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THESIS

COMPUTERIZED SURVIVOR SEARCH PLANNING

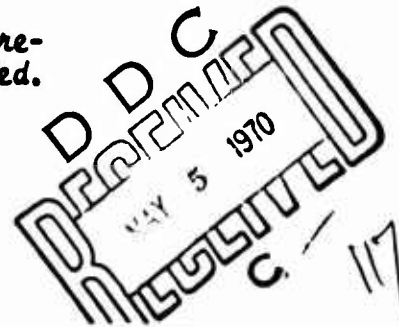
by

Joseph Henry Discenza

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Computerized Survivor Search Planning

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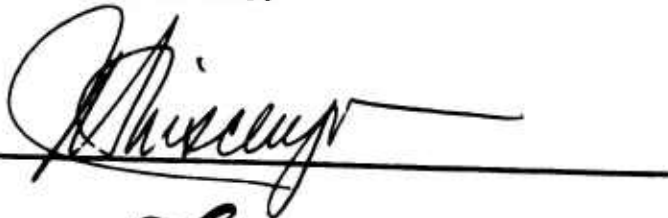
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ABSTRACT

A computer program is presented which solves the search planning problem for survivors at sea. The program is designed to utilize weather data as compiled by the United States Navy at its Fleet Numerical Weather Central, Monterey, California.

An investigation is also made into the search criteria used by the United States Coast Guard in its planning procedures. Guidelines are given for the use of the square search and the Sector search.

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I. INTRODUCTION

A. THE COAST GUARD AND SURVIVOR SEARCH

Survivor search is defined as the process of planning and executing a search for survivors at sea, and the Coast Guard usually accomplishes this in the following steps:

1. Initial Notification

This stage involves gathering all available data about persons or craft in distress, including characteristics of the survivor craft, number of survivors, etc.

2. Initial Distress Position

In this stage, the search planner puts together all the available data concerning the survivor and makes a judgement as to what the most likely position of the survivor was at the time the craft ceased operating normally.

3. Drift Calculations

The survivor's suspected motion is plotted assuming drift in the open ocean, and a position is calculated for some future time, usually the planned beginning of search efforts.

4. Calculation of the Area to be Searched

An estimate is made of the accuracy of the survivor's position as calculated in step 3 and the accuracy of navigation of the search craft. An area, called the

Search Area, is defined based on these errors.

5. Allocation of Search Units

A determination is made of the resources (ships, planes, boats, etc.) to be used in the search, and the way in which these resources will be used.

6. Execution of the Search

Searching is accomplished according to several established search patterns, most of which are different arrangements of a series of parallel paths within the Search Area.

7. Termination of the Search

Either the survivors are located or, after a certain amount of searching is completed without success, the search is terminated. This stage includes reports, and the evaluation of search effort.

B. DOCTRINE

The guidance for all these activities is contained in Coast Guard publication CG-308, the National Search and Rescue Manual, (Ref. 1.). Chapters 3 through 8 of this manual contain the instructions for planning and conducting a search for survivors at sea.

C. PURPOSE

This thesis accomplishes two things:

1. Provides a computerized solution to step 3 of the search planning process, calculating survivor craft drift, and
2. Investigates the criteria used for allocation of resources to a search, steps 4, 5, and 6.

It is intended that the results be understood by the search planner, so that they may be of some use to him.

II. THE SEARCH PLANNING PROGRAM

A. OBJECTIVE

The major objective in designing a computer program for search planning was to have a fast, accurate means of obtaining an estimate of a survivor's oceanic position at the time of the beginning of a search.

B. THE MANUAL METHOD

In order to understand the program, it is first necessary to understand how drift plotting is done manually.

1. Example

A fishing vessel is believed to have sunk at latitude 40-42.0N, and longitude 52-13.0W, at 0900z on 22 June. The probable error of this position is estimated to be 30 miles. Although the standard measure of variability is the standard deviation, all error estimates made in the search planning process are in terms of probable error. It will be demonstrated that this error is defined by the statistical term, "probable error". Survivors are believed to be in rubber rafts.

The proper Coast Guard authorities are notified at

2100Z on 22 June, and a search plane has been dispatched. It is due to arrive on the scene at 0100Z 23 June. The aircraft's navigation error (again a probable error) is estimated to be 10 miles.

2. Gathering Data

The first task of the search planner is to estimate wind, wind current, and sea current at the position of the sinking. Wind is obtained from observations, weather maps, Navy Fleet weather services, or the U.S. Weather Bureau, whichever is available. Wind current is computed from the wind by means of a graph given in the National Search and Rescue Manual. Average Sea Current is obtained from ocean current charts or pilot charts. These sources for average sea current are compiled from observations made over several years. (Thus this data may not be accurate for the time and place of concern, but so far they have been the only data available to the search planner.)

3. Drift Plotting

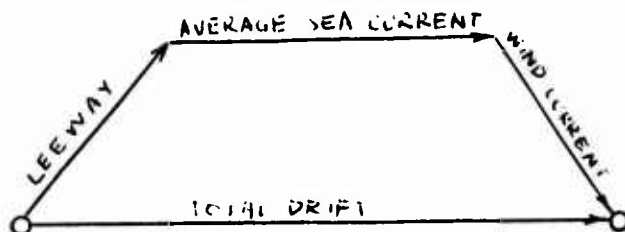
a. Leeway

Leeway is the motion of the survivor craft caused by wind. For the example case of a life raft, two graphs are provided in the SAR Manual for computing leeway. One graph is for when a drogue is attached to the raft (a drogue is a type of sea anchor designed to retard life raft leeway) and the other is for when a drogue is not attached. If it is not known whether a drogue is attached, both conditions are

considered separately.

b. Total Drift

Once leeway, wind current, and average sea current have been determined, they are added vectorially to produce total liferaft drift.



This calculation can be done for intervals of any length - one hour, three hours, twelve hours - but the interval most commonly used is the interval between wind observations. That is if wind is available for 0900Z, 1200Z, 1500Z, etc., the search planner would probably compute total drift in three hour intervals, from 0900Z on the 22nd to 0100Z on the 23rd. Each time total drift is calculated (another probable error), 12.5% of that distance is retained as "drift error", and the drift errors are summed to obtain total drift error.

Example: In this manner, the position of the example liferaft is calculated to be 40-58.0N, 51-55.0W, and the drift error is 4.0 miles.

c. Minimax Plotting

If it is unknown whether a drogue was in use, two plots are made, and the final ("datum") position is defined to be midway between the two positions calculated.

The drift error is a function of the two calculated drift errors and the distance between the two positions. This process of plotting two positions is called Minimax plotting in the SAR Manual.

d. Error of Position

Once the datum has been computed, it is then necessary to find total probable error of position, c , where

de = total drift error

X = error in initial position of survivor craft

Y = navigation error of search craft

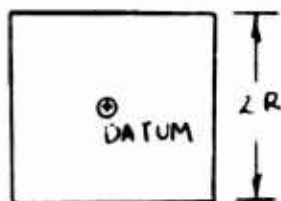
$$c = \sqrt{de^2 + X^2 + Y^2}$$

For the example, $c = \sqrt{16+100+900} = \sqrt{1016} = 31.9$ miles.

e. Safety Factor

To determine the size of the area to be searched, a search "radius", R is found by multiplying c by a safety factor, depending on which search in a sequence is being planned. For searches one through five, the respective safety factors are 1.1, 1.6, 2.0, 2.3, and 2.5. The example of the sunken fishing boat is a first search, so $R = 1.1 \times 14.7 = 16.2$ miles.

The area to be searched, then, is a square with sides = $2xR$, centered on datum:



f. Sweep Width

The standard measure of the effective search width of a search craft is called "sweep width". The value of the sweep width is obtained from a table in the Search and Rescue Manual, based on the type of target, search altitude, and meteorological visibility. The sweep width thus obtained is corrected for the effect of sea state by multiplying by a "whitecap correction factor" which is tabulated for various wind speeds.

c. THE COMPUTER PROGRAM

1. Objective

The computer program accomplishes the objective of providing an estimate of the survivor's position by automating the steps of the manual method of drift plotting.

2. Source of Weather Data

In choosing a source of weather data for the computer program, three criteria were considered: a. availability, b. computer access time, and c. accuracy. The final selection for data source was the Navy Fleet Numerical Weather Central, Monterey.

a. Availability

FNWC Weather data is compiled twice daily, at

0000Z and 1200Z, and is directly available, either by data link or, for testing purposes, on magnetic tape. For use with this program, the data is stacked chronologically on a master tape.

b. Computer Access Time

With the exception of the mounting of the master weather tape, all weather data handling is eliminated. Access speed, then, is limited only by the speed of the tape transport.

c. Accuracy

Although the data used is intended for wide area coverage, its probable error is less than the probable error assumed when computing drift error (12.5%). Although there will be occasions when local weather reports are available and may be more accurate, the bulk of search planning is done under conditions of incomplete weather analysis and forecasts, and when gross estimates must be made. Since the weather analyses for a particular time period and geographical location, once assembled for this program, are fixed parameters, repeated computations of the same search problem will always produce identical answers. This permits a rigorous evaluation of the data, methods, and assumptions used in search planning by a systematic testing procedure.

3. Data Description

The weather data are produced by FNWC for 3,969 geographical points in the northern hemisphere. These data

points are intersections of a 63 X 63 square grid superimposed on a polar stereographic map projection. Grid point (32,32) is at the north pole, and the vertical line (i=32) is coincidental with the 80 W and 100 E meridians. A sample projection is shown as Figure 1.

The polar stereographic projection provides a plotting reference which shows an entire hemisphere with the least possible distortion (Ref. 6), and the scale is true at 60 degrees North Latitude. Conversion from latitude (L) and longitude (λ) to grid coordinates is accomplished by the following formulas:

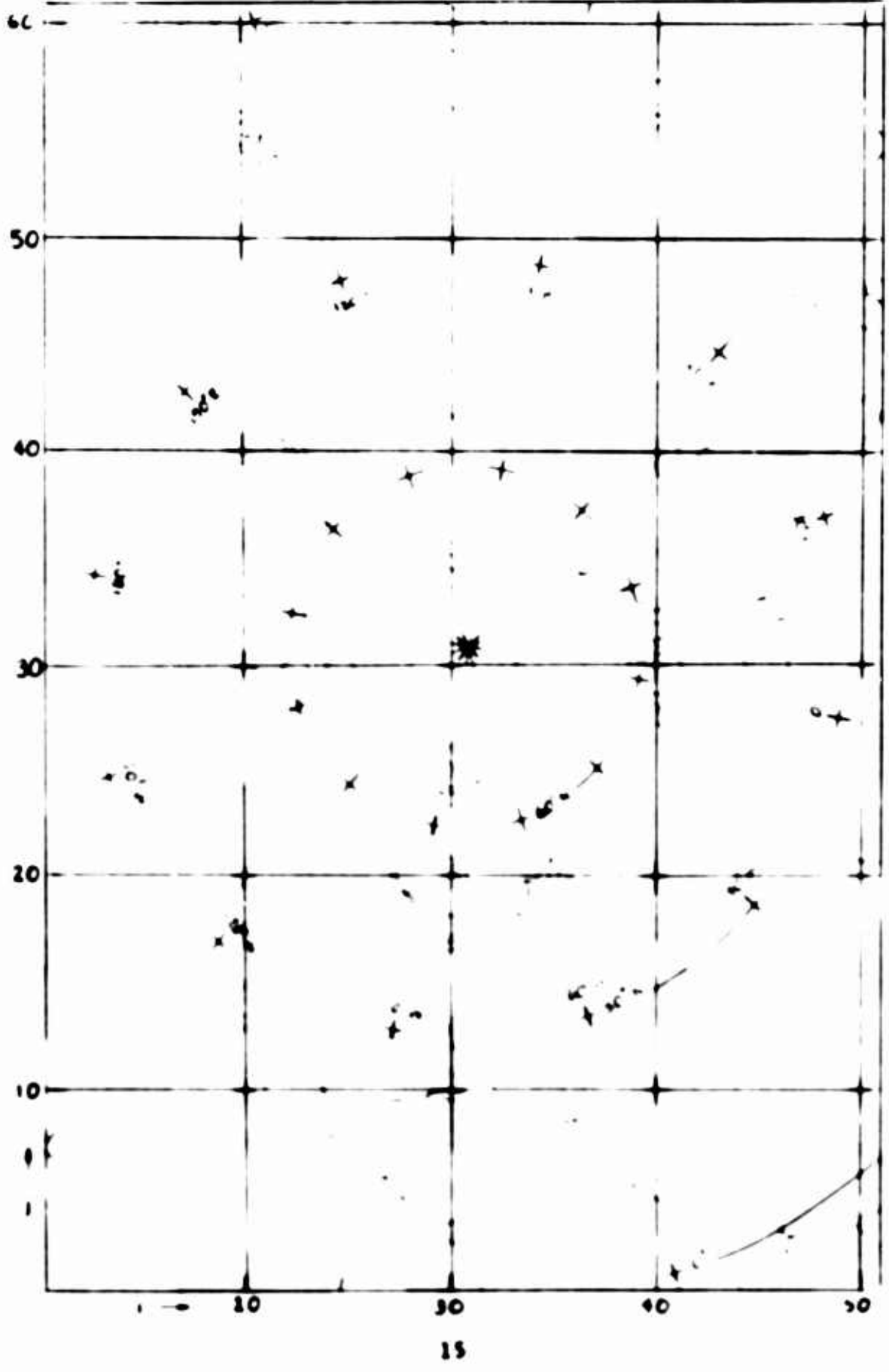
$$i = 32 + 31.205 \left(\frac{1 - \sin L}{1 + \sin L} \right)^{\frac{1}{2}} \cos(\lambda + 10^\circ) \quad (1)$$

$$j = 32 - 31.205 \left(\frac{1 - \sin L}{1 + \sin L} \right)^{\frac{1}{2}} \sin(\lambda + 10^\circ) \quad (2)$$

For the example, $i = 38.008$, and $j = 19.0143$.

The data is stored in "fields" of 3,969 words (numbers), each word being some component of atmospheric or oceanic conditions at its corresponding (i,j) grid position. The fields required for direct input to this program are:

Figure 1. Portion of Polar Stereographic Projection Showing FMC (i,j) Coordinates



U Curr	U- component of surface current
V Curr	V- component of surface current
U Marine	U- component of surface wind
V Marine	V- component of surface wind

where the U direction is parallel to the "i" or horizontal axis and the V direction is parallel to the "j" or vertical axis, in the FNMC grid system.

The Current information as provided by FNMC is total surface current, including wind current.

Fleet Numerical did not regularly produce U Marine and V Marine wind fields, so these fields are computed by a separate computer program provided by the Weather Facility using the following data fields as input:

D 1000	Height of the 1000-mb pressure line
T Air	Air temperature at the surface
T Sea	Sea temperature at the surface

D. CALCULATING DRIFT WITH THE COMPUTER

1. Leeway

In addition to the liferaft drift tables given in the Search and Rescue manual, there are other ways to predict the leeway of a survivor craft. Most of these methods involve using a percent of the wind speed to

determine the leeway speed, and some deflection in degrees to determine the direction of leeway off the wind line. For example, a boat type may be known to drift in a direction 40 degrees off the wind line, and at a speed equal to 4% of the wind. To accommodate these methods as well as the liferaft drift table from the SAR Manual, several options are available to the user of this computer program.

2. Options for Leeway

a. A function approximating the liferaft drift tables in the National SAR Manual has been provided; drifting speeds for with drogue and without drogue are both available.

b. Leeway speed can also be specified as a percent of wind, in whole numbers, from 2% to 9%.

c. For each of the leeway velocities in b., a deflection off the wind line of plus or minus some angle, in tens of degrees, from 0 to 90 degrees, may be specified.

d. A minimum-maximum leeway speed option with the minimum being 1% of the wind, and the maximum being some whole number percent from 2% to 9% of wind speed, is available.

e. No leeway at all (as in the case of a man in the water or some other almost completely submerged object) may be specified.

3. Adjustment of Input Data

a. Dates

All dates are converted from month and day to julian dates, to permit reference to weather data and adjustment of the program "clock".

b. Latitude and Longitude

All initial positions are converted to FNWC (i,j) coordinates.

c. Leeway Options

Leeway options are entered by means of a two-digit code, which is converted to speed and direction of drift within the program.

d. Weather

Wind and current are provided in units of cm./sec. and are scaled in the program to nautical miles per hour. They are further scaled to decimal fractions of the FNWC grid distance.

4. Interpolation of Weather Data

a. Interpolation for Position

For each position in (i,j) coordinates there are four neighboring grid intersections for which weather is tabulated. Example:

GRID POSITION: i=38.00787

j=19.01413

GRID POINTS: . (38,20) . (39,20)

. (38,19) . (39,19)

All weather data are interpolated linearly among

these four neighboring points. For example, if U Current at 0000Z at grid points (i,j) is:

$$(38,20) = 50.0 \quad (39,20) = 49.0$$

$$(38,19) = 42.0 \quad (39,19) = 40.0$$

then for $i=38, j=19.01413$,

$$U \text{ Current} = 42.0 + .01413 \times (50-42) = 42.112$$

and for $i=39$, a similar computation results in U Current = 40.12717.

U Current for the position is then,

$$42.112 + .00787 \times (-1.985) = 42.097 \text{ cm./sec.}$$

b. Interpolation for Time

For each hour in the computation, there are two observation times which are used to supply weather data: 0000Z and 1200Z, one of which will be prior to the hour, and one which will be after the hour. A linear interpolation for position is done for each observation, and then these two values are interpolated linearly for time. For example, if the U Curr for 1200Z is calculated as above and found to be 37.25 cm./sec., the interpolation for time is accomplished as follows:

$$46.09 + 9/12 \times (-8.84) = 39.46 \text{ cm./sec.}$$

c. The Clock

A complete set of interpolations is done for each position and for each weather parameter at the start of the drift calculations, and each position is advanced for an hour's worth of drift. This interval is used as a

compromise between accuracy requirements and computer time. If an interval much smaller than one hour were used, a large increase in computer time would be required. A problem which would take 20 seconds at one hour intervals would cost almost 20 minutes of computer time if one minute intervals were used.

After the one hour's worth of drift is computed, and the positions updated, the clock is advanced one hour, and the process is repeated over and over until the end of the problem.

5. Drift Plotting

Drift calculations are applied to the (i,j) coordinates of the survivor craft plot. That is, the U-component of drift is added to the "i" coordinate of the survivor position and the V-component is added to the "j" coordinate.

Example: The interpolated values of current and wind for 0900Z on 22 June are

Parameter	cm./sec.	miles/hour
U Curr	+ 39.460	+ .766
V Curr	+ 36.128	+ .702
U Marine	+250.78	+ 4.87
V Marine	-850.25	-16.55

the wind speed then equals $\sqrt{4.87^2 + 16.55^2} = 17.25$ nautical miles/hour. For a liferaft without drogue, this wind speed produces a leeway of 0.94 miles per hour as

follows:

$$\text{Leeway} = .226 \times \sqrt{17.25} = 0.94$$

This formula is an approximation to the liferaft drift table given in the Search and Rescue Manual.

