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Surveillance Radar Detection (SURDET) Program

LAURA C. DAVIS and GERARD V. TRUNK

Radar Analysis Staff
Radar Division

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Surveillance Radar Detection (SURDET) model is a user-oriented computer model that produces target detections and position estimates for each radar scan. The model employs a variety of target trajectories and environments including jamming, multipath propagation, and rain and sea clutter. The model is a Monte-Carlo simulation, and the automatic detector is simulated on a pulse-to-pulse basis that takes into account target suppression and resolution effects in a dense-target environment. The output of this program can be used as the input for the Multiple Radar Integrated Tracking (MERIT) program.

(Continues)

20. ABSTRACT (Continued)

A model overview, instructions for the use of SURDET, sample outputs, and a detailed description of each SURDET routine are included in the report.

CONTENTS

SURVEILLANCE RADAR DETECTION (SURDET) PROGRAM

INTRODUCTION

The Radar Analysis Staff of the Naval Research Laboratory has previously developed the Surveillance Radar Systems Evaluation Model (SURSEM) [1] for evaluating radar systems. SURSEM produces radar single-scan and cumulative probability-of-detection values as a function of target range and orientation. The radar operates within a specified scenario, defined by the user to include the target to be detected, up to nine additional sources of jamming radiation, and an optional environment of wind, rain, and multipath propagation.

Future radars will use automatic detection and tracking systems; consequently probability-of-detection values are insufficient for evaluating system performance. For instance, in a scenario involving a target raid, questions arise as to whether the multiple targets can be resolved, how accurate the position estimates are, and whether the correct tracks can be initiated. To solve some of these problems, SURSEM was modified into a Monte-Carlo simulation that produces target detections and estimates of position. This Monte-Carlo program, called the Surveillance Radar Detection (SURDET) Program, can be used as the input for the Multiple Radar Integrated Tracking (MERIT) program [2] to solve some of the proposed questions.

This report describes the current status of the computer model and provides the potential user with instructions for its independent use. This section gives the background and a general description of the model. The second and third sections describe the computer routines unique to the 2D and 3D versions of SURDET: SURDET2D and SURDET3D respectively. In addition, in each section instructions to the user include a description of the input to SURDET and the output from SURDET. Finally, the routines common to both versions of SURDET are discussed in the fourth section.

Model Overview

SURDET produces radar detections and position estimates for each radar scan. These detections correspond not only to target detections but also to correlated and uncorrelated false alarms. The radar operates within a specified scenario defined by up to 20 targets and jammers in a clutter environment of rain or sea, in addition to multipath propagation. Each target trajectory can take one of three forms: a straight line between the starting point and the endpoint, a straight line in the xy plane with different altitude legs, or a constant-altitude flight with a turn between two straight-line legs.

SURDET has been constructed as a modified time-step model. The time steps involved are determined by the elapsed time between radar scans illuminating the target. The surveillance radar under examination is characterized by its radar scan modes. A radar scan mode is

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a means of defining radar operating characteristics for the illumination of a specific geometrical region. Typical radar scan modes include elevation beams, long-range search, high-angle low-energy search, burnthrough, and horizon scan. At the onset of the engagement (when the earliest target leaves its initial position), the time when each operational radar scan mode will first illuminate any target is determined. The minimum time minus 30 s is compared to a maximum start time, which is an input value, and the smaller of these two times is used as the start of the simulation. The additional time before the first possible target detection is necessary for clutter generation for realistic tracking studies.

For each radar scan the signal (target), noise, jamming, and clutter energies are calculated for each target and each radar scan mode. If a target detection is possible (depending on the signal-to-interfering-power ratio), the radar return is simulated pulse to pulse in the test cell of interest and in the surrounding reference cells. This level of detail is required in order to take into account the problems of target suppression and target resolution caused by nearby targets. Next, target detections are declared by comparing the test cell of interest to a threshold generated from the surrounding reference cells.

Since multiple detections of a single target can occur, such detections are merged into a centroided detection. Finally, the centroided detection is corrupted by the effects of roll and pitch. The results of SURDET can be printed out and/or written onto a file for later processing by the MERIT tracking program [2].

SURDET currently exists in two versions: SURDET2D to be used with 2D radars and SURDET3D to be used with 3D radars. Although the majority of the subroutines in SURDET are common to the two versions, SURDET2D and SURDET3D each has a unique executive routine plus a small set of unique associated routines. The second section describes the SURDET2D routines, and the third section describes the SURDET3D routines. These sections also describe the required user input, which differs slightly between the two versions. The fourth section describes subroutines common to both the SURDET2D and SURDET3D versions of SURDET. Therefore the reader should consult both the second and fourth sections for a complete description of all routines comprising SURDET2D and the third and fourth sections for similar coverage of SURDET3D.

Future Growth

As with most computer programs, SURDET will continually change. Areas identified for future modification include:

- Generation of realistic clutter-to-noise ratios (presently the values are 34.8937 and 30.54 for fixed and variable clutter detections respectively),
- Generation of other automatic detectors in addition to the present amplitude integrators,
- Modification of the signal-processing algorithm by including MTI and coherent integration, and
- Inclusion of more-detailed models of target radar cross sections as applications dictate.

The authors of this report are available on a limited basis for consultation on problems related to the compilation and execution of the model. Fortran listings are found in appendixes B, C, and D, and a program deck is available on request. The authors are also interested in negotiating with potential sponsors for the development of the model's growth potential and in some aspects of performing analyses of radar systems through the application of the model.

ROUTINES EXCLUSIVE TO SURDET2D

SURDET2D Executive Routine

The SURDET2D executive routine drives the detection model for 2D surveillance radar systems. The model itself consists of subroutines that perform specialized functions; the SURDET2D executive routine links these routines together (Fig. 1). The modular construction of the model facilitates changes and additions to the existing version.

The SURDET2D executive routine begins by setting constants and conversion factors for use by the model's subroutines. It then reads the first two data input cards. (The next subsection describes user input, and Table 1 describes the variables.) The first card contains the output-control parameter ANS1, which determines the amount of printed output produced. The options include no output printed (ANS1 = 0), only the detection output printed (ANS1 = 1), and the detailed output printed (ANS1 = 2). The second input card contains the run identification, which consists of an integer radar identification followed by alphanumeric descriptive information of the user's choice. The reader identification is used to label the output disk files for subsequent use as input to the MERIT tracking program [2].

SURDET2D monitors the input of the scenario data by calling a sequence of subroutines. Subroutine INITAL reads the radar data, subroutine TARGET reads the parameters defining the targets and jammers, and subroutine ENVIRN reads the environmental data. Subroutines FCINIT and VCINIT are called to input the data defining the fixed clutter area and variable clutter areas respectively. Roll and pitch characteristics of the radar platform are read by subroutine STBINT.

The game time by which the radar must be initialized, RINIT, is next read as an input directly by the executive routine and then modified by the radar scan offset, if any. Subroutine MATCH is called to determine the time each target first comes within the instrumented range of the radar. The minimum time among this set of times from MATCH is then further decreased by 30 s to insure clutter samples prior to detections, and the earlier of this result and RINIT, the maximum radar initialization time, becomes the game initialization time. The end of the game is set to coincide with the last target's reaching the end of its trajectory. At this point an identification record for the detection output file consisting of the radar identification and the radar scan rate is written on the logical unit specified by the parameter IOUT.

The recursive portion of the routine begins with the calculation of the positions of all targets and jammers at current game time T by subroutine NEWPOS. Then for each defined radar scan mode, all active targets are examined for possible detections. In particular, for a

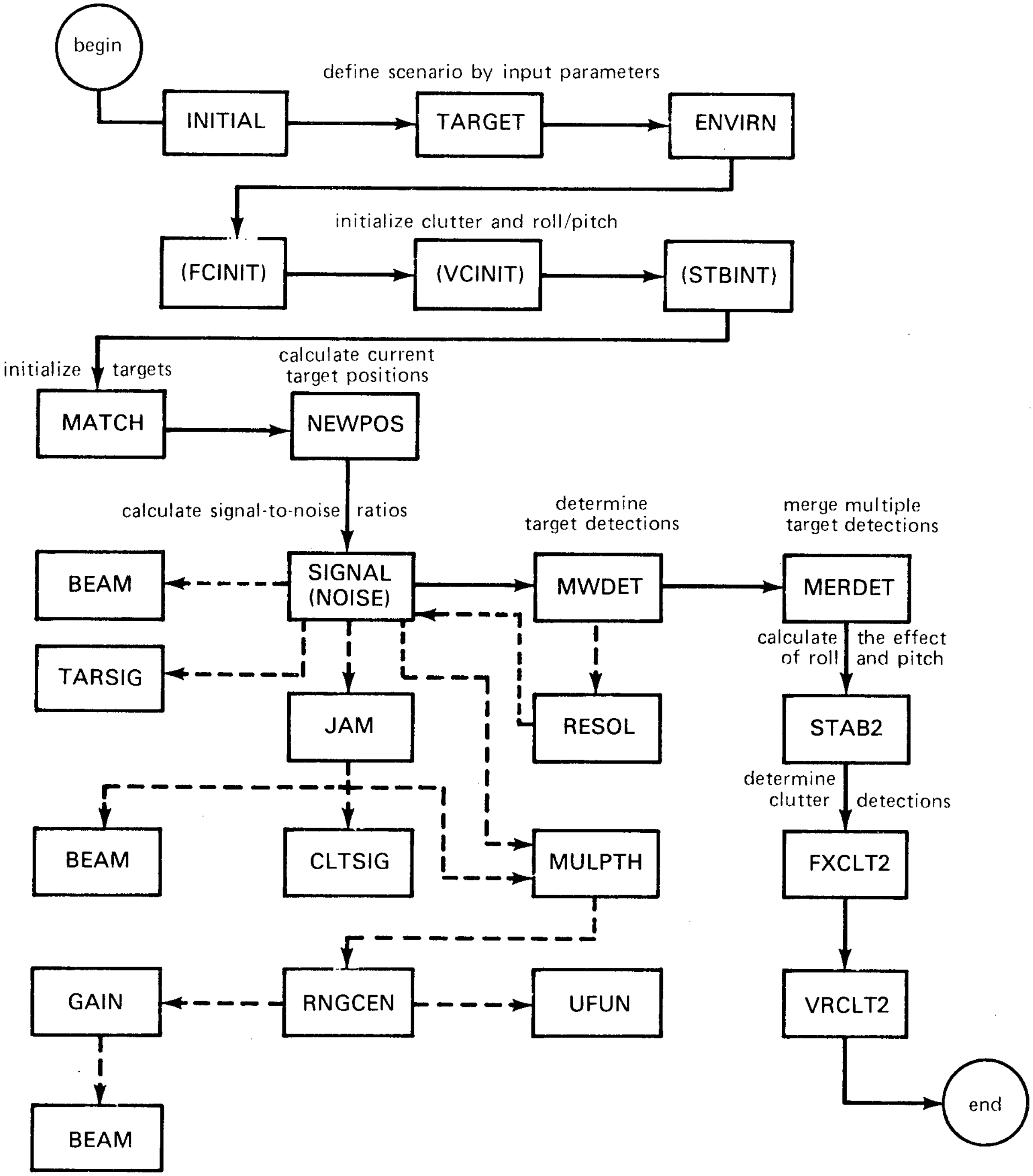


Fig. 1 — Subroutine linkage by the SURDET2D executive routine. The solid lines indicate program flow, and the dashed lines indicate subroutines called. The names in parentheses are entry points. The loops for multiple radar modes and multiple targets are not indicated.

given radar scan mode J, the executive routine first determines if a target I is within instrumented range, is above the radar horizon, is within the appropriate angular vertical coverage of the pencil beam or the cosecant-squared beam, and is beyond the minimum radar range. Unless all of these conditions are met, target I is dropped from further consideration by this scan mode. The routine next computes the signal energy and the noise and clutter energies for target I by calling subroutines SIGNAL and NOISE respectively. It then uses subroutine MWDET to determine any detections of the target by radar scan mode J, printing a record of each detection if the print-control parameter ANS1 indicates that detailed output is desired.

When all targets active at current game time T have been examined by scan mode J, subroutine MERDET is called to merge adjacent detections and estimate the range, azimuth, and signal power of the centroided detections for scan mode J. The centroided detections are further modified for roll and pitch of the radar platform by subroutine STAB2. Once this procedure has been completed for all radar scan modes at game time T, detections of fixed and of variable clutter at time T are determined by calls to subroutine FXCLT2 and VRCLT2 respectively. A report of centroided target detections by all scan modes and false alarms (clutter detections) for game time T is printed if ANS1 indicates that any printed output is desired. A similar output scan record for use as subsequent input to the MERIT tracking program [2] is written on the logical unit specified by IOUT.

To initiate a new radar scan, the current game time T, which represents the time the radar starts its current scan at zero azimuth, is increased by the radar scan period (as specified for radar scan mode 1). If the new game time does not exceed ENDTIM, the time at which the run ends, then control is returned to the beginning of the recursive portion of the program. Otherwise a recycle control parameter is read which specifies one of the following four options:

- A new scenario is to be read to initiate a new run, in which case program control is transferred to the beginning of the executive routine;

- Radar parameters from the run just completed are to be retained, but the rest of the scenario is to be redefined for a new run, so program control is transferred to the point where subroutine TARGET is called;

- Radar and target parameters are to be retained, but a new environment is to be specified for a new run, so program control is transferred to the point where subroutine ENVIRN is called;

- All runs are completed.

Table 1 — SURDET2D Variables

Fortran Variable	Description
ACON	Constant used in sea-state calculations (described in a later section in the subsection on subroutine JAM)
ACONZ	Azimuth separation for declaring two detections (rad)
ALPHAD	Grazing angle of a clutter patch (deg)
AMBN	Thermal noise energy (J)
ANS1	Printed output control: 0 = no output printed 1 = detection output only printed 2 = detailed output printed
AZ(I,K)	Azimuth of the *k*th centroided detection of target I
AZOUT(L)	Azimuth of the *l*th clutter detection
BETA	Constant used in sea-state calculations (described in the subsection on subroutine JAM)
BHDEG	Azimuth of target I (deg) for printing
BUF	Scan-output-ID array written on logical unit IOUT
BUF(1)	Scan number
BUF(2)	Start time of the present scan (s)
BUF(3)	Number of detections (including false alarms)
BUF(4)	Radar ID
BUF(5)	Ship's heading (rad)
BUF(6)	Total number of targets
BUFA	Detection-history array written on logical unit IOUT for each target detection or false alarm K
BUFA(1,K)	Target number or clutter detection number of the *k*th detection
BUFA(2,K)	Range of the *k*th detection (n.mi.)
BUFA(3,K)	Azimuth of the *k*th detection (rad)
BUFA(4,K)	Elevation of the *k*th detection (rad)
BUFA(5,K)	Time of the *k*th detection (s)
BUFA(6,K)	Signal energy of the *k*th detection (dB)
BUFA(7,K)	Roll angle of the *k*th detection (rad)
BUFA(8,K)	Pitch angle of the *k*th detection (rad)
BUFB	Target-true-position array written on logical unit IOUT for each defined target
BUFB(1,I)	Target number (I)
BUFB(2,I)	Slant range to the true target-I position (n.mi.)
BUFB(3,I)	Azimuth of the true target-I position (rad)
BUFB(4,I)	Elevation of the true target-I position (rad)
BUFB(5,I)	Time when the radar scans by target-I (s)
BVDEG	Elevation of target I measured from the horizon in degrees for printing
CCM	Speed of light (cm/s)
CNM	Speed of light (n.mi./s)
CONV	Conversion factor for converting natural logarithms to dB ($10 \log_{10} e$)
DBE	Signal energy of target I with respect to mode J (dB re 1 J)

Table continues.

