0 degree for slow target speeds, we also experienced a relatively low MOE for slow targets in the range 45 to 105 degrees attack angle, compared to fast targets. But as a compensation, MOE is increased for small attack angles and the astern attack angle compared to fast target. Obviously, some type of a breaking point is experienced for target speed of .4 or less of torpedo speed.

Why a slow target produces this increase in MOE in the two extreme cases (ahead and astern) may be explained by the balance between time to reach detection range and the total relative speed. It is, however, more difficult to give any explanation of why a slow target should produce a lower MOE for some attack angles than a faster target does. One would have anticipated an increase in MOE over the whole range of attack angles for a slow target.

Torpdo Parameters: Tactical Situation:
 TO Speed 32 40 Knots Range 3000m
 Lobe width 20 20° Det. range 750m
 Sweep angle 40 30°
 Turn rate 15 18°/s


One detection

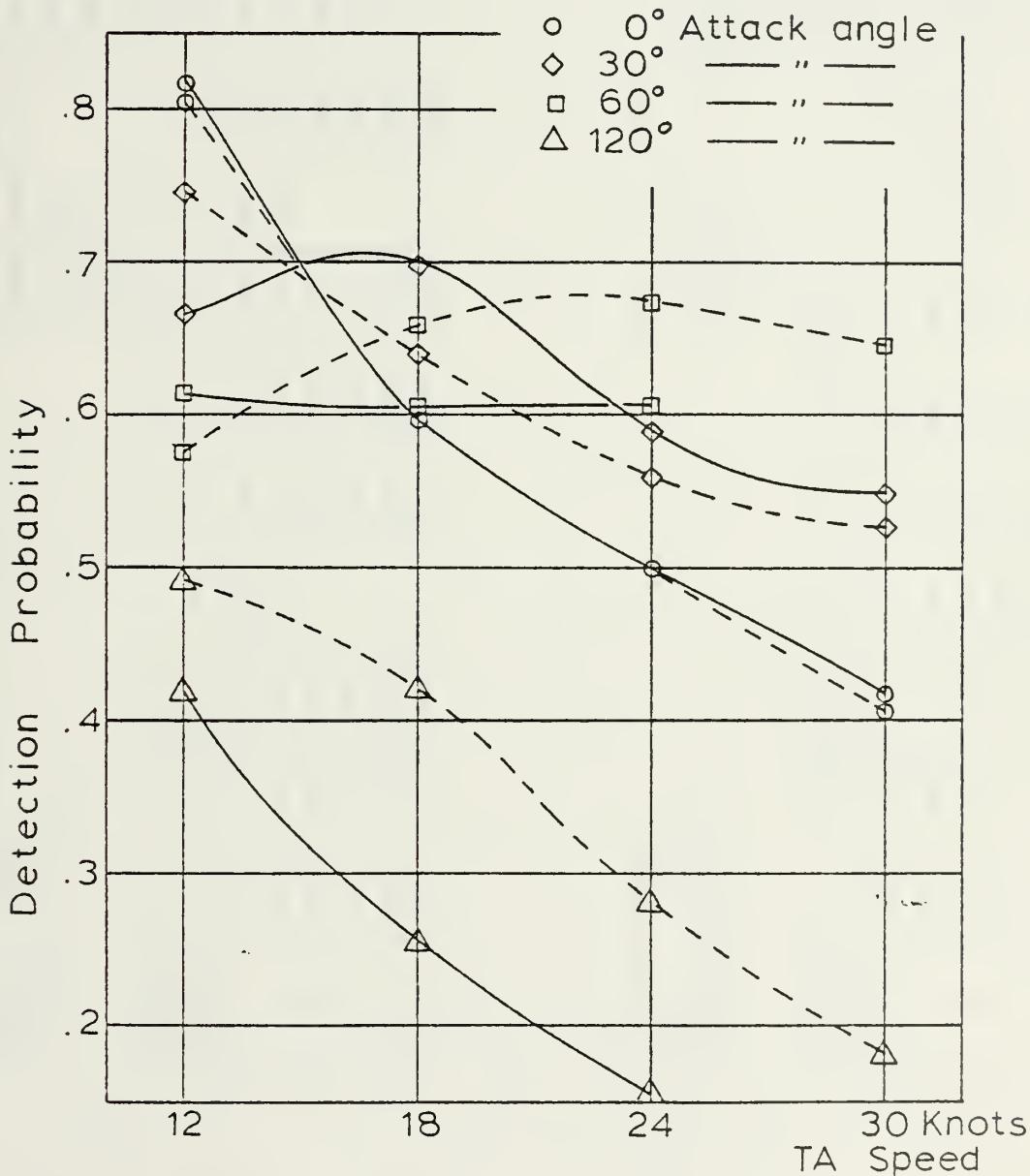


Figure 24 - COMPARISON OF TWO TORPEDOES WITH CHANGE IN TARGET SPEED

Tactical situation
Range 3000 m
Detection range 750 m

Torpedo parameters
Torpedo speed 32 knots
Sweep angle 40 degrees
Lobe width 20 degrees
Turn rate 15 deg/sec

Attack angle	12	1 detection		30	12	2 detections		30	12	3 detections		30	Target speed knots
		18	24			18	24			18	24		
0	.8200	.5933	.5000	.4200	.7067	.4733	.3800	.3200	.4667	.3600	.2533	.1867	
30	.6667	.7000	.5867	.5467	.5467	.5667	.4600	.4000	.4200	.3667	.3267	.2867	
60	.6133	.6067	.6067	.5533	.5533	.5067	.4533	.	.3933	.4267	.3667		
90	.4933	.4000	.3067	.3600	.3533	.3467	.	.3133	.2730	.2133			
120	.4200	.2533	.1533	.3267	.2133	.1267	.	.2400	.1733	.1067			
180	.4200	.2000	.0000	.3667	.2000	.0000	.	.2667	.1733	.0000			

Tactical situation
Range 3000 m
Detection range 750 m

Torpedo parameters
Torpedo speed 40 knots
Sweep angle 30 degrees
Lobe width 20 degrees
Turn rate 18 deg/sec

Attack angle	12	1 detection		30	12	2 detections		30	12	3 detections		30	Target speed knots
		18	24			18	24			18	24		
0	.8067	.5933	.5000	.4067	.6000	.4600	.3467	.2600	.4133	.2867	.1933	.1400	
30	.7467	.6400	.5600	.5267	.6000	.5067	.4000	.3667	.4267	.3733	.3267	.3267	
60	.5733	.6600	.6733	.6467	.4867	.5933	.5867	.5133	.3600	.4800	.5333	.4267	
90	.4667	.4933	.4600	.4067	.4067	.3867	.3400	.3200	.2933	.3333	.3333	.2667	
120	.4933	.4200	.2800	.1800	.4133	.3467	.2333	.1267	.2333	.2600	.1867	.1000	
180	.5000	.2267	.2000	.3733	.2000	.1467	.	.2467	.2000	.0067			

Table VIII - VARIATION IN TARGET SPEED

VII. TACTICAL ANALYSIS

In addition to the detailed parametric analysis, which has been shown previously, we also could expand the analysis to cover more tactical related problems. If we assume a given target speed, we could construct detection probability charts as shown in Fig. 25. a. and b.

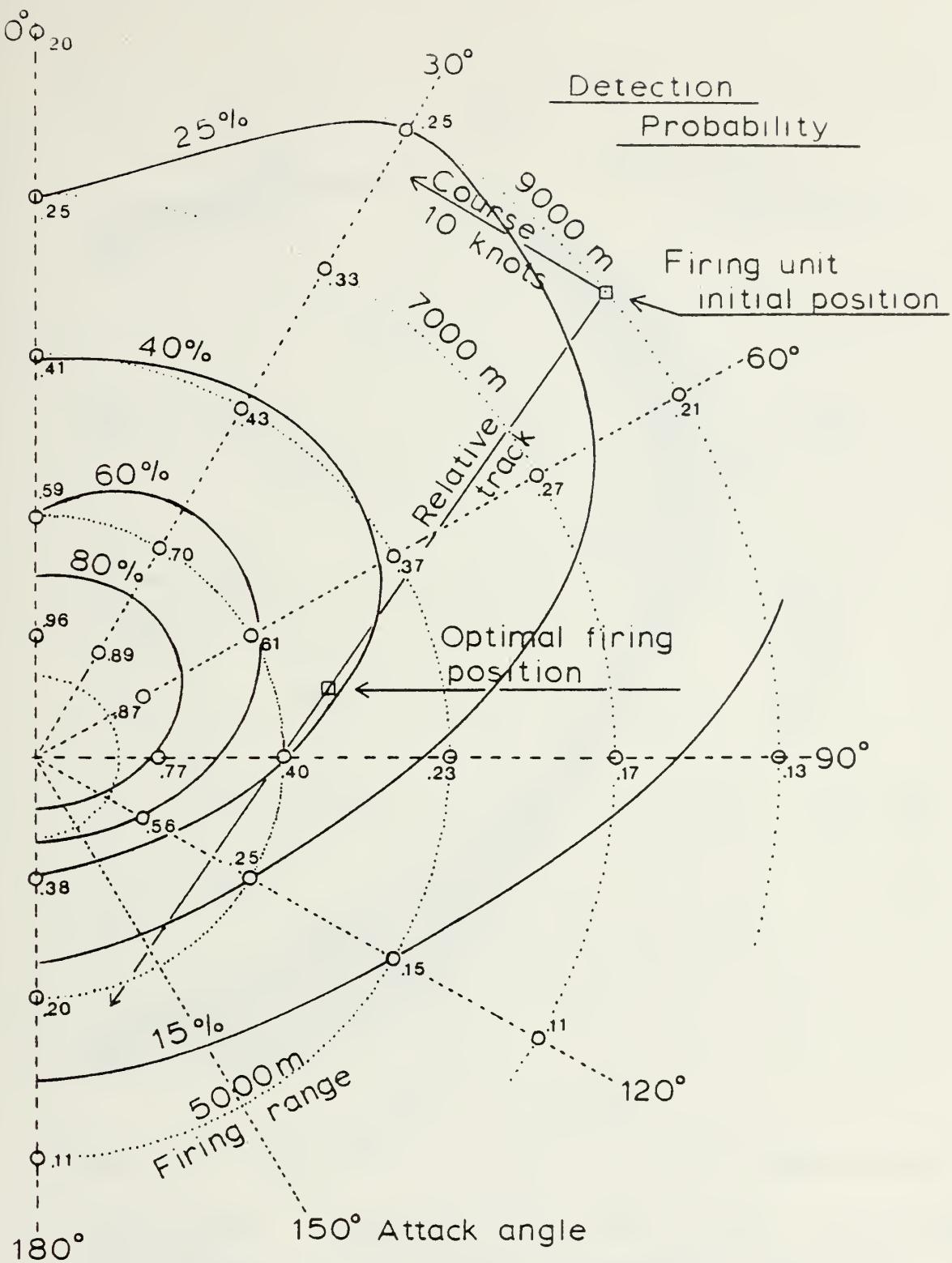
This analysis would then naturally fall into two areas:

- direct comparison of two or more different types of torpedoes.
- effect of tactical situation on the detection probability.

The two charts (Figs. 25.a. and b.) were formed by running simulation runs for different tactical situations (range and attack angle), and then fitting constant detection probability curves through the data points.

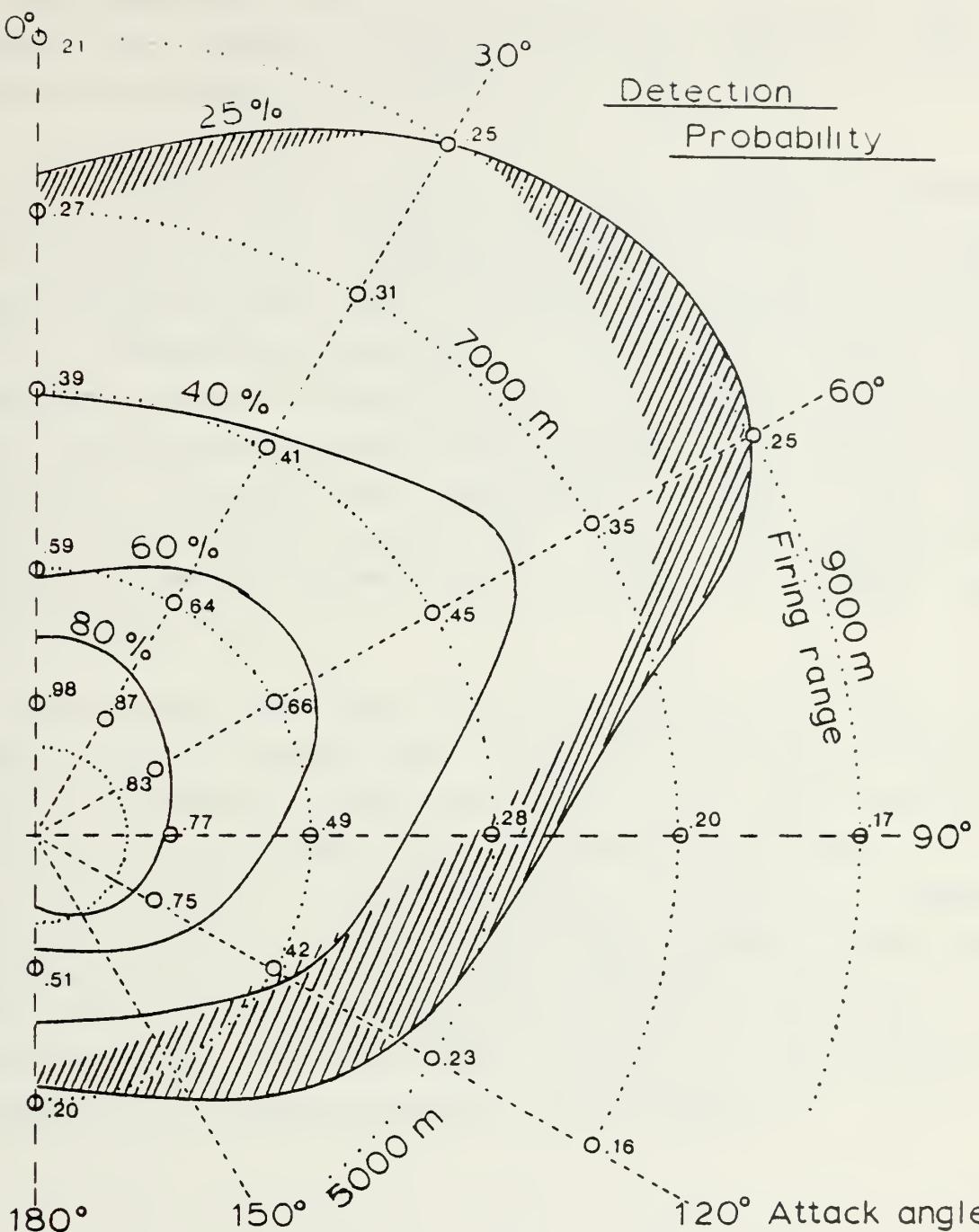
The use of these types of charts falls into two areas: Evaluate different torpedo types for different tactical situations; essentially, which torpedo is best. Or for a given tactical situation, how could the situation be improved, and what options exist.