Since $\arctan(4.87/-16.55)$ equals 163.6 degrees, this angle is a measure of the wind angle (measured clockwise from the vertical (in the FNWC system):



If leeway deflection is specified by the user, it is applied to this wind angle, before the U and V components of leeway are calculated. The reduction of Leeway and wind angle to U and V components is as follows:

$$U \text{ Leeway} = 0.94 \times \sin(163.6^\circ) = 0.266$$

$$V \text{ Leeway} = 0.94 \times \cos(163.6^\circ) = -0.902$$

The leeway and current are applied to the position

as follows:

	U	V
Leeway	.266	-.902
Current	<u>.766</u>	<u>.702</u>
Total	1.032	-.200 knots

These values are then divided by the distance between gridpoints, at this latitude = 235.37 miles:

	.00439	-.00085
+ position	<u>38.00787</u>	<u>19.01413</u>
New Position	38.01226	19.01328 for 1000Z 22 June.

This process is repeated hour by hour until the last datum has been calculated, drift plotting ceases, and calculations for position error and Search Radius begin.

6. Position Error

Just as in the manual method, the initial position error of the survivor craft is computed as follows:

x = distance of initial (or distress) position from last known position.

A = error of last known position

B = navigation error of survivor craft as a percent of distance traveled

The initial position error, X, is

$$X = A + Bx$$

Since Y is the navigation error of the searcher, and de is the drift error, the Total Probable Error, c, of

Position is

$$c = \sqrt{x^2 + y^2 + d^2}$$

7. Safety Factor

c, Total Probable Error of Position is multiplied by the safety factor to find the Search Radius as prescribed in the Search and Rescue Manual.

8. Sweep Width

A numerical approximation to the data in Richardson's Sweep Width tables (Ref. 4) may be seen to be:

$$W = -3.36377 + 1.25887 \log(l) + 2.55662 \log(V) + .01023 h$$

where l is boat length

V is visibility in miles, and

h is search altitude in thousands of feet.

In addition, corrections to Sweep Width for whitecaps based on wind speed (v) and cloud cover (C) can be approximated by:

$$F1 = .886 + .298X - .116 X^2 \text{ (whitecaps, } X = v/10)$$

$$F2 = 1.131 - .672C + .152C^2 \text{ (cloud cover)}$$

These correction factors are multiplied by W to obtain final Sweep Width. This Sweep Width function is applicable to small boats only. No Sweep Width for large ships or for liferafts is available in the program.

E. VERSIONS OF THE PROGRAM

The Search Planning Program is written in FORTRAN IV for

use on a remote computer terminal. A second version is written for use on the operations computer at Fleet Numerical Weather Facility. No remote terminal operation is available there, so these two versions are different in several ways:

1. INPUT-OUTPUT

a. The time sharing version is written for entry of data by the search planner onto a remote console, and the results are printed out immediately on the same console. This permits the planner to control the program during execution, and to make intermediate decisions concerning the problem. An example of the output of the time-sharing version is shown on the next two pages. Note that items typed in by the user are shown in lower case, and the replies typed on the console by the computer are in upper case. The final output includes sweep width, total probable error of position, search radius, and calculated wind.

b. The batch-processing version at FMNC differs from this in that it requires cards to be punched for input, and the output is printed in message form, ready for transmission back to the requestor.

2. Features Omitted

For the operational version of the program at Fleet Numerical Weather Facility the following items of output shown on the sample time-sharing printout were not made available:

```

$ sar
EXECUTION BEGINS...
MONTEREY SEARCH PLANNING PROGRAM
ENTER LEEWAY CODE, 1 PLANK, THEN DESCRIPTION
> 11 liferaft
HOW MANY STARTING POINTS WILL BE ENTERED?
> 1
LIST CHRONOLOGICALLY: STARTING TIMES AND POSITIONS, EX:
070930Z MAR,3822.5N,06806.5W
> 220900Z Jun,4042.0N,05213.0W
    40    42.0    52    13.0    CHECK: N    Y
CHECK, TYPE Y OR N
> Y
ENTER NUMBER OF TIMES DATUM IS TO BE COMMITED NOW:
> 2
ENTER THESE DTGS. EX:020900 MAR,031030 MAR
> 230100 Jun,230700 Jun
SEARCH 1, TRACK 1, DATUM:    40 50.21    51 51.96
SEARCH 2, TRACK 1, DATUM:    40 53.26    51 44.04
(ENTER LAST KNOWN POSITION, EX: 3522.0N,07653.0W
> 4100.0N,05400.0W
IS LIFERAFT
A (1)BOAT, (2)SHIP, OR (3)AIRCRAFT?(ENTER 1,2,OR3)
> 1
ENTER SEARCH UNIT FIX ERROR, V. EX: 5.0
> 5.0
INDICATED DISTRESS CRAFT POSITION ERROR, X:
X= 15.00(1) + 0.15(2) TIMES DIST. FROM LAST KNOWN POSITION.
ANY CORRECTIONS? (TYPE 0,1,2, OR 12)
> 1
ENTER PARAMETER(1):
> 20.0
IS EACH DATUM TIME A DIFFERENT SEARCH (1,2,3,ETC.)?
> no
ENTER SEARCH NUMBER CORRESPONDING TO DATUM TIME:
.. 1 0 SEARCH:
> 1
.. 2 0 SEARCH:

```

> 0
 THE FOLLOWING ARE THE DATUM POINTS FOR THE
 1: 0 SEARCH:
 40-50.2N 51-52.0W POS. ERROR: 41.8, RADIUS: 46.0 MILES;
 WIND 36.6KTS FROM 267.
 SWEEP WIDTH? Y OR N
 > Y
 ENTER SEARCH ALTITUDE (FX:800.)
 > 1000.
 ENTER VISIBILITY IN MILES (FX:10.0)
 > 20.0
 ENTER ROAT LENGTH IN FEET (FX:36.0)
 > 10.
 ENTER CLOUD COVER IN FRACTION (FX: 0.9)
 > 0.1
 SWEEP WIDTH= 4.6 MILES.
 THE FOLLOWING ARE THE DATUM POINTS FOR THE
 7: 0 SEARCH:
 40-53.3N 51-46.0W POS. ERROR: 41.9, RADIUS: 46.0 MILES;
 WIND 36.6KTS FROM 267.
 GOOD LUCK ON YOUR SEARCH! LET ME KNOW IF YOU FIND
 THE AIRCRAFT

INCO021 STOP 0
 R; T=1.00/2.87 13.11.18

Note: Inputs marked with ">"

a. Printout of intermediate track positions (SEARCH 1, TRACK 1, etc.) is not produced.

b. On scene Wind

Since the wind printout as shown in the sample time-sharing output is only the wind velocity and direction at the beginning of the search, and may not be representative of the average weather conditions throughout the search, this value is not included.

c. Sweep Width

Since the the computation of sweep width requires data which may not be immediately available to the search planner at the time of his request, and since the formula applies only to small boats, this feature was not included in the Fleet Numerical version.

d. Leeway

For the Fleet Numerical version, leeway is calculated as described in D.2. The time sharing version uses a square root function for all leeway. If N is the percentage drift specified (1% to 9%), the leeway function in the time sharing version is

$$\text{Leeway} = \frac{N}{25} \sqrt{\text{WIND}} \quad (3)$$

This function produces leeway which is equal to N% of the wind for wind speeds of 16.0 knots. For other wind velocities the function follows the general contour of the liferaft leeway (without drogue) table in the Search and Rescue Manual.

III. SEARCH THEORY

In part III the method of estimating the position of the search object and the rules for determining the size of the search area were discussed. This is only part of the search planning process; this section will consider how resources are assigned to the search, and how the effectiveness of the search is measured.

In a search pattern employing parallel sweeps, the distance between these sweeps is called track spacing, S . The Search and Rescue Manual recommends that for urgent cases the track spacing used be equal to the Sweep Width, W , and for less urgent cases it be equal to twice the Sweep Width. Once the value of track spacing has been decided upon, the amount of searching required (in miles flown) L can be computed from S and the area A to be searched:

$$L = A/S$$

The measure of effectiveness of a search which is given in the Search and Rescue Manual is called Probability of Detection, and it is presented as a series of curves plotted against "coverage factor" or W/S . These curves are called

"first search", "second search", etc., probabilities. If p is the probability of detection in the first search curve, the probabilities 2,..n..5 are given by

$$p = 1 - (1 - p)^m$$

These curves do not take into account the size of the area searched, however, so that a search can be conducted in a very small area using a high coverage factor which will yield a very high probability of detection according to the graph. Common sense indicates that to confine the search to a very small area will probably not result in the detection of the target. Nowhere does the Search and Rescue Manual define the probability that the target is in the search area.

The absence of the treatment of this seemingly critical factor led the author to a review of the field of search theory as it applies to survivor search.

The basis for most of the search planning criteria in the National Search and Rescue Manual was found in Koopman's (1966) work, Search and Screening (Ref. 2). This treatise developed the concept of sweep width, and found the probability of detection for various situations.

A. DETECTION LAWS

1. Instantaneous Probability of Detection

If γ is defined so that the probability of detecting a target in a short period of time dt is γdt , then the quantity γ is called the instantaneous probability density of detection. When the searching is done during a time t under constant conditions, the probability $p(t)$ of detection is given by

$$p(t) = 1 - e^{-\gamma t} \quad (4)$$

Search and Screening developed this quantity for various situations.

a. Definite Range Law

This law assumes that there is a certain range R from the observer beyond which it is impossible to detect the target; inside this range detection is certain. Instantaneous probability of detection by this law is

$$\begin{aligned} \gamma(r) &= \infty & r \leq R \\ \gamma(r) &= 0 & r > R \end{aligned} \quad (5)$$

b. Inverse Cube Law

The inverse cube law is the result of making the following assumptions:

- (1) The observer is at an altitude h above the ocean.
- (2) The observer detects the target by seeing its wake.
- (3) The instantaneous probability of detection

is proportional to the solid angle subtended at the point of observation by the wake.

The calculation of the solid angle is shown in figure 2.

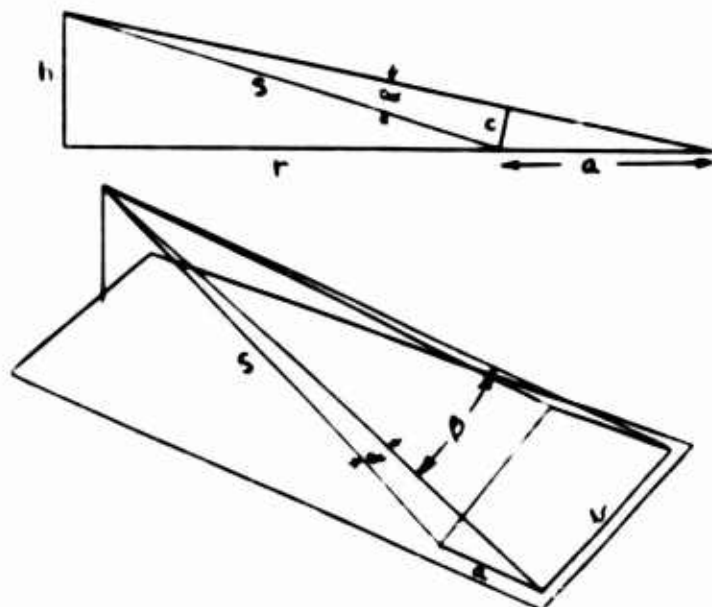


Figure 2. Calculation of Solid Angle

$$\text{Solid Angle} = \alpha \beta$$

$$\alpha = c/s, \quad \beta = h/s$$

$$\text{but } c/a = h/s$$

$$\text{thus } c = a h/s$$

$$\text{Solid Angle} = a h/s^3 = a h/(r^2 + h^2)^{3/2}$$

Since γ was assumed to be proportional to the solid angle,

$$\gamma = \frac{k h}{(h^2 + r^2)^{3/2}}$$

where k included all factors such as meteorological visibility, etc.

Assuming further that in the majority of cases r is much larger than h , then

$$\gamma = \frac{K^2}{13}$$

2. Lateral Range

When the observer and the target are on their straight courses at constant speeds for a long time before and after their closest point of approach the probability of detection may be shown to be a function only of the distance at closest point of approach. This distance is called the lateral range, and is denoted as x . This probability of detection, $p(x)$, plotted against lateral range, is called the lateral range curve.

Twice the area under the lateral range curve is defined as effective search width (or Sweep Width),

$$W = 2 \int_0^{\infty} p(x) dx \quad (6)$$

Koopman shows that:

"The effective search width is twice the range of a definite range law of detection which is equivalent to the given law of detection in the sense that each of the two laws detects the same number of uniformly distributed targets of identical velocity."

Thus, for the definite range law of detection $p(x) = 1$ if $x \leq R$, and $p(x) = 0$ if $x > R$, so that $W = 2R$. To find W for the inverse cube law, first $p(x)$ may be shown to be

$$p(x) = 1 - e^{-\frac{2kh}{\omega^2}} \quad (7)$$

where w is searcher's speed.

From (6),

$$W = \int_{-\infty}^{+\infty} 1 - e^{-\frac{2kh}{\omega^2}} \quad (8)$$

$$= 2 \sqrt{\frac{2\pi kh}{\omega}} \quad (9)$$

3. Random Search

To find the probability of detecting a target known to be in an area A , where both searcher and target are moving over the ocean in complicated paths, the situation called random search may be considered. This requires the following assumptions:

- a. The target's position is uniformly distributed in A , given it has not been detected
- b. The observer's path is random in A in the sense that it can be thought of as having its different (not too near) portions placed independently of one another in A .
- c. W is small with respect to the area A .

If the searcher's path, of length L , can be considered to be composed of n separate and equal portions of length L/n , then the probability that the target be detected in any one path is WL/nA . The probability that the

target not be detected at all, then is

$$P = 1 - \left(1 - \frac{WL}{nA}\right)^n \quad (10)$$

and for large n ,

$$P = 1 - e^{-WL/A} \quad (11)$$

This is the formula of random search.

4. Parallel Sweeps

The most common method of non-random searching is one which uses a series of straight parallel sweeps a distance S (or track spacing) apart, where the position of the target is fixed with relation to the sweeps. Let the target be uniformly distributed in an area of size A . Search and Screening gives the following result for $P(L)$, the probability of detecting with path length $L=A/S$.

(1) Definite Range Law

Since detection will surely occur if the target is within the detection range $W/2$, then the probability of detection is equal to the coverage factor W/S .

Thus,

$$\begin{aligned} p &= WL/A & L \leq A/W \\ p &= 1 & L > A/W \end{aligned} \quad (12)$$

(2) Inverse Cube Law

$$p = \operatorname{erf}\left(\frac{\pi\sqrt{2m}}{S}\right) = \operatorname{erf}\left(\frac{\sqrt{\pi}}{2} \frac{WL}{A}\right) \quad (13)$$

(3) Uniform Random Search

From (11),

$$p = 1 - e^{-wL/A}$$

or when $S=L/A$,

$$p = 1 - e^{-w/S} \quad (14)$$

The three probabilities using parallel sweeps are shown in Figure 3.

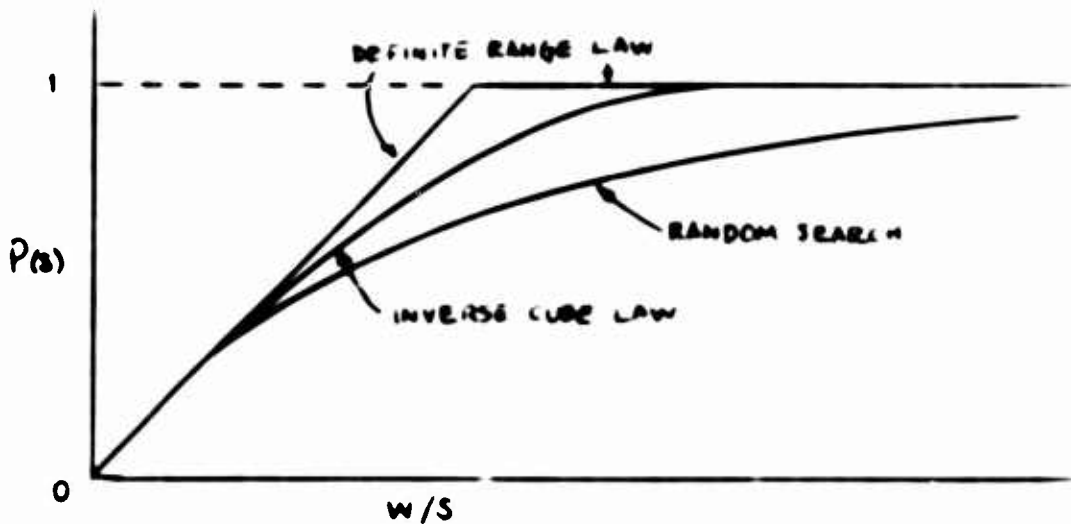


Figure 3. Probability of Detection

B. DISTRIBUTION OF SEARCH EFFORT

1. General

Another result in Search and Screening involves the definition of search effort density as a function of (x,y) in A.

If B is the area of a subregion in A, and L is the

length of the observer's path in B, then the expression L/B is defined to be the observer's track density in B. As B becomes very small (approaches a point (x,y)) the search density $\psi(x,y)$ is the limit of WL/B , or $Wl(x,y)$, where

$$\iint_A l(x,y) dx dy = L \quad (15)$$

and

$$\iint_A \psi(x,y) dx dy = WL = E \quad (16)$$

Thus if $\psi(x,y)$ is applied at (x,y) , the probability of detecting a target located there is

$$p = 1 - e^{-\psi(x,y)} \quad (17)$$

Given the search density function $\psi(x,y)$ and the target's distribution $p(x,y)$, the probability of detecting the target is

$$P(\psi) = \iint_A p(x,y) (1 - e^{-\psi(x,y)}) dx dy \quad (18)$$

The $\psi(x,y)$ which maximizes $P(\psi)$ is shown by Koopman to be

$$\psi(x,y) = \log \frac{p(x,y)}{b} \quad (19)$$

when (x,y) is in A, and

$$\psi(x,y) = 0 \quad (20)$$

when (x,y) is not in A,

where A denotes that portion of A in which the expression (19) is non-negative. The value of b is determined by using equation (16).