Table 1 (Continued) — SURDET2D Variables

Fortran Variable	Description
DBN	Total noise energy with respect to mode J (dB re 1 J)
DWL(J)	Frequency increment for mode J (Hz)
ELEV(I,K)	Elevation of the *k*th centroided detection of target I
ELOUT(L)	Elevation of the *l*th clutter detection
ENDTIM	Time at which the current run terminates (h)
ENVIR(3)	Multipath indicator: 0 = no multipath 1 = multipath
FAC4	Multipath propagation factor to the fourth power
FOPIQB	$(4\pi)^3$
FOPISQ	$(4\pi)^2$
GN	One-way antenna gain
IANS	Recycle run control: 1 = new run with a new radar and new targets and environment 2 = new run with the current radar and new targets and environment 3 = new run with the current radar and targets and a new environment 4 = all runs completed
IC	Number of fixed clutter detections on the current scan
ICNT	Detection counter used for the output file
IMODE(J,1)	Number of pulses integrated for mode J
IOUT	Logical unit for the detection output file
ISC	Radar-scan counter
ISTAT(I)	Status indicator for target I: 0 = target is inactive 1 = target is active
ISWIT	Frequency indicator: 0 = frequency of the current scan mode is different from the previous mode 1 = no change in frequency from the last scan mode
ITITLE	Array containing alphanumeric run identification
IV	Number of fixed and variable clutter detections on the current scan
MER(I)	Indicator of interfering-target problems with respect to target I: 0 = no merging problem -1 = merging problem with target I, target detected -2 = merging problem with target I, target not detected
MUL	Multipath indicator: 0 = no multipath 1 = multipath
NC(K)	Index of the *k*th detected fixed clutter point
NCONZ	Pulse separation for declaring two detections
NDET(I)	Number of centroided detections of target I
NEXT	Current radar scan mode

Table continues.

Table 1 (Continued) -- SURDET2D Variables

Fortran Variable	Description
NREF	Number of reference cells on each side of the test cell
NSCAN	Number of radar scan modes defined
NTARG	Number of targets (to be detected)
OFR	Frequency of the current radar scan mode (MHz)
PBBS	Elevation beam center of the current radar mode
PITCH(I)	Pitch angle at the time of detection of target I
PTOUT(K)	Pitch at the time of the kth clutter detection
RADIAN	Conversion factor for radians to degrees ($180/\pi$)
RANGE(I,K)	Range of the kth centroided detection of target I
RC(1)	Basic radar frequency (MHz)
RC(4)	Horizontal 3-dB beamwidth (rad)
RC(5)	Vertical 3-dB beamwidth (rad)
RC(6)	One-way antenna gain
RC(11)	Power received for target I (W)
RC(12)	Signal energy for target I (J)
RC(13)	Clutter energy for target I (J)
RC(14)	Thermal noise plus jamming for target I (J)
RC(15)	Number of reference cells on each side of the target cell used in the moving-window detector
RC(16)	Clutter correlation coefficient
RC(17)	Number of standard deviations used in the detection threshold
RC(18)	Azimuth offset between beam positions (rad)
RC(20)	Detector video type: 0 = linear video 1 = log video
RC(21)	Number of reference cells used to calculate the threshold: 0 = all cells used <0 = half with smaller mean value used >0 = half with larger mean value used
RC(22)	Parameters used to calculate the threshold: 1 = mean used 2 = mean and variance used
RE	4/3 of the earth's radius (m)
RFR	Ratio of the basic radar frequency to the frequency of the current radar mode
RINIT	Latest time by which the radar is to begin scanning
RLOUT(K)	Roll at the time of the kth clutter detection
RMODE(J,1)	Lower 3-dB point of the elevation-angle coverage for mode J (deg)
RMODE(J,2)	Upper 3-dB point of the elevation-angle coverage for mode J (deg)
RMODE(J,5)	Interlook period for mode J (h)
RMODE(1,6)	Scan offset for mode 1 (h)
RMODE(J,7)	Instrumented range for mode J (n.mi.)
RMODE(J,9)	Earliest time any target enters the instrumented range of radar mode J (h)
ROLL(I)	Roll angle at the time of detection of target I

Table continues.

Table 1 (Concluded) — SURDET2D Variables

Fortran Variable	Description
ROUT(K)	Range of the *k*th clutter detection
SHIP(5)	Heading of the ship (rad)
SIGC	Total sea-clutter energy
SMODE(J,1)	Blanking range for mode J (n.mi.)
SN	Signal-to-noise ratio (dB), assuming the radar is pointing at the target
SNDET(I,K)	Signal energy of the *k*th centroided detection of target I
SNTRUE	Signal energy
SOUT(K)	Signal energy of the *k*th clutter detection
T	Current game time (h)
TARCS	Target cross section
THH	Basic radar horizontal 3-dB beamwidth (rad)
THV	Basic radar vertical 3-dB beamwidth (rad)
TIME(I)	Time of the detection of target I (s)
TOUT(K)	Time of the *k*th clutter detection (s)
TRGPOS(I,4)	Slant range of target I (n.mi.)
TRGPOS(I,5)	Azimuth of target I (rad)
TRGPOS(I,6)	Elevation of target I measured from the horizon (rad)
TSCAN(I,J)	Time when target I comes within the instrumented range or radar mode J (h)
V	Range extent of the clutter cell (m)
XJAMN	Total jamming energy (J)
XKTOMS	Conversion factor for knots to meters per second
XNMTOM	Conversion factor for nautical miles to meters
XYZF(I,4)	Time when target I reaches the endpoint of its trajectory (h)

Input for SURDET2D

An engagement scenario consists of a radar, one or more targets to be detected, and an optional number of sources of jamming radiation (subsequently referred to as jammers) set in a specified environment. The number of targets and jammers together is limited to 20. The required input information is divided into the definitions of the radar, targets, and jammers, an environment with optional clutter, and output and recycle control parameters. The data cards required are:

Data card 1—printed-output control integer (I5 format):

0 = no output printed,
1 = only the detection output printed,
2 = detailed output printed;

Data card 2—title card (I4, 19A4 format):

1. Radar integer ID,
2. Alphanumeric run identification;

Data card 3—ship (radar) position (4F8.2 format):

1-3. Position coordinates (x, y, z) (kft),
4. Ship heading (deg);

Data card 4—11 basic radar parameters (9F8.2,I2,F6.2 format):

1. Radar frequency (MHz),
2. Antenna pattern function indicator (0 = pencil beam and 1 = cosecant-squared beam),
3. Receiver noise (dB),
4. Horizontal 3-dB beamwidth (deg),
5. Vertical 3-dB beamwidth (deg),
6. One-way antenna gain (dB),
7. One-way sidelobe level (dB down from peak),
8. Receiver loss (dB),
9. Transmitter loss (dB),
10. Number of scan modes (limited to 30),
11. Linear polarization (0° to 90°, where 0° = horizontal and 90° = vertical);

Data cards 5 and 6 (one set for each radar scan mode)—15 parameters for each mode (10F8.2/5F8.2 format):

1. Lower 3-dB point of the elevation-angle coverage (deg),
2. Upper 3-dB point of the elevation-angle coverage (deg),
3. Peak power (MW),
4. Pulse length (μs),
5. Interlook period (s) (must be identical for all modes),
6. Scan offset (s),
7. Instrumented range (n.mi.),
8. Mode-dependent loss (dB),
9. Number of pulses integrated (limited to 99),
10. Compressed-pulse length (μs),
11. Sea-clutter improvement factor (dB),
12. Intermediate-frequency bandwidth (MHz) (if 0, the bandwidth is set at 1.0/compressed-pulse length),
13. Mode-dependent frequency increment (MHz),
14. Blanking time (μs) (if 0, the blanking time is set at the pulse length),
15. Rain-clutter improvement factor (dB);

Data card 7—seven parameters for the moving-window detector (7F8.2 format):

1. Number of reference cells on each side of the target cell,
2. Clutter correlation coefficient,

3. Number of standard deviations used in the threshold, which determines the probability of false alarm (guidance in setting the threshold value is given by Appendix A),
4. Number of detections that can be missed with the detections still merging into a single detection,
5. Video-type indicator (0 = linear video and 1 = log video),
6. Number of reference cells used for the threshold (0 = all cells used, <0 = half with smaller mean value used, and >0 = half with larger mean value used),
7. Parameters used to calculate the threshold (1 = mean used and 2 = mean and variance used);

Data card 8—number of targets and jammers (total limited to 20) (2I5 format):

1. Number of targets,
2. Number of jammers;

Data card 9 (one card for each target and jammer, paired with a card 10)—13 target parameters (12F6.2,I3 format):

1–4. Initial coordinates (x, y, z) (kft) and time (s),
5–8. Terminal coordinates (x, y, z) (kft) and time (s),
9–11. Head-on, broadside, and minimum radar reflective areas (m^2),
12. Jamming power density (W/MHz),
13. Marcum-Swerling cross-section model number;

Data card 10 (one card for each target and jammer, paired with a card 9)—target profile parameters (I4,7F6.2 format):

1. Target profile type (0 = straight-line trajectory, 1 = altitude legs, and 2 = g maneuver at constant altitude), with profile parameters 2 through 8 that follow being ignored for target profile type 0 and being as indicated for target types 1 and 2,
2. Number of altitude nodes (maximum of three), for target type 1, or target speed (kft/s), for target type 2,
3. First altitude node (kft), for target type 1, or initial heading of the target (deg), for target type 2,
4. Time of the target arrival at the first node (s), for target type 1, or time the maneuver begins (s), for target type 2,
5. Second altitude node (kft), for target type 1, or radial acceleration of the maneuver (g's), for target type 2,
6. Time of the target arrival at the second node (s), for target type 1, or ignored for target type 2,
7. Third altitude node (kft), for target type 1, or ignored for target type 2,
8. Time of the target arrival at the third node (s), for target type 1, or ignored for target type 2;

Data card 11—four environmental parameters (4F8.2 format):

1. Wind speed (knots),
2. Height of the wind-speed measurement (kft),
3. Multipath indicator (1 = multipath and 0 = no multipath),
4. Rainfall rate (mm/h);

Data card 12—nine fixed clutter parameters (2I8,7F8.2 format):

1. Initialization for the random-number generator for generation of fixed clutter points,
2. Number of fixed clutter points,
3. Probability that a clutter point is detected,
4. Initial range of the clutter area (kft),
5. Final range of the clutter area (kft),
6. Standard deviation of the range measurement (percent of the range-resolution cell size),
7. Initial azimuth of the clutter area (deg),
8. Final azimuth of the clutter area (deg),
9. Standard deviation of the azimuth measurement (percent of the horizontal 3-dB beamwidth);

Data card 13—two basic variable clutter parameters (2I8 format):

1. Initialization for the random-number generator for generation of variable clutter points,
2. Number of clutter regions;

Data card 14 (one card for each clutter region)—five parameters for each clutter region (5F8.2 format):

1. Average number of clutter points in the region,
2. Initial range of the clutter area (kft),
3. Final range of the clutter area (kft),
4. Initial azimuth of the clutter area (deg),
5. Final azimuth of thre clutter area (deg);

Data card 15—four roll and pitch parameters (4F8.2 format):

1. Maximum roll angle (deg),
2. Maximum pitch angle (deg),
3. Roll period (s) (a number >0 should be specified),
4. Pitch period (s) (a number >0 should be specified);

Data card 16—time parameter (F8.2 format):

1. Game time (s) by which the radar must initiate scanning;

Data card 17—recycle control parameter (I5 format):

1 = a new scenario is to be read, with the next data card being data card 1,
2 = current radar parameters are to be retained, but new targets and environment are to be read, with the next data card being data card 8,
3 = current radar and target parameters are to be retained, but a new environment is to be read, with the next data card being data card 11,
4 = all runs completed.

All input data from data cards 2 through 16 are printed as output at the beginning of each run.

Output from SURDET2D

An engagement is initiated either 30 s prior to the time a target first comes within the instrumented range of a radar mode or at the latest time by which the radar must be initialized (as specified by input), whichever occurs first. Once initiated, the simulation produces an output detection report for each radar scan until the engagement terminates with the last target reaching its final position. A sample printed output for a single scan is reproduced in Fig. 2.

The sample report is identified as scan number 30 on line 1. The radar involved has only a single scan mode; the results of scan mode 1 looking at target 1 and target 2 are given in lines 3 through 5 and 6 through 8 respectively. Lines 3 and 6 contain the following information, as indicated by the heading in line 2:

TARGET	Target number,
MODE	Radar scan mode number,
TIME	Time of the scan (s),
RANGE	Slant range of the target from the radar (kft),
AZIM	Azimuth angle of the target (deg),
ELEV	Elevation angle of the target (deg),
SIGMA	Radar cross section of the target (m^2),
FACTOR	Multipath pattern-propagation factor (dB),
ESIG	Signal energy (dB re 1 J),
NAMB	Ambient noise (dB re 1 J),
NCLT	Clutter energy (dB re 1 J),
NJAM	Jamming energy (dB re 1 J),
E/N	Signal-energy-to-noise-energy ratios (dB), with the first ratio being the value when the radar is pointing at the target and the second ratio being the actual value used to determine a detection,
MER	Indicator of the interfering-target problem (to be described in the subsection on subroutine MWDET).