The first type of use applies mainly to operational planning; operational requirement in the design phase of a torpedo and procurement. By laying one chart atop of the other; we get a visual picture of how much is improved when using a 'better' torpedo, and for which tactical situation. The shaded area in Fig. 25.b. shows how many more tactical situations have been covered when going from a 32 knots torpedo to a 40 knots torpedo for 0.25 detection probability.



Det. range	750 m	TO Speed	32 Knots
TA Speed	18 Knots	Sweep angle	40°
Turn rate	15 °/s	Lobe width	20°

Figure 25 - EXAMPLE OF TACTICAL GUIDELINES



Det. range	750 m	TO Speed	40 Knots
TA Speed	18 Knots	Sweep angle	30 °
		Lobe width	20 °
		Turn rate	18 °/s

Figure 25.b. - EXAMPLE OF TACTICAL GUIDELINES

The other type of use of the charts is tactical. When a firing unit decides to attack, and finds itself in a given tactical situation, the question is: What to do ?

For given target speed and own max speed, the charts make it possible in a simple way to decide where to go and what course to keep. Also from the charts, one can decide where on the relative course is the optimal firing position. For a submarine attacking a zig-zagging target, the Commanding Officer can better make his evaluation of when to fire, as the attack angle and the distance are continuously changing. He can see what improvement to expect when the target will change course next time. An example of a tactical situation and the course of action to follow are given in Fig. 25.a.

These points also bring up the question of what to improve in the operational picture; the firing unit's ability to achieve a good firing position or the torpedo's ability to detect target from non-optimal situations. In this discussion, the guided torpedo has to be brought into the picture. The effectiveness of guidance has not been addressed at all in this study, basically because that would have significantly expanded the scope of the study, as well as bringing in the whole problem of fire control equipment, its effectiveness and its reliability.

VIII. CONCLUSIONS

The study was carried out in order to investigate the detection process of an active sonar homing torpedo used against surface ships.

Specifically, we wanted to study the effect of changes in torpedo parameters such as torpedo speed, turn rate, sweep angle and detection range, as well as changes in the tactical situation such as target speed, firing range and attack angle.

In an attempt to gain insight into the complexity of a homing torpedo, the described model was built and the simulations done as previously shown.

In designing a homing torpedo and evaluating torpedo tactics the detection probability is an essential part of the total effectiveness of the torpedo.
To be able to hit the target, the torpedo has first to detect it, which justifies why we started out with analyzing the detection process.

Also, as part of this analysis we investigated certain aspect of the next step in the operational process; acquisition.

It is not difficult to visualize tests which may be used in order to recognize an echo as a detection and subsequently a target to attack. Some of these tests may be doppler, successive detections, detections within a given range, 2-of-3 detections, size of echo, length of echo etc.
The problem of false echo, however, was not approached in

this study. That would have to be the next to consider in relation to reducing the number of successive detections in order to acquire a target.

In order to allow for the errors in tracking of the target before firing and also small maneuvering of the target after firing, we introduced errors in the target speed and course when calculation of the torpedo main firing course was done.

During runs the torpedo was unguided, and did not react on any detection; i.e. it did not attack the target. For sonar condition, isovelocity was assumed and no surface effect was built into the model.

The result gave certain insight into the complexity of the detection process, stressing the importance of a good tactical firing position, and of a high speed torpedo with long detection range.

However, the data also showed the relationship between detection range, lobe width and turn rate, as well as weighting the sweep angle in relation to torpedo speed. It can also be concluded from the results that changes in torpedo parameters as turn rate and sweep angle, which may be inexpensive modifications, will not give a significant improvement.

Generally, the overall important factor was the time the torpedo used in order to travel within the detection range of the target. This was due primarily to the error generated in the target data, obviously the actual value of the result is sensitive to these assumptions. However, the understanding and insight in the detection process achieved by simulation should not be reduced by other assumptions with regard to error in target data.

With regard to the analysis, the result has shown a consistent and general trend that if we are able to require only one detection for acquiring a target, the detection probability is significantly higher than if more than one detection is required. And what is more important, the potential for improving/optimizing a homing torpedo is also significantly higher for one detection only. This implies a large payoff for other methods of keeping down the probability of false detections.

Secondly, a high speed torpedo has shown a general superiority in MOE. This was specially obvious in attack angles greater than 90 degrees, which tends to make a high speed torpedo more of an all-round/reliable torpedo with regard to tactical situations.

Thirdly, except for changes in attack angle and firing range, the detection range seems to influence the MOE strongly.

These three remarks all point towards an improvement in the sonar-/filtering-area as the most promising area in which to carry out research and invest effort.

This study has also pointed out the advantage of high torpedo speed and firing at short ranges. There exists therefore considerable argument for a short range, high speed torpedo, given that one is able to position the torpedo at a short firing range; i.e. a small, simple torpedo.

Basically, there are two schools of thought;

- a highly sophisticated torpedo; long range, guidance, expensive, but close to the one shot-one hit idea.
- a simple, high speed torpedo; short range,

non-guidance, inexpensive, and requiring either a firing unit which can get into an optimal firing position or a larger number of shots to achieve hit.

The result may be useful in giving example of how tactical guidelines can be evaluated by the simulation approach. But more significant is pointing out the importance of torpedo capability and the tactical situation. Obviously, we have to look on the whole torpedo system, including the firing unit. Investment in resources and effort should not necessarily be spent only on the torpedo in order to increase its effectiveness, but may be spent on the firing unit as well in order to make the unit able to reach a better firing position.

A follow-on of this study may be to investigate the attack process of the torpedo, including the acquisition-and hit-problem.

Then the question of guidance during torpedo run should be analyzed in order to better evaluate the problem of choosing between a few sophisticated, expensive, guided torpedo system or many simple, inexpensive, nonguided torpedo systems.

APPENDIX A

PRINT OUT OF SIMULATION PROGRAM

```

A TCRPECC SIMULATION IS ACTIVE IN 0.5 SEC STEPS.
THE PROGRAM IS RUN IN 0.5 SEC STEPS.
COMMON ISSEE C2 TIME, TA, STRATE, RANGE, ALFA, LANECC, TACEC,
*CLEAR, RAD, TAC, CCOR, DEVSP, BNG, PHZ, ACCURS, TCCR, STAR, ICIS, MCIS,
*NEXT, MX, INTVAL, DT, ICIS, MCIS, DIST, IFRINT
*TURATE, INTERVAL, PRI, RMAX(5,6), RANGE, DIST, IFRINT
CCMPCN/LAT/LAT/CFLC
CCMPCN/TARGET/TACG, TAN1, RANGE, CCUR, CE(IC), SE(15), JRUN,
*FLAG CA2 EN(5,5), VAR(5), CET(150,5), DTE(150,5), SIE(5),
*SPEC(150,5), DERB(150,5), CLCSB(150,5), KCN(150,5)
REAL LANBC, MCOUR, MX, MCIS, MCIS, LANECC
INTEGER RUNCNT

C SETTING OF CONSTANTS (STEP 1)
CALL CFLCH
PF1=2.141592654
PF2=2.*FH1
FAC=PH2/36C
ISSEED1=262716
ISSEED2=261695
CCREC=15.0
CCREC=CC*CREC*RAD
SPEED=ST-SDV IN TARGET SPEED ESTIMATE
SPEED=C*SPEED*0.5
DETIME=1
CTIME=1

C SET NUMBER OF ITERATIONS
IRLN=15C

C SET PRINT CTL NCDE
IFFINT=1

C SET LCBE OFF TCRPECC CENTER BEARING
CFLCB=0.

C SET TABLES IC ZERO (STEP 2)
CC11=1,5
CC12=1,5
RN(1,J)=C.
CC11INE
CC12INE
CC14=1,5
KCN(1,J)=0
12
11

```


13

CONTINUE
CA2=C.

C

CONTINUE

CCPUTE TARGET ERRORS AND SCORE
CCPTE (20)=11C
CCPTE (1)=11C
CCPTE (1)=-(15.*RAD+CCCR/10.)*I*I*2.

2C

CCPTE (2)=1.8727*DEVSP
CCPTE (3)=-1.2825*DEVSP
CCPTE (4)=-C.96E*DEVSP
CCPTE (5)=-0.7285*DEVSP
CCPTE (6)=-C.525*DEVSP
CCPTE (7)=-0.24*DEVSP
CCPTE (8)=-C.1675*DEVSP
CCPTE (9)=0*DEVSP
CCPTE (10)=C.167E*DEVSP
CCPTE (11)=C.34*DEVSP
CCPTE (12)=C.52E*DEVSP
CCPTE (13)=0.72E5*DEVSP
CCPTE (14)=0.968*DEVSP
CCPTE (15)=1.2E25*DEVSP
CCPTE (16)=1.8727*DEVSP

C

10C

CCS00 JRUN=1 IRUN
SET RUN COUNTERS (STEP 3)

IFLAG=1; TCC LCW TORPEDO SPEED

IFLAG=0

JCOUNT=0

JTYPE=0

JL=C

JH=C

CL=0.

NXT=0.

RNCLT=C

READ IN SETTING(TCRP AND TACTICAL)
FIRST IRUN? (STEP 4)

IF(JRUN .GT. 1) GO TO 160

CALL PAINET

C

22E

WEITE(6,228)CFLCB
*EEARING,IX,IX,SCALAR MAIN LCEE CFF-SET,FRCE CENTER ,/
TIMES DEFLECTION ANGLE*,/

TCR00490
TCR00510
TCR00520
TCR00540
TCR005560
TCR005570
TCR005580
TCR005590
TCR005600
TCR005610
TCR005620
TCR005630
TCR005640
TCR005650
TCR005660
TCR005670
TCR005680
TCR005690
TCR005700
TCR005710
TCR005720
TCR005730
TCR005740
TCR005750
TCR005760
TCR005770
TCR005780
TCR005790
TCR005800
TCR005810
TCR005820
TCR005830
TCR005840
TCR005850
TCR005860
TCR005870
TCR005880
TCR005890
TCR005900
TCR005910
TCR005920
TCR005930
TCR005940
TCR005950
TCR005960


```

TCIST=TC/2.
TLEN=TAT/E/2
INTVAL=IFIX((TTIME/C*5)+0.5)
INTVAL GIVES NUMBER OF TIME STEPS FOR EACH TRANSMISSION

C IF(IPRINT .EQ. 0) GO TO 160

C PRINT OF HEADING
C WRITE(6,230)
FCFNAT(1X,/,1X,'RUN',4X,'EST OF TARGET',7X,'TCP',4X,
*8X,'TORF',CCRF,',5X,'TARGET SCORE',3X,'TCP',4X,
*1X,'NO CCLRSE',10X,'CCLRSE',10X,',',6X,
*1X,',7X,0X,',6X,',Y,',6X,',STCP,',2X,',RUN')

C CALCULATE TORPEDO START POSITION (STEP 5)
XTAR=15000.
YTAR=15000.
CFA1=RANGE
BNG=TAC+BEAR
PH1(BNG+GT*0)BNB=BNB-PH2
IF(ENG+LT*0)BNB=PH2+BNB
X1=XTAR+RANGE*SIN(BNG)
Y1=YTAR+RANGE*COS(BNG)
IF(IPRINT EQ 1)EC TO 152
WRITE(6,198)JRUN
FCFNAT(1X,/,6X,'RLN NUMBER',14)
198
C CALCULATE TORPEDO DEFLECTION ANGLE AND FIRING SITUATION
CALL FIRING
C SET DETECTABLES TO ZERO (STEP 6)
EC 10 I=1,5
EC 19 J=1,6
IF(A(X(I,J))=0.
CCN1INUE
CCN1INUE
152
C TEST TORPEDO RLN CLT (STEP 7)
TRUN=TRANGE/TO
CCSP=TA*CCS(BEAR)+TO*CCS(DA)
FLRN=TRANGE/CLOSP
IF(TRUN .GT. HRUN)GO TC 499
WFILE(6,231)
FCRMAT(1X,/,1X,'TARGET OUTSIDE TORPEDO RANGE')
231
C ZERFC TABLES
EC 22 J=1,E