2. Normal Target Distribution

If the target's distribution is a bivariate circular normal distribution about a point $(0,0)$ in a cartesian coordinate system,

$$p(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, \quad r^2 = x^2 + y^2 \quad (21)$$

then the search effort density which maximizes $P(\phi)$ is

$$\phi(x,y) = \frac{a^2 - r^2}{2\sigma^2} \quad r \leq a \quad (22)$$

and

$$\phi(x,y) = 0 \quad r > a \quad (23)$$

Thus letting a be the radius r at which $p(x,y)$ assumes the critical value b ,

$$A_b = \pi a^2, \quad b = \frac{1}{2\pi\sigma^2} e^{-\frac{a^2}{2\sigma^2}} \quad (24)$$

where

$$a = \left[\frac{4\sigma^2 E}{\pi} \right]^{1/2} \quad (25)$$

The form of this equation is an inverted parabola of revolution with its center at $(0,0)$ with a maximum value of $a^2/2\sigma^2$.

IV. THE UNIFORM COVERAGE SQUARE SEARCH

Although (19) gives the "optimum" search effort distribution, this optimum distribution is difficult to achieve in practice. Flying in a large circular area with a continuously varying effort is no simple navigational task. Much easier is the common practice of (1) defining a square area with its center at the center of the target's distribution and (2) conducting a regular search of uniform density throughout this area. If the target is not found, then (3) the area is expanded and the search repeated. Although a single search of this type does not conform to the parabolic optimum search effort distribution, a series of them, each larger than the one before, may be a very good approximation.

The most important advantage of this plan is its ease of navigation, allowing the pilot(s) free time to look for the target.

A. THE PROBLEM

The problem was to determine the optimum size of a square area within which a uniform search with parallel sweeps is to be conducted.

A. TERMS

The terms and definitions in the Search and Rescue Manual differ from those in Search and Screening. In the Search and Rescue Manual, probability of detection is used only for the probability of detection with parallel sweeps, (given a uniform target distribution within the search area). In order to avoid confusion, the following terms are defined:

- P - Probability of Success - The probability that on a given search the target will be found.
- p - Location Probability - The probability that a target is within a specified area.
- d - Probability of Detection - The probability of detecting a uniformly distributed target given parallel sweeps.
- W - Sweep Width - The effective search width of the searcher; the area under the lateral range curve.
- S - Track Spacing - The mean distance between adjacent parallel sweeps of the searcher.
- L - Path Length - The total number of miles flown by the searcher within the search area.
- c - Probable Error of Position - Probable error of the target's position from datum; given a normal distribution, $c=1.18$ x standard deviation of the target's distribution.
- R - Search Radius - The search radius is defined as one-half the side of a square

search area.

C. THE SOLUTION

1. The Objective

The objective is to maximize the Probability of Success P , where the detection function for a uniformly distributed target known to be in the area is defined as $d(W,L,R,x,y)$. P is expressed as

$$P(W,L,c,R) = \iint p(x,y) d(W,L,R,x,y) dx dy$$

For a uniform search, the probability of detection is constant and equal to $d(W,L,R)$ inside the search area A , and is zero outside, (given uniform visibility and other factors), and so $d(W,L,R)$ can come out of the integral:

$$P(W,L,c,R) = d(W,L,R) \iint_A p(x,y) dx dy$$

It is convenient to choose x and y as distances in a cartesian coordinate system with the target's most likely position (datum) at $(0,0)$.

2. Calculation of Individual Terms

Based on the inverse cube law for parallel sweeps,

Koopman derives the following expression for probability of detection, from (13):

$$J(S) = \operatorname{erf} \left(\frac{\sqrt{\pi}}{2} \frac{W}{S} \right)$$

$$\text{where } S = A/L = (2R)^2/L.$$

This is equivalent to the "First Search" probability of detection given in the National Search and Rescue Manual.

The location probability, p , is given by the formula for the circular bivariate normal distribution:

$$p(R) = \int_{-R}^{R} \int_{-R}^{R} \frac{1}{2\pi\sigma^2} e^{-\frac{x^2 + y^2}{2\sigma^2}} dx dy$$

Where R defines a square centered at $(0,0)$ with sides $=2R$.

Figure 4 is a graph of this function, along with a similar curve showing the cumulative probability for a circle with radius R . Since the square area is actually larger (it is circumscribed about the circle) its probability for any radius R is greater. However, if these cumulative probabilities are plotted against the area of the search, the probability for a square will be slightly less than for a circle (see figure 5). Although there is some loss of efficiency in searching a square instead of a circle, this loss is very minimal, about 1%.

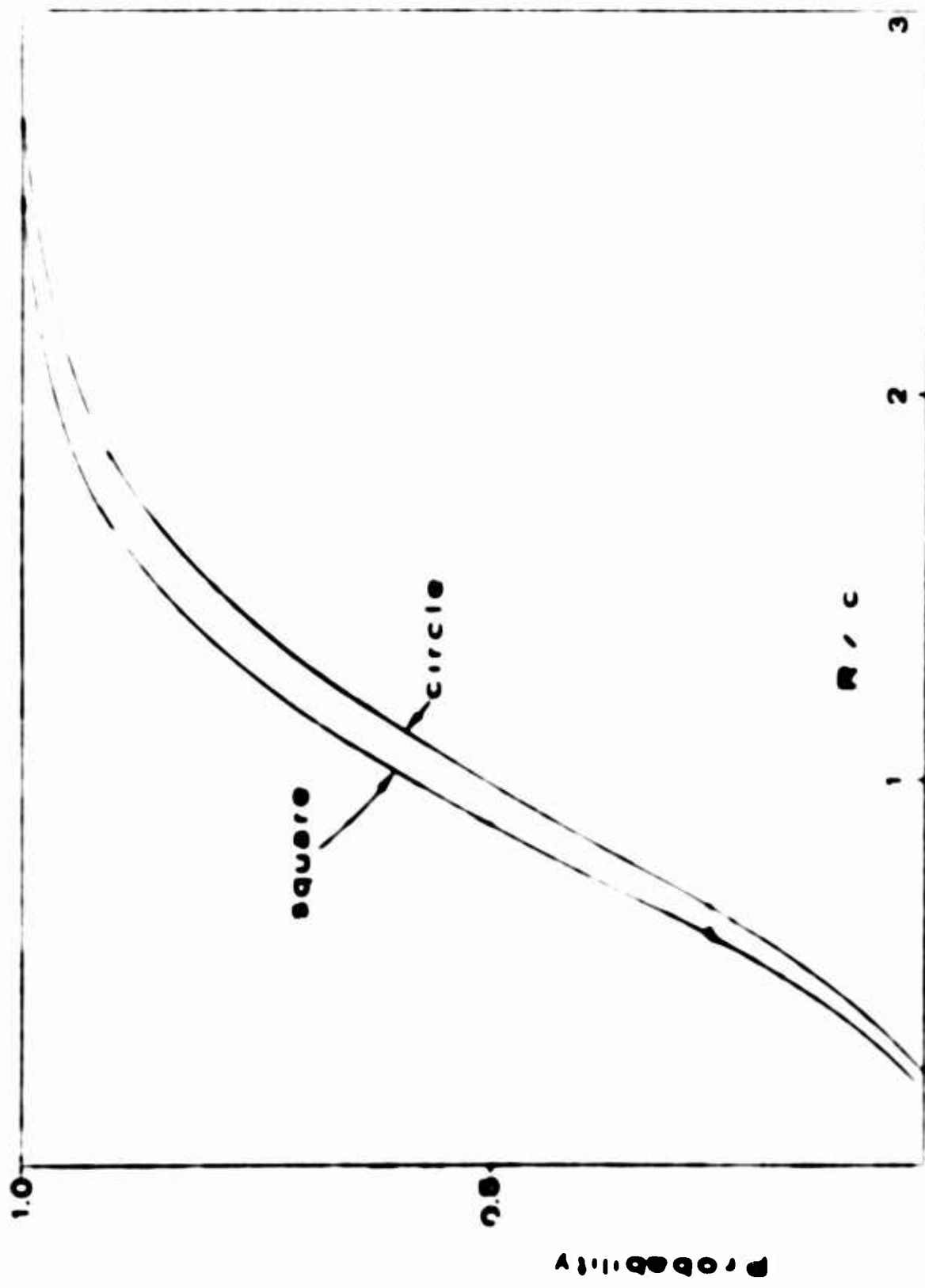


Figure 6. Cumulative Probability for Circle with Radius R and for Square with Sides equal to 2R.

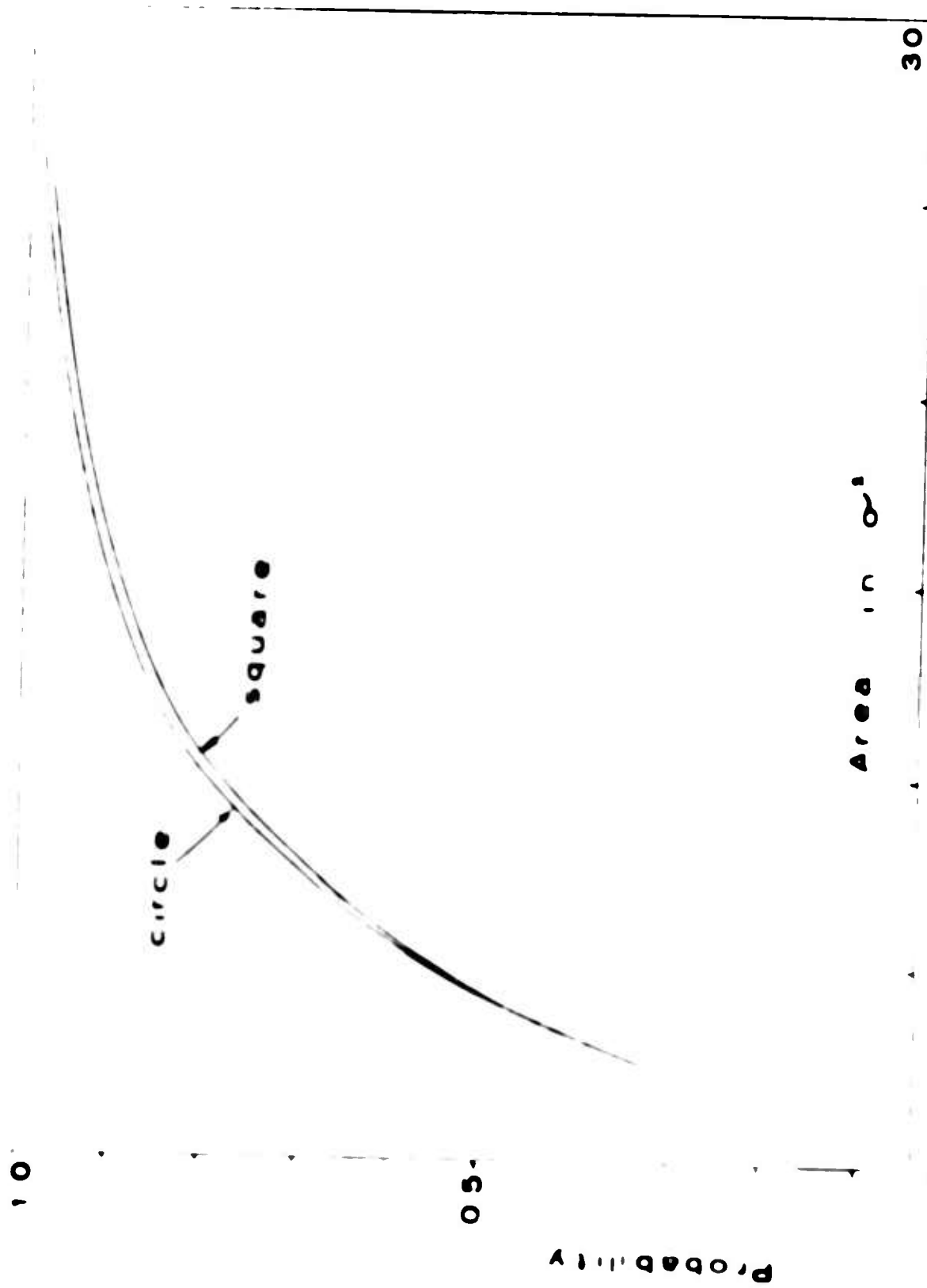


Figure 5. Cumulative Probability for Circle and Square Plotted against Area.

NOTE: Although the standard deviation is the commonly accepted measure of variability, the National Search and Rescue Manual uses the term, "Total Probable Error of Position". Its value is computed using estimates for drift error, target's position error, and search craft navigation error. These errors are squared and added, and then a square root is taken to produce Total Probable Error. This term is not specifically defined in that publication, so that one of the objectives of this solution was to demonstrate that it is equivalent to the statistically well-defined term 'Probable Error', which is a median error: that is, half of all errors have absolute values greater than that error, and half have absolute values which are smaller. The absence of this definition is a gap in the present search planning process, because planners are called upon to make estimates of errors without knowing how these errors are defined.

3. The General Solution

To determine the optimum size for a square search, given a certain amount of searching miles available (L), sweep width (W), and probability distribution ($p(x,y)$), a straightforward maximization method is employed in the following sequence:

- a. Determine total effort, E .

$$E = W \times L$$

b. Choose some arbitrary initial search radius, x .

c. Determine the search area, A , for this x :

$$A = 4 x^2$$

d. Determine effort density for a uniform search:

$$\frac{WL}{A} \quad \left(= \frac{W}{S} \right)$$

e. Determine probability of detection d from (3).

f. Determine the probability p from (2) with $R =$

x .

g. Determine the probability of success,

$$P(x) = p(x)d(x).$$

h. Increase x by Δx and repeat calculations. If $P(x)$ increases, continue adding Δx until a local maximum is encountered. If $P(x)$ decreases initially, reduce x by $2\Delta x$ and continue subtracting Δx until a local maximum is reached.

Since a cumulative probability distribution is continuous and has a slope throughout its range of ≥ 0 , and since the probability of detection function $d(x)$ is continuous with a slope of < 0 , the function $P(x) = p(x)d(x)$ can be shown to be unimodal, and so a local maximum in $P(x)$ will be an absolute maximum.

4. Application

The first use of this method was to check the National Search and Rescue Manual's recommended search planning guidelines to see if they produce square searches of optimum sizes. These guidelines are given in the form of

'Safety Factors', or search radii, for repeated searches, as multiples of Total Probable Error of Position, e.g.,

Search	Safety Factor
1	1.1
2	1.6
3	2.0
4	2.3
5	2.5

As far as effort density is concerned, there are two recommendations given in the SAR Manual. One is for a track spacing equal to sweep width, for urgent cases, and the other for a track spacing equal to twice the sweep width, for less urgent searches. Both of these recommendations were tested.

The approach used was:

- a. Set some arbitrary value for W
- b. Set $S=W$ so that $WL/A = 1$.
- c. Find R from "safety factor" table for the appropriate search (starting at 1).

d. Find path length, L:

$$L = \frac{4R^2}{S}$$

- e. Beginning at $x = R$, and with W and L above, use the general solution process described in paragraph 3. to

find x' , the optimum search radius for that path length.

f. Assuming that the optimal search is executed unsuccessfully, reevaluate the target's distribution $p(x)$ (see Para. 5.) and repeat the process from c. above. After five successive searches have been computed, stop the computation.

g. Compare the resulting five optimum sizes with the sizes recommended in the Safety Factor table from the Search and Rescue Manual.

5. Bayesian Analysis

Bayes' Law of Probability says that an estimate of the probability of a hypothesis can and should be revised on the basis of the outcome of a related event. In the case of search theory, the hypothesis is that the target is inside a given area. A search is conducted, and the event is either the detection or the non-detection of the target. This event should revise the initial estimate of the probability that the target was in the area. Of course, if the event is detection, the new probability that the target is in the area is 1. If the event is non-detection, then Bayes' formula must be used to calculate the new probability.

1. Example

The probability that a target is in a certain search area has been determined to be 50%, and a search is conducted in this area with a uniform probability of detection of 50%. The resulting probability of success is .5

$x .5 = .25$ or 25%.

For the use of Bayes' formula, the following terms are defined:

- A The hypothesis that the target is in the area.
- \bar{A} The hypothesis that the target is not in the area.
- D The event of detection.
- \bar{D} The event of non-detection.

Then

$$P(A|D) = \frac{P(A) \cdot P(D|A)}{P(A) \cdot P(D|A) + P(\bar{A}) \cdot P(D|\bar{A})}$$

When the target is detected:

$$P(A|D) = \frac{0.5 \times 0.5}{0.5 \times 0.5 + 0.5 \times 0.0} = 1.0$$

as expected. If the target is not detected, the new probability would be

$$\begin{aligned} P(A|\bar{D}) &= \frac{P(A) \cdot P(\bar{D}|A)}{P(A) \cdot P(\bar{D}|A) + P(\bar{A}) \cdot P(\bar{D}|\bar{A})} \\ &= \frac{0.5 \times 0.5}{0.5 \times 0.5 + 0.5 \times 1.0} = \frac{1}{3} \end{aligned}$$

Whereas the target had a 50% a priori probability of being in the search area, its new, or a posteriori probability of being in the area is 33.3%.

For the solution in paragraph 4., the entire probability distribution of the search object was reevaluated between successive searches. This was done for $p(x)$ inside the search area by

$$p'(x) = \frac{p(x)(1-d)}{(1-p(R)d)} \quad (26)$$

and for $p(x)$ outside the search area by

$$p'(x) = \frac{(p(x) - p(R))}{(1 - p(R)d)} + p'(R) \quad (27)$$

where R is the radius of the search conducted.

In order to illustrate the general form of the probability distributions between searches, a function was used which is similar to a density function. This function, $f(x)$ was defined to be

$$f(x) = \left(\frac{d(p(x))}{dx} \right) \left(\frac{1}{\delta x} \right) \quad (28)$$

where x is the measure of radius, or again, one-half of one side of a square, and $\delta x dx$ is the differential of

area (Figure 6).

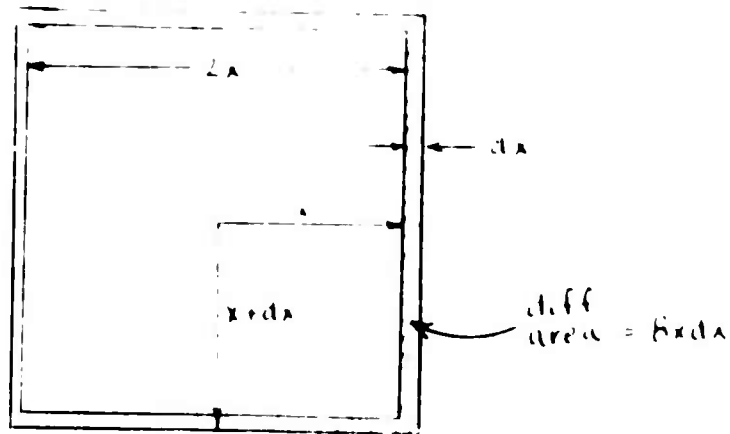


Figure 6. Derivation of Density Function for Square Area

Curve 1 in Figure 7 is the density function before any searching is done, as derived by (28) from (21). Curves 2 through 5 are these functions after successive searches.

Figure 8 is a similar set of curves showing the cumulative probability distributions.