Lines 4 and 5 report two detections of target 1. The range and azimuth of the reference cell in which each detection took place are given under RANGE and AZIM respectively. The signal amplitude corresponding to each detection is given in decibels (dB re noise energy) under ESIG. Similarly lines 7 and 8 report detections of target 2.

```
 1                      +++++++  SCAN NUMBER =   30  +++++++

        MODE                                                SIGMA
 2  TARGET          TIME        RANGE      AZIM       ELEV         FACTOR    ESIG    NAMB    NCLT    NJAM        E/N          MER
 3    1   1        105.3        32.35     102.14     17.56   0.1    -1.     -192.   -202.   -298.   -740.      9.59   9.44    -1
 4      *DETECTION*             32.19     101.82                              42.
 5      *DETECTION*             32.78     102.22                              38.
 6    2   1        105.3        33.67     102.14     17.57   0.1    -3.     -191.   -202.   -299.   -740.     10.61   2.39    -1
 7      *DETECTION*             33.37     102.07                              36.
 8      *DETECTION*             33.96     101.86                              35.

 9  SCAN NUMBER=  30.    TIME=   103.92    NO. DETECTIONS=  18.    RADAR ID= 2063.    HEADING=   1.57    NO. TARGETS=  2.

10                    ID      RANGE      AZIM      ELEV       TIME       ESIG      ROLL      PITCH
11  DETECTION NUM     1.     5.2935    1.7399    0.0000   105.2816   42.0651   -0.1057    0.0839
12  DETECTION NUM   101.     5.0021    1.5260    0.0000   105.0925   34.8937   -0.1437    0.0803
13  DETECTION NUM   103.     8.5959    3.8884    0.0000   106.8608   34.8937    0.2188    0.0628
14  DETECTION NUM   104.    10.4414    2.8249    0.0000   106.0810   34.8937    0.0641    0.0847
15  DETECTION NUM   105.    22.2911    4.9394    0.0000   107.6911   34.8937    0.3223    0.0236
16  DETECTION NUM   107.    18.5030    3.1371    0.0000   106.3174   34.8937    0.1133    0.0804
17  DETECTION NUM   108.    21.2227    1.2672    0.0000   104.8901   34.8937   -0.1821    0.0750
18  DETECTION NUM   110.    21.4169    1.0450    0.0000   104.7230   34.8937   -0.2117    0.0697
19  DETECTION NUM   200.    21.7083    0.9722    0.0000   104.6625   30.4567   -0.2219    0.0676
20  DETECTION NUM   200.    24.3308    4.0485    0.0000   107.0126   30.4567    0.2401    0.0574
21  DETECTION NUM   200.     8.1103    4.9839    0.0000   107.7272   30.4567    0.3252    0.0216
22  DETECTION NUM   200.    23.9423    5.2301    0.0000   107.9152   30.4567    0.3377    0.0110
23  DETECTION NUM   200.    13.0638    6.2413    0.0000   108.6878   30.4567    0.3407   -0.0323
24  DETECTION NUM   200.    24.3308    1.0967    0.0000   104.7576   30.4567   -0.2058    0.0709
25  DETECTION NUM   200.    22.4853    1.1298    0.0000   104.7828   30.4567   -0.2014    0.0717
26  DETECTION NUM   200.    21.0284    1.1449    0.0000   104.7944   30.4567   -0.1993    0.0721
27  DETECTION NUM   200.    23.4566    1.1499    0.0000   104.7982   30.4567   -0.1987    0.0722
28  DETECTION NUM   200.    23.2624    1.1882    0.0000   104.8275   30.4567   -0.1934    0.0731
```

Fig. 2 — SURDET2D output report. In this reproduction the line numbers at the left have been added to facilitate the discussion in the text.

Lines 9 through 28 are the data constituting the output record written on logical unit IOUT for subsequent use as input to the MERIT tracking program [2]. (In addition the actual range, azimuth, and elevation of each target and the time each is scanned by the radar are also written on IOUT.) Line 9 identifies the current record by specifying the scan number, current game time in seconds, number of detections (including false alarms), radar identification augmented by 2000, ship's heading in radians, and number of targets defined. The remaining lines, labeled by detection number, provide data as labeled by line 10 for each centroided target detection and false alarm (fixed or variable clutter detection). The information provided for each detection starts with a detection number: 0 through 99 identifies a target, 101 through 199 indicates a fixed clutter point, and 200 represents a variable clutter point. Following the detection number are the estimated range in nautical miles, the azimuth and elevation angles in radians, the time of detection in seconds, the signal energy in decibels, and the roll and pitch angles in radians. Presently the signal energy for fixed and variable clutter points is set to 34.8937 and 30.4567 dB respectively. If the signal energy is to be used by a tracking program, an appropriate signal energy must be generated.

An output report as shown in Fig. 2 is printed for each radar (azimuth) scan when the print output control parameter (data card 1) is 2. If the parameter is 1, then only the detection history given by lines 9 through 28 is printed. If the parameter is 0, then no output scan reports are printed.

Subroutine FXCLT2

Subroutine FXCLT2 generates fixed clutter points and is called once per scan by the executive routine. The routine is initialized by calling the entry point FCINIT. The initialization section reads in the following nine inputs with a (2I8,7F8.2) format (Table 2):

ISET	—	initialization number for the random-number generator,
N	—	number of fixed clutter points,
PROB	—	probability that a clutter point is detected,
RS	—	initial range of the clutter area (kft),
RF	—	final range of the clutter area (kft),
SIGR	—	standard deviation of the range measurement (fractions of a range cell),
THS	—	initial azimuth of the clutter area (deg),
THF	—	final azimuth of the clutter area (deg),
SIGA	—	standard deviation of the azimuth measurement (fractions of a beamwidth).

The initialization section calculates the range-cell dimension ΔR by

$$\Delta R = c\tau_c/2, \tag{1}$$

where c is the speed of light and τ_c is the compressed pulsewidth. Next the input values are converted to nautical miles and radians for internal use. Finally, N fixed clutter points are generated by

$$\underset{\sim}{R}_i = R_S + (R_F - R_S)\underset{\sim}{U}_i \tag{2}$$

and

$$\theta_i = \theta_S + (\theta_F - \theta_S)V_i, \tag{3}$$

where R_i and θ_i are the range and azimuth of the clutter points, R_S and R_F are the initial and final range boundaries of the clutter area, θ_S and θ_F are the initial and final azimuth boundaries of the clutter area, and U_i and V_i are independent, uniformly distributed random numbers.

The detected clutter points are generated by calling FXCLT2 once per scan. For each clutter point a uniform random number U is compared to P_r, the probability of detecting the clutter point. If $U \leqslant P_r$, the clutter point is assumed to be detected, Gaussian errors are added in range and azimuth, and the azimuth measurement is corrupted by roll and pitch. The range measurement is

$$R_m = (K + 0.5)\Delta R, \tag{4}$$

where

$$K = \text{integer}\,\{[R_i + \sigma_R(-2\log U_i)^{1/2}\cos 2\pi V_i]/\Delta R\}, \tag{5}$$

in which σ_R is the measurement standard deviation and U_i and V_i are uniformly distributed random numbers. The error in azimuth is

$$\epsilon_a = \sigma_\theta(-2\log U_i)^{1/2}\sin 2\pi V_i, \tag{6}$$

where σ_θ is the standard deviation of the azimuth measurement. The angles of roll R and pitch P at time T are

$$R = R_{\max}\sin(2\pi t/T_R + \phi_R) \tag{7}$$

and

$$P = P_{\max}\sin(2\pi t/T_P + \phi_P), \tag{8}$$

where $R_{\max}$ and $P_{\max}$ are the maximum roll and pitch angles, T_R and T_P are the corresponding periods, and ϕ_R and ϕ_P are uniform phase angles between 0 and 2π. The measured azimuth position a_m (in the deck plane) is [3]

$$a_m = \tan^{-1}\left[\frac{\sin a\cos R + (\cos a\sin P + \tan e\cos P)\sin R}{\cos a\cos P - \tan e\sin P}\right] + \epsilon_a, \tag{9}$$

and the measured elevation position e_m is

$$e_m = 0, \tag{10}$$

where $a = \theta_i$ is the true azimuth, $e = 0$ is the true elevation of the clutter point, and ϵ_a is the previously calculated azimuth error. The detection time T_i is proportional to the azimuth:

$$T_i = T_0 + (\Delta T)\theta_i/2\pi, \tag{11}$$

where T_0 is the time of the start of the scan and ΔT is the scan period.

Table 2 — FXCLT2 Variables

Fortran Variable	Description
A	Azimuth of the clutter point in the deck plane with zero measurement error
AA	True azimuth of the clutter point with respect to the ship (a in Eq. 9)
AM	Azimuth measurement (between π and 3π)
AZ	True azimuth of the clutter point (θ_i in Eq. 11)
AZOUT	Azimuth measurement (a_m in Eq. 9)
CP	Cosine of the pitch angle
CR	Cosine of the roll angle
ELOUT	Elevation measurement $e_m = 0$ (Eq. 10)
IC	Number of fixed clutter points detected this scan
ISET	Initialization number for the random-number generator
K	Range cell of the measurement (K in Eq. 4)
N	Number of fixed clutter points
NC	Index of the clutter point detected
N2	Two times N
N3	Three times N
N4	Four times N
PFAC	Frequency of the pitch cycle
PHASE(1)	Phase angle of the roll (ϕ_R in Eq. 7)
PHASE(2)	Phase angle of the pitch (ϕ_P in Eq. 8)
PMAX	Maximum pitch angle ($P_{\max}$ in Eq. 8)
PROB	Probability that the clutter point is detected (P_r in text preceding Eq. 4)
PTOUT	Pitch at the time of the ith detection (P in Eq. 8)
R	True range of the clutter point (R_i in Eq. 2)
RADIAN	57.29578°, the number of degrees in a radian, or $180/\pi$
RAN	Array of uniform random numbers (U_i in Eqs. 2, 5, and 6)
RAY	Rayleigh random number
RC(4)	Azimuth beamwidth
RC(19)	Range-cell dimension (ΔR in Eq. 1)
RES	Range-cell dimension (ΔR in Eq. 1)
RF	Final range of the clutter area (R_F in Eq. 2)
RFAC	Frequency of the roll cycle
RLOUT	Roll at the time of the ith detection (R in Eq. 7)
RMAX	Maximum roll angle ($R_{\max}$ in Eq. 7)
RMODE(1,5)	Scan period (ΔT in Eq. 11)
ROUT	Range measurement (R_m in Eq. 4)
RS	Initial range of the clutter area (R_S in Eq. 2)
SHIP(5)	Ship heading
SIGA	Standard deviation of the azimuth measurement (σ_θ in Eq. 6)
SIGR	Standard deviation of the range measurement (σ_R in Eq. 5)
SOUT	Energy of the ith detection
SP	Sine of the pitch angle
SR	Sine of the roll angle
T	Time of the start of the radar scan (T_0 in Eq. 11)

Table continues.

Table 2 (Concluded) — FXCLT2 Variables

Fortran Variable	Description
TAU	Compressed pulsewidth (s) (τ_c in Eq. 1)
TE	Tangent of the elevation angle (zero)
TH	Uniform distributed phase angle
THF	Final azimuth of the clutter area (θ_F in Eq. 3)
THS	Initial azimuth of the clutter area (θ_S in Eq. 3)
TIMSCN	Scan period (ΔT in Eq. 11)
TIMZB	Time of the zero-bearing crossing (T_0 in Eq. 11)
TOUT	Detection time (T_i in Eq. 11)
TWOPI	Two times 3.1415926536, or 2π

Subroutine INITAL

Subroutine INITAL is called once by the SURDET2D executive routine. Its purpose is to establish constants, to read ship (radar platform) and radar data in kilofeet and seconds, and to convert the units to internal units (nautical miles and hours) for use by other subroutines (Table 3).

The location and heading of the ship or radar platform, which is assumed to remain stationary throughout an engagement, and the antenna height above sea level are specified by four radar-position input parameters read into the SHIP array:

SHIP(1) — x position coordinate (kft),
SHIP(2) — y position coordinate (kft),
SHIP(3) — z position coordinate (antenna height above sea level) (kft),
SHIP(5) — ship heading (deg).

It is often convenient to let the radar platform be located at the origin (0, 0) of the scenario coordinate system.

A radar is described by specifying 11 basic parameters followed by 16 descriptors for each of up to 30 operational radar scan modes and moving-window detector data. Typical radar scan modes include long-range search, high-angle low-energy search, burnthrough, and horizon scan. The 11 basic radar input parameters, which are stored in the RC array, in NSCAN, and in POLRZ, are:

RC(1) — radar frequency (MHz),
RC(2) — antenna-pattern indicator (0 = pencil beam and 1 = cosecant-squared beam),
RC(3) — receiver noise (dB),
RC(4) — horizontal 3-dB beamwidth (deg),
RC(5) — vertical 3-dB beamwidth (deg),
RC(6) — one-way antenna gain (dB),
RC(7) — one-way sidelobe level (dB down from peak),
RC(8) — receiver line loss (dB),
RC(9) — transmitter line loss (dB),

NSCAN — number of scan modes to be defined, (a number not to exceed 30),
POLRZ — linear polarization from 0° to 90° (0° = horizontal and 90° = vertical).

Each radar scan mode J is described by the following 15 input parameters, which are read into the RMODE, IMODE, SUBC, DWL, and SMODE arrays:

RMODE(J,1) — lower 3-dB point of the elevation-angle coverage (deg),
RMODE(J,2) — upper 3-dB point of the elevation-angle coverage (deg),
RMODE(J,3) — peak power (MW),
RMODE(J,4) — pulse length (μs),
RMODE(J,5) — interlook period (time between scans) (s),
RMODE(J,6) — scan offset (relative to radar initialization) (s),
RMODE(J,7) — instrumented range (n.mi.),
RMODE(J,8) — mode-dependent loss (dB),
IMODE(J,1) — number of pulses integrated (a number not to exceed 99)
RMODE(J,11) — compressed-pulse length (μs),
SUBC(J) — sea-clutter improvement factor (dB),
RMODE(J,12) — intermediate-frequency bandwidth (MHz) (if 0 is entered, the bandwidth is set at 1.0/(compressed-pulse length)),
DWL(J) — mode-dependent frequency increment (MHz) (if DWL(J) is nonzero, the effective horizontal and vertical beamwidths and antenna gain for this scan mode are also affected),
SM — blanking time (μs) (if 0 is entered, the blanking time is set at the pulse length),
SMODE(J,2) — rain-clutter improvement factor (dB).

These radar scan modes are numbered in ascending order as they are defined, beginning with 1.

The moving-window detector is defined by the following seven input parameters, stored in the RC array:

RC(15) — number of reference cells on each side of the target cell,
RC(16) — clutter correlation coefficient,
RC(17) — number of standard deviations used in the threshold (determines the probability of a false alarm),
RC(18) — number of detections that can be missed with the detections still merging into a single detection,
RC(20) — video-type indicator (0 = linear video and 1 = log video),
RC(21) — number of reference cells used for the threshold (0 = all cells used, <0 = half with smaller mean value used, and >0 = half with larger mean value used,
RC(22) — parameters used to calculate the threshold (1 = mean used and 2 = mean and variance used).

Subroutine INITAL also performs checks on the input data with the result that:

- The number of radar scan modes is limited to 30,

- The interlook period for each mode is set equal to 10 s if its input value is zero or negative,

- The IF bandwidth for each mode is set equal to the reciprocal of the compressed pulse length if its input value is zero or negative, and

- The blanking time for each mode is set equal to the pulse length if its input value is zero.