```



```

C ETE(JRUN,J)=0.
C DET(JRUN,J)=0.
C ASPEC(JRUN,J)=0.
C CLSB(JRUN,J)=0.
C CERET(JRUN,J)=0.

22 CC 10 900
      IF (JFLAG .EQ. 1) GO TO 950
      IF (NXT .GE. RANGE) RLACUT=1
      IF (RNGLT .EQ. 1) GC TO 990
C
C CALCULATE NEW POSITIONS
C
C CHECK IF TARGET IS DETECTED
C ALL DETECT
C
C CHECK CPA(CLOSEST POINT OF APPROX) (STEP 8)
C IL=IL+1
      IF (IL .LE. 20) GO TO 500
C
C FA=DIST
      IF (CPA1-CPA .LE. 0.) RINOUT=1
      CPA=CPA
      CC 10 500
C
C GENERATE STATISTICS (STEP 9)
C
C KDN( ) = DETECTION/N DETECTION
      IF (RMAX(IKL,1) .GT. 1.) KDN(JRUN,IKL)=1
C
C DET( ) = DISTANCE IC TARGET AT DETECTION
      DET(JRUN,IKL)=RMAX(IKL,1)
C
C CTE( ) = BEARING IC TARGET AT DETECTION
      CTE(JRUN,IKL)=RMAX(IKL,2)
C
C ASPEC( ) = TARGET ASPECT AT DETECTION
      ASPEC(JRUN,IKL)=RMAX(IKL,3)
C
C CLSB( ) = BEARING IC CLOSEST PART OF TARGET
      CLSB(JRUN,IKL)=RMAX(IKL,4)
C
C CERE( ) = REL BEARING FROM MAIN TCRP COURSE IC TARGET
      CERE(JRUN,IKL)=RMAX(IKL,6)
C
C CONTINUE
S1C

```



```

C IF(IFLAG .EQ. 1) GO TO 991
C PRINT OUT (STEP 10)
C CCR=MCCURS/RAD
C TC=TCOURS/RAD
I=1
1 IF(IPRINT.EQ.0) GO TO 195
1 WRITE(6,232)JRUN,TACMG,TAM1,RNGMCC,DA1,COUR,XT,YT,XIAF,YTAR,
* F5*17X,F6*1X,13*3X,F5*1*2X,F4*1*1X,F6*1*2X,F5*1*3X,
* F5*17X,F6*0*2X,F6*0*1X,F6*0*3X,I4,2X,F6*0*1*3X,
* F5*17X,F6*0*1X,F6*0*1X,F6*0*1X,F6*0*1X,F6*0*1X,
* IF(IRMAX(1,1).EQ.0) GO TO 991
C CTO SCC
156 WRITE(6,200)IT
156 WFCFPAT(1X,'RUN STUFFED AFTER ',15,' SECACS',//,
* 1X,'RUN DATA'S FOLLOW AT END 'CF RUN.')
202 FCRNAT(1X,2C2)MXT,DIST TOTAL TCRP RUN ,F9.1,/1X,'DIST TC TARGET ',F9.1)
204 WCRNAT(1X,2C2)MXT,YT,XTAR,YTAR,COUR,1C
* 1X,TCP X-COORD ,F9.1,2X,F9.1,4X,*TORG Y-CCORD ,2X,FS.1,/,
* 1X,TARGET X-COORD ,F9.1,4X,1ARGET,Y-CCCR ,F9.1,1/
* 1X,TORP MAIN COURSE ,1X,F9.1,4X,TCRP COURSE ,1X,FS.2}
* IF(FMAX(1,1).EQ.0) GO TO 991
206 WCRNAT(1X,2C2)MXT,J=1,5,I=1,5)
206 * 1X,MAXIMUM DETECTION RANGES AND EEARINGS,
* 1X,SUCCESSIVE,4X,MAXDET,5X,DETAPEATING,
* 5X,MAXDET,11X,DET BEARING,4X,TARGET,/,,
* 1X,INTER ,4X, RANGE - CEN 1ER ,4X
* EX1,ASPECT ,9X, RANGE - CLOSEST ,4X,CLOSEST ,,
* FCFPAT(2X,14)7X,F1C.1,7X,F8.2,7X,F10.1,9X,
* F8.2,7X,F8.2)
* GCTO SCC
991 WRITE(6,220)
C ALL RUN' COMPLETED ? (STEP 11)
C SOC CONTINUE
C CALCULATE SUMMARY RESULT (STEP 12)
C 27 KR=1,5
C 28 LR=1,IRUN
RN(KR,1)=RN(KR,1)+FLOAT(KON(LR,KR))
RN(KR,2)=RN(KR,2)+CET(LR,KR)
RN(KR,3)=RN(KR,3)+ABSPEC(LR,KR)
RN(KR,4)=RN(KR,4)+DET(LR,KR)
RN(KR,5)=RN(KR,5)+DEFB(LR,KR)
CONTINUE

```



```

27 CC S2C KK=1,5
C   CCNFLTING MEANS
C   CEL=RM( KK,1 )
C   IF(CEL .LE. 1.) DEL=1.
C   RM(KK,2)=RN(KK,2)/DEL
C   RM(KK,3)=RN(KK,3)/DEL
C   RM(KK,4)=RN(KK,4)/DEL
C   RM(KK,5)=RN(KK,5)/DEL
C
C   CCNTINUE
C   CC 25 KK=1,5
C   VAR(KK)=0.
C   CC 170 I=1,IRUN
C   IF(KCN(I,KK) .EQ. 0) GO TO 170
C   VAR(KK)=VAR(KK)+(CET(I,KK)-RM(KK,2))*2)
C
C   CCNTINUE
C   CC 26 KR=1,5
C   DEL=FM(KR,1)
C   IF(DEL .LE. 2.) DEL=2.
C   STC(KR)=SQR(T(VAR(KR)/(DEL-1.))
C   FM(KR,1)=RN(KR,1)/FLCAT(IRUN)
C
C   CCNTINUE
C
C   PFILE(6197)JRUN * SUMMARY CF RESULT AFTER *,3X,14,2X,*FUNS*
197 FCFMATE(6195)(CRM(I,J)) * J=1,2) STC(I,J)(CRM(I,J),J=3,5),I=1,5)
198 FCFMATE(6195) * PROBABILITY OF DETECTION*,8X*,AVERAGE*,7X*,STD DEVIATION*,7X*,AVERAGE*,7X*,TARGET ASPECT*,4X*,DET BEARING*,1
199 *7X* AVERAGE*,41X* DEF RANGE*,7X*,REL BEARING*,/*DETECTIONS*/5X*,F6*4,5((EX,F5*4)/*1
*2X* CNE SUCCESSIVE DETECTIONS*/4X*,F6*4,5((EX,F5*4)/*1
*1X* *TWO SUCCESSIVE DETECTIONS*/2X*,F6*4,5((EX,F5*4)/*1
*1X* *THREE SUCCESSIVE DETECTIONS*/2X*,F6*4,5((EX,F5*4)/*1
*1X* *FOUR SUCCESSIVE DETECTIONS*/2X*,F6*4,5((EX,F5*4)/*1
*1X* *FIVE SUCCESSIVE DETECTIONS*/2X*,F6*4,5((EX,F5*4)/*1
220 FCFMATE(6195) * NO DETECTION MADE DURING THIS RUN)
221 FCFMATE(6195)DA2
222 FCFMATE(6195)DA2
198 FCFMATE(6195) * AVERAGE DEFLECTION ANGLE : *,5X,F8.4,/,/
199 FCFMATE(6195) * DISTRIBUTION OF RUN RESULT - CENTER CF TARGET *,/,/
234 FCFMATE(6195) * DISTRIBUTION OF RUN RESULT - CENTER CF TARGET *,/,/

```



```

*6X,*CNE SUCCESSIVE DETECTION, '10X', TWO SUCCESSIVE DETECTIONS.,
*8X,*THREE SUCCESSIVE DETECTIONS, '12X', THREE SUCCESSIVE DETECTIONS.,
*2X,*BEAR, '2X', BEAR ASPECT BEAR CLCS, '5X', BEAR CLCS, '10X', BEAR CLCS.
*2X,*RANGE ASPECT BEAR CLCS, '2X', BEAR CLCS, '5X', BEAR CLCS, '10X', BEAR CLCS.

C      WRITE(6,236) ((DET(I,1),DET(I,2),ASPEC(I,1),CLCS(I,1),
C      *DET(I,2),DET(I,3),ASPEC(I,2),CLCS(I,2),CE1B(I,1),
C      *DET(I,3),ASPEC(I,3),CLCSB(I,1),CLCSB(I,2),CE1B(I,2),
C      *DET(I,1),IRUN),IRUN)
236      FORMAT(2(1X,F6.1,1X,F6.1,1X,F6.1,1X,F6.1,1X,F6.1,1X))
      END

C      SUBROUTINE PARMET
      READ(5,100) TTIME, TRATE, RANGE, ALFA, LANED, TACEC,
      COMMON/LSEEC/TTIME, TRATE, RANGE, ALFA, LANED, TACEC,
      *CLEAR, TAC, TCCR, DEVSP, BNC, FN, PH2, ACCURS, TACURS,
      *MX, IKT, IDTINE, ITIME, XT, YT, TAR, DIST, DIST,
      *LIST, TURNTO, INTERVAL, IPHI, RMAX, DIST, DIST,
      REAL(LANBC), MCOURS, MXT, MXN, MCISF, LANEG
      INTEGER RUNCUT

100     TEC = TECHNICAL DETECTION RANGE (STEP A1)
      LEVEL OF VARIATION: 375-750-1125-1500 METERS
      TACEC = TACTICAL DETECTION RANGE
      TEC = 750
      TACEC = TEC
      TAC = TCKN/2

      TIME = 2.*TEDEC/15CC.

      TCKN = TORP SPEED IN KNOTS, TO - TORP SPEED IN M/SEC (STEP A2)
      LEVEL OF VARIATION: 24-32-40 KNOTS
      TCKN = 40
      TAC = TCKN/2

      TAKN - TARGET SPEED IN KNOTS, TA - TARGET SPEED IN M/SEC (STEP A3)
      LEVEL OF VARIATION: 12-18-24-30 KNOTS
      TAKN = 18
      TAC = TAKN/2

      TACG - TARGET COURSE IN DEGREE (STEP A4)
      TACG = 27
      TAC = TACG*RAD

      ALFAG - SWEEP ANGLE IN DEGREE, ALFA - SWEEP ANGLE IN FACIAS

```



```

LOC   *FCFIREAT(1X,'TACTICAL SITUATION WHEN FIRING',/,1X,
      *'FIRING RANGE 13X, ATTACK ANGLE 13X,
      *TARGET COURSE 12X, TARGET SPEED 1)
      *FIRETE(6102)RANGE,RELERTACG,TAKK
      FCFIREAT(1X4(2X,F6.1,7X),/)

102   *FIRETE(1X4(1X4 TORPEDO PARAMETERS',VAL*,2X,'TCRF SPEED',2X,
      *TECDEP.ATT.RANGE,2X,TRANS.INT.VAL*,2X,'TCRF SPEED',2X,
      *TECDEP.ANGLE,1)
      *FIRETE(1X2(1X2(2X,F7.2(7X),2(FE.1,7X),/)

104   *FCFIREAT(6108)LAMBCC,TRATEG
      *FCFIREAT(1X4LOBE WIDTH,6X,TURN RATE,/,1
      *3XFIRE(1X10X)SRNG,CRATIC
      *FCFIREAT(1X4THEORETICAL WIDTH OF TACTICAL SWEEP-LANE,FG.1
      *FCFIREAT(1X4THEORETICAL COVERAGE RATIC,FG.4
      RELRN
      END

105   *FCFIREAT(1X4REAL LAMBDCOURSES, MXT, MXN, MCIST, LAMEEC
      END

C     SUBROUTINE FIRING
C     CALCULATE THE TORP DEFLECTION ANGLE MAIN CURSE, FIRING CURSE
C     BASED ON ESTIMATE OF TARGET DATA (UNCERTAINITY)

106   DIMENSION U(2)
      CCRN=ISSEE2(1 TIME, TO TA, RATE, RANGE, ALFAR LAMEEC,TAEC,
      *CLEAR, RAD, DEVS, BNC, FN, PHZ, ACCURS, ISTAR, DIST,
      *NEXT, MX TURN, ITIME, XT1,YT1,INTERVAL, PHI, RMAX(5,6),
      *CUNION/CATATA/DA/QFLCB, TARGET/TACG,TAM1,RNGNOD,CA1,COUR,CE(1C),SE(15),JRLN,
      *IFLAG,CA2,REAL LAMBDCOURSES, MXT, MXN, MCIST, LAMEEC
      INTEGER RUNCT
      PN=-1
      PP=1
      KSEEC=MOD((JRUN-1)/15)+1
      KCCRS=IFIX((JRUN-1)/15.0)+1
      CALL EGUB(ISEED2,2,U)

107   CALCULATE ESTIMATE OF TARGET CCURSE (STEP B1)
      TACN=TAC+CE(KCCRS)
      DIFCC=TACM-TAC
      IF(TACN .GE. PH2) TACM=TACM-PH2