6. Results

This method (from 4.) gives the following optimum searches:

Search	Optimum Radius	Safety Factor
1	1.08	1.1
2	1.64	1.6
3	2.07	2.0



Figure 7. Probability Density with Application of Bayes' Law Between Successive Optimum Square Searches.

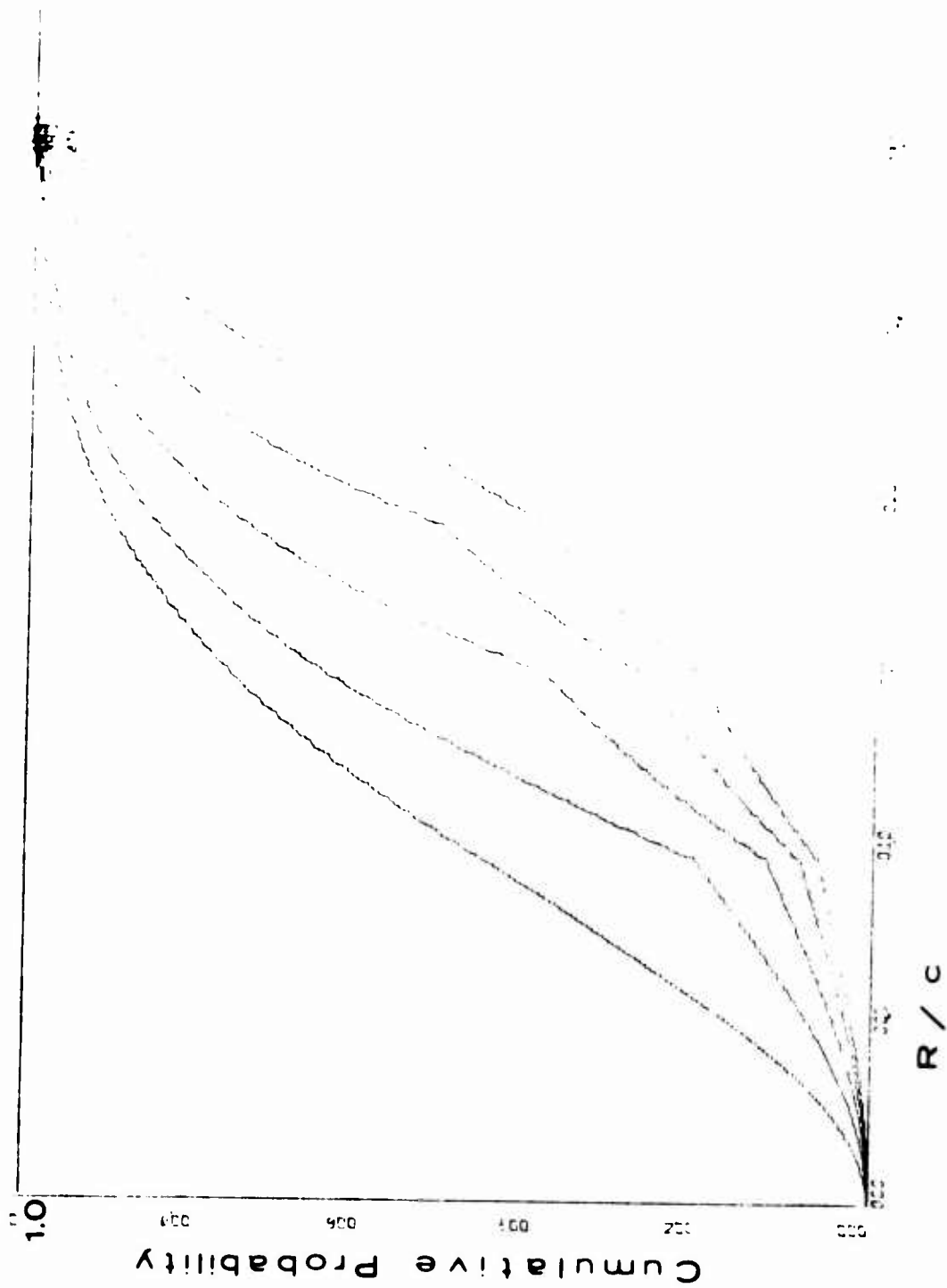


Figure 8. Cumulative Probability with Application of Bayes' Law Between Successive Optimum Square Searches.

4	2.43	2.3
5	2.74	2.5

Since these results were very close to the 'Safety Factors' listed above, it was concluded that (1) the safety factors were originally good calculations, and (2) they were calculated using the mathematical definition of probable error.

It should be noted, however, that these safety factors are close to optimum search radii only for the condition where track spacing equals sweep width. The second recommendation, track spacing equals twice sweep width, does not produce anywhere near optimum search areas. When a track spacing S' equal to twice the sweep width is used, the new path length L' is given by

$$L' = \frac{4R^2}{S'} = \frac{4R^2}{2W} = \frac{1}{2} L$$

For this new path length, optimum search sizes were found to be:

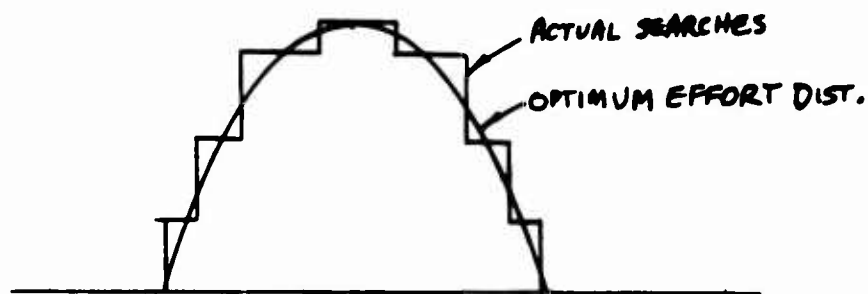
Search	Optimum Radius
1	0.85
2	1.30
3	1.66
4	1.95
5	2.20

When there is less search effort available the size of the search area as well as the effort density should be reduced. The SAR Manual gives no guidance as to how much the area should be reduced with a given amount of available effort. Conversely, there is no indication as to how excess search resources should be used, if such a condition should exist.

What is needed is some way for the search planner to determine the optimum search configuration directly from the amount of search effort available.

D. THE GENERAL CASE

Assume that a series of optimum square searches, each larger than the preceding one, is a good approximation of an optimum search effort distribution. Consider all the searches of the series combined into one search effort, so that the search effort density $\rho(r)$ assumes a step function which is close to the ideal effort density.



The radius r of the combined search is equal to the

radius of the last (and the largest) individual search in the sequence.

If the search had been a circular one, and if the effort density had conformed to the optimum, the expression for this radius would be

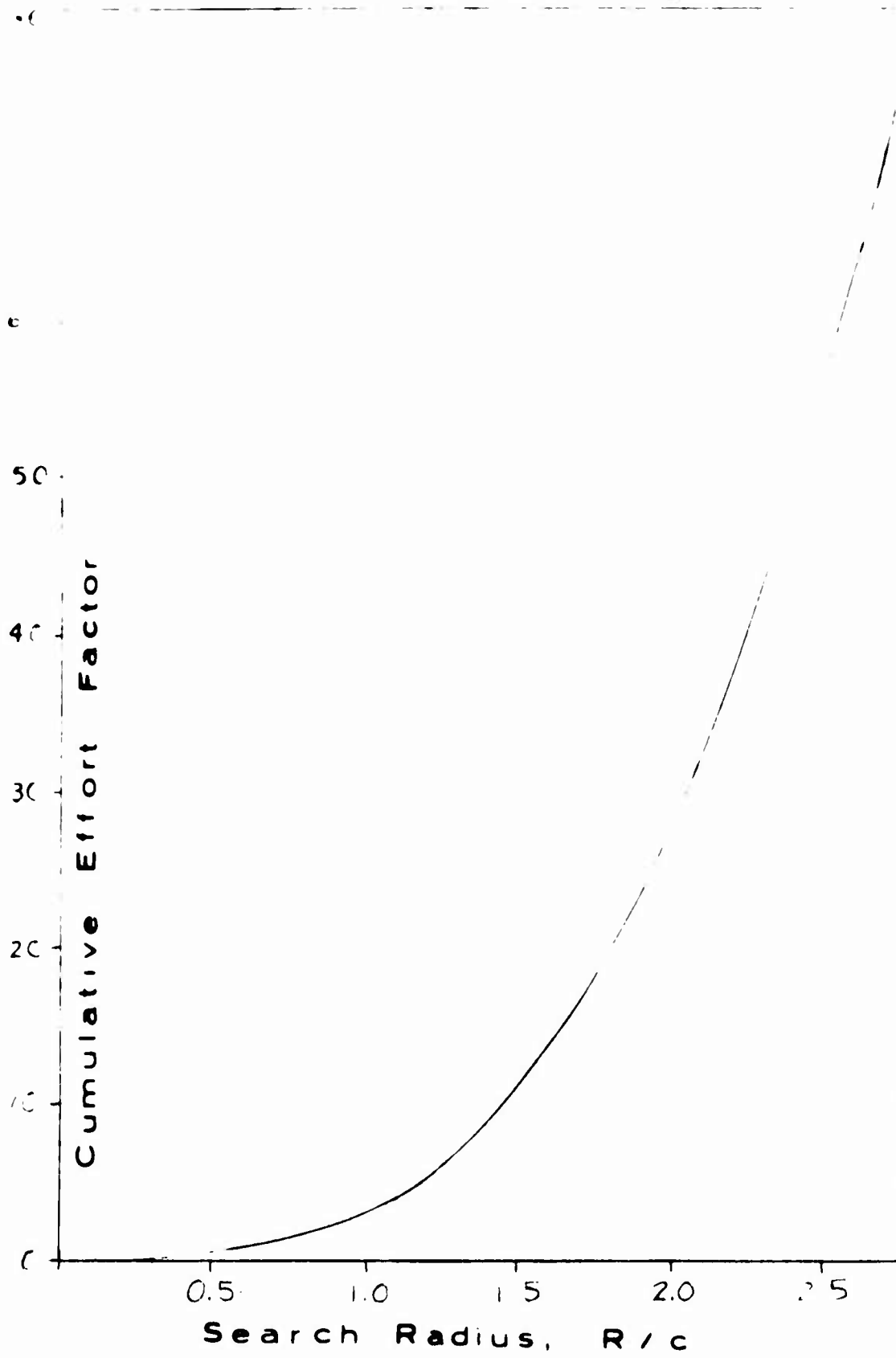
$$a = \left[\frac{4\sigma^2 E}{\pi} \right]^{\frac{1}{4}}$$

But since the search is composed of a small number of square searches, this same formula is not expected to apply. There should, however, be some way to approximate a function which will define the optimum radius based on available effort and the target's distribution. The simplest way to do this is to compute total search effort for a few optimum square searches, plot the radius of each of the searches against the cumulative search effort, and attempt to smooth a curve through them.

This was done for the ten searches (five at $W = S$ and five at $W = 2S$) calculated above, and the resulting curve is shown in Figure 9. Just as radius is in terms of probable error, so are the factors W and L of total effort 'normalized' by dividing each by probable error. Thus 'normalized' effort is a multiple of the square of probable error.

It should be cautioned that the curve is only an

Figure 9. Optimum Size of Square Search based on Cumulative Normalized Effort Factor.



approximation, and will not be valid if the effort available for a single search is very large. Thus if a search is computed which shows a coverage factor (W/S) greater than 1.8, then the results of the curve will not give an optimum search, and some other method will be required. Again, the effort plotted is cumulative, so that all the effort exerted in earlier searches must be added to the effort available for the present search before entering the table.

Example: One 150-knot aircraft is available for six hours of searching; the total probable error of position has been calculated to be 31.9 miles, and W is estimated at 10 miles.

Total effort then is found as follows:

$$E = 150\text{kts} \times 6\text{hrs} \times 10\text{miles}(W) \\ = 9000 \text{ square miles}$$

In terms of probable error, (c=31.9)

$$E(\text{normalized}) = 9000 / (31.9 \times 31.9) = 8.9$$

From the graph, $r = 1.4$,

$R = 1.4 \times c = 44.6$ miles, or 89.2 miles on a side, and

$$S = 4 \times R \times R / L = 8.75 \text{ miles.}$$

If the target is not found on the first search, and a second is to be conducted, the amount of available effort is calculated for the second search. The normalized effort for this search must be combined with all previously expended effort before entering the graph. Thus if $E(\text{normalized})$ for the second search is calculated to be 10.0, the graph should be entered with a figure of $10.0+8.9$ or 18.9 to find the radius of the second search. Each search area will be larger than the preceding one.

This decision curve should prove to be a more flexible tool for search planning than the Safety Factor table, since it provides a continuous range of search radii for different amounts of effort available.

V. THE SECTOR SEARCH

There is one search pattern in general use which does effect a greater concentration of effort at the center of the search area, and that is the sector search. This search pattern is executed by a series of sweeps crossing over the center of the search area at various angles. These sweeps are connected at their endpoints by chords flown near the perimeter of the area. This pattern covers a circular area and, perfectly navigated, produces a track as shown in Figure 10.

A. SEARCH EFFORT DISTRIBUTION

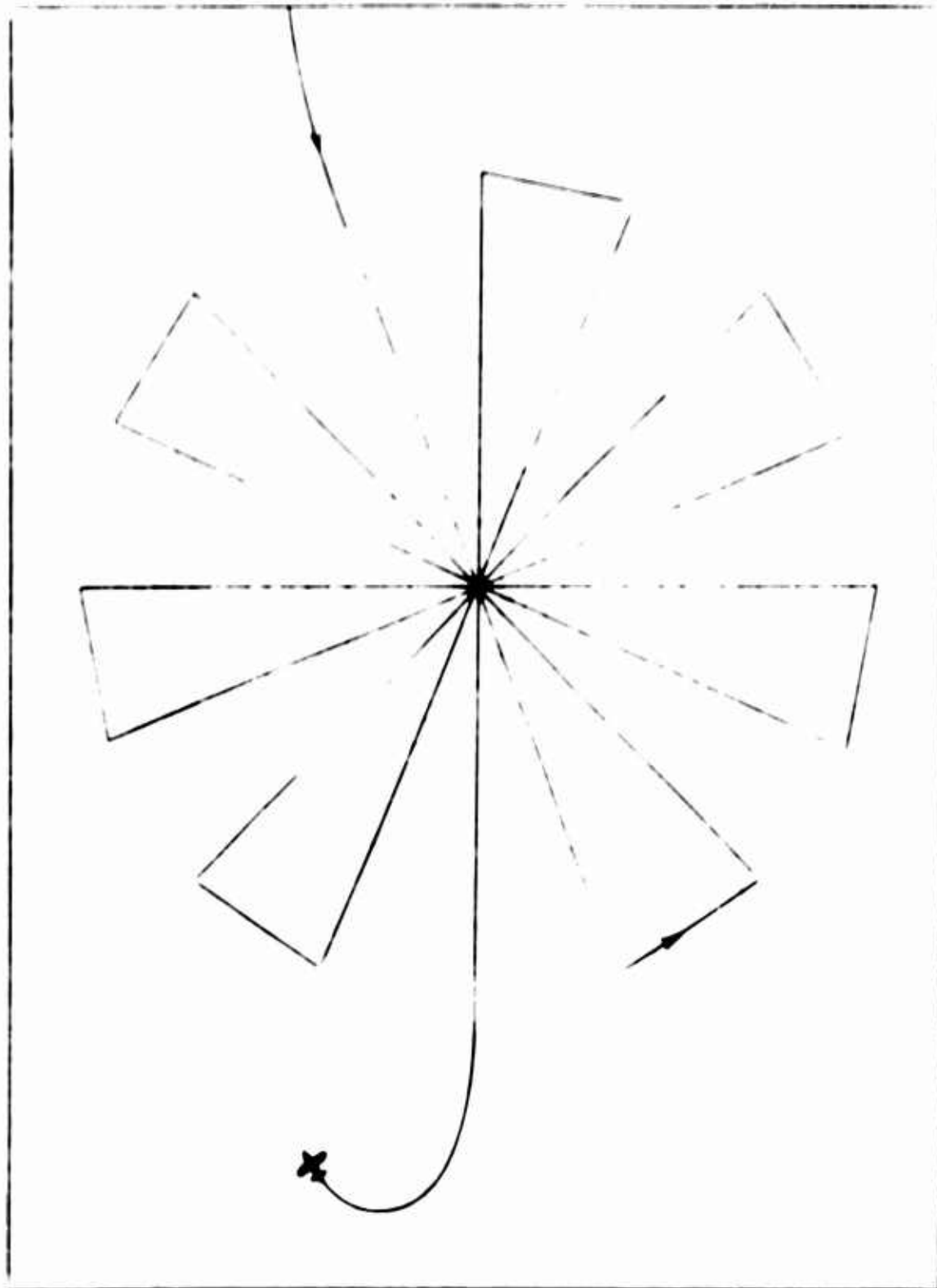
The total effort expended in a sector search can be expressed by the integral

$$E = \int_0^R \phi(r) 2\pi r dr$$

where R is search radius

r is the distance from the center of the search

Figure 10. The Sector Search



$\phi(r)$ is the search effort density at some distance r .