Table 3 — INITAL Variables

Fortran Variable	Description
DWL(J)	Frequency increment for mode J (MHz)
IMODE(J,1)	Number of pulses integrated for mode J
IMODE(J,2)	max ($B_{IF}\tau_c$, 1) rounded to the nearest integer for mode J, where B_{IF} is RMODE(J,12)
MILLION	10^6
MM	Effective number of pulses integrated
NSCAN	Number of scan modes
PI	3.1415926536, or π
PIOVER2	One-half of 3.1415926536, or $\pi/2$
POLRZ	Linear polarization (0° to 90°, where 0° = horizontal and 90° = vertical)
RADIAN	57.29578°, the number of degrees in a radian, or $180/\pi$
RC(1)	Radar frequency f (MHz)
RC(2)	Indicator of the antenna-pattern function: 0 = pencil beam 1 = $\csc^2$ beam
RC(3)	Receiver noise
RC(4)	Horizontal 3-dB beamwidth (deg to rad)
RC(5)	Vertical 3-dB beamwidth (deg to rad)
RC(6)	One-way antenna gain
RC(7)	One-way sidelobe level
RC(8)	Receiver losses
RC(9)	Transmitter losses
RC(10)	Boltzman's constant times the system temperature, or kT (J)
RC(15)	Number of reference cells on each side of the target cell used in the moving-window detector
RC(16)	Clutter correlation coefficient
RC(17)	Number of standard deviations used in the detection threshold
RC(18)	Number of detections that can be missed with the detections still merging into the single detection
RC(20)	Detector video type: 0 = linear video 1 = log video
RC(21)	Number of reference cells used to calculate the threshold: 0 = all cells used <0 = half with smaller mean value used >0 = half with larger mean value used

Table continues.

Table 3 (Concluded) — INITAL Variables

Fortran Variable	Description
RC(22)	Parameter to denote whether the mean (RC(22) = 1) or the mean and variance (RC(22) = 2) should be used to calculate the threshold
RMODE(J,1)	Lower 3-dB point of the elevation-angle coverage for mode J (deg)
RMODE(J,2)	Upper 3-dB point of the elevation-angle coverage for mode J (deg)
RMODE(J,3)	Peak power for mode J (MW to W)
RMODE(J,4)	Pulse length for mode J (μs to s)
RMODE(J,5)	Interlook period for mode J (s to h)
RMODE(J,6)	Scan offset for mode J (s to h)
RMODE(J,7)	Instrumented range for mode J (n.mi.)
RMODE(J,8)	Mode-dependent loss for mode J
RMODE(J,11)	Compressed-pulse length for mode J (μs)
RMODE(J,12)	Intermediate-frequency bandwidth for mode J (MHz to Hz) (B_{IF})
SHIP(1)	x coordinate of the ship position (kft to n.mi.)
SHIP(2)	y coordinate of the ship position (kft to n.mi.)
SHIP(3)	Antenna height (kft to n.mi.)
SHIP(5)	Ship heading (deg to rad)
SM	Blanking time used to calculate SMODE(J,1) (μs)
SMODE(J,1)	Blanking range for mode J (n.mi.)
SMODE(J,2)	Rain-clutter improvement factor for mode J
SUBC(J)	Sea-clutter improvement factor for mode J
TAU(J)	Compressed-pulse length for mode J, or τ_c (s)
TWOPI	Two times 3.1415926536, or 2π

Subroutine MERDET

Subroutine MERDET is called once at the end of each radar scan for each radar mode after all the detections for each target have been made. The purpose of this routine is to produce the centroided detections when several targets are close to one another, a condition denoted for each target I by MER(I) = -1 (Table 4).

Let N_i be the number of detections of the ith target, A_{ij} be the initial azimuth, F_{ij} be the final azimuth, and R_{ij} be the range of the jth detection of the ith target. The procedure for producing the centroided detections is to order (in initial azimuths A_{ij}) all M detections of targets that are close to one another, that is, all targets for which MER(I) = -1. Let the array of ordered initial azimuths be A_k and let the corresponding final azimuths and ranges be F_k and R_k respectively. Thus

$$A_1 \leqslant A_2 \leqslant A_3 \leqslant \ldots \leqslant A_{M-1} \leqslant A_M. \tag{12}$$

A detection is inhibited if it is close to another which has a smaller initial azimuth. Specifically, detection i is inhibited by target detection j, which has previously been accepted, if

$$A_j < A_i, \tag{13a}$$

$$|R_j - R_i| \leqslant \Delta R, \tag{14a}$$

and

$$F_i \leqslant F_j + \Delta A, \tag{15a}$$

or, alternately, detection i is inhibited by detection k, which has previously been inhibited, if

$$A_k < A_i, \tag{13b}$$

$$|R_i - R_k| \leqslant \Delta R, \tag{14b}$$

and

$$F_i \leqslant F_k, \tag{15b}$$

where ΔR is the range-resolution-cell dimension and ΔA is the azimuth separation based on the pulse detection separation specified at input, which should be approximately the 3-dB beamwidth. If a detection is not inhibited, it is accepted.

Thus a detection can easily be accepted or inhibited by examining sequentially the ordered detections. The first detection is always accepted, and the jth detection is accepted if it is not close to any of the previously accepted or inhibited detections, where closeness is defined either by Eqs. 14a and 15a or by Eqs. 14b and 15b. The estimate of the azimuth for an accepted target detection is

$$\hat{A}_k = (A_k + F_k)/2. \tag{16}$$

Table 4 — MERDET Variables

Fortran Variable	Description
A	Initial azimuth of the jth detection of the ith target (ΔA in Eq. 15)
ACONZ	Azimuth interval used to inhibit detection (ΔA in Eq. 15)
AZ(I,2J-1)	Initial azimuth of the jth detection of the ith target which has a target close by (A_k in Eq. 16)
AZ(I,2J)	Final azimuth of the jth detection of the ith target which has a target close by (F_k in Eq. 16)
AZ(I,J)	Azimuth of the jth detection of the ith target ($\hat{A}$ in Eq. 16)
II	Number of detections
K	Number of ordered detections (M in Eq. 12)
KC	Counter used for ordering
KDET(I)	Detection index of the ith ordered azimuth
KDTT(I)	Detection index of the ith ordered inhibited azimuth

Table continues.

Table 4 (Concluded) — MERDET Variables

Fortran Variable	Description
KK	Number of accepted detections
KTAR(I)	Target index of the *i*th ordered azimuth
KTRR(I)	Target index of the *i*th ordered inhibited azimuth
MER(I)	Indicator of interfering target problems: 0 = no interfering targets -1 = interfering target but target detected -2 = interfering targets and target not detected
N	Number of targets
NDET(I,J)	Number of detections of the *i*th target, or N_i
RANGE(I,J)	Range of the *j*th detection of the *i*th target
RES	Range-cell dimension (ΔR in Eqs. 14a and 14b)
SNDET(I,J)	Signal amplitude of the *j*th detection of the *i*th target

Subroutine MWDET

Subroutine MWDET is called for every target on each radar scan for each radar mode. The purpose of the routine is to declare target detections by generating pulse-to-pulse video returns as the beam sweeps over the target, integrating the returned signal, and comparing it to an adaptive threshold which is generated from the surrounding reference cells. Detections can be made in either adjacent range cell in addition to the range cell in which the target is present. Thus in theory a 2D radar can report three detections of a single target.

The routine initially tests whether appropriate input parameters (Table 5) are less than preassigned values: the number of pulses integrated M is less than 100, the number of reference cells N_R on each side of the test cell is less than ten, and the absolute value of clutter correlation coefficient ρ is less than 1.0. If any parameter exceeds its limit, an error message is printed and the program stops.

Next, M times the ratio of signal to clutter-plus-noise is compared to 2. If the value is less than 2, the target is declared not detected, the number of detections of target NTAR, the target of interest, by the *j*th mode NDET(NTAR,J) is set to 0, and control is returned to the calling routine. Otherwise the detailed simulation is begun by finding all the targets which lie within the reference cells of target NTAR. The list of interfering targets INF is initialized by setting INF(1) = NTAR, and the corresponding signal energy SNREF(1) is set equal to the target energy S. The remaining interfering targets are found by calling subroutine RESOL, which calculates the number of interfering targets NI, lists the index of the interfering targets in the array INF, and lists the corresponding signal energies in SNREF.

As the radar beam sweeps over the target, the returned signal will be modulated by the antenna pattern. The azimuth position of the pulse closest to the target is

$$\theta = A + (U - 0.5)\Delta\theta, \tag{17}$$

where A is the azimuth of the target, U is a random number uniformly distributed between 0 and 1, and $\Delta\theta$ is the antenna azimuth movement between transmitted pulses. To simplify the location of the interfering target and have the storage required to integrate up to 100 pulses, 401 pulses (corresponding to different azimuth positions) are saved for each range cell, and the 201st location corresponds to θ. The azimuth of pulse 0 is

$$\theta_0 = \theta - 201\Delta\theta, \tag{18}$$

Furthermore, since only M pulses are within the 3-dB azimuth beamwidth, all 401 pulses need not be generated when $M < 100$. Specifically, for the target of interest, the signal will be assumed to occupy the center $2M$ pulses. Also, to allow for the buildup and decay of the moving-window detector, M noise samples are generated on each side of the signal return. Thus, the first pulse generated is

$$NS = 201 - 2M, \tag{19}$$

and the final pulse generated is

$$NF = 201 + 2M. \tag{20}$$

Also, the video return is generated only in the reference cells surrounding the target. Thus, to save computer storage, only 25 range cells are saved and the target is always placed in the 13th range cell. Consequently the range to the start of the first range cell is

$$R_S = \Delta R(K_{RS} - 13), \tag{21}$$

where ΔR is the range-cell dimension and K_{RS} is the integer defined by

$$K_{RS} = \text{integer}\,(R/\Delta R), \tag{22}$$

in which R is the target range.

The first step in generating the radar video return is to generate the signal (target) return in the appropriate range cells. Specifically, the index of the first range cell is

$$N_F = 11 - N_R, \tag{23}$$

and the index of the last range cell is

$$N_L = 15 + N_R. \tag{24}$$

Thus, if $N_R = 10$, signal must be placed in all 25 range cells. The signal return for the ith pulse and the jth range cell S_{ij} and an indicator of signal in the jth range cell $I(j)$ are initially set to 0 for all i and j. Then the signal return from each of the NI interfering targets lying within the reference cells is generated. For the kth target this is accomplished by first generating the appropriate fluctuating amplitudes F_i for the ith pulse. For Swerling case NSW, F_i is given by the following equations, in which the U_i, $i = 1, \ldots, M$, are independent random numbers uniformly distributed between 0 and 1. For NSW = 0 (nonfluctuating target)

$$F_i = 1, \qquad i = 1, \ldots, M. \tag{25}$$

For NSW = 1 (scan-to-scan fluctuations, Rayleigh density)

$$F_i = -\log U_1, \quad i = 1, \ldots, M \tag{26}$$

For NSW = 2 (pulse-to-pulse fluctuations, Rayleigh density)

$$F_i = -\log U_i, \quad i = 1, \ldots, M. \tag{27}$$

For NSW = 3 (scan-to-scan fluctuations, chi-square density)

$$F_i = -0.5(\log U_1 + \log U_2), \quad i = 1, \ldots, M \tag{28}$$

For NSW = 4 (pulse-to-pulse fluctuations, chi-square density)

$$F_i = -0.5(\log U_i + \log U_{M+i}), \quad i = 1, \ldots, M. \tag{29}$$

The signal is next placed in the appropriate range cell and the adjacent range cells by reducing the returned signal by a $[(\sin x)/x]^2$ pulse shape and a $[(\sin x)/x]^4$ antenna pattern. The return signal from the kth target is centered in range cell K_R:

$$K_R = \text{integer}\,[(R_k - R_S)/\Delta R], \tag{30}$$

where R_k is the range of the kth target. The signal-return reduction F in the adjacent range cell

$$K_T = K_R + I, \quad I = -1, 0, 1, \tag{31}$$

is given by (because of the $(\sin x)/x$ pulse shape)

$$F = [(\sin F_d)/F_d]^2, \tag{32}$$

where

$$F_d = 2.7832(R_k - R_T)/\Delta R, \tag{33}$$

in which

$$R_T = (K_T + 0.5)\Delta R + R_S. \tag{34}$$

At this time the indicator $I(K_T)$ is set equal to 1.

The closest pulse (in azimuth) to the kth interfering target is

$$NC = \text{integer}\,[(A_k - \theta)/\Delta\theta] + 201, \tag{35}$$

where A_k is the azimuth of the kth target. Thus, of the pulses to be generated (NS to NF), the kth target contributes signal to the pulses from

$$NNS = \max\,\{NS, NC - M\} \tag{36}$$

to

$$NNF = \min \{NF, NC + M\}. \tag{37}$$

Therefore, for the ith pulse, the signal reduction G due to the $(\sin x)/x$ antenna pattern is

$$G = [(\sin G_d)/G_d]^4, \tag{38}$$

where

$$G_d = 2.7832(\theta_0 + i\Delta\theta - A_k)/\theta_{3dB}, \tag{39}$$

in which θ_{3dB} is the antenna 3-dB azimuth beamwidth. Finally, the signal (normalized by the clutter energy C and noise energy N) in the K_Tth range cell (for the ith pulse) is

$$S_{i,K_T}\ (\text{new}) = S_{i,K_T}\ (\text{old}) + GFF_i P_k/(C + N), \tag{40}$$

where P_k is the signal energy of the kth interfering target.

The calculation indicated by Eqs. 38 through 40 is first repeated for all pulses specified by Eqs. 36 and 37. Then the calculation indicated by Eqs. 31 through 40 is repeated for the adjacent range cells indicated in Eq. 31. Finally the calculation indicated by Eqs. 25 through 40 is repeated for all NI targets in the reference cells. Thus at the end of all of these repetitions $S_{i,j}$ is the signal energy in the ith pulse and jth range cell due to all the targets in the reference cells.