```



```

C IF (TACM .LT. 0.) TACN=PH2+TACM
C CALCULATE EST OF TARGET SPEED (STEP B2)
C TAN=TAT*(RSPEED)
C CALCULATE TORPEDO DEFLECTION ANGLE (STEP B2)
C ASF=BEAR-DIFCD
C IF (ASP .LT. -PHI) ASP=PH2+ASP
C TACS=TAN*SIN(ABS(ASP))
C TAA=TACS/TAC
C IF ((TAA .GE. 1.0) GO TO 26
C AA=ARSIN((CAA))
C AA=SIGN((DA,ASP))
C
C CALCULATE TORPEDO MAIN FIRING CURSE (STEP E4)
C MCCURS=BNG+PHI+DA
C IF (MCOURS < GT) PH2=MCCURS-PH2
C IF (MCOURS > LT) 0.1*MCCURS=PH2+MCCURS
C IF (MCOURS < GT) PH2 GO TO 10
C
C CALCULATE TORPEDO PRESENT FIRING CURSE (STEP B5)
C DIFALF=(U(1)*2.*ALFA)-ALFA
C MCCURS=MCCURS+DIFALF
C IF (TCOURS < GT) PH2=TCCURS-TCCURS-PH2
C IF (TCOURS > LT) 0.1*TCCURS=PH2+TCCURS
C IF (DIFALF < GE) 0.1*FN=-FN
C
C CALCULATE ESTIMATE OF TARGET RANGE (STEP B6)
C IF ((2) .LT. C5) FF=-PP
C IF C1F=(1.-L(2))*RANGE*0.15
C RANGCD=RANGE+SIGN(RANGDIF,PP)
C TACNG=TACM/RAD
C TAP1=TAN**2
C TAP2=CA/RAD
C TAP2=(CA2+DA1
C
C FINIT CLT CEF FIRING DATA
C IF (IPRINT .EQ. 1) GO TO 25
C WRITE(6,122) TACNG,TAM1,RNGMCD
C FCFMAT(1X,FST,0,FST,DATA FCF FIRING',/,,
C *4X,*COUSE*,5X,*SPEED*,6X,*RANGE*,2X)
C *1X,2(F8.12)1
C WRFNAT(1X,TORP1 DEFLECTION ANGLE IS *,F6.2)
C CCUR=RCCURS/RAD
C WRFNAT(1X,125)COUR
C FCFMAT(1X,TORPEDO MAIN COURSE*,8X,F6.2)
C CONTINUE

```


26
30

IF(FIREAT(6,2),
FCRMAT(6,1), NOT FEASIBLE TC FIRE DUE TO LC)
IFLAG=1
RETURN
END

CC TC 25
FCRMAT(6,2)
IFLAG=1
RETURN
END

25

CC CC CC

SUBROUTINE FOSIS
CALCULATING NEW POSITIONS OF TARGET AND TCFPEDC IN
EACH TIME STEP

CC MCN ISSEE22 TTINE, TC, TA, TRATE, RANGE, ALFA, LANED, TAEC,
*PEAR, RAD, IAC, TCCR, DEVSP, BN, PH2, ACCURS, TCURRS,
*NEXT, MX, IK, IDTIME, ITIME, XT, YT, XTA, YTA,
*NEILT, TURNTO, INTERVAL, PHI, RMAX(56), TRANSE, DIST, IRINT
REAL LAMBDA, MCOURS, MXN, NCIS, LANEDC
INTEGER RUNCUT

TIME COUNT (STEP C1)

IK=IK+1

IDTIME=IDTIME+IDTIME

CALCULATE TACTICAL TCRF RUN AND TARGET RUN (STEP C2)

XI=XI+DIST

YI=YI+MDIST

CALCULATE NEW POSITIONS (STEP C3)

XI=XT+SIN(TCOURS)*TCIST

YI=YI+CCS(TCOURS)*TCIST

XIAR=XSTAR+SIN(TAC)*MDIST

YIAR=YSTAR+CCS(TAC)*MDIST

CALCULATE NEW TORP CURSE (STEP C4)

TCCUR=TCCUR+SIGN(TCURTO, FN)

TCCUR=ABS(MCOURS-TCCUR)

IF(TXCCIF .GT. PHI) TXCCIF=PH2-1 TXCCIF

IF(TXCCIF .LE. ALFA) GO TO 15

ALFA=TXCCIF-ALFA

TCCUR=TXCCUR+2.*SIGN(ALFA, PN)

TCCUR=TXCCUR

IF(TCOURS .GT. PH2) TCCURS=TCCURS-PH2

IF(TCOURS .LT. 0.) TCCURS=PH2+TCCURS

15

25

CC CC CC


```

      C
      C SUBROUTINE CELECT IF TARGET IS DETECTED AND STORE DETECTION DATA
      C
      C COMMON ISSEC2,TTIME,TG,TA,TRATE,BNG,FN,PH2,ACCURS,TDEC,
      *BEAR,RAD,TAC,CCOR,DEVS,P,ITIME,XT,YT,XSTAR,YSTAR,ICIST,
      *XT1,XT2,INTVAL,ITIME,XT1,YT1,XT2,YT2,TRANGE,DIST,IRINT
      C
      C COMMON/DATA/DAFLCB,MCOURS,MXT,MXN,MCIST,LAMECC
      C
      C REAL LAMP,RCUT
      C
      C INTEGER RUNCT,EPSIONDE(3,2)
      C
      C DOUBLE PRECISION FCWMAX,B'REX1'REX2,X1'X2'X3,XX1,
      *V1,V2,V,U,FACT,X01,X02,X03,XX2,PCWER,RELB,ALAN
      C
      C SETTING OF TARGET DIMENSION, A - TARGET LENGTH,
      C E - TARGET WIDTH,C - TARGET DEPTH. (STEP C1)
      C
      C A=100.
      C E=15.
      C C=4.
      C
      C CHECK IF TRANSMISSION (STEP C2)
      C
      C IF(IK.LT.INTVAL) GOTO 20
      C
      C
      C CALCULATE RANGE TO TARGET (STEP C3)
      C
      C CIX=XSTAR-XT
      C CIFY=YSTAR-YT
      C DIST=SQRT((CIX**2)+(CIFY**2))
      C
      C TEST IF TARGET IS WITHIN POSSIBLE DETECTION RANGE
      C IF(DIST.GT.(TDEC+A/2.)) GOTO 20
      C
      C DETECTION THRESHOLD (STEP D4)
      C FCYMAX=1./(B*TDEC)**4
      U=SCALE(P-1/2)
      CCNST=(A**2)*(B**2)*(C**2)
      FCWMAX=CCNST*PCWMAX*U
      C
      C CALCULATE TIME TO TARGET (STEP E5)
      TTIME=DIST/1500
      XTARGET=XT+TAC*SIN(TAC)*(TMDL1*TIA)
      YTARGET=YSTAR+CCS(TAC)*(TMDL1*TIA)
      C

```


C CENTER - BEARING CF CENTER CF LCEE (STEP E6)

CC=C*CFCE
CENTB=TCURS+DD
IF(CENTE • LT. 0.) CENTB=PH2+CENTE
IF(CENTE • GT. PH2) CENTB=CENTB-PH2

C CALCULATE BEARING S TC TARGET1 (STEP D7)

RE=EEARIN(XTAR1,YTAR1,XT,YT)
X1=XTAR1+SIN(TAC)*A/2.
Y1=XTAR1+COS(TAC)*A/2.
C1=ST1=SQRT((XTAR2-XT)*Y1²+(YTAR2-YT)*Y1²)

RE1=EEARIN(XTAR2,YTAR2,XT,YT)
X1=XTAR1-SIN(TAC)*A/2.
Y1=XTAR1+COS(TAC)*A/2.
D1=ST2=SQRT((XTAR3-XT)*Y1²+(YTAR2-YT)*Y1²)

RE2=EEARIN(XTAR3,YTAR3,XT,YT)
REL1=RBI-CENTB
IF(REL1 • GT. PHI) REL1=REL1-PH2
IF(REL1 • LT. -PHI) REL1=PH2+REL1

REL2=RE-CENTB
IF(REL0 • GT. PHI) REL0=REL0-PH2
IF(REL0 • LT. -PHI) REL0=PH2+REL0

REL2=RE2-CENTB
IF(REL2 • GT. PHI) REL2=REL2-PH2
IF(REL2 • LT. -PHI) REL2=PH2+REL2

C CALCULATE TRANSMISSION GAIN FACTOR (STEP E8)
RE>1=REL1
REX1=RELC
REX2=REL2
ALAN=ALAMB

C COMPUTE SEPARATE GAIN FACTORS (STEP E9)

CAFE=(TBX1,ALAM)
ANTRE=RE+PH1
ANTRE=ANTRE-G1*PH2
ANTRE=ANTRE-TAC
FELA=ANTRE-G1*PH2
IF(FELA • GT. PHI) FELA=PH2-RELA
IF(FELA • LT. -PHI) FELA=PH2+RELA
FELA=ABS(FELA)
V1=(A**2)*(CCOS(RELE)**2)
V2=(B**2)*(DSIN(RELB)**2)

C CALCULATE TARGET ASPECT AND TARGET SONAR CROSSED
CAFE=(TARGET STRENGTH) DUE TO ASPECT (STEP E10)

ANTRE=ANTRE+PH1
ANTRE=ANTRE-G1*PH2
ANTRE=ANTRE-TAC
FELA=ANTRE-G1*PH2
IF(FELA • GT. PHI) FELA=PH2-RELA
IF(FELA • LT. -PHI) FELA=PH2+RELA
FELA=ABS(FELA)

CC=C
C1=1
C2=2
C3=3
C4=4
C5=5
C6=6
C7=7
C8=8
C9=9
C10=10
C11=11
C12=12
C13=13
C14=14
C15=15
C16=16
C17=17
C18=18
C19=19
C20=20
C21=21
C22=22
C23=23
C24=24

$V = (V_1 + V_2) * 2$

C COMPUTE SCALING FACTOR DUE TO ASPECT (STEP C11)
L=SCALE(REFLE)
F1FACT=L/Y

C CALCULATE RETURN TIME FOR ECHO (STEP C12)
T1REL2=2.*TINDL1

C CALCULATE REL BEARING FOR RETURNING ECHO (STEP D13)
TURNST=TCCLRS+SIGN(TURNST,FN)
1>C=APC(MCURS-TXC)
1>C=APC*(MCURS-TXC)
1>C=APC*GT*PHI*TXDC=PH2+TXDC
1>C=TXDC*LE ALFA GC TC 18

ALFA=TXDC-C-ALFA
RELTO=REL0-SIGN((TURNST-ALFA),PN)+SIGN(ALFA,PN)
CC RELTO=REL0-SIGN(TURNST,FN)

REL0IF=RELTC-REL0
REL1=REL1+RELDIF
REL2=REL2+RELDIF
RELTC=G1*PHI*RELTO=PH2-RELTC
IF(CRELTC < LT) -PHI*RELTO=PH2+RELTC
IF(CRELTC < GT) -PHI*RELTO=PH2-RELTC
IF(CRELTC < LT) -PHI*RELTO=PH2+RELTC
IF(CRELTC < GT) -PHI*RELTO=PH2-RELTC
IF(CRELTC < LT) -PHI*RELTO=PH2+RELTC

TEST FCB DCFFPLER
FRQDEF=50.**2.*((TC*COS(DD)-1.)/1500.
FFCFCIF=50.*2.*((TO*COS(DD)+1.)/1500.

REL2=RELB
FRQSF=5C.*2.*((TO*COS(DD)+TA*COS(FELC))/1500.
IF((FRQSF < LT).FRQDF) .AND. (FRQSF > GT).FRQDEF)
TEST FCB DCFFPLER

C CALCULATE RANGE AND BEARING TO CLOSEST PART CF TARGET (STEP C14)
CCE(1,1)=DIST
CCE(1,2)=REL10+DD
CCE(2,1)=DIST1
CCE(2,2)=REL11+DD
CCE(3,1)=DIST12
CCE(3,2)=REL12+DD
CCE(4,1)=CB(1,1)

IF(CMIN < GT) DB(2,1))GO TO 10
IF(CMIN > GT) DB(3,1))GO TO 11
IF(TC12 < CMIN) GO TO 12
IF(TC12 > CMIN) GO TO 11

18

115

5


```

1C      E11=D1E(2,1)
1C      PC=TC S
1C      CN1A=CB(3,1)
11      PC=TC
11      EEF1=CE(MC2)
11      IF(BREL .GT. PHI)BREL=PHI2-BREL
11      IF(CREL .LT. -PHI)BREL=PHI2+BREL

C      CALCULATE RECEIVING GAIN FACTOR (STEP D15)
C      FEX=RELTO
C      FEX2=RELTO2
C      XC1=XFACT(REX1,ALAM)
C      XC2=XFACT(REX2,ALAM)
C      XC3=XFACT(REX3,ALAM)
C      XC1+XC2+XC3)/3.

C      CALCULATE FRACTION OF POWER IN TO RECIEVER (STEP C16)
C      FCER=CNST*XX1*XX2*FACT/(DIST**4)

C      TEST FOR DETECTION THRESHOLD (STEP C17)
C      IF(FCHER .LT. POWMAX)GO TO 15

C      COMPUTE BEARING RATE (STEP C18)
C      ACF=RB+PH-TAC
C      IF(CASP .GT. PHI)ASP=ASP-PH2
C      IF(CASP .LT. -PHI)ASP=PH2+ASP
C      AF=ASPF*RELTO
C      ACS=TA*SIN(ABS(ASF))
C      CCS=T0*SIN(ABS(RELTO))
C      ERATE=(TAC*SIGN(TCCS,AP))/DIST

C      CHECK BEARING RATE AGAINST TURNRATE (STEP DIS)
C      IF(ERATE .GE. TRATE)GO TO 15

C      CHECK TCRFC SPEED ADVANTAGE (STEP D20)
C      TAUS=TA*CCS(ABS(ASF))
C      TCLS=TC*CCS(ABS(RELTO))
C      IF(TAES(ASF)*GT(PHI/2)*TALUS-TALS
C      IF(TAES(RELTO)*GT(PHI/2)*TCLS-TCLS
C      IF((TALUS+TOLS)*LE.0.)GC 15

C      FILE=RE-NCGLFS
C      IF(RLB .GT. PHI)RLE=RLB-PHI2
C      IF(RLB .LT. -PHI)RLE=PHI2+RLB
C      TORC7190
C      TORC7200