This density function $\phi(r)$ is simply W times the number of paths which intersect a circle of radius r , multiplied by dr to give total path length between r and $r+dr$, and then divided by the area between r and $r+dr$. Thus

$$\phi(r) = \frac{Wn \, dr}{2\pi r \, dr} = \frac{Wn}{2\pi r} \quad (19)$$

Then,

$$E = WL = \int_0^{\infty} \frac{Wn}{2\pi r} 2\pi r \, dr = WnR \quad (30)$$

and,

$$L = nR$$

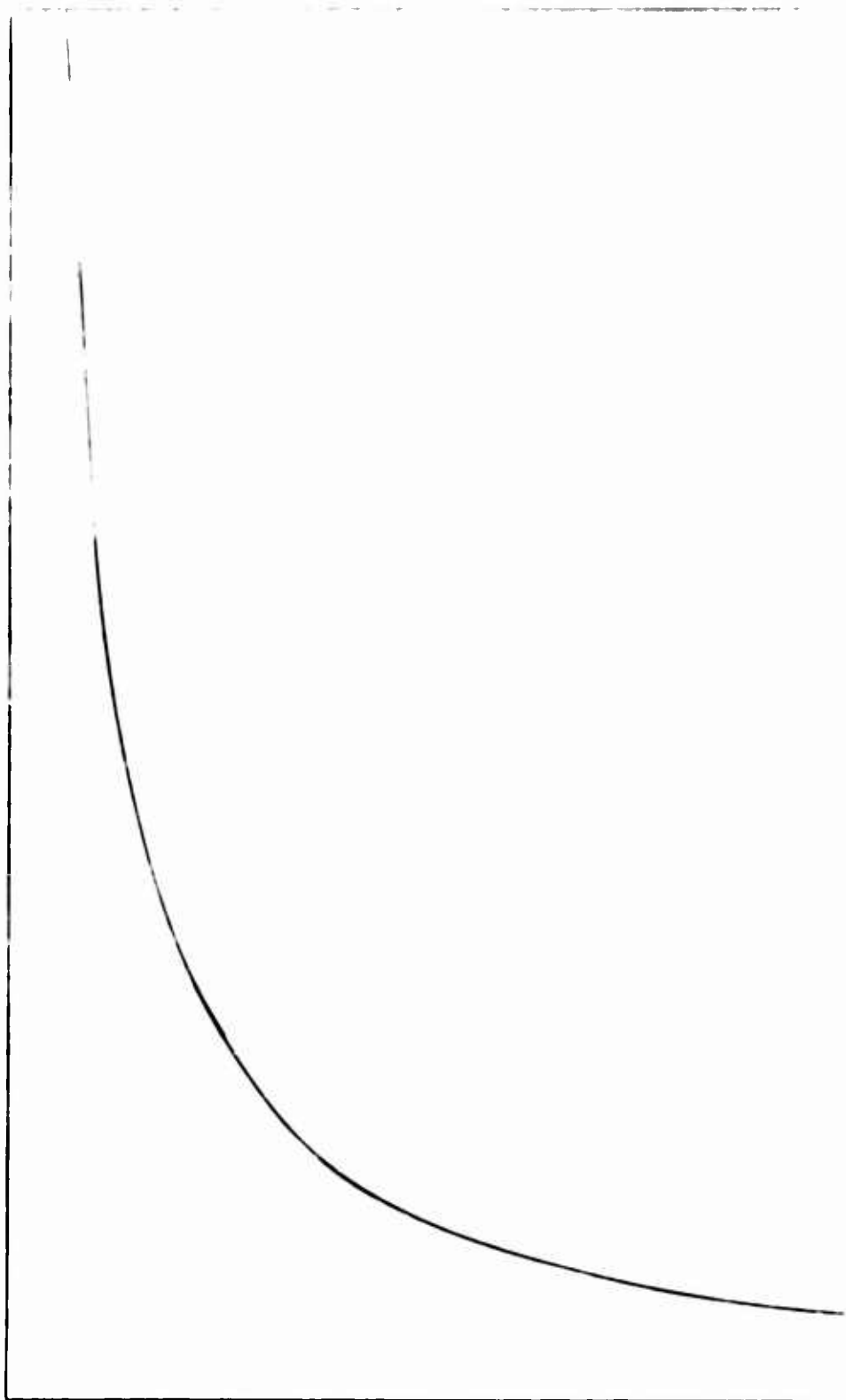
as expected.

Here n is the number of 'spokes' produced, or twice the number of complete sweeps across the circle. This density function is illustrated in Figure 11.

B. PATTERN ERROR

There will always be some error in flying any search pattern, which should be taken into account for the sector search. The navigation error of the searcher has already been taken into account when computing the Total Probable Error of Position. The pattern error, however, can be

Search Effort Density



Distance from Center, R

Figure 11. Search Effort Density in a Perfectly Navigated Sector Search.

different from this navigation error. Whereas navigation error considers only the searcher's ability to find the datum point in order to define the search area, pattern error, as it is used here, describes his flying error within the area. If, once the searcher finds what he thinks to be datum, he drops a smoke float or some other marking device, then his pattern error will be much smaller than his navigation error. Conversely, if when arriving in the search area he stops referring to his navigation aids and relies thenceforth on dead reckoning only, his pattern error will be greater than his navigation error.

Although by its nature, a flying error is bivariate (like the error of target position) a simplification was made. Since the pilot is flying long sweeps which have their endpoints relatively far away from the area of concern (the center of the area), only his lateral position error (which is univariate) was considered.

It was assumed for this analysis that the lateral component of pattern error is nearly normal, and that it can somehow be calculated or estimated.

The expression for the total effort expended in flying the spokes of a sector search is

$$E = 2 W_n \int_0^R \int_0^{\frac{\pi}{2}} \frac{1}{\sqrt{2\pi} \sigma_p} e^{-\frac{r^2 \sin^2 \alpha}{2\sigma_p^2}} r dr d\alpha \quad (31)$$

(r sin α = Lateral range)
(σ_p = σ Lateral pattern error)

The derivative of this expression with respect to r was used as the search effort density function for a sector search with pattern error.

$$\psi(r) = \frac{2Wn}{\pi} \int_{-\pi/2}^{\pi/2} \frac{1}{\sqrt{2\pi} \sigma_r} e^{-\frac{r^2 \sin^2 \alpha}{2\sigma_r^2}} d\alpha \quad (32)$$

For the analysis this basic density function was computed with sweep width, standard deviation of pattern error, and number of spokes all equal to 1. To find the density function for any particular set of parameters, the density is multiplied by W and n , and the horizontal scale is multiplied by the standard deviation of the pattern error.

C. OPTIMUM SECTOR SEARCH

The plot of this density function is found in Figure 12. An inspection of this plot will show that it is close to a quadratic function out to $r = 3$ standard deviations. Since Koopman's ideal search is a quadratic, some guidance was provided as to the optimum radius for the sector search, based on the pattern error. It was then necessary to adjust the number of spokes to arrive at the ideal effort expenditure to match this radius. Koopman's ideal search effort density is a function of search radius and target's position error:

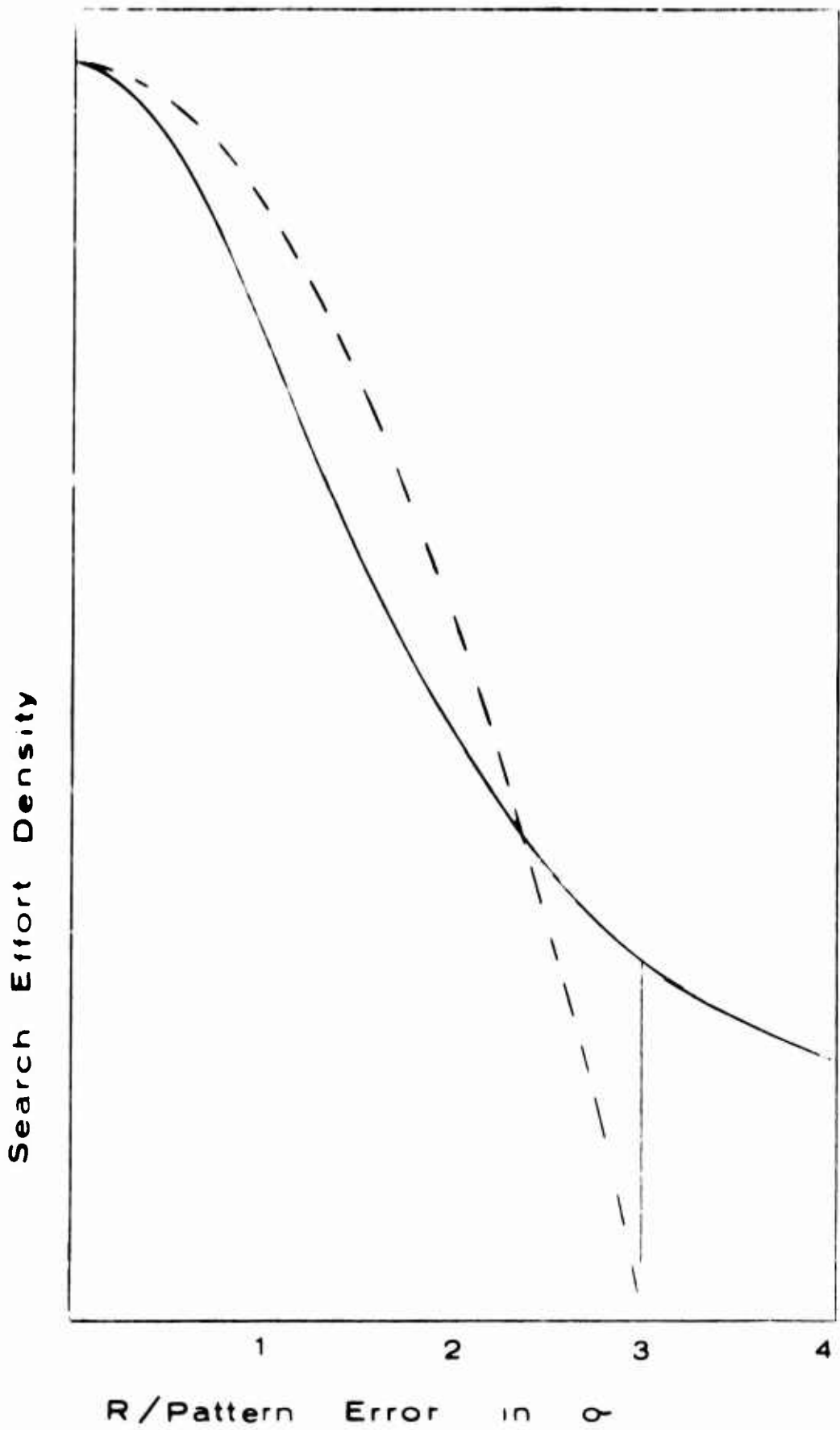


Figure 12. Search Effort Density in a Sector Search with Pattern Error.

$$Q(r, y) = \frac{a^2 - r^2}{2c^2} \quad \begin{array}{l} r \leq a \\ r > a \end{array}$$

and the radius is a function of target position error and available effort:

$$a = \left[\frac{4c^2 E}{\pi} \right]^{1/4}$$

Solving for effort, E:

$$E = \frac{a^4 \pi}{4c^2} = WL$$

However, in the case of the sector search, L, the number of miles flown, is simply the number of sprkes, n, times the radius. The chords flown at the perimeter are disregarded in this analysis:

$$L = a \times n$$

Substituting, and solving for n:

$$n = \frac{a^3 \pi}{4c^2 W}$$

Ideally, then, since the optimum a is known to be

close to three standard deviations:

$$m = \frac{27 \sigma_p^3 \pi}{4 \sigma^2 W}$$

(33)

or, when all errors are expressed as probable errors,

$$c_p = .67 \sigma_p$$

$$c = 1.18 \sigma$$

$$m = \frac{11.95 c_p^3}{W c^2}$$

(34)

Table 1 is a tabulation of this function for various conditions of total probable error of position c , and pattern error. The n derived from the table must be divided by sweep width W to obtain number of spokes.

From the example of the sunken fishing boat, $c = 31.9$ and $W = 10.0$ miles. If the searcher's pattern error were 13 miles, then search radius R would equal 58.5 miles.

Interpolating in the table, $n = 100$, then

$$\text{Number of spokes} = 100/10 = 10$$

and the angle between adjacent search legs $= 360/10 = 36$ degrees.

Total search miles flown would be

$$10 \times 58.5 = 585$$

plus the amount of flying at the perimeter (in order to fly the pattern, the aircraft must traverse a distance somewhat less than one-half the circumference of the area):

$$585 + 58.5 \times \pi = 585 + 184 = 770 \text{ miles.}$$

This table for sector search will not be useful until an accurate means of predicting pattern error is found. The function given in (34) is extremely sensitive to pattern error, and thus accuracy for this parameter is required to use the table.

Even if it is not actually used to determine the parameters of a sector search, the table does serve to

SECTOR SEARCH

TABLE OF OPTIMUM RADIUS AND NUMBER OF SEARCH LEGS

PATTERN ERROR	OPTIMUM RADIUS	POSITION ERROR, C				
		5	10	15	20	25
1.00	16	0	0	0	0	0
2.00	150	0	0	0	0	0
3.00	1193	1	3	7	7	7
4.00	2033	1	5	13	14	16
5.00	4041	1	5	13	14	16
6.00	6573	1	5	13	14	16
7.00	13670	1	5	13	14	16
8.00	24831	1	5	13	14	16
9.00	42231	1	5	13	14	16
10.00	71322	1	5	13	14	16
11.00	113120	1	5	13	14	16
12.00	18709	1	5	13	14	16
13.00	32231	1	5	13	14	16
14.00	51322	1	5	13	14	16
15.00	76660	1	5	13	14	16
16.00	10907	1	5	13	14	16
17.00	16887	1	5	13	14	16
18.00	26229	1	5	13	14	16
19.00	41824	1	5	13	14	16
20.00	66662	1	5	13	14	16
		3	3	3	3	3
		4	4	4	4	4
		5	5	5	5	5
		6	6	6	6	6
		7	7	7	7	7
		8	8	8	8	8
		9	9	9	9	9
		10	10	10	10	10
		11	11	11	11	11
		12	12	12	12	12
		13	13	13	13	13
		14	14	14	14	14
		15	15	15	15	15
		16	16	16	16	16
		17	17	17	17	17
		18	18	18	18	18
		19	19	19	19	19
		20	20	20	20	20

Table 1. Optimum Sector Search. Divide quantity in "N x W" table by Sweep Width to obtain number of search legs.

illustrate that accurate navigation does not necessarily produce the optimum sector search, and that only under the unusual conditions of an extremely accurate estimate of target position is it desirable to reduce pattern error. On the contrary, in most instances, effectiveness may be enhanced by increasing pattern error.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. THE SEARCH PLANNING PROGRAM

It is recommended that the Coast Guard begin immediately to make full use of the Search Planning Program now operational and undergoing testing at the Fleet Numerical Weather Central, Monterey. A guide for users of this program is included as Appendix A.

1. Precautions

The following cautions are appropriate for users of the information provided by this program.

a. Region of Validity.

Because the weather data points used in this program are approximately 200 miles apart, drift calculations provided for areas within 100 miles of shore should be double-checked by hand before using. If hand calculations produce a larger value for total drift, then the hand-calculated answers should be used in lieu of the computer solution.

b. Time of Datum

Weather predictions in the format required for this program are not produced by the Weather Facility for more than 48 hours in advance. Accordingly, users should

avoid requesting plots for time periods beyond 36 hours from the time the request is submitted. If a plot is requested which is later in time than the last computed weather, the information will be provided for that plot and a caution statement will appear in the message reply.

c. Numbers of Initial and Datum Positions

No more than nine initial positions may be entered, and no more than nine datum times will be calculated, in any one run of the program.

The user is encouraged to request whatever number of datum points may be useful to him. Thus if a search is planned for 0800Z, the search planner may wish to request additional data for target position at 1000Z, 1200Z, 1400Z, and 1600Z.

2. Leeway

It is suggested that further experimentation be done in the area of survivor craft leeway to determine the general shape of the leeway function. It is expected that this shape will be close to that of the liferaft drift tables, and to the formula of Witting given in Ref.3.

$$V = k \sqrt{\text{Wind}} \quad (35)$$

and which is used in the time-sharing version of the program for all leeway. This same function is used in both versions to approximate liferaft leeway.

When better data is available, the program at Fleet Numerical can be changed to accommodate the curved leeway function.

3. Testing

It is suggested that a rigorous program of testing and evaluation of the results of the Search Planning Program be initiated. If the program proves to be more accurate than other methods, its contribution to the search planning process, and to oceanographic research in general, will be substantial.

4. Operational Use in the Coast Guard

Although the program will be available to the Coast Guard via the facilities of the Fleet Numerical Weather Central, there are further possible advantages of such a program which are not available through these facilities.

a. Optimum Search Areas

The computer method of solving for optimum searches shown in part IV of this thesis could be added to the Search Planning Program.

b. Other Applications

Computation of on-scene aircraft endurance, time enroute search areas, division of search area among different search units, maximum rescue coverage intercepts, fixes from radio direction finder bearings, and many other calculations familiar to search planners could all be available instantly from a remote computer terminal.

The Coast Guard Amver computer center at Governor's Island New York regularly receives weather data by wire from Fleet Numerical Weather Central which is used to produce weather maps. The fields required for the Search Planning Program could also be transmitted to a central Coast Guard computer facility. Remote terminals connected to this facility and installed in Rescue Coordination Centers (RCC's) could provide the output from this program, Amver surface picture plots, and other useful data directly to search planners.

B. DETERMINATION OF SEARCH AREAS

It is recommended that the findings of parts IV and V of this thesis be evaluated by the Coast Guard and applicable portions be included in the National Search and Rescue Manual.

C. FUTURE RESEARCH

There are many unexplored areas in the field of Search Planning in which further research may yield valuable results.

1. The Trackline Search

Although the type of point-datum search presented in parts IV and V are computed in two dimensions, there are times when the target's distribution is centered on a line of position (or trackline), which presents a problem

essentially one dimensional in nature.



If a boat departs point A intending to follow a certain track AB to point B, and does not arrive at point B, and if no other information is available as to his probable position, a one-dimensional or trackline search problem is presented.

a. Partial Solution

Assuming that it is decided to begin the searching efforts by executing just one sweep along the length of the trackline, what is the probability that the target will be located? The following analysis is for the inverse cube law of detection.

Given the standard deviation of the target's error of position σ , and given sweep width, W , where

$$W = 2\sqrt{2\pi m} \tag{36}$$

Solving for m , which includes visibility and other factors,

$$m = \frac{W^2}{8\pi} \tag{37}$$

The probability of detecting a uniformly distributed target is

$$d(x) = 1 - e^{-\frac{W}{x^2}} \quad (38)$$

$$= 1 - e^{-\frac{W}{4\pi x^2}} \quad (39)$$

Introducing a new variable, $\beta = \frac{2\sigma}{W}$

$$d(x) = 1 - e^{-\frac{\sigma^2}{\beta^2 \pi x^2}} \quad (40)$$

The probability that the target is located at some distance x from the trackline may be assumed to be

$$p(x) = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{x^2}{2\sigma^2}} \quad (41)$$

Thus, the probability of detecting this target

is

$$P = \int_{-\infty}^{+\infty} \left(1 - e^{-\frac{\sigma^2}{\beta^2 \pi x^2}}\right) \left(\frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{x^2}{2\sigma^2}}\right) dx \quad (42)$$

$$= 1 - \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi} \sigma} e^{-\left(\frac{x^2}{2\sigma^2} + \frac{\sigma^2}{\beta^2 \pi x^2}\right)} dx \quad (43)$$

Introducing $\gamma = \frac{x}{\sqrt{2}} \sigma$, $d\gamma = \frac{1}{\sqrt{2}} dx$

$$P = 1 - \sqrt{2} \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi}} e^{-\left(\gamma^2 - \frac{1}{2\pi\beta^2\gamma^2}\right)} d\gamma \quad (44)$$

which has the solution

$$P = 1 - e^{-\frac{\sqrt{2}}{A}} = 1 - e^{-\frac{W}{\sqrt{2}\sigma}} \quad (45)$$

b. General Solution

The solution for probability P of detecting a target on a trackline search for more than one sweep involves a more complicated expression, one which does not lend itself to such a simple solution. Since a trackline search is executed one sweep at a time, a general solution for the optimum distance of each sweep from the trackline is indicated, and should be the subject of further study.