Next Rayleigh noise (and possibly correlated clutter) is added to the signal to produce the total video return x_{ij}. The video return is generated (because of computer-speed considerations) for three distinct cases: clutter insignificant and no signal present in the range cell, clutter insignificant and signal energy S_{ij} present in the range cell, and clutter significant. The significance of clutter is indicated by the product of clutter and the number of pulses integrated CM being greater than N, and signal present in the jth cell is indicated by $I(j) = 1$. Thus, the ith return in the jth cell x_{ij} is given as follows. For clutter insignificant ($CM \leqslant N$) and no signal in the jth cell ($I(j) = 0$)

$$x_{ij} = (-2 \log U_i)^{1/2}, \qquad i = 1, ..., M, \tag{41}$$

where the U_i are independent uniform random numbers between 0 and 1 different for each j. For clutter insignificant ($CM \leqslant N$) and signal in the jth cell ($I(j) = 1$)

$$x_{ij} = \{[\alpha_i \cos \phi_i + (2S_{ij})^{1/2}]^2 + (\alpha_i \sin \phi_i)^2\}^{1/2}, \tag{42}$$

where

$$\alpha_i = (-2 \log U_i)^{1/2} \tag{43}$$

and

$$\phi_i = 2\pi U_{i+M}. \tag{44}$$

For clutter significant ($CM > N$)

$$x_{ij} = \{[CX_i + \alpha_i \cos \phi_i + (2S_{ij})^{1/2}]^2 + (CY_i + \alpha_i \sin \phi_i)^2\}, \quad (45)$$

where the Rayleigh-noise components $\alpha_i \cos \phi_i$ and $\alpha_i \sin \phi_i$ are given by

$$\alpha_i = N'(-2 \log U_{i+M})^{1/2} \quad (46)$$

and

$$\phi_i = 2\pi U_{i+3M}, \quad (47)$$

with

$$N' = [N/(C+N)]^{1/2}, \quad (48)$$

the clutter is given by

$$CX_i = \rho CX_{i-1} + (1-\rho^2)^{1/2} \alpha_i' \sin \phi_i' \quad (49)$$

and

$$CY_i = \rho CY_{i-1} + (1-\rho^2)^{1/2} \alpha_i' \cos \phi_i', \quad (50)$$

in which

$$\alpha_i' = C'(-2 \log U_i)^{1/2} \quad (51)$$

and

$$\phi_j' = 2\pi U_{j+2M}, \quad (52)$$

with

$$C' = [C/(C+N)]^{1/2}, \quad (53)$$

and the initial clutter values are

$$CX_0 = C'\alpha_0 \cos \phi_0' \quad (54)$$

and

$$CY_0 = C'\alpha_0 \sin \phi_0'. \quad (55)$$

At this point all the data pulses x_{ij} have been generated, and the simulation of the detector can begin. First, a decision is made whether to use linear video (Fortran variable XLOG = 0.0) or log video (XLOG = 1.0), according to the value of XLOG specified at input. Next the moving-window detector is initiated by integrating the first M pulses:

$$Z_j = \sum_{i=NS}^{MS} x_{ij}, \qquad j = N_F, ..., N_L, \tag{56}$$

where

$$MS = NS + M - 1. \tag{57}$$

For each of the remaining pulses ($i = MS + 1$ to NF) the moving window for each cell is updated:

$$Z_j = Z_j + x_{ij} - x_{i-M,j}. \tag{58}$$

The detection threshold T_j for the jth range cell ($j = 12, 13,$ and 14) uses either all the reference cells, the half with the minimum mean value, or the half with the maximum mean value. Furthermore the threshold may be based on either one parameter (the mean) or two parameters (the mean and the variance). Thus the mean is

$$\overline{Z}_j = \frac{1}{2N_R} \sum_{i=1}^{N_R} (Z_{j+1+i} + Z_{j-1-i}), \tag{59a}$$

$$\overline{Z}_j = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j+1+i}, \tag{59b}$$

or

$$\overline{Z}_j = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j-1-i}, \tag{59c}$$

and the corresponding mean squares are

$$\overline{Z_j^2} = \frac{1}{2N_R} \sum_{i=1}^{N_R} (Z_{j+1+i}^2 + Z_{j-1-i}^2), \tag{60a}$$

$$\overline{Z_j^2} = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j+1+i}^2, \tag{60b}$$

and

$$\overline{Z_j^2} = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j-1-i}^2. \tag{60c}$$

The standard deviation is

$$\sigma_j = [\overline{Z_j^2} - (\overline{Z}_j)^2]^{1/2}, \tag{61}$$

where $\overline{Z_j^2}$ and $\overline{Z}_j$ use the same reference cells. The two-parameter threshold for either linear or log video is

$$T_j = \overline{Z}_j + N_\sigma \sigma_j, \tag{62}$$

where N_σ is the number of standard deviations specified at input. (Appropriate values of N_σ are given in Appendix A.) The two-parameter threshold for log video has dubious meaning, since the threshold can be dominated by the shape of the density function near zero. The one-parameter threshold is

$$T_j = N_\sigma \overline{Z}_j \tag{63}$$

for linear video and

$$T_j = N_\sigma + \overline{Z}_j \tag{64}$$

for log video.

For each range cell j the first (FC_j) and last (LC_j) azimuth crossings of the threshold T_j are saved. These values are calculated under the restrictions that there is at least one $Z_j < T_j$ at an azimuth smaller than LC_j and that there is no azimuth interval larger than ΔA (the azimuth separation based on the pulse detection separation specified at input) between LC_j and FC_j for which all $Z_j < T_j$. Furthermore the range cell of the initial detection (smallest azimuth) is J_1, of the second smallest is J_2, and of the last is J_3.

The action taken by the program in providing centroided detections from the N_i detections of the ith target depends on whether any of the interfering targets are within three range cells of the test cell, a condition which can cause merging problems with other targets.

If there are no merging problems for target NTAR, then MER(NTAR) = 0 and the J_1 detection is a valid detection. The J_2 detection is valid if either

$$|J_1 - J_2| > 1 \tag{65}$$

or

$$LC_{J_2} > LC_{J_1} + \Delta A. \tag{66}$$

The J_3 detection is valid if J_2 is not valid and

$$|J_1 - J_3| > 1 \tag{67}$$

and

$$LC_{J_3} > LC_{J_2}. \tag{68}$$

If J_2 is valid, either Eq. 67 or

$$LC_{J_3} > LC_{J_1} + \Delta A \tag{69}$$

must be true and either

$$|J_2 - J_3| > 1 \tag{70}$$

or

$$LC_{J_3} > LC_{J_2} + \Delta A \tag{71}$$

must be true for all three detections to be valid. For the kth valid detection of the ith target (the target of interest NTAR) the range is

$$\hat{R}_{ik} = R_S + (J_k + 0.5)\Delta R, \tag{72}$$

the azimuth is

$$\hat{A}_{ik} = (LC_{J_k} + FC_{J_k} - \theta_{3\text{dB}})/2, \tag{73}$$

and the signal energy is

$$\hat{S}_{ik} = \max\,(Z_{J_k}/T_{J_k}), \tag{74}$$

where k equals 1 if there is only one valid detection and takes on a maximum value of 3.

On the other hand, if there are merging problems (MER(I) = -1), a decision on valid detections can be made only by considering all the detections from all targets. This decision is made by calling subroutine MERDET at the end of the radar scan. The values saved for this decision are the ranges given by Eq. 72 and the initial and final threshold crossings given by

$$\hat{A}_{i,2k-1} = FC_{J_k} - \theta_{3\text{dB}}/2 \tag{75a}$$

and

$$\hat{A}_{i,2k} = LC_{J_k} - \theta_{3\text{dB}}/2. \tag{75b}$$

Table 5 — MWDET Variables

Fortran Variable	Description
A	Rayleigh random variable (α_i in Eq. 43)
AA	Azimuth of the kth interfering target (A_k in Eqs. 35 and 39)
ACONZ	Azimuth separation for declaring two detections (ΔA in Eq. 66)
AOLDX	Gaussian-clutter random variable (CX_i in Eq. 49)

Table continues.

Table 5 (Continued) — MWDET Variables

Fortran Variable	Description
AOLDY	Gaussian-clutter random variable (CY_i in Eq. 50)
AZ(I,2J-1)	Initial azimuth of the *j*th detection of the *i*th target which has a target close by ($\hat{A}_{i,2j-1}$ in Eq. 75a)
AZ(I,2J)	Final azimuth of the *j*th detection of the *i*th target which has a target close by ($\hat{A}_{i,2j}$ in Eq. 75b)
AZ(I,J)	Azimuth of *j*th detection of *i*th target ($\hat{A}_{ij}$ in Eq. 73)
AZIM	Azimuth position of the pulse closest to the target (θ in Eq. 17)
AZIMS	Azimuth of pulse 0 (θ_0 in Eq. 18)
A1	Rayleigh random variable (α_i' in Eq. 51)
B	Uniformly distributed phase angle (ϕ_i in Eqs. 44 and 47)
B1	Uniformly distributed phase angle (ϕ_i' in Eq. 52)
C	Clutter energy (C in Eqs. 40, 48, and 53)
CC	Normalized clutter energy (C' in Eq. 53)
COR	Clutter correlation coefficient (ρ in Eqs. 49 and 50)
D(J)	Detection threshold for the *j*th range cell (T_j in Eqs. 63 and 64)
DEL	Antenna azimuth change between pulses ($\Delta\theta$ in Eq. 17)
F	Signal reduction due to the pulse shape (F in Eq. 32)
FDIF	Normalized difference between the target range and the center of the range cell (F_d in Eq. 34)
FFN	Normalized noise energy (N' in Eq. 48)
FL	Fluctuation amplitude when the amplitude is the same for all pulses
FLUCT(I)	Fluctuation amplitude of the *i*th pulse and the *j*th interfering target (F_i in Eqs. 25 through 29)
FN	Noise energy (N in Eqs. 40, 48, and 53)
FSIG	Number of standard deviations used in the calculation of the threshold (N_σ in Eq. 62)
G	Signal reduction due to the antenna pattern (G in Eq. 38)
GDIF	Normalized difference between the target azimuth and the center of the beam (G_d in Eq. 39)
IC(J)	Countdown to zero after the last threshold crossing in the *j*th range cell
ID(K)	Range cell of the *k*th earliest detection (J_k in Eq. 72)
IDET(J)	Status of the *j*th range cell: previous detection, looking for the first threshold crossing, looking for the final crossing, or after the final crossing
II	Number of detections
IMERGE	Indicator that the interfering target is in the 9th to the 17th range cell
INF(I)	Index of the *i*th interfering target
IS(J)	Indicator that the signal is in the *j*th range cell ($I(j)$ in text preceding Eq. 41)
KK	Counter for random numbers
KR	Range cell in which the *k*th interfering target lies (K_R in Eq. 30)

Table continues.

Table 5 (Continued) — MWDET Variables

Fortran Variable	Description
KRS	Range cell in which target NTAR lies (K_{RS} in Eq. 22)
KT	Range cell adjacent to the target cell (K_T in Eq. 31)
M	Number of pulses generated
MER(I)	Indicator of the interfering-target problem (target within three range cells and 2.4 azimuth beamwidths of the ith target) for the ith target
MODEL(I)	Swerling fluctuation index for the ith target (NSW in text preceding Eq. 25)
MS	Last pulse for initiation of the moving window (MS in Eq. 57)
M2	Two times the number of pulses generated
M3	Three times the number of pulses generated
M4	Four times the number of pulses generated
N	Number of targets
NC	Closest pulse in azimuth to the kth interfering target (NC in Eq. 35)
NCONZ	Pulse separation for declaring two detections
NDET(I)	Number of detections of the ith target
NF	Last pulse simulated (NF in Eq. 20)
NI	Number of targets in the reference cells (NI in text preceding Eq. 25)
NNF	Last signal pulse for the kth interfering target (NNF in Eq. 37)
NNS	First signal pulse for the kth interfering target (NNS in Eq. 36)
NREF	Number of reference cells on each side of the test cell (N_R in Eqs. 59 and 60)
NREF2	Two times NREF ($2N_R$ in Eqs. 59a and 60a)
NRF	Last range cell used (N_L in Eq. 24)
NRS	First range cell used (N_F in Eq. 23)
NS	First pulse simulated (NS in Eq. 19)
NSW	Index of Swerling fluctuation model (NSW in text preceding Eq. 25)
NTAR	Target of interest NTAR
N3DB	Number of pulses integrated M
P	Function of the clutter correlation ($(1 - \rho^2)^{1/2}$ in Eqs. 49 and 50)
PARM	Parameter to denote whether the mean (PARM = 1) or the mean and variance (PARM = 2) should be used to calculate the threshold
R(I)	Uniform random numbers (U_i in Eqs. 27, 29, 41, and 43)
RANGE(I,J)	Range of the jth detection of the ith target ($\hat{R}_{ij}$ in Eq. 72)
RES	Range-cell dimension (ΔR in Eq. 21)
RR	Range of the kth interfering target (R_k in Eq. 30)
RS	Range of the first of 25 range cells (R_S in Eq. 21)
RTEMP	Range to the center of the K_Tth range cell (R_T in Eq. 34)

Table continues.

Table 5 (Concluded) — MWDET Variables

Fortran Variable	Description
S	Signal energy S
SM	Normalized signal energy including the effects of the pulse shape
SN(J)	Maximum normalized signal amplitude in the jth range cell
SNDET(I,J)	Maximum signal amplitude of the jth detection of the ith target ($\hat{S}_{ij}$ in Eq. 74)
SNINT	Maximum integrated signal-to-noise ratio
SNREF(K)	Signal energy of the kth interfering target (P_k in Eq. 40)
SS(I,J)	Signal energy of the ith pulse in the jth range cell (S_{ij} in Eqs. 42 and 45)
SUM	Integrated sum of the jth range cell (Z_j in Eq. 56)
THRSH	Indicates the reference cells to be used
TH3DB	The antenna 3-dB azimuth beamwidth (θ_{3dB} in Eqs. 39 and 73)
TIME(I)	Detection time of the ith target
TRGPOS(I,4)	Range of the ith target (R_k in Eq. 30)
TRGPOS(I,5)	Azimuth of the ith target (A_k in Eq. 35)
TWOPI	Two times 3.1415926536, or 2π
U	Mean value of the reference cells ($\overline{Z}_j$ in Eq. 59a)
ULOW	Mean value of the lower half of the reference cells ($\overline{Z}_j$ in Eq. 59c)
UUP	Mean value of upper half of the reference cells ($\overline{Z}_j$ in Eq. 59b)
X(I,J)	Video return of the ith pulse in the jth cell (x_{ij} in Eqs. 41, 42, and 43)
XFIRST(J)	First threshold crossing in the jth cell (FC_j in text after Eq. 64)
XLAST(J)	Last threshold crossing in the jth cell (LC_j in text after Eq. 64)
XLOG	Denotes the type of video to be used (linear video if XLOG = 0 and log video if XLOG = 1)
XMS	Mean square of the reference cells ($\overline{Z_j^2}$ in Eq. 60a)
XMSLOW	Mean square of lower half of the reference cells ($\overline{Z_j^2}$ in Eq. 60c)
XMSUP	Mean square of upper half of the reference cells ($\overline{Z_j^2}$ in Eq. 60b)

Subroutine STAB2

Subroutine STAB2 generates a new azimuth position for each target detection, because the radar is unstabilized. The routine is initialized by calling the entry point STBINT. The initialization section first reads four input parameters with a 4F8.2 format (Table 6):

RMAX — maximum roll angle (deg),
PMAX — maximum pitch angle (deg),
RPER — roll period (s),
PPER — pitch period (s).

Next, the angles are converted to radians, and the random-number generator is used to generate uniform phase angles for the roll and pitch cycles.