```



```

C C S1CRE DETECTION DATA ( STEP C21)
C C JCCNT=JCONT+1
C C JMAX=(JMAX,JCCNT)
C C JCCNT=JCCNT
C C IF (JCCNT .GE. 5) JCCNT=5
C C
C C S1CRE DATA IN ACCCRANCE WITH NUMBER SUCCESSIVE
C C DETECTIONS (STEP C22)
C C CC TO (3,3,1,1)=1ST .0. ICNT
C C IF (RMAX(1,1)=1ST .0.) GO TO 20
C C RMAX(1,2)=(REL TO+DD)/RAD
C C IF (FMAX(1,2)=0) GT. 180.) RMAX(1,2)=RMAX(1,2)-360.
C C FMAX(1,3)=DMIN
C C FMAX(1,4)=BREL/RAD
C C FMAX(1,5)=RELA/RAD
C C FMAX(1,6)=RLB/RAD
C C CC TO 20
C C IF (FMAX(2,1)=0) NE. 0.) GO TO 20
C C FMAX(2,2)=(REL TO+DD)/RAD
C C IF (RMAX(2,2)=0) GT. 180.) RMAX(2,2)=RMAX(2,2)-360.
C C FMAX(2,3)=DMIN
C C FMAX(2,4)=BREL/RAD
C C FMAX(2,5)=RELA/RAD
C C FMAX(2,6)=RLB/RAD
C C CC TO 20
C C IF (FMAX(3,1)=0) NE. C.) GC TO 20
C C FMAX(3,2)=(REL TO+DD)/RAD
C C IF (RMAX(3,2)=0) GT. 180.) RMAX(3,2)=RMAX(3,2)-360.
C C FMAX(3,3)=DMIN
C C FMAX(3,4)=BREL/RAD
C C FMAX(3,5)=RELA/RAD
C C FMAX(3,6)=RLB/RAD
C C CC TO 20
C C IF (FMAX(4,1)=0) NE. C.) GC TO 20
C C FMAX(4,2)=(REL TO+DD)/RAD
C C IF (FMAX(4,2)=0) GT. 180.) RMAX(4,2)=RMAX(4,2)-360.
C C FMAX(4,3)=DMIN
C C FMAX(4,4)=BREL/RAD
C C FMAX(4,5)=RELA/RAD
C C FMAX(4,6)=RLB/RAD
C C CC TO 20
C C IF (FMAX(5,1)=0) NE. 0.) GC TO 20

```



```

FN(X(5,1)=CIST
FN(X(5,2)=(RELTO+DD)/RAD
IF(RMAX(5,2)>180.)FMAX(5,2)=FMAX(5,2)-360.

IF(X(5,2)=CPI
IF(X(5,2)=CPI
IF(X(5,4)=BREL/RAD
IF(X(5,5)=RELA/RAD
IF(X(5,6)=RLB/RAD
GC10 2C

C IF NO DETECTION, SET DETECTION STATUS
      15 ICNT=0
      JCN=T=C
      RETURN
      END

C FUNCTION BEARING(A,B,C,D)
C CALCULATE BEARING FROM TCFPEC TC TARGET
      C1FX=A-C
      C1FY=B-C
      C1FZ=C-D
      PH2=141592654
      FLC=PH2/260.
      IF((C1FY>0.)IGC TO 16
      RE=(C1C**RAD
      IF((C1FZ<0.)RE=RE+(180.*RAD)
      GC117
      RE=ATAN2(DIFX,DIFY)
      16 IF(RB>LT. C.)RB=RE+PH2
      EEAFIN=FB
      RETURN
      END

C FUNCTION XFACT(X,Y)
C CALCULATE REDUCTIVE BEARING OFF CENTER-FACING CUE
C CUBLE PRECISION X,XFACT,XY,Y
      PH1=3.141592654
      IF((X>Y)EQ. C.)GO TO 10
      XFACT=X/Y
      XFACT=CAbs((DCOS(X*0.5)*DSIN(XY*PH1))/(XY*PH1))
      RETURN
      XFACT=1.

      10

```



```
TORCE17C  
TCRQ8180  
TCRQ8190  
TCRC8200  
TCF08210  
TCRQ8220  
TORO8230  
TCRC8240  
TCRQ8250  
TCRQ8260  
TCRQ8270  
TCRC8280  
TORO8290  
TCRC8300  
TCRQ8310  
TCRQ8320  
TCRQ8330
```

```
FUNCTION SCALE(Y)  
CALCULATE SCALING FACTOR IN THE PROCESS CF  
CALCULATING TARGET STRENGTH  
SCALE PRECISION SCALE, RELB, Z, Y  
C  
P1=3.151592654  
IF(Y>C1) P1/2.0) Y=P1-Y  
Z=C.2*1.635*(Y**2)-(C.18555*Y  
Z=Z+0.0265*DSIN(3.* (Y+0.17453)) + C.015*(Y**2)*DSIN(5.*Y/2.)  
SCALE=1./Z  
FEILFN  
END  
C  
C  
C  
C
```


APPENDIX B

FLOW CHART FOR SIMULATION PROGRAM

A TORPEDO SIMULATION. MAIN PROGRAM.

PAGE 1

A TORPEDO SIMULATION. MAIN PROGRAM.

A TORPEDO SIMULATION.

SIMULATING AN ACTIVE HOMING TORPEDO DURING SEARCH.

THE PROGRAM IS RUN IN 0.5 SEC STEPS.

```
COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBD, TADEC,  
SEAB, RAD, TAC, CCCR, DEVSP, ENG, FN, PH2, MCCURS, TCOUAS  
MXT, MM, IK, IDTIME, ITIME2, XT, YT, XTAB, YTAB, IDIST, MDIST,  
TURNTO, ITIVAL, PHI, RMAX(5,6), IRANGE, DIST, IPINT  
COMMON/DATA/IA,OPLOB  
COMMON/TARGET/TACMG, RAM1, RNGMOD, DA1, COUR, CE(10), SE(15), JRUN,  
IFLAG, DA2  
DIMENSION RM(5,5), VAR(5), DET(150,5), DETB(150,5), STD(5),  
ASPEC(150,5), DERB(150,5), CLOSB(150,5), KON(150,5)  
REAL LAMEE, MCCURS, MXT, MM, MDIST, LAMBDG  
INTEGER BUNOUT
```

SETTING OF CONSTANTS (STEP 1)

CALL OVFLCW

```
| PI = 3.141592654  
| EH1 = 2.*PI  
| RAD = EH1/360.  
| ISEED1 = 362776  
| ISEED2 = 961695
```

CCOREC - MAX ERROR IN TARGET COURSE ESTIMATE

```
| CCOREC = 15.  
| CCOR = CCOREC*RAD
```

CSPEED - ST DEV IN TARGET SPEED ESTIMATE

```
| CSPEED = 3.  
| DEVSP = CSPEED*0.5  
| ITIME = 1
```

SET NUMBER OF ITERATIONS

```
| JRUN = 150
```

(CONTINUED ON PAGE 2)

SET PRINT OUT MODE

IPRINT = 1

SET LCEE OFF TORPEDO CENTER BEARING

CFLOB=0.

SET TABLES TO ZERO (STEP 2)

EM(I,J) = 0.

12 *****+CONTINUE

11 *****+CONTINUE

KCN(I,J) = 0

14 *****+CONTINUE

13 *****+CONTINUE

IA2 = 0.

(CONTINUED ON PAGE 3)


```
COMPUTE TARGET ERRORS AND STORE
```

```
+-----+
+ DO      +
+ 20      +
+ I=1,10  +
+-----+
|
| CE(I) =-(15.*RAD+CCOR/10.) + (CCOR
| /10.)*I*2.
|-----+
20 +++++++CCNTINUE
|-----+
```

SE(1) =-1.8737*DEVSP
 SE(2) =-1.2825*DEVSP
 SE(3) =-0.6666*DEVSP
 SE(4) =-0.7285*DEVSP
 SE(5) =-0.525*DEVSP
 SE(6) =-0.34*DEVSP
 SE(7) =-0.1675*DEVSP
 SE(8) =0*DEVSP
 SE(9) =0.1675*DEVSP
 SE(10) =0.34*DEVSP
 SE(11) =0.525*DEVSP
 SE(12) =0.7285*DEVSP
 SE(13) =0.6666*DEVSP
 SE(14) =1.2825*DEVSP
 SE(15) =1.8737*DEVSP

```
+-----+
+ DO      +
+ 900     +
+ JRUN=1,15N  +
+-----+
|
SET RUN COUNTERS (STEP 3)
```

```
IFLAG=1; TOC LOW TORPEDO SPEED
```

```
+-----+
+ IFLAG=0
+ ICNT=0
+ JCONT=0
+ ITIME=0
+ IL=0
+ IK=0
+ DIST=0.
+ XXT=0.
+ XM=0.
+ BUNOUT=0
+-----+
(CCNTINUED ON PAGE 4)
```


A TORPEDO SIMULATION. MAIN PROGRAM.

PAGE 4

READ IN SETTING(TORP AND TACTICAL)

FIRST RUN ? (STEP 4)

* . * . * . *
* : * IF : * . *
* : * JRUN.GI.1 * . *
* . * . * . * . *-----
* . * . * . * . * T | 160 |
* . * . * . * . *

CALL PARMET

***WRITE(6,228) OFLOB

228 FORMAT(1X,/,1X,'SCNAH MAIN LOSE OFF-SET FROM CENTER ',
'BEARING',F6.2,' TIMES DEFLECTION ANGLE',//)

| IDIST=IC/2.
| MDIST=IA/2.
| TURNTO =TSTATE/2.
| INTERVAL =IXIX((TTIME/0.5)+0.5)|

INTERVAL GIVES NUMBER OF TIMESTEPS FOR EACH TRANSMISSION

* . * . * . *
* : * IF : * . *
* : * IERINI.EQ.0 * . *
* . * . * . * . *-----
* . * . * . * . * T | 160 |
* . * . * . * . *

PRINT OF BEADING

151 ***WRITE(6,230)

230 FORMAT(1X,/,1X,'RUN',4X,'EST OF TARGET',7X,'TORP. TORP M',
8X,'TORP CCCAD',5X,'TARGET COORD',4X,'RUN',3X,'TORP',/,1X,
1X,'NO',1X,'COURSE',1X,'SPEED',1X,'RANGE',1X,'DA',4X,'COURSE',10X,'X',6X,
'Y',7X,'X',6X,'Y',6X,'STOP',2X,'RUN')

(CONTINUED ON PAGE 5)

A TORPEDO SIMULATION. MAIN PROGRAM.

PAGE 5

CALCULATE TORPEDO START POSITION (STEP 5)

160

```
| XSTAR = 1500C.  
| YTAR = 1500C.  
| CPA1 = RANGE  
| ENG = IAC+BEAR
```

```
* . * IF  
* . * ENG.GI.PH2 * . *  
* . * . * . * T | ENG=BNG-PH2
```

```
* . * IF  
* . * BNG.L1.C. * . *  
* . * . * . * T | BN=PH2+BNG
```

```
| XT = XSTAR+RANGE*SIN(BNG)  
| YT = YTAR+RANGE*COS(BNG)
```

```
* . * IF  
* . * IPBINT.EQ.1 * . *  
* . * . * . * T | 152 |
```

***WRITE(6,198) JRUN

198 FORMAT(1X,/,6X,'RUN NUMBER : ',I4)

CALCULATE TORPEDO DEFLECTION ANGLE AND FIRING SITUATION

152 CALL FIRING

(CONTINUED ON PAGE 6)

A TORPEDO SIMULATION. MAIN PROGRAM.

PAGE 6

SET DETECTION TABLES TO ZERO (STEP 6)

+-----+
+ DC +
+ I=1,5 +
+-----++-----+
+ DO +
+ J=1,6 +
+-----+

| FMAX(I,J) = 0. |

9 +++++++CONTINUE

10 +++++++CONTINUE

TEST TORPEDO GUN CUT (STEP 7)

+-----+
| TRUN = IRANGE/TO
| CLOSP = TA*CCS(BEAR) + TO*COS(DA)
| HRUN = RANGE/CLOSP |+-----+
* . * . * . * .
* . * . IF . * . * .
* . * . T . * . * .
* . * . 499 . * .
* . * .
* . * .
* . * .

***WAIT(6,231)

231 FORMAT(1X,/,1X,'TARGET OUTSIDE TORPEDO RANGE')

ZER0 TABLES

+-----+
+ DO +
+ J=1,5 +
+-----+

| DETE(JRUN,J) = 0. |

(CONTINUED ON PAGE 7)

A TORPEDO SIMULATION. MAIN PROGRAM.

PAGE 7

```
+      DET(JRUN,J)=0.  
+  
+      ASPEC(JRUN,J)=0.  
+      CLOS8(JRUN,J)=0.  
+      LERB(JRUN,J)=0.  
  
23 ++++++CCNTINUE  
+  
+      | 900 |  
  
499 +      * . * IF  
+      * . * IFLAG.EQ.1 * . *  
+      * . * . * . * T | 990 |  
  
500 +      * . * IF  
+      * . * EXT.GE.THANGE * . *  
+      * . * . * . * T | RUNOUT=1 |  
  
+      * . * IF  
+      * . * RUNOUT.EQ.1 * . *  
+      * . * . * . * T | 990 |  
  
+      CALCULATE NEW POSITIONS  
+  
+      CALL POSIS  
  
+      CHECK IF TARGET IS DETECTED  
+  
(CONTINUED ON PAGE 8)
```



```
+-----+
| CALL DETECT
+-----+
+
+-----+
| CHECK CPA(CLOSEST POINT OF APPROACH) (STEP 8)
+-----+
| IL = IL+1
+-----+
* . * IF * .
* . IL.LI.20 * .
* . * - * . * . T | 500 |
+-----+
| IL = 0
| CPA = CIST
+-----+
155 * . * IF * .
* . CPA1-CPA.LI.0. * .
* . * - * . * . T | RUNOUT=1
+-----+
| CPA1 = CPA
+-----+
| 500 |
+-----+
+
+-----+
| GENERATE STATISTICS (STEP 9)
+-----+
990 CCNTINUE
+-----+
+ DO 910
+ IKL=1,5
+-----+
(CCNTINUED ON PAGE 9)
```


A TORPEDO SIMULATION. MAIN PROGRAM.