2. Optimum Search Speed

The Search and Rescue Manual prescribes a "moderate" speed for searching. Koopman's formula for sweep width, from (9) gives

$$W = \sqrt{\frac{2kh}{\omega}}$$

This indicates that sweep width is inversely proportional to the square root of the relative speed of the target, w . When search speed is very large in comparison to target speed, w takes on the value of the searcher's speed. As w increases, however, the amount of search path length L that can be covered in a certain period of time increases proportionally:

$$L = K_1 \omega$$

It follows that the amount of search effort, $W \times L$, that can be effected by a certain number of aircraft in a fixed period of time increases as the square root of search speed:

$$\frac{W}{S} = K_2 = \frac{WL}{A}$$

$$A = \frac{WL}{K_2}$$

$$\frac{WL}{K_2} = A = \frac{\sqrt{2kh} K_1 W}{K_2} = \frac{K_1}{K_2} \sqrt{2khW} \quad (47)$$

It may be argued, then, that when time is a factor, such as where persons in distress may not survive for long periods of time, searching should be accomplished at the highest speed practicable. In addition, since the coverage of a designated search area will take less time at a higher speed, lookouts may encounter less fatigue, and the effectiveness of the search may be enhanced.

D. CONCLUSION

In conclusion, there is a need for more scientific research in the practical aspects of search planning, and a corresponding need for the education of search planners in the fields of probability and search theory.

APPENDIX A

USER'S GUIDE TO SEARCH PLANNING PROGRAM

1. Description

The MONTEREY SEARCH PLANNING PROGRAM is a computer program which solves open ocean drift plotting problems, and provides datum, minmax datum, Total Probable Error of Position, and Search Radius for both simple and complex searches. The use of this program is available upon request, on a test basis, to all Rescue Coordination Centers through the facilities of the U.S. Navy Fleet Numerical Weather Facility, Monterey, California.

2. Input Data

a. Leeway Code

For this program, leeway is expressed as a two-digit code as shown in Table 1.

Leeway Code

00	No Leeway
10	Liferaft with Drogue
11	Liferaft without Drogue
12	Liferaft (Minimax)
13 - 19	Downwind drift (minimax) Minimum = 1% of wind velocity Maximum = Second digit as % of Wind Velocity.
20,30,etc.	Downwind drift at 2%,3%, etc. of the wind velocity
21 - 99	Minimax drift at some fixed percent of wind velocity equal to first digit; Deflection to the right and left of the wind line equal to 10 degrees times the second digit.

Table 1. Leeway Code

Example: 43 = 4% of wind velocity

\pm 30 degrees off wind line

b. Number of Starting Points

The number of starting (or distress) positions must be indicated. The maximum number that can be supplied is nine.

c. Number of Datum Times

The number of datum (or search) times for which plots are requested must be supplied. The maximum number of these is also nine.

d. Starting Point Data

Starting positions must be entered in chronological order and each point must be fully identified by:

(1) Date-time group (time zone Zu'u)

(2) Month

(3) Latitude and Longitude in degrees and minutes.

Tenths of minutes must be specified. The number of these starting positions must agree with paragraph 2.a.

e. Datum Times

Complete Date-time group (including month) for each datum time must be supplied, in chronological order. The number of these datum times must agree with paragraph 2.c.

f. Last Known Position

This is the last known position of the search object (see Para. 611, National Search and Rescue Manual) to be

used in computing DR position error. This position must be complete with degrees, minutes, and tenths of minutes. If DR position error is not applicable, enter one of the initial positions from 2.d.

g. Error Factors

These factors must all be specified to at least one decimal place, in the following order:

(1) Probable navigation error of search craft.

(2) Initial probable error in position of the search object.

(3) Percent of DR distance to be applied as DR error (See Para. 611, National Search and Rescue Manual). Enter 0.0 if not applicable.

h. Search Designators

These should be one-digit numbers, from 0 to 5, which describe which Safety Factors are to be applied to the Total Probable Error of position for each datum time. One digit must be supplied for each datum time.

0 No search radius is to be computed for that datum time

1,2,3,4,5 The Safety Factor corresponding to search 1,2,3,4, or 5 is to be applied.

3. Message Request Format

A message request to Fleet Numerical Weather Central

will insure that the data is entered correctly into the computer:

FM CEA

TO FLENUMWEACEN MONTEREY

BT

UNCLAS

DISTRESS HOMEY 65 OVERDUE

1. REQUEST SAR PLOT.

2. DATA:

A. 12/2/3//

B. 030900Z AUG,3520.0N,05216.5W/031200Z AUG,
3600.0N,05140.0W//

C. 031600Z AUG/032200Z AUG/040200Z AUG//

D. 3500.0N,05140.0W/5.0/10.0/0.10/102//

This sample message requests a minimax plot of a liferaft from two initial positions, with data requested for three different times (para. 2.A.). The initial positions and date-time groups are given in para. 2.B. (note that 2 digits are used to express degrees latitude and 3 digits are used for degrees longitude).

Paragraph 2.C. gives the date-time groups of the datum times. Paragraph 2.D. gives the last known position, error factors, and search designators. for this example, the first search is to be computed for 031600Z and a second

search for 040200Z. No search radius is to be computed for 032200Z; positions and position errors will still be provided.

4. Caution: Offshore Regions

This program is designed primarily for open ocean search; when data is supplied for water areas within 100 miles from shore, answers should be checked by hand calculations. Requests for SAR Plots within 10 miles from shore should be avoided.

Weather information used in this program is applicable to the Northern Hemisphere only.

EXAMINATION OF CRITERIA FOR REPEATED SEARCHES

TABLE 1. PARALLEL SWEEPS FOR PROBABILITY OF DETECTION

BY J. F. FISHER, USCG

SEARCH NUMBER	TRACK SPACING	PROBABILITY OF DETECTION IN AREA	PROBABILITY OF SUCCESS	STANDARD RADIUS	TRACK SPACING	PROBABILITY TARGET IN AREA	PROBABILITY OF DETECTION	PROBABILITY OF SUCCESS
1	1.00	0.03	0.004	0.512	1.10	0.04	0.790	0.511
2	1.00	0.04	0.006	0.604	1.60	0.04	0.790	0.603
3	1.00	0.04	0.007	0.663	2.00	0.04	0.790	0.660
4	1.00	0.04	0.008	0.740	2.30	0.04	0.790	0.639
5	1.00	0.04	0.009	0.831	2.50	0.04	0.790	0.579

SWEEP WIDTH SET TO 0.04 TIMES PROBABLE ERROR

MILES FLOWN/PROBABLE ERROR	TOTAL EFFORT (M X MILES FLOWN/PROBABLE ERROR)	PROBABILITY OF DETECTION	PROBABILITY OF SUCCESS
114.2	4.9	0.647	0.511
241.7	10.2	0.764	0.603
377.6	16.0	0.915	0.660
432.6	21.2	0.800	0.639
600.0	25.0	0.742	0.579

REDUCE EFFORT 50%

SEARCH NUMBER	TRACK SPACING	PROBABILITY OF DETECTION IN AREA	PROBABILITY OF SUCCESS	STANDARD RADIUS	TRACK SPACING	PROBABILITY TARGET IN AREA	PROBABILITY OF DETECTION	PROBABILITY OF SUCCESS
1	0.5	0.04	0.004	0.320	0.08	0.647	0.465	0.304
2	1.00	0.05	0.005	0.427	0.08	0.829	0.469	0.398
3	1.00	0.06	0.005	0.473	0.08	0.907	0.469	0.424
4	1.00	0.07	0.005	0.488	0.08	0.935	0.465	0.430
5	1.00	0.07	0.005	0.520	0.08	0.940	0.460	0.440

MILES FLOWN/PROBABLE ERROR	TOTAL EFFORT (M X MILES FLOWN/PROBABLE ERROR)	PROBABILITY OF DETECTION	PROBABILITY OF SUCCESS
57.1	2.4	0.647	0.304
120.9	5.1	0.829	0.398
184.9	8.0	0.907	0.424
243.7	10.6	0.935	0.430
324.0	12.5	0.940	0.440

SAR00010
 SAR00020
 SAR00030
 SAR00040
 SAR00050
 SAR00060
 SAR00070
 SAR00080
 SAR00090
 SAR00100
 SAR00110
 SAR00120
 SAR00130
 SAR00140
 SAR00150
 SAR00160
 SAR00170
 SAR00180
 SAR00190
 SAR00200
 SAR00210
 SAR00220
 SAR00230
 SAR00240
 SAR00250
 SAR00260
 SAR00270
 SAR00280
 SAR00290
 SAR00300
 SAR00310
 SAR00320
 SAR00330
 SAR00340
 SAR00350
 SAR00360
 SAR00370
 SAR00380
 SAR00390
 SAR00400
 SAR00410
 SAR00420
 SAR00430
 SAR00440
 SAR00450
 SAR00460
 SAR00470
 SAR00480

MONTEREY SEARCH PLANNING PROGRAM

PROGRAMMER: LT J. M. DISCENZA, USCG
 NAVAL POSTGRADUATE SCHOOL, MONTEREY, CALIFORNIA

PURPOSE: TO PROVIDE THE SEARCH AND RESCUE MISSION COORDINATION
 WITH A COMPUTER AID IN PLANNING AN OCEAN SEARCH.
 REFERENCES:

- (1) NATIONAL SEARCH AND RESCUE MANUAL, CG-308
- (2) W.E. HUBERT, T. LAEVASTI, SYNOPTIC ANALYSIS AND
 FORECASTING OF SURFACE CURRENTS, JUNE 1967
- (3) W.H. RICHARDSON, EMPIRICAL SWEEP WIDTH ANALYSIS,
 SCRIPPS INSTITUTION OF OCEANOGRAPHY, 1968

DISCUSSION: BASIC PLANNING PROCESS IN THE PROGRAM IS ONE OF
 THE BASIC PLANNING FOR A DISTRESSED CRAFT WHERE SOME OF
 AN OPENING SEARCH ARE KNOWN, AND WHERE A DATUM (OR DATUM POINT
 REGIONS) ARE REQUIRED FOR SOME FUTURE TIME. ALTHOUGH THE PROGRAM
 IS SPECIFICALLY DESIGNED TO WORK WITH WEATHER DATA FROM A
 TAPE OR DISK DATA BANK OF WEATHER INFORMATION, PROVISION IS
 MADE FOR OPERATOR ENTRY OF WEATHER INFORMATION IF SUCH DATA
 BANK OF WEATHER IS NOT AVAILABLE.

ENTERIX: AND DRIFTING CHARACTERISTICS - RELATES TO SIZE
 OF CLASS NUMBER OF SEARCH OBJECT
 DESC: ALPHAMERIC DESCRIPTION OF SEARCH OBJECT
 M1: THE NUMBER OF STARTING POINTS FOR COMPUTATION
 OF DATUM
 A1: THE DATES AND TIMES OF THE STARTING POSITIONS
 LAD, YLA, D: LATITUDE OF STARTING POSITIONS
 LCD, YLD, H: LONGITUDE OF STARTING POSITIONS
 M2: NUMBER OF TIMES DATUM IS TO BE COMPUTED
 T2: TIMES FOR WHICH DATUM IS TO BE COMPUTED

OUTPUTS:
 LAF, FLA, DE: LATITUDE OF DATUM POINTS
 LCF, FLO, HE: LONGITUDE OF DATUM POINTS

WRITE(6,100)
 FORMAT(11) MONTEREY SEARCH PLANNING PROGRAM'//'
 1001,ITS'//', CLASS',2I2)


```

CV3=0.
CV4=0.
IF(IX1).NE.1160 TO 10
CD1=0.
CD2=0.
IF(IX2).GT.2160 TO 2
CV1=.098
CV2=.226
CV3=0.
CV4=0.
IF(IX2).LT.21M4=M1
EQ.1)CV1=CV2
EQ.1)CV3=CV4
IF(IX2).EQ.1)
IF(IX2).EQ.1)
GO TO 10
CV2=FLOAT(IX2)/100.
CONTINUE
IF(O11).EQ.1)WRITE(8,1003)M4
NUMBER OF SEPARATE TRACKS TO BE PLOTTED,M4=, I2)
FORMAT(, DIVERGENCE(8,1015)CD1,CD2
F4.1, AND',F5.1)
1003
1015
1016
IF(O12).EQ.1)WRITE(8,1016)CV3,CV1
LEEWAY=, F7.4, X WIND')
IF(O12).EQ.1)WRITE(8,1016)CV3,CV1
IF(O12).EQ.1)WRITE(8,1016)CV4,CV2
33
106
FORMAT(, LIST CHRONOLOGICALLY: STARTING TIMES AND POSITIONS, EX:)
107
FORMAT(, 070930Z MAR,3822.5N,06806.5W ')
READ(5,203)((A1(I,J),I=1,3),FZ(J),MCN(J),LAD(J),YLA(J),D(J),LOD(J)
1
YLO(J),H(J),J=1,M1)
IF(O11).EQ.1)WRITE(8,101C)
STARTING TIMES AND POSITIONS ENTERED:)
1010
DO 40 J=1,M1
AL(J)=JULIAN(MON(J),A1(1,J))
40
IF(O11).EQ.1)WRITE(8,1017)
IF(O11).EQ.1)WRITE(8,1023)((A1(I,J),I=1,3),LAD(J),YLA(J),D(J),LOD(
1
J),YLO(J),H(J),J=1,M1)
F5.2,A1,I5.0,F5.2,A1)
1023
1017
FORMAT(, DATE-TIME
LONGITUDE')
FORMAT(, A1,IX,A3,IX,I2,F4.1,A1,IX,I3,F4.1,A1)
203
CALL MNSW
IF(O12).EQ.1)WRITE(8,1004)CHECK
ANSWER TO CHECK: ',A1)
1004
FORMAT(, LONG/1HM/
DATA WRK,IOB)
IF(CHECK(6).EQ.10B)
WRONG)GO TO 33
108
FORMAT(, ENTER NUMBER OF TIMES DATUM IS TO BE COMPUTED NOW:)
204
FORMAT(, 204)M2,TAP
FORMAT(, 211)

```

```

R C0970
R C0980
R C0990
R C1000
SAR C1010
SAR C1020
SAR C1030
SAR C1040
SAR C1050
SAR C1060
SAR C1070
SAR C1080
SAR C1090
SAR C1100
SAR C1110
SAR C1120
SAR C1130
SAR C1140
SAR C1150
SAR C1160
SAR C1170
SAR C1180
SAR C1190
SAR C1200
SAR C1210
SAR C1220
SAR C1230
SAR C1240
SAR C1250
SAR C1260
SAR C1270
SAR C1280
SAR C1290
SAR C1300
SAR C1310
SAR C1320
SAR C1330
SAR C1340
SAR C1350
SAR C1360
SAR C1370
SAR C1380
SAR C1390
SAR C1400
SAR C1410
SAR C1420
SAR C1430
SAR C1440

```

```

1005 IF(0(I),EQ,1)WRITE(9,1005)M2
32   FORMAT(, DATUM TO BE COMPUTED ',I1, TIMES.,)
109  FORMAT(6, 109)
205  READ(5,205)((T2(I,J),I=1,3),MON(J),J=1,M2)
     EX:020900 MAR,031030 MAR,1)
     FFORMAT(5,205)((T2(I,J),I=1,3),MON(J),J=1,M2)
     IF(0(I),EQ,1)WRITE(8,1006)((T2(I,J),I=1,3),J=1,M2)
41   DD 41 J=1; J=JULIAN(MON(J),T2(I,J))
1006  FORTL WXCUM
     CALL DATUM
     CALL RADII
     DD 61 J=1, M1 GO TO 62
     IF(M4, EQ, M1 GO TO 62)
133  WRITE(6, 133)
     FORTL 63
     GO TO 63
62   WRITE(6, 130)
130  FORTL 131) THE FOLLOWING ARE THE DATUM POINTS FOR THE.1)
131  FORTL 132) T2(2; J) T2(3; J)
     FORTL 133) SEARCH:
     WRITE(6, 131) (LAF(J, I), FLO(J, I), DE(J, I), FLO(J, I), HE(J, I),
132  1) C(J, I), RADIUS(J, I), WIND(M, I), MM=1, 2), I=1, M1)
     FORTL 132) F4.4X, WIND: F5.1, K1$ FROM: F5.0
     FORTL 133) WIND: F5.1, K1$ FROM: F5.0
     IF(RADIUS(J, I), EQ, 0.1 GO TO 61
     WRITE(6, 134) AMS
     READ(5, 135) AMS
     IF(AMS, EQ, WRONG) GO TO 61
     WRITE(6, 136)
     PEAT(5, 137) ALT
     PEAT(5, 138) VIS
     PEAT(5, 139) VIS
     PEAT(5, 140) VLEN
     READ(5, 137) CLOUDS
     WRITE(6, 137) CLEN, VIS, ALT, WIND(1, I, J), CLOUDS)
     WRITE(6, 141) SW
     FORTL 141) SWEEP WIDTH? Y OR N
     FORTL 141) ENTER SEARCH ALTITUDE (EX:800.1)
     FORTL 141) ENTER VISIBILITY IN MILES (EX:10.0)
     FORTL 141) ENTER BOAT LENGTH IN FEET (EX:36.0)
     FORTL 141) ENTER CLOUD COVER IN FRACTION (EX: 0.9)
     FORTL 141) ENTER SWEEP WIDTH=, FLO.I, MILES.
134  134
135  135
136  136
137  137
138  138
139  139
140  140
141  141

```

```

SAR01450
SAR01460
SAR01470
SAR01480
SAR01490
SAR01500
SAR01510
SAR01520
SAR01530
SAR01540
SAR01550
SAR01560
SAR01570
SAR01580
SAR01590
SAR01600
SAR01610
SAR01620
SAR01630
SAR01640
SAR01650
SAR01660
SAR01670
SAR01680
SAR01690
SAR01700
SAR01710
SAR01720
SAR01730
SAR01740
SAR01750
SAR01760
SAR01770
SAR01780
SAR01790
SAR01800
SAR01810
SAR01820
SAR01830
SAR01840
SAR01850
SAR01860
SAR01870
SAR01880
SAR01890
SAR01900
SAR01910
SAR01920

```

SARCI930
 SARCI940
 SARCI950
 SARCI960
 SARCI970
 SARCI980
 SARCI990
 SAR02000
 SAR02010
 SAR02020
 SAR02030
 SAR02040
 SAR02050
 SAR02060
 SAR02070
 SAR02080
 SAR02090
 SAR02100
 SAR02110
 SAR02120
 SAR02130
 SAR02140
 SAR02150
 SAR02160
 SAR02170
 SAR02180
 SAR02190
 SAR02200
 SAR02210
 SAR02220
 SAR02230

SAR02240
 SAR02250
 SAR02260
 SAR02270
 SAR02280
 SAR02290
 SAR02300
 SAR02310
 SAR02320
 SAR02330
 SAR02340
 SAR02350

```

61 CONTINUE
   WRITE(6,999)
   WRITE(6,998)DESC
999 FORMAT(' GOOD LUCK ON YOUR SEARCH LET ME KNOW IF YOU FIND. ')
998 FORMAT(' THE',15A4////)
   STOP
   END
  
```

```

-----
SUBROUTINE NSEW
PROGRAMMER: LT J. H. DISCENZA, USCG

THIS SUBROUTINE CONVERTS LATITUDE AND LONGITUDE AS
EXPRESSED IN "NORTH" AND "SOUTH" TO ALGEBRAIC (+ OR -)
QUANTITIES. IN ADDITION IT READS THE ALGEBRAIC QUANTITIES
BACK TO THE OPERATOR FOR HIM TO DOUBLE CHECK.

ENTERING ARGUMENTS:
LAD,YLA,D:  LATITUDES (D=N,S)
LCD,YLD,H:  LONGITUDES (H=E,W)
MI:         THE NUMBER OF POSITIONS TO BE CONVERTED

OUTPUTS:
LAD,YLA:    ALGEBRAIC VERSION OF LATITUDE
LCD,YLD:    ALGEBRAIC VERSION OF LONGITUDE
CHECK:      A "Y" OR "N" ANSWER FROM THE OPERATOR WHICH
            INDICATES WHETHER THE LIST OF LATITUDES AND
            LONGITUDES PRODUCED ARE CORRECT.
  