The modified azimuth positions are generated by calling STAB2 once per scan from the executive routine (after all detections have been obtained). The roll R and the pitch P angles at time t are

$$R = R_m \sin(2\pi t/T_R + \phi_R) \tag{76}$$

and

$$P = P_m \sin(2\pi t/T_P + \phi_P), \tag{77}$$

where R_m and P_m are the maximum roll and pitch angles, T_R and T_P are the corresponding periods, and ϕ_R and ϕ_P are uniform phase angles between 0 and 2π. The measured azimuth position α_m (in the deck plane) is [3]

$$\alpha_m = \tan^{-1}\left[\frac{\sin\alpha\cos R + (\cos\alpha\sin P + \tan e\cos P)\sin R}{\cos\alpha\cos P - \tan e\sin P}\right] + \epsilon, \tag{78}$$

where α and e are the true azimuth (re ship heading) and elevation angles of the target and e is the previously calculated azimuth error.

Table 6 — STAB2 Variables

Fortran Variable	Description
A	Azimuth of the target in the deck plane with zero measured error
AA	Azimuth of the target (α in Eq. 78)
ATEMP	Azimuth measurement (between π and 3π)
AZ	Azimuth measurement (between 0 and 2π) (α_m in Eq. 78)
CP	Cosine of the pitch angle
CR	Cosine of the roll angle
K	Number of detections per target
NDET(I)	Number of detections of the ith target
NTARG	Number of targets
PFAC	Frequency of the pitch cycle
PHASE(1)	Phase angle of the roll (ϕ_R in Eq. 76)
PHASE(2)	Phase angle of the pitch (ϕ_P in Eq. 77)
PI	3.1415926536, or π
PITCH	Pitch angle (P in Eqs. 77 and 78)
PMAX	Maximum pitch angle (P_m in Eq. 77)
PPER	Period of pitch cycle (T_P in Eq. 77)
RADIAN	57.29578°, the number of degrees in a radian, or $180/\pi$
RFAC	Frequency of the roll cycle
RMAX	Maximum roll angle (R_m in Eq. 76)
ROLL	Roll angle (R in Eqs. 76 and 78)
RPER	Period of the roll angle (T_R in Eq. 76)
SHIP(5)	Ship heading
SP	Sine of the pitch angle
SR	Sine of the roll angle
TE	Tangent of the target elevation
TIME	Time of detection
TRGPOS(I,5)	Azimuth of the target
TRGPOS(I,6)	Elevation of the target
TWOPI	Two times 3.1415926536, or 2π
X	Trigonometric function of the angles
Y	Trigonometric function of the angles

Subroutine VRCLT2

Subroutine VRCLT2 generates scan-to-scan independent clutter points in specified areas and is called once per scan by the executive routine after FXCLT2 has been called. The routine is initialized by calling the entry point VCINIT. The initialization section first reads two parameters with a 2I8 format (Table 7):

ISET — initialization number for the random-number generator,
NREG — number of clutter regions.

Next for *each* clutter region (a maximum of five regions) five parameters are specified according to a 5F8.2 format:

FN — average number of detections in the clutter region,
RS — initial range of the clutter region (kft),
RF — final range of the clutter region (kft),
THS — initial azimuth of the clutter region (deg),
THF — final azimuth of the clutter region (deg).

The input parameters are converted to nautical miles and radians for internal use, and the inverse of the density per unit azimuth F_i is generated by

$$F_i = (\theta_F - \theta_S)/N_i, \tag{79}$$

where θ_S and θ_F are the initial and final azimuth boundaries of the ith clutter region and N_i is the average number of detections in the ith region.

The detected clutter points are generated by calling VRCLT2 once per scan. The clutter regions are processed one at a time. For each clutter region the azimuth interval Δ_i between detections is generated by $\Delta_i = - F_i \log U_i$, where U_i is a uniformly distributed random number. If

$$\sum_{j=1}^{i} \Delta_j \leqslant (\theta_F - \theta_S), \tag{80}$$

the new detection is accepted. Its measured azimuth and range are

$$\theta = \theta_S + \sum_{j=1}^{i} \Delta_j \tag{81}$$

and

$$R = (K + 0.5)\Delta R, \tag{82}$$

where ΔR is the range-cell dimension and

$$K = \text{integer } \{[R_S + (R_F - R_S)V_i]/\Delta R\}, \tag{83}$$

in which R_S and R_F are the initial and final range boundaries of the ith clutter region and V_i is a uniformly distributed random number. The associated detection time is

$$T_i = T_0 + (\Delta T)\theta/2\pi, \tag{84}$$

where T_0 is the time of the zero-bearing crossing and ΔT is the scan period. The roll and pitch angles at time t are

$$\text{roll} = R_m \sin(2\pi t/T_R + \phi_R) \tag{85}$$

and

$$\text{pitch} = P_m \sin(2\pi t/T_P + \phi_P), \tag{86}$$

where R_m and P_m are the maximum roll and pitch angles, T_R and T_P are the corresponding periods, and ϕ_R and ϕ_P are uniform phase angles between 0 and 2π.

On the other hand, if

$$\sum_{j=1}^{i} \Delta_j > (\theta_F - \theta_S), \tag{87}$$

then the new detection is out of the present clutter region and the next clutter region is considered.

Table 7 — VRCLT2 Variables

Fortran Variable	Description
A	Azimuth of the detection (θ in Eq. 81)
AZOUT	Azimuth of the detection (output) (θ in Eq. 81)
ELOUT	Elevation of detection E (equals zero)
FLAM	Inverse azimuth density of the clutter points in the ith clutter region (F_i in Eq. 79)
FN	Average number of detections in the region (N_i in Eq. 79)
IC	Number of fixed clutter points detected
IRAN	Random-number counter
ISET	Initialization number for the random-number generator
IV	Total number of clutter detections (fixed plus variable)
K	Range-cell number (K in Eqs. 82 and 83)
NREG	Number of regions (maximum of five)
PFAC	Frequency of the pitch cycle
PHASE(1)	Phase angle of the roll (ϕ_R in Eq. 85)
PHASE(2)	Phase angle of the pitch (ϕ_P in Eq. 86)
PMAX	Maximum pitch angle (P_m in Eq. 86)
PTOUT(I)	Pitch angle at the time of the ith detection (pitch in Eq. 86)

Table continues.

Table 7 (Concluded) — VRCLT2 Variables

Fortran Variable	Description
RADIAN	57.29578°, the number of degrees in a radian, or $180/\pi$
RAN	Array of random numbers U_i, V_i, and W_i
RC(19)	Range-cell dimension (ΔR in Eq. 82)
RES	Range-cell dimension (ΔR in Eq. 82)
RF	Final range of the clutter region (R_F in Eq. 83)
RFAC	Frequency of the roll cycle
RLOUT(I)	Roll angle at the time of the ith detection (roll in Eq. 85)
RMAX	Maximum roll angle (R_m in Eq. 85)
RMODE(1,5)	Scan period (ΔT in Eq. 84)
ROUT(I)	Range of the ith detection (R in Eq. 82)
RS	Initial range of the clutter region (R_S in Eq. 83)
SOUT(I)	Power of the ith detection
T	Time of the zero-bearing crossing (T_0 in Eq. 84)
THF	Final azimuth of the clutter region (θ_F in Eq. 79)
THS	Initial azimuth of the clutter region (θ_S in Eq. 79)
TIMSCN	Scan period (ΔT in Eq. 84)
TIMZB	Time of the zero-bearing crossing (T_0 in Eq. 84)
TOUT(I)	Time of the ith detection
TWOPI	Two times 3.1415926536, or 2π

ROUTINES EXCLUSIVE TO SURDET3D

SURDET3D Executive Routine

The SURDET3D executive routine drives the detection model for 3D surveillance radar systems. The model itself consists of subroutines that perform specialized functions; the SURDET3D executive routine links these routines together (Fig. 3). The modular construction of the model facilitates changes and additions to the existing version.

The SURDET3D executive routine begins by setting constants and conversion factors for use by the model's subroutines. It then reads in the first two data input cards. (The next subsection describes user input, and Table 8 describes the variables.) The first card contains the output-control parameter ANS1, which determines the amount of printed output produced. The options include no output printed (ANS1 = 0), only the detection output printed (ANS1 = 1), and the detailed output printed (ANS1 = 2). The second input card contains the run identification, which consists of an integer radar identification followed by alphanumeric descriptive information of the user's choice. The radar identification is used to label the output files for subsequent use as input to the MERIT tracking program [2].

SURDET3D monitors the input of the scenario data by calling a sequence of subroutines. Subroutine INITAL reads the radar data, subroutine TARGET reads the parameters defining the targets and jammers, and subroutine ENVIRN reads the environmental data. Subroutines FCINIT and VCINIT are called to input the data defining the fixed clutter

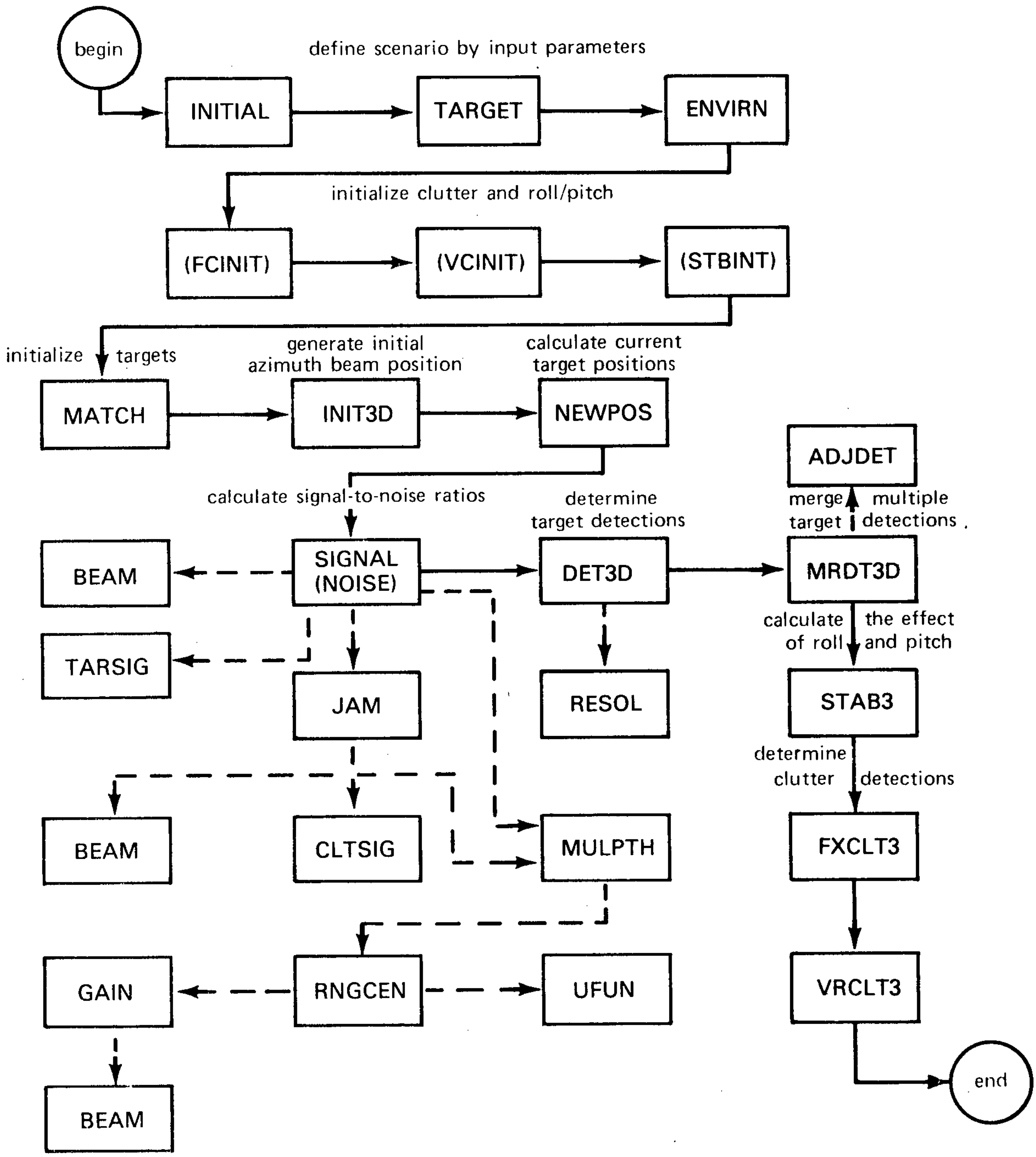


Fig. 3 — Subroutine linkage by the SURDET3D executive routine. The solid lines indicate program flow, and the dashed lines indicate subroutines called. The names in parentheses are entry points. The loops for multiple radar modes and multiple targets are not indicated.

area and variable clutter areas respectively. Roll and pitch characteristics of the radar platform are read by subroutine STBINT.

The game time by which the radar must be initialized, RINIT, is next read as an input directly by the executive routine and then modified by the radar scan offset, if any. Subroutine MATCH is called to determine the time each target first comes within the instrumented range of the radar. The minimum time among this set of times from MATCH is then further decreased by 30 s to insure clutter samples prior to detections, and the earlier of this result and RINIT, the maximum radar initialization time, becomes the game initialization time. The end of the game is set to coincide with the last target's reaching the end of its trajectory. At this point an identification record for the detection output file consisting of the radar identification and the radar scan rate is written on the logical unit specified by the parameter IOUT.

The recursive portion of the routine begins with a call to subroutine INIT3D, which generates an initial azimuth beam position for the start of the first elevation scan. The positions of all targets and jammers at current game time T are determined by subroutine NEWPOS. An elevation scan is then performed for each target active at current time T as follows. Given an active target I, SURDET3D steps through the defined radar (elevation) modes. For each mode the routine first determines if target I is within instrumented range, is above the radar horizon, is within the appropriate angular vertical coverage of the pencil beam or the cosecant-squared beam, and is beyond the minimum radar range. Unless all of these conditions are met, target I is dropped from further consideration by this (elevation) mode. The routine next compares the elevation angle of target I to the current mode's (mode J) elevation beam center. If the difference exceeds the radar's vertical 3-dB beamwidth, target I is dropped from further consideration by this mode. Otherwise, SURDET3D proceeds to compute the signal energy and the noise and clutter energies for target I by calling subroutines SIGNAL and NOISE respectively. It next uses subroutine DET3D to determine any detections of target I by the current radar mode, printing a record of each detection if the print-control parameter ANS1 indicates that detailed output is desired.

When an elevation scan has been completed for each target active at time T, subroutine MRDT3D is called to merge adjacent detections and estimate the range, azimuth, elevation, and signal power of the centroided detections. The centroided detections are further modified for roll and pitch of the radar platform by subroutine STAB3. Detections of fixed and of variable clutter for current game time T are determined by calls to subroutines FXCLT3 and VRCLT3 respectively. A report of centroided target detections and false alarms (clutter detections) is printed if ANS1 indicates that any printed output is desired. A similar output scan record for use as subsequent input to the MERIT tracking program [2] is written on the logical unit specified by IOUT.