PAGE 9

KON() = DETECTION/NO DETECTION

* * * * * IF * * *
* RMAX(IKL,1) .GT. 1: *-----
* * * * * T | KON(JRUN,IKL)=1
* * * * *

DET() = DISTANCE TO TARGET AT DETECTION

| DET(JRUN,IKL) = RMAX(IKL,1) |

DETE() = BEARING TO TARGET AT DETECTION

| DETE(JRUN,IKL) = RMAX(IKL,2) |

ASPEC() = TARGET ASPECT AT DETECTION

ASPEC(JRUN,IKL)=RMAX(IKL,5)

CLCSB() = BEARING TO CLOSEST PART OF TARGET

CLCSB(JRUN,IKL)=RMAX(IKL,4)

DERE() = REL BEARING FROM MAIN TORP COURSE TO TARGET

| DERE(JRUN,IKL) = RMAX(IKL,6) |

910 ++++++CONTINUE

(CONTINUED ON PAGE 10)

A TORPEDO SIMULATION. MAIN PROGRAM.

PAGE 10

A TORPEDO SIMULATION. MAIN PROGRAM.

PAGE 11

CALCULATE SUMMARY RESULT (STEP 12)

+-----+
+ DO 27
+ KR=1,5
+-----+
(CONTINUED ON PAGE 12)

A TORPEDO SIMULATION. MAIN PROGRAM.

PAGE 12

(CONTINUED ON PAGE 13)

A TORPEDO SIMULATION. MAIN PROGRAM.
+
+
+
++++++CCNTINUE

PAGE 14

PRINT SUMMARY (SIEE 13)

```
***WRITE(6,197)IRUN
197    FCFMAT(1X,/,6X,'SUMMARY OF RESULT AFTER',3X,I4,2X,'RUNS')
***WRITE(6,199)((RM(I,J),J=1,2),STD(I),(RM(I,J),J=3,5),I=1,5)
199    PCFMAT(10X,'PROBABILITY OF DETECTION',3X,
           'AVERAGE',6X,'STD DEVIATION',7X,'AVERAGE',7X,'AVERAGE',
           7X,'AVERAGE',/,41X,
           'DET RANGE',6X,'DET RANGE',7X,'TARGET ASPECT',4X,'DET BEARING',
           3X,'REL BEARING',/,
           1X,'ONE SUCCESSIVE DETECTION',5X,F6.4,5(6X,F9.4),/,
           1X,'TWO SUCCESSIVE DETECTIONS',4X,F6.4,5(6X,F9.4),/,
           1X,'THREE SUCCESSIVE DETECTIONS',5X,F6.4,5(6X,F9.4),/,
           1X,'FOUR SUCCESSIVE DETECTIONS',3X,F6.4,5(6X,F9.4),/,
           1X,'FIVE SUCCESSIVE DETECTIONS',3X,F6.4,5(6X,F9.4),/
220    PCFMAT(1X,'NO DETECTION MADE DURING THIS RUN')
-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
1 DA2 =DA2/FICAT(IRUN)
-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
***WRITE(6,190)DA2
190    FORMAT(1X,/,1X,'AVERAGE DEFLECTION ANGLE :',5X,F8.4,/)
***WRITE(6,234)
234    PCFMAT(1X,/,1X,'DISTRIBUTION OF RUN RESULT - CENTER OF TARGET',/,
           6X,'ONE SUCCESSIVE DETECTION',10X,'TWO SUCCESSIVE DETECTIONS',/,
           8X,'THREE SUCCESSIVE DETECTIONS',/,2X,
           'BEAR',2X,'RANGE ASPECT BEAR CLCS',6X,'BEAR',2X,
           'RANGE ASPECT BEAR CLCS',/,'RANGE ASPECT BEAR CLCS')
-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
***WRITE(6,236)((DETB(I,1),DET(I,1),ASPEC(I,1),CLOSB(I,1),
               DET(I,2),DET(I,2),ASPEC(I,2),CLOSB(I,2),DETS(I,3),
               DET(I,3),ASPEC(I,3),CLCSB(I,3)),I=1,IRUN)
236    FORMAT(3(1X,F6.1,1X,F6.1,1X,F6.1,2X,F6.1,5X))
999    STOP
END
```


A TORPEDO SIMULATION. SUBROUTINE PARMET.

PAGE 1

A TORPEDO SIMULATION. SUBROUTINE PARMET.

SUBROUTINE PARMET
READING IN DATA AND PARAMETERS

```
COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBDA, TADEC,  
BEAR, RAD, TAC, CCOR, DEVSP, BNG, EN, PH2, MCOURS, TCOURS,  
MXT, MMX, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST,  
MDIST, TURNTO, INTERVAL, PHI, RMAX(5,5), TRANGE, DIST, IPINT  
REAL LAMBD, MCOURS, MXT, MMX, MDIST, LAMBDG  
INTEGER SUNCUT
```

TEDEC - TECHNICAL DETECTION RANGE (STEP A1)

LEVEL OF VARIATION: 375-750-1125-1500 METERS

TADEC - TACTICAL DETECTION RANGE

```
-----  
| TEDEC=750.  
| TADEC=TEDEC  
-----
```

ITIME - TRANSMISSION INTERVAL

```
-----  
| ITIME=2.*TEDEC/1500.  
-----
```

TCKN - TORP SPEED IN KNOTS, TO - TORP SPEED IN M/SEC (STEP A2)

LEVEL OF VARIATION: 24-32-40 KNOTS

```
-----  
| TCKN =40.  
| TO =TCKN/2  
-----
```

TAKN - TARGET SPEED IN KNOTS, TA - TARGET SPEED IN M/SEC (STEP A3)

LEVEL OF VARIATION: 12-18-24-30 KNOTS

```
-----  
| TAKN =18.  
| TA =TAKN/2  
-----
```

(CONTINUED ON PAGE 2)

A TORPEDO SIMULATION. SUBROUTINE PARMET.

PAGE 2

TACG - TARGET COURSE IN DEGREE (STEP A4)

```
|-----|
| TACG = 270 |
| TAC = TACG*RAD |
|-----|
```

ALFAG - SWEEP ANGLE IN DEGREE, ALFA - SWEEP ANGLE IN RADIANS

(STEP A5)

LEVEL OF VARIATION: 20-30-40 DEGREES

```
|-----|
| ALFAG=30. |
| ALFA = ALFAG*RAD |
|-----|
```

LAMBEG - LOBE WIDTH EACH SIDE OF TORP HEADING (STEP A6)

LEVEL OF VARIATION: 10-20-30 DEGREES

```
|-----|
| LAMBEG = 20. |
| LAMED=LAMBEG*RAD |
|-----|
```

BELERG - RELATIVE BEARING FROM TARGET TO TORP IN DEGREE (STEP A7)

LEVEL OF VARIATION: 0-30-60-90-120-180 DEGREES

```
|-----|
| BELERG == 60. |
| EEAR = BELERG*RAD |
|-----|
```

RANGE - DISTANCE BETWEEN TARGET AND TORP (STEP A8)

LEVEL OF VARIATION: 1500-3000-5000-7000 METERS

```
|-----|
| RANGE=3000. |
|-----|
```

(CONTINUED ON PAGE 3)

A TORPEDO SIMULATION. SUBROUTINE PARMET.

PAGE 3

TRANGE - MAX TIDE FNU IN METERS (STEP A9)

1 TCHANGE = 18000.

TRATEG - TCRE TURBRATE IN DEGREE PER SEC (STEP A10)

LEVEL OF VARIATION: 3-6-9-12-15-18-21 DEGREES/SEC

TRATEG = 18.
TRATE=TRATEG*RAD

CALCULATE WIDTH OF TACTICAL SWEEP-LANE (THEORETICAL)

SING = TADEC * SIN (ALFA + LAMBDA) * 2.

CALCULATE COVERAGE RATIO (THEORETICAL)

CRATIC = 1. - (TRATE*TTIME/(2.*LAMBD))

POINT OF SITUATION AT START OF RUN (STEP A12)

* . * * IF IPBINI.EQ.0 * . * - T | 90

***WRITE(6,110)

110 FORMAT(1X,'//,1X,'TACTICAL SITUATION WHEN FIRING',6X,
'TORPEDO FASAMETES',/ 2X,'RANGE ATTACK TARGET TARGET',6X,'TECDET TORP',
3X,'SWEEP LCBE TURN SWEEP COVERAGE',/
9X,'ANGLE CCURSE SPEED',7X,'RANGE SPEED',2X,
'ANGLE WIDTH RATE LANE',4X,'RATIO')

(CONTINUED ON PAGE 4)


```

1
***WRITE(6,112) RANGE, RELEBG, TACG, TAKN, TEDEC, TOKN, ALFAG,
112   LAMBEG, TRATEG, SRNG, CRATIO
      FORMAT(1X,F6.0,2X,F6.1,3X,F5.1,3X,F4.1,6X,F6.1,3X,F5.1,3X,
      F4.1,3X,F4.1,2X,F4.1,2X,F6.1,3X,F5.3)
      |
      | 95 |
      |

90   ***WRITE(6,100)
100   FC5MAT(1X,'TACTICAL SITUATION WHEN FIRING',//,1X,
      'FIRING RANGE',3X,'ATTACK ANGLE',3X,
      'TARGET CURSE',2X,'TARGET SPEED')
      ***WRITE(6,102) RANGE, RELEBG, TACG, TAKN
102   FC5MAT(1X,4(2X,F6.1,7X),/)
      ***WRITE(6,104)
104   FC5MAT(1X,'TCPEDC PARAMETERS',//,1X,
      'TECH.DET.RANGE',2X,'TRANS.INT.VAL',2X,'TORP SPEED',3X,
      'SWEEP ANGLE')
      ***WRITE(6,106) TEDEC, TTIME, TOKN, ALFAG
106   FC5MAT(1X,2(2X,F7.2,7X),2(F6.1,7X),/)
      ***WRITE(6,108) LAMBEG, TRATEG
108   FORMAT(1X,'LOBE WIDTH',6X,'TURN RATE',//,
      3X,F6.1,10X,F6.1)
      ***WRITE(6,109) SRNG, CRATIC
109   FC5MAT(1X,'THEORETICAL WIDTH OF TACTICAL SWEEP-LANE',F9.1,
      /,1X,'THEORETICAL COVERAGE RATIO',F9.4)
      95   RETURN
END

```


A TORPEDO SIMULATION. SUBROUTINE FIRING.

PAGE 1

A TORPEDO SIMULATION. SUBROUTINE FIRING.

SUBROUTINE FIRING

CALCULATE THE TORP DEFLECTION ANGLE, MAIN COURSE, FIRING COURSE
BASED ON ESTIMATE OF TARGET DATA (UNCERTAINTY)

DIMENSION U(2)

COMMON ISFED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBD, TADEC,
BEAR, RAC, TAC, CCOS, DEVS, BNG, PN, PH2, MCCURS, TCOURS,
MXT, MXM, IR, IDTIME, ITIME, XT, YT, XTAR, YTAR, DIST,
MDIST, TURNT, INTERVAL, PHI, SMAX(5,6), TRANGE, DIST, IPINT

COMMON/DATA/IA,OPLOS

COMMON/TARGET/TACMG,TAM1,BNGMOD,DA1,COUR,CZ(10),SE(15),JRUN,
IFLAG,DA2

REAL LAMED, MCCURS, MXT, MXM, MDIST, LAMBDG

INTEGER BUNCT

```
| IN = -1
| PP = 1.
| KSPEED = MCD((JRUN-1), 15) + 1
| KCOURS = IFIX((JRUN-1)/15.) + 1
```

CALL GGUE(ISFED2,2,U)

CALCULATE ESTIMATE OF TARGET COURSE (STEP 31)

19

```
| IACM = TAC+CZ(KCOURS)
```

20

```
| IFCO=IACM-TAC
```

(CONTINUED ON PAGE 2)


```
* . * . * IF * . *
* . TACM.GE.PH2 * . *
* . * . * . * . * . * -----+
* . * . * . * . * . * | TACM=TACM-PH2
* . * . * . * . * . * |
* . * . * . * . * . * |
* . * . * . * . * . * |
* . * . * . * . * . * |
* . * . * . * . * . * | local start
* . * . * IF * . *
* . TACM.LT.0. * . *
* . * . * . * . * . * -----+
* . * . * . * . * . * | TACM=PH2+TACM
* . * . * . * . * . * |
* . * . * . * . * . * |
* . * . * . * . * . * |
```

CALCULATE EST OF TARGET SPEED (STEP B2)

```
|-----|
| TAM =TA+SE(KSPEED) |-----|
```

CALCULATE TORPEDO DEPLECTION ANGLE (STEP B3)

```
|-----|
| ASP =EEAR-DIFCO |-----|
|-----|
* . * . * IF * . *
* . ASP.LT.-PHI * . *
* . * . * . * . * . * -----+
* . * . * . * . * . * | ASP=PH2+ASP
* . * . * . * . * . * |
* . * . * . * . * . * |
* . * . * . * . * . * |
|-----|
| TACS =TAM*SIN(AES(ASP)) |
| CAA =TACS/TC |-----|
```

(CONTINUED ON PAGE 3)


```
* * . * IF
* DAA.GE.1. * *
* * . *-----| 26 |
* * . * * * F
* * . *-----|-----|
| DA = ABSIN(DAA)
| DA = SIGN(DA,ASE)
|-----|-----|
```

CALCULATE TOSEFEDC MAIN FIRING COURSE (STEP B4)

10

```
| MCOURS = RNG+PHI+DA |-----|
* * . * IF
* * MCOURS.GT.PH2 * *
* * . *-----| MCOURS=MCOURS-PH2 |
* * . * * * F
* * . *-----|-----|
* * . * IF
* * MCOURS.LT.0. * *
* * . *-----| MCOURS=PH2+MCOURS |
* * . * * * F
* * . *-----|-----|
* * . * IF
* * MCOURS.GT.PH2 * *
* * . *-----| 10 |
* * . * * * F
* * . *-----|-----|
```

(CONTINUED ON PAGE 4)

A TORPEDO SIMULATION. SCRUTINE FIRING.