```

```

SUBROUTINE NSEW
COMMON LAD(9),YLA(9),D(9),LCD(9),YLD(9),H(9),MI,CHECK,O,
1DESC(15),FLA(9,18),FLD(9,18),MON(9),IX1,IX2,TAP,
2CDL,CGR,T2(3,9),T3(3,9),RADIUS(9,9),C(9,18),WIND(2,9,9),
3INTEGER AI(3,9)
INTEGER LAF(9,9),LOF(9,9)
DATA X1,X2,I1,MI
DO 4 I=1,MI
IF(D(I).EQ.XS) GO TO 14
GO TO 25
LAD(I)=-LAD(I)
  
```

SAR02370
 SAR02380
 SAR02390
 SAR02400
 SAR02410
 SAR02420
 SAR02430
 SAR02440
 SAR02450
 SAR02460
 SAR02470
 SAR02480
 SAR02490
 SAR02500
 SAR02510
 SAR02520
 SAR02530
 SAR02540
 SAR02550
 SAR02560
 SAR02570
 SAR02580
 SAR02590
 SAR02600
 SAR02610
 SAR02620
 SAR02630
 SAR02640
 SAR02650
 SAR02660
 SAR02670
 SAR02680
 SAR02690
 SAR02700
 SAR02710
 SAR02720
 SAR02730
 SAR02740
 SAR02750
 SAR02760
 SAR02770
 SAR02780
 SAR02790
 SAR02800
 SAR02810
 SAR02820
 SAR02830
 SAR02840

```

YLA(I)=-YLA(I)
IF(H(I).EQ.XE)GO TO 35
GO TO 44
LOD(I)=-LOD(I)
YLO(I)=-YLO(I)
WRITE(6,800)LAD(I),YLA(I),LCD(I),YLO(I),D(I),H(I)
FORMAT(16,F10.1,16,F10.1,2A4)CHECK:*,2A4)
WRITE(6,801)
FORMAT(1,*)CHECK TYPE Y OR N*)
READ(5,802)CHECK
FORMAT(A1)
RETURN
END
  
```

25
 35
 44
 800
 801
 802

 SUBROUTINE WXCOMP

PROGRAMMER: LT J. H. DISCENZA, USCG

THIS SUBROUTINE HANDLES DATA FROM A WEATHER TAPE, AND COMPUTES SET, DRIFT, AND DRIFT ERROR FOR SEVERAL TRACKS AT A TIME.

THE WEATHER DATA IS STORED ON TAPE IN "FIELDS". THESE FIELDS CONTAIN ALL DATA FOR ONE PARAMETER (WIND, CURRENT) FOR THE NORTHERN HEMISPHERE FOR ONE OBSERVATION TIME. THE REFERENCE SYSTEM FOR THE WEATHER DATA IS A SQUARE GRID, 63 POINTS ON A SIDE, BASED ON A POLAR STEREO-GRAPHIC PROJECTION. THE POINT 32, 32 IS ON THE NORTH POLE. ALL OTHER POINTS MAY BE DETERMINED FROM LATITUDE AND LONGITUDE BY THE FOLLOWING FORMULAE:

$$RI=32+ 31.205((1-SIN LAT)/(1+SIN LAT))^{1/2} \times \cos(LONG+10^{\circ})$$

$$RJ=32- 31.205((1-SIN LAT)/(1+SIN LAT))^{1/2} \times \sin(LONG+10^{\circ})$$

THE PROGRAM BEGINS BY USING THESE FORMULAE TO CONVERT ALL STARTING POSITIONS TO THIS GRID SYSTEM. THEN IT TESTS THESE COORDINATES FOR EXTREMES AND SELECTS A SET OF WEATHER OBSERVATION POSITIONS LARGE ENOUGH TO PROVIDE SUFFICIENT WEATHER DATA FOR THE PROBLEM.
 IT THEN SEARCHES THE DATA BANK FOR THE PROPER TIME INTERVAL AND BEGINS READING IN WEATHER. THE COMPUTATIONS BEGIN AT THE TIME OF THE EARLIEST APPROPRIATE WEATHER OBSERVATION AND ADVANCES HOUR BY HOUR. AT EACH TIME (T) THE WEATHER AT THE PREVIOUS OBSERVATION (A3) AND THE WEATHER AT THE NEXT OBSERVATION (A5) ARE USED. TO FIND THE WEATHER

CC


```

SSAR03770
SSAR03780
SSAR03790
SSAR03800
SSAR03810
SSAR03820
SSAR03830
SSAR03840
SSAR03850
SSAR03860
SSAR03870
SSAR03880
SSAR03890
SSAR03900
SSAR03910
SSAR03920
SSAR03930
SSAR03940
SSAR03950
SSAR03960
SSAR03970
SSAR03980
SSAR03990
SSAR04000
SSAR04010
SSAR04020
SSAR04030
SSAR04040
SSAR04050
SSAR04060
SSAR04070
SSAR04080
SSAR04090
SSAR04100
SSAR04110
SSAR04120
SSAR04130
SSAR04140
SSAR04150
SSAR04160
SSAR04170
SSAR04180
SSAR04190
SSAR04200
SSAR04210
SSAR04220
SSAR04230
SSAR04240

```

```

TEMP2=RI(I)
TEMP3=RJ(I)
TEMP4=RJ(I)
DO 166 I=1,M1
  TEMP1)TEMP1=RI(I)
  IF(RI(I)).GT.TEMP2)TEMP2=RI(I)
  IF(RJ(I)).GT.TEMP3)TEMP3=RJ(I)
  IF(RJ(I)).LT.TEMP4)TEMP4=RJ(I)
166
C
C      SELECT MAXIMUM GRID POINTS 3 MESH LENGTHS OUTSIDE.
IC1=TEMP1+3.
IC2=TEMP2+3.
IC3=TEMP3+3.
IC4=TEMP4+3.
C
C      DETERMINE SIZE OF WEATHER MATRIX TO BE SELECTED
M8=IC1-IC2
M8=IC3-IC4
IF(M8.EQ.0)M1=IC3,IC2,IC1,M8,IC4
IF(M8.EQ.M1)GO TO 263
C
C      IF MINIMAL SIZE TO ACCOMMODATE TWO TRACKS TO DOUBLE
C      ORIGINAL SIZE TO ACCOMMODATE TWO TRACKS FOR EACH STARTING
C      POINT
DO 209 J=1,M1
  K=M1+J
  RI(K)=RI(J)
  RJ(K)=RJ(J)
DO 210 I=1,M1
  K=M1+I
  J=2+I
  RI(J)=RI(K)
  RJ(J)=RJ(K)
  RI(J-1)=RI(K)
  RJ(J-1)=RJ(K)
  IF(M1.EQ.0)GO TO 263
CONTINUE
C
C      SELECT APPROPRIATE WEATHER AND STORE IN A3
DO 169 M=1,4
  IF(MIN.EQ.0)AND(M2.EQ.1)GO TO 168
  IF(TAP.EQ.0)READ(12,EARR=2000)TITLE,M2
  M12=M12+1
  M13=M12/8
  M1(2)=M12+1
  M1(2)=M12/8
  M1(2)=12+(M13-2*(M13/2))

```

166

C

C

C

C

209

210

263

C


```

172 T(I)=Y3(I)
173 IF(N(3).EQ.1)WRITE(9,1117)TA,T
      CONTINUE
      GO TO 170 J=1,M1
      IF(J(2).EQ.1)WRITE(9,1101)
      IF(J(2).EQ.1)WRITE(9,1102)J
      TEST STARTING POINT INITIALIZE SWITCH TO SEE IF THE
      TRACK(S) FOR EACH STARTING POINT HAVE BEGUN DRIFTING.
      IF(ITIN(J).EQ.1)GO TO 175
      IF NOT BEGUN, TEST STARTING DATES AND TIMES.
      IF(O(2).EQ.1)WRITE(9,1103)T(1),A1(1,J)
      IF(T(1)-A1(1,J))170,173,174
      IF(O(2).EQ.1)WRITE(9,1104)T(2),A1(2,J)
      IF(T(2)-A1(2,J))170,176,174
      IF(O(2).EQ.1)WRITE(9,1106)
      IF(T(3)-A1(3,J))177,178,179
      SET VALUE OF R, THE PORTION OF THE FIRST HOUR DRIFTING.
      R=FLCAT(A1(3,J)-T(3))/60.
      GO TO 180
      GO TO 180
      WRITE(9,1107)
      R=1.+FLDAY(T(3)-A1(3,J))/50.
      GO TO 180
      IF(O(2).EQ.1)WRITE(9,1108)
      TEST DATUM TIME TERMINATION SWITCH. IF TRUE, TEST NEXT
      DATUM TIME.
      GO TO 181 I=1,M2
      IF(ITERM(I).EQ.0)GO TO 189
      CONTINUE
      WRITE(6,1105)
      R=1
      IF(O(2).EQ.1)WRITE(9,1109)K
      IF(O(2).EQ.1)WRITE(9,1103)T(1),T2(1,K)
      IF(T(1)-T2(1,K))182,183,174
      IF(O(2).EQ.1)WRITE(9,1104)T(2),T2(2,K)
      IF(T(2)-T2(2,K))182,184,174
      WRITE(5,1105)
      GO TO 200
      SET VALUE OF R, THE PORTION OF AN HOUR THIS PARTICULAR
      TRACK IS TO DRIFT.
      GO TO 182 P=1.

```

```

54720 SAR04720
54740 SAR04740
54750 SAR04750
54760 SAR04760
54770 SAR04770
54780 SAR04780
54790 SAR04790
54800 SAR04800
54810 SAR04810
54820 SAR04820
54830 SAR04830
54840 SAR04840
54850 SAR04850
54860 SAR04860
54870 SAR04870
54880 SAR04880
54890 SAR04890
54900 SAR04900
54910 SAR04910
54920 SAR04920
54930 SAR04930
54940 SAR04940
54950 SAR04950
54960 SAR04960
54970 SAR04970
54980 SAR04980
54990 SAR04990
55000 SAR05000
55010 SAR05010
55020 SAR05020
55030 SAR05030
55040 SAR05040
55050 SAR05050
55060 SAR05060
55070 SAR05070
55080 SAR05080
55090 SAR05090
55100 SAR05100
55110 SAR05110
55120 SAR05120
55130 SAR05130
55140 SAR05140
55150 SAR05150
55160 SAR05160
55170 SAR05170
55180 SAR05180
55190 SAR05190
55200 SAR05200

```

```

7, 8, 9
10, 11, 12
13 - 16
17

```

```

184  GN TO 190
      IF(O(2)-EQ.1)WRITE(8,1106)
      IF(T(3)-T(3,K))1P5,1P6,1P7
C
C
      SET VALUE CF S, THE PORTION CF AN HOUR DRIFTED TOWARD 18,19,20
      A PARTICULAR DATUM TIME.
1P5  S=FLCAT(Y2(3,K)-T(3))/50.
1P6  GN TO 188
      S=0.
1P7  GN TO 198
      WRITE(6,11107)
      S=FLOAT(T2(3,K)-T(3))/60.
C
C
      SET DATUM TIME TERMINATION SWITCH TIME.
18P  ITTERM(K)=1
      IF(K.NE.M2.OR.J.NE.M1)GO TO 180
      TERM=1.
C
C
      INTERPOLATE WIND AND CURRENT FOR THIS POSITION.
18C  IM=M4/M1
      JM=J
      IM=I
      IFIX(RJ(L))-IC2
      JTI= IFIX(RJ(L))-IC2
      QI=RI(L)-FLCAT(JTI+IC2)
      QJ=RJ(L)-EQ.1WRITE(A,1140)OI,0J
      IT2=IT1+1
      JT2=JT1+1
      MU=A3(IT1, JT1, 3)+0J*(A3(IT1, JT2, 3)-A3(IT1, JT1, 3))
      WV=A3(IT1, JT1, 4)+0J*(A3(IT1, JT2, 4)-A3(IT1, JT1, 4))
      XU=A3(IT2, JT1, 3)+0J*(A3(IT2, JT2, 3)-A3(IT2, JT1, 3))
      XV=A3(IT2, JT1, 4)+0J*(A3(IT2, JT2, 4)-A3(IT2, JT1, 4))
      WJ=WV+OI*(XV-MV)
      CU=A3(IT1, JT1, 1)+0J*(A3(IT1, JT2, 1)-A3(IT1, JT1, 1))
      CV=A3(IT1, JT1, 2)+0J*(A3(IT1, JT2, 2)-A3(IT1, JT1, 2))
      DV=A3(IT2, JT1, 1)+0J*(A3(IT2, JT2, 1)-A3(IT2, JT1, 1))
      DI=A3(IT2, JT1, 2)+0J*(A3(IT2, JT2, 2)-A3(IT2, JT1, 2))
      CI=CU+OI*(DU-CU)
      CJ=CV+OI*(DV-CV)
      MU=A5(IT1, JT1, 3)+0J*(A5(IT1, JT2, 3)-A5(IT1, JT1, 3))
      WV=A5(IT1, JT1, 4)+0J*(A5(IT1, JT2, 4)-A5(IT1, JT1, 4))
      XU=A5(IT2, JT1, 3)+0J*(A5(IT2, JT2, 3)-A5(IT2, JT1, 3))
      XV=A5(IT2, JT1, 4)+0J*(A5(IT2, JT2, 4)-A5(IT2, JT1, 4))
      WJ=WV+OI*(XV-MV)
      CU=A5(IT1, JT1, 1)+0J*(A5(IT1, JT2, 1)-A5(IT1, JT1, 1))
      CV=A5(IT1, JT1, 2)+0J*(A5(IT1, JT2, 2)-A5(IT1, JT1, 2))
228  OI=RI(L)-FLCAT(JTI+IC2)
      IF(O(1)-EQ.1)WRITE(A,1140)OI,0J
      IT2=IT1+1
      JT2=JT1+1
      MU=A3(IT1, JT1, 3)+0J*(A3(IT1, JT2, 3)-A3(IT1, JT1, 3))
      WV=A3(IT1, JT1, 4)+0J*(A3(IT1, JT2, 4)-A3(IT1, JT1, 4))
      XU=A3(IT2, JT1, 3)+0J*(A3(IT2, JT2, 3)-A3(IT2, JT1, 3))
      XV=A3(IT2, JT1, 4)+0J*(A3(IT2, JT2, 4)-A3(IT2, JT1, 4))
      WJ=WV+OI*(XV-MV)
      CU=A3(IT1, JT1, 1)+0J*(A3(IT1, JT2, 1)-A3(IT1, JT1, 1))
      CV=A3(IT1, JT1, 2)+0J*(A3(IT1, JT2, 2)-A3(IT1, JT1, 2))
      DV=A3(IT2, JT1, 1)+0J*(A3(IT2, JT2, 1)-A3(IT2, JT1, 1))
      DI=A3(IT2, JT1, 2)+0J*(A3(IT2, JT2, 2)-A3(IT2, JT1, 2))
      CI=CU+OI*(DU-CU)
      CJ=CV+OI*(DV-CV)
      MU=A5(IT1, JT1, 3)+0J*(A5(IT1, JT2, 3)-A5(IT1, JT1, 3))
      WV=A5(IT1, JT1, 4)+0J*(A5(IT1, JT2, 4)-A5(IT1, JT1, 4))
      XU=A5(IT2, JT1, 3)+0J*(A5(IT2, JT2, 3)-A5(IT2, JT1, 3))
      XV=A5(IT2, JT1, 4)+0J*(A5(IT2, JT2, 4)-A5(IT2, JT1, 4))
      WJ=WV+OI*(XV-MV)
      CU=A5(IT1, JT1, 1)+0J*(A5(IT1, JT2, 1)-A5(IT1, JT1, 1))
      CV=A5(IT1, JT1, 2)+0J*(A5(IT1, JT2, 2)-A5(IT1, JT1, 2))

```



```

C C      INCREMENT DRIFT ERROR
C C      DER(L)=DER(L)+SORT(X*X+Y*Y)/8.
C C
C C      ADVANCE POSITIONS TO RATUM TIME IN FNWF COORDINATE SYSTEM
C C      PI(L)=RI(L)+X/FM(J)
C C      PJ(L)=RJ(L)+Y/FM(J)
C C      IF(O(1).EQ.1)WRITE(A,1134)I,L,FM(J),X,Y,PI(L),PJ(L)
C C
C C      CONVERT FROM GRID SYSTEM TO GEOGRAPHIC COORDINATES.
C C      MND=1
C C      CALL FNID(LAF(K,L),FLA(K,L),LOF(K,L),FLO(K,L),PI(L),PJ(L),FM(J),MN
C C      IC)
C C      IF(O(1).EQ.1)WRITE(B,1136)XLAT,XLON,LAF(K,L),FLA(K,L),LOF(K,L),FLO
C C      I(K,L)
C C      WRITE(6,1120)K,L,LAF(K,L),FLA(K,L),LOF(K,L),FLO(K,L)
C C
C C      TEST TERMINATE SWITCH. IF FALSE, ADVANCE ALL TRACKS
C C      ONE HOUR
C C      NN=J*IM
C C      IF(J.NE.M1.AND.L.EQ.NN)ITTERM(K)=0
C C      IF(ITERM.NE.1)GO TO 220
C C      IF(M4.EQ.M1)GO TO 230
C C      IF(L.EQ.N1)GO TO 230
C C      GO TO 240
C C      X=R*(MU+CV)
C C      Y=R*(MV+CV)
C C
C C      INCREMENT DRIFT ERROR
C C      DER(L)=DER(L)+SORT(X*X+Y*Y)/8.
C C
C C      ADVANCE POSITIONS R HOURS IN FNWF COORDINATE SYSTEM.
C C      RI(L)=RI(L)+X/FM(J)
C C      RJ(L)=RJ(L)+Y/FM(J)
C C      IF(N(1).EQ.1)WRITE(B,1135)I,L,FM(J),X,Y,RI(L),RJ(L)
C C      IF(M4.EQ.M1)GO TO 250
C C      NN=J*IM
C C      IF(L.EQ.N1)GO TO 250
C C      L=J*IM
C C      GO TO 228
C C      ITIN(J)=1
C C      CONTINUE
C C
C C      INCREMENT TIME ONE HOUR.
C C      T(2)=T(2)+1
C C      IF(T(2).LT.24)GO TO 251
C C      T(2)=T(2)-24
C C      T(1)=T(1)+1