To initiate a new radar scan, the current game time T, which represents the time the radar starts its current scan at zero azimuth, is increased by the radar scan period (as specified for radar scan-mode 1). If the new game time does not exceed ENDTIM, the time at which the run ends, then control is returned to the beginning of the recursive portion of the program. Otherwise a recycle control parameter is read which specifies one of the following four options:

- A new scenario is to be read to initiate a new run, in which case program control is transferred to the beginning of the executive routine;

- Radar parameters from the run just completed are to be retained, but the rest of the scenario is to be redefined for a new run, so program control is transferred to the point where subroutine TARGET is called;

- Radar and target parameters are to be retained, but a new environment is to be specified for a new run, so program control is transferred to the point where subroutine ENVIRN is called;

- All runs are completed.

Table 8 — SURDET3D Variables

Fortran Variable	Description
ACON	Constant used in sea-state calculations (to be described in the subsection on subroutine JAM in the next main section)
ALPHAD	Grazing angle of the clutter patch (deg)
AMBN	Thermal noise energy (*J*)
ANS1	Printed output control: 0 = no output printed 1 = detection output only printed 2 = detailed output printed
AZ(I,K)	Azimuth of the *k*th centroided detection of target *I*
AZINIT	Azimuth beam position at the start of the elevation scan
AZOUT(L)	Azimuth of the *l*th clutter detection
AZ3(I,K,J)	Azimuth of the *k*th detection of target *I* by mode *J*
BETA	Constant used in sea-state calculations (described in the subsection on subroutine JAM)
BHDEG	Azimuth of target *I* in degrees for printing
BUF	Scan-output-ID array written on logical unit IOUT
BUF(1)	Scan number
BUF(2)	Start time of the present scan
BUF(3)	Number of detections (including false alarms)
BUF(4)	Radar ID
BUF(5)	Ship's heading (rad)
BUF(6)	Total number of targets
BUFA	Detection history array written on logical unit IOUT for each target detection or false alarm *K*
BUFA(1,K)	Target number or clutter detection number of the *k*th detection
BUFA(2,K)	Range of the *k*th detection (n.mi.)
BUFA(3,K)	Azimuth of the *k*th detection (rad)
BUFA(4,K)	Elevation of the *k*th detection (rad)
BUFA(5,K)	Time of the *k*th detection (s)
BUFA(6,K)	Signal energy of the *k*th detection (dB)
BUFA(7,K)	Roll angle of the *k*th detection (rad)
BUFA(8,K)	Pitch angle of the *k*th detection (rad)

Table continues.

Table 8 (Continued) — SURDET3D Variables

Fortran Variable	Description
BUFB	Target true-position array written on logical unit IOUT for each defined target
BUFB(1,I)	Target number (*I*)
BUFB(2,I)	Slant range to the true target-*I* position (n.mi.)
BUFB(3,I)	Azimuth of the true target-*I* position (rad)
BUFB(4,I)	Elevation of the true target-*I* position (rad)
BUFB(5,I)	Time when the radar scans by target *I* (s)
BVDEG	Elevation of target *I* measured from the horizon in degrees for printing
CCM	Speed of light (cm/s)
CNM	Speed of light (n.mi./s)
CONV	Conversion factor for converting natural logarithms to dB ($10 \log_{10} e$)
DBE	Signal energy of target *I* with respect to mode *J* (dB re 1 *J*)
DBN	Total noise energy with respect to mode *J* (dB re 1 *J*)
DWL(J)	Frequency increment for mode *J* (Hz)
ELEV(I,K)	Elevation of the *k*th centroided detection of target *I*
ELOUT(L)	Elevation of the *l*th clutter detection
ENDTIM	Time at which the current run terminates (h)
ENVIR(3)	Multipath indicator: 0 = no multipath 1 = multipath
FAC4	Multipath propagation factor to the fourth power
FOPIQB	$(4\pi)^3$
FOPISQ	$(4\pi)^2$
GN	One-way antenna gain
IANS	Recycle run control: 1 = new run with a new radar and new targets and environment 2 = new run with the current radar and new targets and environment 3 = new run with the current radar and targets and a new environment 4 = all runs completed
IC	Number of fixed clutter detections on the current scan
ICNT	Detection counter used for the output file
IMODE(J,1)	Number of pulses integrated for mode *J*
IOUT	Logical unit for the detection output file
ISC	Radar-scan counter
ISTAT(I)	Status indicator for target *I*: 0 = target is inactive 1 = target is active
ISWIT	Frequency indicator: 0 = frequency of the current scan mode differs from the previous mode 1 = no change in frequency from the last mode

Table continues.

Table 8 (Continued) — SURDET3D Variables

Fortran Variable	Description
ITITLE	Array containing alphanumeric run identification
IV	Number of fixed and variable clutter detections on the current scan
MER3(I)	Indicator of interfering-target problems with respect to target *I*: 0 = no merging problem -1 = merging problem with target *I*, target detected -2 = merging problem with target *I*, target not detected
MUL	Multipath indicator: 0 = no multipath 1 = multipath
NC(K)	Index of the *k*th detector fixed clutter point
NDET(I)	Number of centroided detections of target *I*
NDET3(I,J)	Number of detections of target *I* by mode *J*
NEXT	Current radar scan mode
NREF	Number of reference cells on each side of the test cell
NSCAN	Number of radar scan modes defined
NTARG	Number of targets (to be detected)
OFR	Frequency of the current radar scan mode (MHz)
PBBS	Elevation beam center of the current radar mode
PITCH(I)	Pitch angle at the time of detection of target I
PTOUT(R)	Pitch at the time of the *k*th clutter detection
RADIAN	Conversion factor for radians to degrees ($180/\pi$)
RANGE(I,K)	Range of the *k*th centroided detection of target *I*
RANGE3(I,K,J)	Range of the *k*th detection of target *I* by mode *J*
RC(1)	Basic radar frequency (MHz)
RC(4)	Horizontal 3-dB beamwidth (rad)
RC(5)	Vertical 3-dB beamwidth (rad)
RC(6)	One-way antenna gain
RC(11)	Power received for target *I* (*W*)
RC(12)	Signal energy for target *I* (*J*)
RC(13)	Clutter energy for target *I* (*J*)
RC(14)	Thermal noise plus jamming for target *I* (*J*)
RC(15)	Number of reference cells on each side of the target cell used in the moving-window detector
RC(16)	Clutter correlation coefficient
RC(17)	Number of standard deviations used in the detection threshold
RC(18)	Azimuth offset between beam positions (rad)
RC(20)	Detector video type: 0 = linear video 1 = log video
RC(21)	Number of reference cells used to calculate the threshold: 0 = all cells used <0 = half with smaller mean value used >0 = half with larger mean value used

Table continues.

Table 8 (Concluded) — SURDET3D Variables

Fortran Variable	Description
RC(22)	Parameters used to calculate the threshold: 1 = mean used 2 = mean and variance used
RE	4/3 of the earth's radius (m)
RFR	Ratio of the basic radar frequency to the frequency of the current radar mode
RINIT	Latest time by which the radar is to begin scanning
RLOUT(K)	Roll at the time of the *k*th clutter detection
RMODE(J,1)	Lower 3-dB point of the elevation angle coverage for mode *J* (deg)
RMODE(J,2)	Upper 3-dB point of the elevation angle coverage for mode *J* (deg)
RMODE(J,5)	Interlook period for mode *J* (h)
RMODE(1,6)	Scan offset for mode 1 (h)
RMODE(J,7)	Instrumented range for mode *J* (n.mi.)
RMODE(J,9)	Earliest time any target enters the instrumented range of radar mode *J*
ROLL(I)	Roll angle at the time of detection of target *I*
ROUT(K)	Range of the *k*th clutter detection
SHIP(5)	Heading of the ship (rad)
SIGC	Total sea-clutter energy
SMODE(J,1)	Blanking range for mode *J* (n.mi.)
SN	Signal-to-noise ratio (dB) (assuming the radar is pointing at the target)
SNDET(I,K)	Signal energy of the *k*th centroided detection of target *I*
SNDET3(I,K,J)	Signal energy of the *k*th detection of target *I* by mode *J*
SNTRUE	Signal energy
SOUT(K)	Signal energy of the *k*th clutter detection
T	Current game time (h)
TARCS	Target cross section
THH	Basic radar horizontal 3-dB beamwidth (rad)
THV	Basic radar vertical 3-dB beamwidth (rad)
TIME(I)	Time of the detection of target *I* (s)
TIME3(I)	Time of the detection of target *I* (s)
TOUT(K)	Time of the *k*th clutter detection (s)
TRGPOS(I,4)	Slant range of target *I* (n.mi.)
TRGPOS(I,5)	Azimuth of target *I* (rad)
TRGPOS(I,6)	Elevation of target *I* measured from the horizon (rad)
TSCAN(I,J)	Time when target *I* comes within the instrumented range of radar mode *J* (h)
V	Range extent of the clutter cell (*m*)
XJAMN	Total jamming energy (*J*)
XKTOMS	Conversion factor for knots to meters per second
XNMTOM	Conversion factor for nautical miles to meters
XYZF(I,4)	Time when target *I* reaches the endpoint of its trajectory (h)

Input for SURDET3D

An engagement scenario consists of a radar, one or more targets to be detected, and an optional number of sources of jamming radiation (subsequently referred to as jammers) set in a specified environment. The number of targets and jammers together is limited to 20. The required input information is divided into the definitions of the radar, targets, and jammers, an environment with optional clutter, and output and recycle control parameters. The data cards required are:

Data card 1—printed-output control integer (I5 format):

0 = no output printed,
1 = only the detection output printed,
2 = detailed output printed;

Data card 2—title card (I4, 19A4 format):

1. Radar integer ID,
2. Alphanumeric run identification;

Data card 3—ship (radar) position (4F8.2 format):

1-3. Position coordinate (x, y, z) (kft),
4. Ship heading (deg);

Data card 4—11 basic radar parameters (9F8.2,I2,F6.2 format):

1. Radar frequency (MHz),
2. Antenna pattern function indicator (0 = pencil beam and 1 = cosecant-squared beam),
3. Receiver noise (dB),
4. Horizontal 3-dB beamwidth (deg),
5. Vertical 3-dB beamwidth (deg),
6. One-way antenna gain (dB),
7. One-way sidelobe level (dB down from peak),
8. Receiver loss (dB),
9. Transmitter loss (dB),
10. Number of scan modes (limited to 30),
11. Linear polarization (0° to 90°, where 0° = horizontal and 90° = vertical);

Data cards 5 and 6 (one set for each radar scan mode)—15 parameters for each scan mode (10F8.2/5F8.2 format):

1. Lower 3-dB point of the elevation-angle coverage (deg),
2. Upper 3-dB point of the elevation-angle coverage (deg),
3. Peak power (MW),
4. Pulse length (μs),
5. Interlook period (s) (must be identical for all modes),
6. Scan offset (s),
7. Instrumented range (n.mi.),

8. Mode-dependent loss (dB),
9. Number of pulses integrated,
10. Compressed-pulse length (μs),
11. Sea-clutter improvement factor (dB),
12. Intermediate-frequency bandwidth (MHz) (if 0, the bandwidth is set at 1.0/compressed-pulse length),
13. Mode-dependent frequency increment (MHz),
14. Blanking time (μs) (if 0, the blanking time is set at the pulse length),
15. Rain-clutter improvement factor (dB);

Data card 7—seven parameters for the moving-window detector (7F8.2 format):

1. Number of reference cells on each side of the target cell,
2. Clutter correlation coefficient,
3. Number of standard deviations used in the threshold which determines the probability of false alarm (guidance in setting the threshold value is given by Appendix A),
4. Azimuth offset between beam positions (deg),
5. Video-type indicator (0 = linear video and 1 = log video),
6. Number of reference cells used for the threshold (0 = all cells used, <0 = half with smaller mean value used, and > 0 = half with larger mean value used),
7. Parameters used to calculate the threshold (1 = mean used and 2 = mean and variance used);

Data card 8—number of targets and jammers (total limited to 20) (2I5 format):

1. Number of targets,
2. Number of jammers;

Data card 9 (one card for each target and jammer, paired with a card 10)—13 target parameters (12F6.2,I3 format):

1–4. Initial coordinates (x, y, z) (kft) and time (s),
5–8. Terminal coordinates (x, y, z) (kft) and time (s),
9–11. Head-on, broadside, and minimum radar reflective areas (m^2),
12. Jamming power density (W/MHz),
13. Marcum-Swerling cross-section model number;

Data card 10 (one card for each target and jammer, paired with a card 9)—target profile parameters (I4,7F6.2 format):

1. Target profile type (0 = straight-line trajectory, 1 = altitude legs, and 2 = g maneuver at constant altitude), with profile parameters 2 through 8 that follow being ignored for target profile type 0 and being as indicated for target types 1 and 2,
2. Number of altitude nodes (maximum of three), for target type 1, or target speed (kft/s), for target type 2,
3. First altitude node (kft), for target type 1, or initial heading of the target (deg), for target type 2,

4. Time of the target arrival at the first node (s) for target type 1, or time the maneuver begins, for target type 2,
5. Second altitude node (kft), for target type 1, or radial acceleration of the maneuver (*g*'s), for target type 2,
6. Time of the target arrival at the second node (s), for target type 1, or ignored for target type 2,
7. Third altitude node kilofeet (kft), for target type 1, or ignored for target type 2,
8. Time of the target arrival at the third node (s), for target type 1, or ignored for target type 2;

Data card 11—four environmental parameters (4F8,2 format):

1. Wind speed (knots),
2. Height of the wind-speed measurement (kft),
3. Multipath indicator (1 = multipath and 0 = no multipath),
4. Rainfall rate (mm/h);

Data card 12—nine fixed clutter parameters (2I8,7F8.2 format):

1. Initialization for the random-number generator for generation of fixed clutter points,
2. Number of fixed clutter points,
3. Probability that a clutter point is detected,
4. Initial range of the clutter area (kft),
5. Final range of the clutter area (kft),
6. Standard deviation of the range measurement (percent of the range-resolution cell size),
7. Initial azimuth of the clutter area (deg),
8. Final azimuth of the clutter area (deg),
9. Standard deviation of the azimuth measurement (percent of the horizontal 3-dB beamwidth);

Data card 13—two basic variable clutter parameters (2I8 format):

1. Initialization for the random-number generator for generation of variable clutter points,
2. Number of clutter regions;

Data card 14—(one card for each clutter region)—seven parameters for each clutter region (7F8.2 format):

1. Average number of clutter points in the region,
2. Initial range of the clutter area (kft),
3. Final range of the clutter area (kft),
4. Initial azimuth of the clutter area (deg),
5. Final azimuth of the clutter area in (deg),
6. Initial elevation of the clutter area (deg),
7. Final elevation of the clutter area (deg);

Data card 15—four roll and pitch parameters (4F8.2 format):

1. Maximum roll angle (deg),
2. Maximum pitch angle (deg),
3. Roll period (s) (a number >0 should be specified),
4. Pitch period (s) (a number >0 should be specified);

Data card 16—time parameter (F8.2 format):

1. Game time (s) by which the radar must initiate scanning;

Data card 17—recycle control parameter (I5 format):

1 = a new scenario is to be read, with the next data card being data card 1,
2 = current radar parameters are to be retained, but new targets and environment are to be read, with the next data card being data card 8,
3 = current radar and target parameters are to be retained, but a new environment is to be read, with the next data card being data card 11,
4 = all runs completed.