PAGE 4

CALCULATE TOSEEDC PRESENT FIRING COURSE (STEP 35)

CALCULATE ESTIMATE OF TARGET RANGE (STEP 36)

(CONTINUED ON PAGE 5)

A TORPEDO SIMULATION. SUCCESSION FIRING.

PAGE 5

RNGMOD=RANGE+SIGN(RNGDIF,PP)

```

TACMG=TACM/BAD
TAM1 =TAM*2
CA1 =CA/RAD
CA2 =CA2+CA1

```

PRINT CUT OF FIRING DATA

***WRITE(6, 122) TACMG, IAM1, ZNGMOD

122 FORMAT(1X,'EST. OF TARGET DATA FOR FIRING',/,'4X','COURSE',5X,'SPEED',5X,'RANGE',/,'1X,3(F8.1,3X))

***WRITE(6,124)CA1

124 FCMFMAT(1X,'TCPF DEFLECTION ANGLE IS ',F6.2)

| COUR = MCCUES/RAD

***WRITE(6,125)COUR

125 FORMAT(1X,'TORPEDO MAIN COURSE',8X,F6.2)

126 CONFINUE

125

26 ***WRITE(6,30)

30 FCEMAT(1,1X,'NCT FEASIBLE TO FIRE DUE TO LOW TORPEDO SPEED')

—
1 TFLAG=1

1

25 RETURN

END

A TORPEDO SIMULATION. SUBROUTINE POSIS.

PAGE 1

A TORPEDO SIMULATION. SUBROUTINE POSIS.

SUBROUTINE POSIS
IS CALCULATING NEW POSITIONS OF TARGET AND TORPEDO IN
EACH TIME STEP

```
COMMON ISEED, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBDA, TADEC,  
BEAB, RAD, TAC, CCCR, DEVSP, EN, PH2, MCCURS, TCOURS,  
MXT, MXM, IK, IDTIME, ITIME, XT, YT, Xtar, Ytar, TDIST,  
MDIST, TURNT, INTERVAL, PHI, RMAX(5,6), TRANGE, DIST, IPINT  
REAL LAMEL, MCCURS, MXT, MXM, MDIST, LAMBDG  
INTEGER BUNCT
```

TIME COUNT (STEP C1)

```
|  
| IK = IK+1  
| ITIME=ITIME+IDTIME  
|-----|
```

CALCULATE TOTAL TORP RUN AND TARGET RUN (STEP C2)

```
|  
| MXT = MXT+TDIST  
| MXM = MXM+MDIST  
|-----|
```

CALCULATE NEW POSITIONS (STEP C3)

```
|  
| XT = XT+SIN(TCOURS)*TDIST  
| YT = YT+CCS(TCOURS)*TDIST  
| Xtar = Xtar+SIN(TAC)*MDIST  
| Ytar = Ytar+CCS(TAC)*MDIST  
|-----|
```

CALCULATE NEW TORP COURSE (STEP C4)

```
|  
| TXCOUR = TCCURS+SIGN(TURNTO,EN)  
| TXCDIF = ABS(MCOURS-TXCOUR)  
|-----|
```

(CONTINUED ON PAGE 2)


```

      * . * . * IF * .
      * . TXCDIF.GT.PHI : *
      * . * . * . * . T | TXCDIF=PH2-TXCDIF
      * . * . * . * . F
      * . * . * . * . T | 15 | I

      * . * . * IF * .
      * . TXCDIF.LT.ALFA : *
      * . * . * . * . T | 15 | I
      * . * . * . * . F

      | EN == EN
      | ALFADI =TXCDIF-ALFA
      | TXCOUR =TXCCUR+2.*SIGN(ALFADI,PN)
      | 15
      | TCOURS =TXCCUR
      |
      * . * . * IF * .
      * . TCOURS.GT.PH2 : *
      * . * . * . * . T | TCOURS=TCOURES-PH2
      * . * . * . * . F
      * . * . * . * . T | 15 | I

      * . * . * IF * .
      * . TCOURS.LT.0. : *
      * . * . * . * . T | TCOURS=PH2+TCOURS
      * . * . * . * . F
      * . * . * . * . T | 15 | I

25  RETURN
END

```


A TORPEDO SIMULATION. SUBROUTINE DETECT.

PAGE 1

A TORPEDO SIMULATION. SUBROUTINE DETECT.

SUPERROUTINE DETECT

TO CHECK IF TARGET IS DETECTED AND STORE DETECTION DATA

```

COMMON ISZED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBDA, TADEC,
SELR, RAD, TAC, CCCR, DEVSP, BNG, EN, PH2, MCURS, TCOURS,
MXT, MXM, IX, IDTIME, ITIME, XT, YT, XTAR, YTAR, IDIST,
MDIST, TURNT, INTERVAL, PHI, RMAX(5,5), TRANGE, DIST, IPINT

COMMON/DATA/IA,OFLCB

REAL LAMBDA, MCOURS, MXT, MXM, MDIST, LAMBDG

INTEGER BUNOUT

DIMENSION EB(3,2)

DOUBLE PRECISION PCWMAX, B, RBX, RBX1, RBX2, X1, X2, X3, XX1,
V1, V2, V, U, FIFACT, XC1, X02, X03, XX2, POWER, SELLB, ALAM

```

SETTING OF TARGET DIMENSION, A - TARGET LENGTH,

B - TARGET WIDTH, C - TARGET DEPTH. (STEP D1)

$$\begin{array}{ll} A & = 100. \\ B & = 15. \\ C & = 4. \end{array}$$

CHECK IF TRANSMISSION (STEP D2)

(CONTINUED ON PAGE 2)

CALCULATE RANGE TO TARGET (STEP D3)

```

-----+
| DIFX = XTAR - XT
| DIFY = YTAR - YT
| DIST = SQRT( (DIFX**2) + (DIFY**2) )
-----+

```

TEST IF TARGET IS WITHIN POSSIBLE DETECTION RANGE

```

-----+
* DIST.GT. (TADEC+A/2.) IF T 20
* . * . * . * . * . *
-----+
| P
-----+

```

DETECTION THRESHOLD (STEP D4)

```

-----+
| POWMAX = 1. / (B*TADEC)**4
| U = SCAL * (PHI/2.)
| CONST = (A**2) * (B**2) * (C**2)
| POWMAX = CONST * POWMAX * U
-----+

```

CALCULATE TIME TO TARGET (STEP D5)

```

-----+
| TIMDL1 = DIST/1500.
| XTAR1 = XTAR + SIN(TAC) * (TIMDL1*TA)
| YTAR1 = YTAR + COS(TAC) * (TIMDL1*TA)
-----+

```

CENTB - BEARING OF CENTER OF LOBE (STEP D6)

```

-----+
| DD = -LA*CFLLOB
| CENTB = TCCUES+DD
-----+

```

(CONTINUED ON PAGE 3)


```

* . * . * IF * . *
* . * . * CENTE.LI.O. * . *
* . * . * T | CENTB=PH2+CENTB
* . * . *-----*
* . * . *-----*
* . * . * IF * . *
* . * . * CENTB.GT.PH2 * . *
* . * . * T | CENTB=CENTB-PH2
* . * . *-----*
* . * . *-----*

```

CALCULATE BEARINGS TO TARGET (STEP D7)

```

|-----|
    BB   = EEAFIN (XTAR1, YTAR1, XT, YT)
    XTAR2=XTAR1+SIN (TAC) *A/2.
    YTAR2=YTAR1+COS (TAC) *A/2.
    DIST1=SCRT ((XTAR2-XT)**2+(YTAR2
        -YT)**2)
    BB1  = EEAFIN (XTAR2, YTAR2, XT, YT)
    XTAR3=XTAR1-SIN (TAC) *A/2.
    YTAR3=YTAR1-COS (TAC) *A/2.
    DIST2=SCRT ((XTAR3-XT)**2+(YTAR3
        -YT)**2)
    BB2  = EEAFIN (XTAR3, YTAR3, XT, YT)
    REL1 = BB1-CENTB
|-----|

```

```

* . * . * IF * . *
* . * . * REL1.GT.PHI * . *
* . * . * T | REL1=REL1-PH2
* . * . *-----*
* . * . *-----*

```

(CONTINUED ON PAGE 4)


```
* . . IF * . *
* : REL1.LT.-PHI * : *
* . . * . * T | REL1=PH2+REL1
* . . * . *
* . . * . *
| REL0 = RE-CENTB |
* . . * . *
* . . IF * . *
* : REL0.GT.PHI * : *
* . . * . * T | REL0=REL0-PH2
* . . * . *
* . . * . *
| REL2 = RE2-CENTB |
* . . * . *
* . . IF * . *
* : REL2.GT.PHI * : *
* . . * . * T | REL2=REL2-PH2
* . . * . *
```

(CONTINUED ON PAGE 5)

A TORPEDO SIMULATION. SUFFCUTINE DETECT.

PAGE 5

```
* * . * IF * *
* : REL2.LT.-PHI * .
* * . * . * . * T | RELO=PH2+REL2
```

CALCULATE TRANSMISSION GAIN FACTOR (STEP D8)

```
| RBX1 =REL1
| RBX =REL0
| FBX2 =REL2
| ALAM =LAM2D
```

COMPUTE SEPARATE GAIN FACTORS (STEP D9)

```
| X1 =XFAC(T,BBX1,ALAM)
| X2 =XFAC(T,BBX,ALAM)
| X3 =XFAC(T,BBX2,ALAM)
| XX1 =(X1+X2+X3)/3.
```

CALCULATE TARGET ASPECT AND TARGET SONAR CROSS-
AREA (TARGET STRENGTH) DUE TO ASPECT (STEP D10)

```
| INTBB=RE+PHI
| * . * IF * .
| * : ANTRB.GT.PH2 * .
| * . * . * . * T | ANTRB=ANTRB-PH2
```

```
| RELA =ANTBB-TAC
```

(CONTINUED ON PAGE 6)


```

* . * . * IF * . *
* . RELA.GT.PHI * . *
* . * . * . * . T | RELA=PH2-RELA
* . * . * . * . |
* . * . * IF * . *
* . RELA.LT.-PHI * . *
* . * . * . * . T | RELA=PH2+RELA
* . * . * . * . |
* . * . * . * . |
-----|-----|-----|
| RELE =AES(RELA)
| V1 = (A**2)*(DCCS(RELB)**2)
| V2 = (E**2)*(DSIN(RELB)**2)
| V = (V1+V2)**2
-----|-----|-----|
| |

```

COMPUTE SCALING FACTOR DUE TO ASPECT (STEP D11)

```

| U
| FIPACT =SCALE(RELB)
| FIPACT =0/V
-----|-----|-----|
| |

```

CALCULATE RETURNTIME FOR ECHO (STEP D12)

```

| |
| TIMDL2 =2.*TIMDL1
| |
-----|-----|-----|
| |

```

CALCULATE REL BEARING FOR RETURNING ECHO (STEP D13)

```

| |
| TURNST =RATE*TIMDL2
| TXC =TCOUES+SIGN(TURNST,PN)
| TXDC =AES(MCCUES-TXC)
-----|-----|-----|
| |

```

(CONTINUED ON PAGE 7)


```
* . * . * IF * . *
* . TXDC.GT.PHI * . *
* . * . * - * T | TXDC=PH2-TXDC
* . * . * . * F
* . * . * IF * . *
* . TXDC.IF.ALFA * . *
* . * . * . * T | 18 |
* . * . * . * F
* . * . * ALF = TXDC-ALFA
* . RELTO=RELO-SIGN((TURNST-ALF),PN)
* . +SIGN(ALF,PN)
| 19 |
18 | RELTO=RELO-SIGN(TURNST,PN) |
| |
19 | BLDIF = RELTO-RELO
| RELT1=REL1+BLDIF
| RELT2=REL2+BLDIF
| |
* . * . * IF * . *
* . PELTO.GT.PHI * . *
* . * . * . * T | RELTO=PH2-PELTO
* . * . * . * F
(CONTINUED ON PAGE 8)
```



```
* . * . * IF * . *
* : RELIO.LI.-PHI : *
* . * . * T | RELTO=PH2+RELTO
* . * . *
* . * . * IF * . *
* : RELT1.GT.PHI : *
* . * . * T | RELT1=PH2-RELT1
* . * . *
* . * . * IF * . *
* : RELT1.LI.-PHI : *
* . * . * T | RELT1=PH2+RELT1
* . * . *
* . * . * IF * . *
* : RELT2.GT.PHI : *
* . * . * T | RELT2=PH2-RELT2
* . * . *
* . * . * IF * . *
* : RELT2.LI.-PHI : *
* . * . * T | RELT2=PH2+RELT2
```

(CONTINUED ON PAGE 9)

TEST FOR DOPPLER

```

FRQDEF = 50.*2.* (TO*CCS(DD) - 1.)
/1500.
FRQDIF = 50.*2.* (TO*CCS(DD) + 1.)
/1500.
RELC = RELB
FRQSH = 50.*2.* (TO*COS(DD) + TA*COS(RELC))
/1500.