```

```

SAR0617C
SAR0618C
SAR0619C
SAR0620C
SAR0621C
SAR0622C
SAR0623C
SAR0624C
SAR0625C
SAR0626C
SAR0627C
SAR0628C
SAR0629C
SAR0630C
SAR0631C
SAR0632C
SAR0633C
SAR0634C
SAR0635C
SAR0636C
SAR0637C
SAR0638C
SAR0639C
SAR0640C
SAR0641C
SAR0642C
SAR0643C
SAR0644C
SAR0645C
SAR0646C
SAR0647C
SAR0648C
SAR0649C
SAR0650C
SAR0651C
SAR0652C
SAR0653C
SAR0654C
SAR0655C
SAR0656C
SAR0657C
SAR0658C
SAR0659C
SAR0660C
SAR0661C
SAR0662C
SAR0663C
SAR0664C

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SUBROUTINE CATUM
PROGRAMMER: LT J. H. DISCENZA, USCG
COMMON LAD(9), YLA(3), D(9), LOD(9), YLO(9), H(9), M1, CHECK, O,
1CE(9,9), LHE(9,9), T2, T3, AL, TZ(9), MCN(9), IX1, IX2, TAP,
2DESC(15), FLA(9,18), FLO(9,18), LAF, LOF, M2, M4, M6, CV1, CV2, CV3, CV4,
3CDI, CD2, PD(3,9), DD(9,18), RADIUS(9,9), C(9,18), WIND(2,9,9),
INTEGGER AI(3,9), LCF(9,9)
INTEGER LAF(20)
DATA XN, S, E, W, I, M, N, I, H, S, I, H, E, I, M, W /
IF(O(1)) EQ. 1) WRITE(8,1061)
FORMATT(1): ENTERING DATA
IF(M4 EQ. M1) GO TO 302
IF(O(1)) EQ. M1) WRITE(8,1062)
DO 301 K=1, M1
J=2*K
ALA=(FLOAT(LAF(I, J-1))+LAF(I, J))+(FLA(I, J-1))+FLA(I, J))/60./2.
ALO=(FLO(I, J-1)-DD(I, J))/120.
DLA=(FLOAT(LAF(I, J-1))-LAF(I, J))+(FLA(I, J-1))-FLA(I, J))/60./
DLO=ALOS(ALA*P)*(FLOAT(LOF(I, J-1))+LOF(I, J))/6.
10XX=SORT(DLA*CLA+DLO*DLO)
FLA(I, K)=ALA*60.
LAF(I, K)=FLA(I, K)/60.
FLO(I, K)=FLO(I, K)-FLOAT(LAF(I, K))*60.
LOF(I, K)=ALOS*60.
FLO(I, K)=FLO(I, K)/60.
IF(O(1)) EQ. 1) WRITE(8,1063) I, J, K, ALA, ALO, ADD, DLO, DLA, LAF(I, K), FLA(I, K), LOF(I, K)
1, K) LOF(I, K)
DO CONTINUE I=1, M2
DO 151 J=1, M1
WIND(2, J, I)=WIND(2, J, I)+FLOAT(LOF(I, J))+FLO(I, J)/60.-10.
IF(LAF(I, J)) 152, 55, 53
IF(FLA(I, J)) 152, 53, 53
IF(O(1)) EQ. 1) GO TO 54
GO TO 54
PE(I, J)=S
LAF(I, J)=-LAF(I, J)
FLA(I, J)=-FLA(I, J)
IF(LOF(I, J)) 156, 57, 58
IF(FLO(I, J)) 156, 58, 58
PE(I, J)=H

```

```

C7C40
SAR07050
SAR07060
SAR07070
SAR07080
SAR07090
SAR07100
SAR07110
SAR07120
SAR07130
SAR07140
SAR07150
SAR07160
SAR07170
SAR07180
SAR07190
SAR07200
SAR07210
SAR07220
SAR07230
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SAR07270
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SAR07290
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SAR07310
SAR07320
SAR07330
SAR07340
SAR07350
SAR07360
SAR07370
SAR07380
SAR07390
SAR07400
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SAR07430
SAR07440
SAR07450
SAR07460
SAR07470
SAR07480
SAR07490
SAR07500
SAR07510

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C

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302

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SAR07520
 SAR07530
 SAR07540
 SAR07550
 SAR07560
 SAR07570
 SAR07580
 SAR07590
 SAR07600
 SAR07610
 SAR07620
 SAR07630
 SAR07640
 SAR07650
 SAR07660
 SAR07670
 SAR07680
 SAR07690
 SAR07700
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 SAR07800
 SAR07810
 SAR07820
 SAR07830
 SAR07840
 SAR07850
 SAR07860
 SAR07870
 SAR07880
 SAR07890
 SAR07900
 SAR07910
 SAR07920
 SAR07930
 SAR07940
 SAR07950

```

56 HE(I,J)=E
   LDF(I,J)=-LDF(I,J)
   FLD(I,J)=-FLD(I,J)
2  IF(LDF(I,J).LT.360)GO TO 151
   LDF(I,J)=LDF(I,J)-360
   GO TO 2
151 CONTINUE
1062 FORMAT(2X,'SEARCH',5X,'TRACK',5X,'START',6X,'ALA',7X,'ALO',7X,'ADD',
1063 17X,'DLA',7X,'DLA',7X,'FLA',7X,'LOF',7X,'FLO')
   FORMAT(15,2I10,F13.3,4F10.3,I10,F10.3)
   RETURN
   END
  
```

CC

SUBROUTINE RADII
 PROGRAMMER: LT J.H. DISCENZA,USCG

THIS SUBROUTINE COMPUTES THE PROPER SEARCH RADIUS FOR
 EACH DATUM POINT IN EACH SEARCH. IF THERE IS TO BE "NO"
 SEARCH AT A PARTICULAR DATUM TIME, SEARCH RADII FOR THAT
 TIME ARE SET AT ZERO.

ENTERING ARGUMENTS:

LAD,YLAD,LOD,YLO: LATITUDES AND LONGITUDES OF STARTING
 POSITIONS
 LAK,ALK,LOK,OLK: LATITUDE AND LONGITUDE OF LAST KNOWN
 POSITION
 IX1: DRIFT RATE AS PERCENT OF WIND
 IX2: DRIFT DIVERGENCE IN TENS OF DEGREES
 X1,X2: COEFFICIENTS OF EQUATION FOR DETERMINING
 Y: DISTRESS CRAFT POSITION ERROR
 KJ: SEARCH NUMBER GENERATED
 INTERMEDIATE ARGUMENTS:
 COSLAT: COSINE OF LATITUDE, LAST KNOWN POSITION
 X: DISTRESS CRAFT POSITION ERROR
 C: TOTAL PROBABLE ERROR
 SF: SAFETY FACTOR (BASED ON SEARCH NUMBER)
 DX: DISTANCE FROM LAST KNOWN POSITION

OUTPUTS:
 RADIUS: SEARCH RADIUS (RADIUS=0. INDICATES NO
 CALCULATION OF SEARCH AREA DESIRED FOR THAT TIME.)

```

SUBROUTINE RADII
COMMON LAD(9),YLA(9),D(9),LOD(9),YLO(9),H(9),M1,CHECK,0,
1DE(9,9),HE(9,9),T2,T3,A1,TZ(9),MON(9),IX1,IX2,TAP,
2DESC(15),FLA(9,18),FLO(9,18),LAF,LCF,M2,M4,M6,CV1,CV2,CV3,CV4,
3COL,C02,P,DD(9,18),RADIUS(9,9),C(9,18),WIND(2,9,9)
INTEGER AI(3,9),T2(3,9),T3(3,9)
INTEGER LAF(9,9),LOF(9,9),KR(9)
DIMENSION SF(9)
ENTER LAST KNOWN POSITION
WRITE(6,3001)
FORMAT(1,ENTER LAST KNOWN POSITION. EX: 3522.ON,07653.0M.)
3001 READ(5,3002)LAK,ALK,LCK,CLK
FORMAT(12,F4.0,2X,I3,F4.0)
C
COSLAT=COS((FLOAT(LAK)+ALK/60.)*PI)
C
WRITE(6,3003)DESC
FORMAT(1,IS,15A4)
3003 WRITE(6,3004)
FORMAT(1,A(1),ROAT,(2)SHIP,OR(3)AIRCRAFT?(ENTER 1,2,OR3),
3004 READ(5,3005)LL
FORMAT(1,1)
3005 IF(LL-2)602,603,604
C 602 X1=15
X2=.15
GO TO 605
C 603 X1=5
X2=.05
GO TO 605
C 604 X1=10.
X2=.1
C
WRITE(6,3006)
FORMAT(1,ENTER SEARCH UNIT FIX ERROR, Y. EX: 5.0.)
3006 READ(5,3007)Y
FORMAT(F20.0)
3007 YSQ=Y*Y
C
WRITE(6,3008)
FORMAT(1,INDICATED DISTRESS CRAFT POSITION ERROR,X:.)
3008 WRITE(6,3009)X1,X2
FORMAT(1,X=,F6.2,(1) +,F6.2,(2) TIMES DIST. FROM LAST KNOWN PO
3009 ISITION.))

```

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SAR07960
SAR07970
SAR07980
SAR07990
SAR08000
SAR08010
SAR08020
SAR08030
SAR08040
SAR08050
SAR08060
SAR08070
SAR08080
SAR08090
SAR08100
SAR08110
SAR08120
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SAR08300
SAR08310
SAR08320
SAR08330
SAR08340
SAR08350
SAR08360
SAR08370
SAR08380
SAR08390
SAR08400
SAR08410
SAR08420
SAR08430

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103
)
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610 WRITE(6,3010)
3010 FORMAT(' ANY CORRECTIONS? (TYPE 0,1,2, OR 12)')
3011 READ(5,3011)LI,L2
3011 IF(LI-1)606,607,608
607 WRITE(6,3012)LI
3012 FORMAT(' ENTER PARAMETER(,II,):')
608 IF(L2-2)606,608,609
WRITE(6,3012)L2
608 READ(5,3007)X2
GO TO 606
609 WRITE(6,3013)L2
3013 FORMAT(' INCORRECT RESPONSE:',II,' -NO PARAMETER GREATER THAN 2.')
CO TO 610
C 606 DO 611 J=1,M1
DXN=FLOAT(LAD(J)-LAK)*60.+YLA(J)-ALK
DXW=(FLOAT(LOD(J)-LOK)*60.+YLO(J)-OLK)/COSLAT
DX=SQRT(DXN*DXN+DXW*DXW)
XSQ=X*X
DO 611 I=1,M2
C(I,J)=SQRT(XSQ+YSQ+DD(I,J)*DD(I,J))
611 IF(I)6,3014)
3014 FORMAT(' IS EACH DATUM TIME A DIFFERENT SEARCH (1,2,3,ETC.)?')
3017 READ(5,3017)RESP
FORMAT(11A1)
DATA WRONG/1HN/
IF(RES.EQ.WRONG)GO TO 612
GO TO 613
612 WRITE(6,3015)
3015 FORMAT(' ENTER SEARCH NUMBER CORRESPONDING TO DATUM TIME:')
DO 614 I=1,M2
WRITE(6,3016)(I2(J,I),J=1,3)
3016 FORMAT(3I2,' SEARCH:')
614 READ(5,3005)KR(I)
GO TO 615
613 DO 616 I=1,M2
616 KR(I)=I
615 DO 617 J=1,M2
IF(KR(J).EQ.0)GO TO 618
C IF(KR(J).GE.5)GO TO 625
C KK=KR(J)
C GO TO(621,622,623,624),KK
C

```

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C8440
SAR08450
SAR08460
SAR08470
SAR08480
SAR08490
SAR08500
SAR08510
SAR08520
SAR08530
SAR08540
SAR08550
SAR08560
SAR08570
SAR08580
SAR08590
SAR08600
SAR08610
SAR08620
SAR08630
SAR08640
SAR08650
SAR08660
SAR08670
SAR08680
SAR08690
SAR08700
SAR08710
SAR08720
SAR08730
SAR08740
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SAR08780
SAR08790
SAR08800
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SAR08880
SAR08890
SAR08900
SAR08910

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SAR09360
 SAR09370
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 SAR09690

```

TLO=6C.*(XLCN-FLCAT(LOT))
FM=388.8556/(1.+O)
RETURN
END
PEAL FUNCTION SWIDTH(SL,VIS,ALT,MIND,CC)
X=ALOG(SL)
Y=ALOG(VIS)
IF(ALT.GE.200.1GO TO 1
Z=ALT 2
O TO 2
Z=ALT/1000
XX=-3.34377+1.25887*x+2.55442*y+0.01023*7
XM=WIND/10.
F1=.086+XM*(.298-.116*XM)
F2=1.131-CC*(.472+.152*CC)
SWIDTH=XX*F1*F2
RETURN
END
INTEGER FUNCTION JULIAN(X=O,N)
DIMENSION C(12),J(12)
DATA C(1),C(2),C(3),C(4),C(5),C(6),C(7),C(8),C(9),C(10),C(11),C(12)
/31JAN,31FEB,30MAR,31APR,30MAY,30JUN,31JUL,31AUG,30SEP,30OCT,
23NOV,31DEC/
DATA J(1),J(2),J(3),J(4),J(5),J(6),J(7),J(8),J(9),J(10),J(11),
1 J(12)/0,31,59,90,120,151,181,212,243,273,304,334/
DO 1 I=1,12
IF(C(I).EQ.XM)GO TO 2
CONTINUE=O
JULIAN=O
GO TO 3
JULIAN=J(I)+N
CONTINUE
RETURN
END
  
```

```

C
C
C
PROGRAM TC EVALUATE OPTIMUM SIZES FOR SUCCESSIVE SQUARE
SEARCHES
DOUBLE PRECISION XX(400)
DIMENSION PRC(400)
DIMENSION XSP(400),YSP(400)
DOUBLE PRECISION D,P(400),X(400)
DIMENSION CM(SF15)
DOUBLE PRECISION RADIUS,ORD,XXX,AREA,DAREA,SAREA,PI2,PI0,RPEP,ALPHA
IA RPRIME(5)
REAL LAB(5)
1 REAL*8 TITLE(12)/96MDIS10432 - PROBABILITY DENSITIES BETWEEN SICCE
2 ISSIVE OPTIMUM SQUARE SEARCHES - J.M.DISCENZA
DATA LAB/4HINIT,4HIST,4H2ND,4H3RD,4H4TH /
C
C
EVALUATE BIVARIATE NORMAL PROBABILITY DISTRIBUTION
FOR SQUARE AREAS WITH RESPECT TO R, R=1/2 OF ONE SIDE
P12=0.000/PI2
P10=3.1415926536/4.000
CPIQ=PI/45.000
SDPIO=DSIM(DPIO)
CTYPE=PI8*SDPIO*0.0100
RADIUS=0.000
AREA=0.000
DO 1 I=1,RADIUS*0.0100
ALPHA=DPIO/2.000
DAREA=0.000
DO 5 K=1,3(ALPHA)
COSD=CC(CALUS/COSD)
RPRIME=RADIUS/COSD
CALL MP(CA(9,14)
IF(ALPHA=ALPHA+DPIO
CAREA=DAREA+CRD*PRIME/COSD
IF(I.FO.1)GO TO 50
PRO(I)=PRO(I-1)+DAREA*CORR
GO TO 51
50 PRO(I)=DAREA*CORR
C
C
FIND DENSITY FUNCTION XX
51 XX(I)=DAREA*CORR/(.06*RADIUS)
1 CONTINUE
SOLC0040
SOL00050
SOL00060
SOL00070
SOL00080
SOL00090
SOL00100
SOL00110
SOL00120
SOL00130
SOL00140
SOL00150
SOLC0170
SOL00180
SOL00190
SOL00200
SOL00210
SOL00220
SOL00230
SOL00240
SOL00250
SOL00260
SOL00270
SOL00290
SOL00320

```

SOL00330
SOL00350

SOL00410
SOL00360
SOL00370
SOL00380
SOL00390
SOL00400

SOL00420

SOL00430

SOL00440

SOL00490
SOL00450

```
14 TC 6  
6 WRITE(6,22)I,RADIUS  
CONTINUE  
40 I=1,400  
40 XSP(I)=FLOAT(I)/100.  
40 W=0.  
WRITE(6,100)  
SF(1)=1.  
SF(2)=1.6  
SF(3)=2.  
SF(4)=2.3  
SF(5)=2.5  
DO 99 I1Q=1,2 WIDTH  
C SET SWEEP WIDTH  
W=0.05  
WPER=W/1.18  
IF(I1Q.GT.1)WRITE(6,106)  
WRITE(6,103)WPER  
DO 99 IQ=1,2  
IF(I1Q.EQ.2)WRITE(6,105)  
DO 42 I=1,400  
X(I)=XX(I)  
P(I)=PRC(I)  
DO 41 I=1,400  
7SP(I)=P(I)  
YSP(I)=X(I)  
MN=2  
IF(I1.EQ.1)MN=1  
IF(I1.EQ.5)MN=3  
C  
C USING SAFETY FACTOR FIND LENGTH, EFFORT  
SIZE=SF(I)*1.18  
XL=4.*SIZE*SIZE/(FLOAT(IQ)*W)  
XLER=XL/1.18  
EFFORT=XLER*WPER*XLER, EFFORT  
WRITE(6,104)XLER, EFFORT  
C  
C FIND PROBABILITY OF SUCCESS FOR THIS SEARCH AREA  
NSTAN=P00(W*XL/(4.*SIZE*SIZE))  
D=0.01000  
J=SIZE*100.  
IF(J.GT.400)J=400  
FOLD=P(J)*PCD(W*XL/(4.*SIZE*SIZE))  
SIZE=SIZEF+.01  
NSTAN=POLD  
J=SIZE*100.  
IF(J.GT.400)J=400
```


14 CRN=0.3535533005MRRD
17 CRR=C.0
14 C) TO 19
1A CRR=1.0
END

SOL02190
SOL02200
SOL02210
SOL02220
SOL02230
SOL02240

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<p>A computer program is presented which solves the search planning problem for survivors at sea. The program is designed to utilize weather data as compiled by the United States Navy at its Fleet Numerical Weather Central, Monterey, California.</p> <p>An investigation is also made into the search criteria used by the United States Coast Guard in its planning procedures. Guidelines are given for the use of the square search and the Sector search.</p>		

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