```

```

* . * . * .
* (FRQSH.LT.FRQDIF) : AND. (FRQSH.GT.FRQDEF)
* . * . * . *----- T | 20 | .
* . * . * .
F

```

CALCULATE RANGE AND BEARING TO CLOSEST PART OF TARGET (STEP D14)

```

LB{1,1} = DIST
LB{1,2} = RELT0+DD
LB{2,1} = DIST1
LB{2,2} = RELT1+DD
LB{3,1} = DIST2
LB{3,2} = RELT2+DD
DMIN = LB(1,1)
MD = 1

```

```

* . * . * .
* (DMIN.GT.LB(2,1)) : *
* . * . * . *----- T | 10 | .
* . * . * .
F

```

```

* . * . * .
* (DMIN.GT.LB(3,1)) : *
* . * . * . *----- T | 11 | .
* . * . * .
F

```

(CONTINUED ON PAGE 10)


```

      |
      | 12 |
      |
      |-----|
10   | DMIN = DE(2,1)
      | MD   = 2
      |
      |-----|
      | 9   |
      |
      |-----|
      |
      |-----|
11   | DMIN = DE(3,1)
      | MD   = 3
      |
      |-----|
12   | EREL = DE(MD,2)
      |
      |-----|
      * . * IF * . *
      * . * BREL.GT.PHI * .
      * . * . * . * . * T | BREL=PH2-BREL
      |
      |-----|
      * . * IF * . *
      * . * BREL.LT.-PHI * .
      * . * . * . * . * T | BREL=PH2+BREL
      |
      |-----|
      F
      |
      |-----|

```

CALCULATE RECEIVING GAIN FACTOR (STEP D15)

```

      |
      |-----|
      | RBX1 = RELT1
      | RBX  = RELTC
      | RBX2 = RELT2
      | X01  = XFACT1(RBX1, ALAM)
      | X02  = XFACT1(RBX2, ALAM)
      | X03  = XFACT1(RBX2, ALAM)
      | XX2  = (X01+X02+X03)/3.
      |
      |-----|

```

(CONTINUED ON PAGE 11)

A TORPEDO SIMULATION. SCEROUTINE DETECT.

PAGE 11

CALCULATE FRACTION OF POWER IN TO RECIEVER (STEP D16)

```
|-----  
|   POWER=CCNST*XX1*XX2*FIPACT/(DIST  
|   **4)  
|-----|
```

TEST FCR DETECTION THRESHOLD (STEP D17)

```
|-----  
*   *   *   *   *  
*   POWER.LT.FCRMAX   *  
*   *   *   *   *-----|  
*   *   *   *   *  
|-----|  
|-----|
```

COMPUTE BEARING RATE (STEP D18)

```
|-----  
|   ASP =PHI+TAC  
|-----|  
|-----  
*   *   *   *   *  
*   ASP.GT.PHI   *  
*   *   *   *   *-----|  
*   *   *   *   *  
|-----|  
|-----  
*   *   *   *   *  
*   ASP.LT.-PHI   *  
*   *   *   *   *-----|  
*   *   *   *   *  
|-----|  
|-----|  
|   AP   =ASP*SELTO  
|-----|
```

(CONTINUED ON PAGE 12)

A TORPEDO SIMULATION. SUBROUTINE DETECT.

PAGE 12

```
TACS=TA*SIN(AES(ASP))
      |
-----| TOCS=TC*SIN(ABS(RELTO))
      | ERATE=(TACS+SIGN(TOCS,AP))/DIST
      |
      |
```

CHECK BEARING RATE AGAINST TURNRATE (STEP D19)

```

      |
      * * * IF * *
      * ERATE.GE.IRATE * *
      * * * . * * * T | 15 |
      * * * . * * *
      |
      F
```

CHECK TORPEDO SPEED ADVANTAGE (STEP D20)

```

      |
-----| TALS=TA*CCS(ABS(ASP))
      | TOLS=TC*CCS(ABS(RELTO))
      |
      * * * IF * *
      * AES(ASP).GT.PHI/2. * *
      * * * . * * * T | TALS=-TALS
      * * * . * * *
      |
      * * * IF * *
      * AES(RELTC).GT.PHI/2. * *
      * * * . * * * T | TOLS=-TOLS
      * * * . * * *
      |
      F
```

(CONTINUED ON PAGE 13)


```
* (TALS+TCIS).LE.0. *-----  
* . * . * . * . T | 15 |  
* . * . * . *
```

```
|-----|  
| RLB = RE-MCCURS |-----|
```

```
* . * . * . * .  
* . * . IF * . * .  
* . * . RLB.GT.PHI * . * .-----  
* . * . * . * . T | RLB=RLB-PHI |-----  
* . * . * . *
```

```
* . * . * . * .  
* . * . IF * . * .  
* . * . RLB.LT.-PHI * . * .-----  
* . * . * . * . T | RLB=PH2+RLB |-----  
* . * . * . *
```

STORE DETECTION DATA (STEP D21)

```
|-----|  
| JCONT=JCONT+1  
| JMAX = $BX0(JMAX,JCONT)  
| ICNT=JCONT |-----|
```

(CONTINUED ON PAGE 14)


```

* * * * *
*   IF   *
*   ICONT.GE.5   *
* * * * *
*   *   *   *   *   T   | ICONT=5
*   *   *   *   *
*   F   *
*   |

```

STORE DATA IN ACCORDANCE WITH NUMBER SUCCESSIVE
DETECTIONS (STEP D22)

```

25      GO TO (30,31,32,33,34),ICONT
*
30      * * * * *
*   IF   *
*   RMAX(1,1).NE.0.   *
* * * * *
*   *   *   *   *   T   | 20   |
*   *   *   *   *
*   F   *
*   |
*   |
*   FMAX(1,1) =DIST
*   RMAX(1,2) =(RELTC+DD)/RAD
*   |
*   |
*   * * * * *
*   IF   *
*   RMAX(1,2).GT.180.   *
* * * * *
*   *   *   *   *   T   | RMAX(1,2)=RMAX(1,2)-360.
*   *   *   *   *
*   F   *
*   |
*   |
*   SMAX(1,3) =DMIN
*   SMAX(1,4) =SSEL/RAD
*   RMAX(1,5) =RELA/RAD
*   SMAX(1,6) =SEL/RAD
*   |
*   |
*   20   |

```

(CONTINUED ON PAGE 15)


```

* * * * * IF * * *
* . . . . NE.0. . .
* * * * * T | 20 | *
* * * * * F
* * * * * RMAX(2,1) =DIST
* * * * * RMAX(2,2) =(BELTO+DD)/RAD
* * * * * T | RMAX(2,2) =RMAX(2,2)-360.
* * * * * F
* * * * * RMAX(2,3) =DMIN
* * * * * RMAX(2,4) =BHEL/RAD
* * * * * RMAX(2,5) =BELA/RAD
* * * * * RMAX(2,6) =BLE/RAD
* * * * * T | 20 | *

```

32

(CONTINUED ON PAGE 16)


```

* * * IF * *
* EMAX(3,2).GT.180: *
* * * . * . * T | RMAX(3,2)=RMAX(3,2)-360.
* * * . * . *

```

EMAX{3,3}	=DMIN
EMAX{3,4}	=ESEL/RAD
EMAX{3,5}	=RELA/RAD
EMAX{3,6}	=FLE/RAD

```

| 20 |

```

33

```

* * * IF * *
* EMAX(4,1).NE.0: *
* * * . * . * T | 20 |
* * * . * . *

```

EMAX{4,1}	=CIST
EMAX{4,2}	=RELTO+DD)/RAD

```

* * * IF * *
* EMAX(4,2).GT.180: *
* * * . * . * T | RMAX(4,2)=RMAX(4,2)-360.
* * * . * . *

```

EMAX{4,3}	=DMIN
EMAX{4,4}	=ESEL/RAD
EMAX{4,5}	=RELA/RAD
EMAX{4,6}	=FLE/RAD

(CONTINUED ON PAGE 17)

A TORPEDO SIMULATION. EXECUTING DETECT.

PAGE 17

34

```

*   * IF EMAX(5,1).NE.0. *
*   * - * - * T | 20 | -
*   * - * - * F
*   * - * - *
*   * RMAX(5,1) =DIST
*   * RMAX(5,2) =(RELTO+DD)/RAD
*   * - * - * -
*   * IF EMAX(5,2).GT.180. *
*   * - * - * T | RMAX(5,2)=RMAX(5,2)-360 |
*   * - * - * F
*   * - * - *
*   * RMAX(5,3) =DMIN
*   * RMAX(5,4) =EEEL/RAD
*   * RMAX(5,5) =BELA/RAD
*   * RMAX(5,6) =BLE/RAD
*   * - * - * -
*   * 20 |

```

IF NO DETECTION, SET DETECTION STATUS

15

20

END

A TORPEDO SIMULATION. FUNCTION BEARIN.

PAGE 1

A TORPEDO SIMULATION. FUNCTION BEARIN.

FUNCTION BEARIN(A,B,C,D)
TO CALCULATE BEARING FROM TORPEDO TO TARGET

|-----|
| DIFX = A-C
| DIFY = B-D
| E2 = $\sqrt{A^2 + B^2}$
RAD = E2/360.

* * . *
* . * DIFX.NE.0. * . *
* . * . * . * T | 16 |
* . * . * . * . *
* . * . * . * . *
* . * . * . * . *
* . * . * . * . *
* . * . * . * . *
* . * . * . * . *

| BE = 90.*RAD |

* * . *
* . * DIFX.LT.0. * . *
* . * . * . * T | RB=RB+(180.*RAD) |
* . * . * . * . *
* . * . * . * . *
* . * . * . * . *
* . * . * . * . *

| 17 |

16

| RB = ATAN2(DIFX,DIFY) |

(CONTINUED ON PAGE 2)

A TORSPEDO SIMULATION. FUNCTION BEARING.

PAGE 2

```
      *   *   *   *   *  
      IF  
      BB.LI.0.  
      *   *   *   *   *  
      T | BB=RB+PH2  
      F |  
| EEARIN =RB |  
|  
RETURN
```


A TORPEDO SIMULATION. FUNCTION XFACT.

PAGE 1

A TORPEDO SIMULATION. FUNCTION XFACT.

FUNCTION XFACT(X,Y)

CALCULATE REDUCTION-FACTOR IN TRANSDUCER GAIN DUE
TO RELATIVE BEARING OFF CENTER-HEADING OF TORPEDO

DOUBLE PRECISION X,XFACT,XY,Y

| PHI = 3.141592654 |

* . * - * *
* . * - * *
* . * - * *
* . * - * *

T

| 10 |

| XY = X/Y
| XFACT=DCOS((X*0.5)*DSIN(XY
| *PHI))/(XY*PHI)) |

RETURN

10

| XFACT=1. |

RETURN

END

A TORPEDO SIMULATION. FUNCTION SCALE.

PAGE 1

A TORSIONAL SIMULATION. FUNCTION SCALE.

FUNCTION SCALE (Y)

CALCULATE SCALING FACTOR IN THE PROCESS OF
COMPUTING TARGET STRENGTH

DCUELE PRECISION SCALE, RELS, Z, Y

```

| PHI = 3.151592654
| IF Y.GT.EHI/2. T | Y=PHI
| Z = 0.251635*(Y**2)-0.18555*Y
| Z = Z+0.0365*D$IN(3.* (Y+0.17453))
| +0.015*(Y**2)*D$IN(9.*Y/2.)
SCAT=-1/2

```

RETURN

ENC

APPENDIX C

DETAILED RUN PRINTOUT

TACTICAL SITUATION WHEN FIRING
 FIRING RANGE ATTACK ANGLE TARGET COURSE TARGET SPEED
 3000.0 -60.0 270.0 18.0

TORPEDO PARAMETERS
 TECH. DET. RANGE TRAV. INT. VAL TORP SPEED SWEEP ANGLE
 750.00 1.00 40.0 50.0

LOSE WIDTH TURN RATE
 20.0 6.0

THEORETICAL WIDTH OF TACTICAL SWEEP-LINE 1149.1

THEORETICAL COVERAGE RATIO 0.0500

RUN NO. 1: LOSE OFF-SET FROM CENTER BEARING 0.0 TIMES REFLECTION ANGLE

RUN NUMBER : 1
 EST OF TARGET DATA FOR FIRING
 COURSE SPEED RANGE
 256.5 12.4 3545.1
 TORP REFLECTION ANGLE IS -12.07
 TORPEDO MAIN COURSE 17.03
 RUN STOPPED AFTER 136 SECONDS

RUN DATA AS FOLLOWS AT END OF RUN
 TOTAL TORP RUN 2730.0
 DIST TO TARGET 515.0
 TORP X-COORD 14274.5 TORP Y-COORD 14889.0
 TARGET X-COORD 13771.5 TARGET Y-COORD 15000.0
 TORP MAIN COURSE 17.027 TORP COURSE 557.025
 NO DETECTION MADE DURING THIS RUN

RUN NUMBER : 2
 EST OF TARGET DATA FOR FIRING
 COURSE SPEED RANGE
 256.5 14.2 2792.4
 TORP REFLECTION ANGLE IS -14.87
 TORPEDO MAIN COURSE 15.13
 RUN STOPPED AFTER 147 SECONDS

RUN DATA AS FOLLOWS AT END OF RUN
 TOTAL TORP RUN 2343.0
 DIST TO TARGET 631.1
 TORP X-COORD 14260.7 TORP Y-COORD 15000.0
 TARGET X-COORD 13677.0 TARGET Y-COORD 15000.0
 TORP MAIN COURSE 15.120 TORP COURSE 11.500

MAXIMUM DETECTION RANGES AND BEARINGS
 SUCCESSIVE MAX DET BEARING DET BEARING
 DET NO. RANGE - CENTER CENTER RANGE - CLOSEST CLOSEST
 1 502.5 5.17 500.5 10.00 -97.50
 2 545.8 -1.40 530.5 3.00 -00.50
 3 0.0 0.0 0.0 0.0 0.0
 4 0.0 0.0 0.0 0.0 0.0
 5 0.0 0.0 0.0 0.0 0.0

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