All input data from data cards 2 through 16 are printed as output at the beginning of each run.

Output from SURDET3D

An engagement is initiated either 30 s prior to the time a target first comes within the instrumented range of a radar mode or at the latest time by which the radar must be initialized (as specified by input), whichever occurs first. Once initiated, the simulation produces an output detection report for each radar (azimuth) scan until the engagement terminates with the last target reaching its final position. A sample printed output for a single scan is reproduced in Fig. 4.

The sample report is identified as scan number 11 in line 1. The results of each step in the elevation scan of target 1 and target 2 are given in lines 3 through 11 and 12 through 18 respectively. Lines 3, 6, 9, 11, 12, 14, 16, and 18 contain the following information, as indicated by the heading in line 2:

TARGET	Target number,
MODE	Radar scan mode number (step in elevation scan),
TIME	Time of the scan (s),
RANGE	Slant range of the target from the radar (kft),
AZIM	Azimuth angle of the target (deg),
ELEV	Elevation angle of the target (deg),
SIGMA	Radar cross section of the target (m^2),
FACTOR	Multipath pattern-propagation factor (dB),
ESIG	Signal energy (dB re 1 J),
NAMB	Ambient noise (dB re 1 J),
NCLT	Clutter energy (dB re 1 J),
NJAM	Jamming energy (dB re 1 J),

```
1                      +++++++  SCAN NUMBER =   11   +++++++

      MODE                                          SIGMA
2  TARGET          TIME       RANGE      AZIM       ELEV        FACTOR   ESIG    NAMB    NCLT    NJAM        E/N         MER3
3    1   1         15.9      365.00     100.72     1.19   0.1   -2.     -183.   -202.   -740.   -740.    18.46  16.95    -1
4     *DETECTION*            364.87     100.54                            22.
5     *DETECTION*            365.07     100.54                            25.
6    1   2         15.9      365.00     100.72     1.19   0.1   -3.     -184.   -202.   -740.   -740.    17.19  15.68    -1
7     *DETECTION*            364.87     100.54                            21.
8     *DETECTION*            365.07     100.54                            25.
9    1   3         15.9      365.00     100.72     1.19   0.1   -1.     -188.   -202.   -740.   -740.    13.84  12.33    -1
10    *DETECTION*            365.07     100.54                            20.
11   1   4         15.9      365.00     100.72     1.19   0.1   -3.     -202.   -202.   -740.   -740.     0.06  -1.45    -1
12   2   1         15.9      365.44     100.72     1.19   0.1   -2.     -183.   -202.   -740.   -740.    16.20  18.00    -1
13    *DETECTION*            365.46     100.54                            27.
14   2   2         15.9      365.44     100.72     1.19   0.1   -3.     -185.   -202.   -740.   -740.    17.01  16.81    -1
15    *DETECTION*            365.46     100.54                            25.
16   2   3         15.9      365.44     100.72     1.19   0.1   -1.     -188.   -202.   -740.   -740.    13.77  13.57    -1
17    *DETECTION*            365.46     100.54                            23.
18   2   4         15.9      365.44     100.72     1.19   0.1   -3.     -202.   -202.   -740.   -740.    -0.09 -99.00    -1

19 SCAN NUMBER=  11.    TIME=    14.50    NO. DETECTIONS=  22.    RADAR ID= 3059.    HEADING=   1.57    NO. TARGETS=  2.

20                      ID     RANGE      AZIM      ELEV      TIME      ESIG      ROLL      PITCH
21 DETECTION NUM        1.   60.0309    1.7512    0.0316   15.9030   25.3616   0.3233   -0.0534
22 DETECTION NUM        2.   60.1066    1.7512    0.0316   15.9030   26.7080   0.3233   -0.0534
23 DETECTION NUM      101.    5.0669    1.5360    0.0055   15.7257   34.8937   0.3070   -0.0610
24 DETECTION NUM      103.    8.5959    3.8711    0.0054   17.5885   34.8937   0.2776    0.0375
25 DETECTION NUM      104.   10.5061    2.8217    0.0153   16.7553   34.8937   0.3457   -0.0088
26 DETECTION NUM      105.   22.3234    4.9484    0.0242   18.4326   34.8937   0.1357    0.0733
27 DETECTION NUM      107.   18.5354    3.1369    0.0035   17.0016   34.8937   0.3345    0.0053
28 DETECTION NUM      108.   21.1903    1.2689    0.0270   15.5148   34.8937   0.2829   -0.0690
29 DETECTION NUM      110.   21.4493    1.0433    0.0120   15.3407   34.8937   0.2594   -0.0747
30 DETECTION NUM      200.   15.8806    0.8445    0.0000   15.1761   30.4567   0.2344   -0.0791
31 DETECTION NUM      200.   22.3234    2.8824    0.0000   16.7978   30.4567   0.3444   -0.0063
32 DETECTION NUM      200.   22.1939    3.5156    0.0000   17.3017   30.4567   0.3105    0.0222
33 DETECTION NUM      200.   17.2728    3.7417    0.0000   17.4816   30.4567   0.2909    0.0319
34 DETECTION NUM      200.   23.0357    5.3356    0.0000   18.7500   30.4567   0.0707    0.0815
35 DETECTION NUM      200.   24.5898    1.0598    0.1227   15.3474   30.4567   0.2603   -0.0745
36 DETECTION NUM      200.   23.0357    1.0733    0.1715   15.3582   30.4567   0.2619   -0.0741
37 DETECTION NUM      200.   22.9062    1.1527    0.1708   15.4213   30.4567   0.2706   -0.0722
38 DETECTION NUM      200.   20.0571    1.1628    0.0116   15.4294   30.4567   0.2717   -0.0719
39 DETECTION NUM      200.   23.0481    1.1712    0.1162   15.4360   30.4567   0.2726   -0.0717
40 DETECTION NUM      200.   22.3862    1.1768    0.1446   15.4405   30.4567   0.2732   -0.0715
41 DETECTION NUM      200.   21.2874    1.1921    0.1693   15.4527   30.4567   0.2749   -0.0711
42 DETECTION NUM      200.   22.7120    1.2165    0.1579   15.4721   30.4567   0.2774   -0.0705
```

Fig. 4 — SURDET3D output report. In this reproduction the line numbers at the left have been added to facilitate the discussion in the text

E/N Signal-energy-to-noise-energy ratios (dB), with the first ratio being the value when the radar is pointing at the target and the second ratio being the actual value used to determine a detection,

MER3 Indicator of the interfering-target problem (to be described in the subsection on subroutine DET3D).

Lines 4 and 5 report two detections of target 1 by scan mode 1. The range and azimuth of the reference cell in which each detection took place are given under RANGE and AZIM respectively. The signal amplitude (re noise energy) corresponding to each detection is given in decibels under ESIG. Similarly lines 7 and 8 report detections of target 1 by scan mode 2, line 10 reports a detection of target 1 by mode 3, line 13 reports a detection of target 2 by mode 1, line 15 reports a detection of target 2 by mode 2, and line 17 reports a detection of target 2 by mode 3.

Lines 16 through 38 are the data constituting the output record written on logical unit IOUT for subsequent use as input to the MERIT tracking programs [2]. (In addition the actual range, azimuth, and elevation of each target and the time each is scanned by the radar are also written on IOUT.) Line 19 identifies the current record by specifying the scan number, current game time in seconds, number of detections (including false alarms), radar identification augmented by 3000, ship's heading in radians, and number of targets defined. The remaining lines, labeled by detection number, provide data as labeled by line 20 for each centroided target detection and false alarm (fixed or variable clutter detection). The information provided for each detection starts with a detection number: 0 through 99 identifies a target, 101 through 199 indicates a fixed clutter point, and 200 represents a variable clutter point. Following the detection number are the estimated range in nautical miles, the azimuth and elevation angles in radians, the time of detection in seconds, the signal energy in decibels, and the roll and pitch angles in radians. Presently the signal energy for fixed and variable clutter points is set to 34.8937 and 30.4567 dB respectively. If the signal energy is to be used by a tracking program, an appropriate signal energy must be generated.

An output report as shown in Fig. 4 is printed for each radar (azimuth) scan when the print output control parameter (data card 1) is 2. If the parameter is 1, then only the detection history given by lines 19 through 42 is printed. If the parameter is 0, then no output scan reports are printed.

Subroutine ADJDET

Subroutine ADJDET is called by subroutine MRDT3D. The routine determines whether the ith detection of target KTAR in the jth mode is adjacent to any detection k in the set of K detections which have previously been determined to be adjacent (Table 9). Two detections are adjacent if two of their three parameters (range, azimuth, and elevation) are the same and the other parameter differs by at most the resolution element: range-resolution cell ΔR, azimuth beamwidth θ, or elevation beamwidth γ respectively. To avoid roundoff errors, the ith detection is added to the previous set of K adjacent detections if any of three conditions is satisfied for any kth detection in the set. The first condition is

$$|R - R_k| \leqslant 1.2\,\Delta R,$$

$$|A - A_k| \leqslant 0.1\,\theta,$$

$$|E - E_k| \leqslant 0.1\,\gamma;$$

the second condition is

$$|R - R_k| \leqslant 0.1\,\Delta R,$$

$$|A - A_k| \leqslant 1.2\,\theta,$$

$$|E - E_k| \leqslant 0.1\,\gamma;$$

and the third condition is

$$|R - R_k| \leqslant 0.1\,\Delta R,$$

$$|A - A_k| \leqslant 0.1\,\theta,$$

$$|E - E_k| \leqslant 1.2\,\gamma;$$

where R, A, and E are the range, azimuth, and elevation of the detection being tested and R_k, A_k, and E_k are the range, azimuth, and elevation of the kth detection in the set of adjacent detections. If the test detection is adjacent to any of the K adjacent detections, K is increased by one and the range, azimuth, elevation, and integrated signal power of the test detection are stored in the four elements of DETPAR(K,4). If the test detection is not adjacent to any of the K adjacent detections, NEWJJ is increased by one, and the parameters (range, azimuth, and signal power) for the ith detection are stored in the location of the parameters for the NEWJJth detection.

Table 9 — ADJDET Variables

Fortran Variable	Description
A	Azimuth angle A of the ith detection of target KTAR by the jth radar mode
AZ3(KTAR,I,J)	Same as variable A
DETPAR(K,1)	Range R_k of the kth adjacent detection
DETPAR(K,2)	Azimuth A_k of the kth adjacent detection
DETPAR(K,3)	Elevation E_k of the kth adjacent detection
DETPAR(K,4)	Signal power of the kth adjacent detection
E	Elevation angle E of the jth radar mode
EL3DB	The antenna 3-dB elevation beamwidth γ
I	Index of the detection being tested
J	Index of the radar mode being tested
K	Present number of adjacent detections
KTAR	Target under consideration
NEWJJ	Present number of nonadjacent detections in the previous set of $I - 1$ detections of target KTAR by the jth mode
R	Range R of the ith detection of target KTAR by the jth radar mode
RANGE3(KTAR,I,J)	Same as variable R
RES	Range-cell dimension ΔR
RMODE(J,1)	Elevation angle E of the jth radar mode
SNDET3(KTAR,I,J)	Signal power of the ith detection of target KTAR by the jth radar mode
TH3DB	The antenna 3-dB azimuth beamwidth θ

Subroutine DET3D

Subroutine DET3D is called for every target and radar mode on each radar scan as long as the difference between the center of the elevation beam of the radar mode and the target elevation angle is less than the 3-dB elevation beamwidth. The purpose of the routine is to declare target detections by generating pulse-to-pulse video returns, integrating the returned signal, and comparing the returned signal to an adaptive threshold which is generated from the surrounding reference cells. Detections can be made in adjacent range cells and adjacent azimuth beam positions in addition to the range-azimuth cell in which the target is present. Thus in theory a radar mode can report nine detections of a single target.

The routine initially tests whether appropriate input parameters (Table 10) are less than preassigned values: the number of pulses integrated M is less than 32, the number of reference cells N_R on each side of the test cell is less than ten, and the absolute value of clutter correlation coefficient ρ is less than 1.0. If any parameter exceeds its limit, an error message is printed and the program stops.

Next, M times the ratio of signal to clutter-plus-noise is compared to 2. If the value is less than 2, the target is declared not detected, the number of detections of target NTAR by the jth mode NDET3(NTAR,J) is set to 0, and control is returned to the calling routine. Otherwise the detailed simulation is begun by finding all the targets which lie within the reference cells of target NTAR. The list of interfering targets INF is initialized by setting INF(1) = NTAR, and the corresponding signal energy SNREF(1) is set equal to the target energy S. The remaining interfering targets are found by calling subroutine RESOL, which calculates the number of interfering targets NI, lists the index of the interfering targets in the array INF, and lists the corresponding signal energies in SNREF.

The main recursive section of the routine generates the azimuth beam positions on either side of the azimuth beam position with maximum gain. It first generates the azimuth beam position preceding the main-gain beam position. This beam position θ is

$$\theta = \theta_B(K_\theta + \text{IAZ} - 2), \tag{88}$$

where IAZ = 1 for the first beam position, θ_B is the azimuth angle between complete elevation scans, and K_θ is the integer defined by

$$K_\theta = \text{integer}\,[(A - \theta_I)/\theta_B + 0.5], \tag{89}$$

in which A is the target azimuth and θ_I is the azimuth angle of the first elevation scan.

In the simulation the video return is generated only in the reference cells surrounding the target. Thus, to save computer storage, only 25 range cells are saved and the target is always placed in the 13th cell. Consequently the range to the start of the first range cell is

$$R_S = \Delta R(K_{RS} - 13), \tag{90}$$

where ΔR is the range-cell dimension and K_{RS} is the integer defined by

$$K_{RS} = \text{integer}\,(R/\Delta R), \tag{91}$$

in which R is the target range.

The first step in generating the radar video return is to generate the signal (target) return in the appropriate range cells. Specifically, the index of the first range cell is

$$N_F = 11 - N_R, \tag{92}$$

and the index of the last range cell is

$$N_L = 15 + N_R. \tag{93}$$

Thus, if $N_R = 10$, signal must be placed in all 25 range cells. The signal return for the ith pulse and the jth range cell S_{ij} and an indicator of signal in the jth range cell $I(j)$ are initially set to zero for all i and j. Then the signal return from each of the NI interfering targets lying within the reference cells is generated. For the kth target this is accomplished by first generating the appropriate fluctuating amplitudes F_{ik} for the ith pulse, if the valid fluctuating amplitudes have not been calculated previously; IKEY(NTAR) = 1 indicates that F_{ik} has been calculated previously for Swerling cases 1 and 3 (scan-to-scan fluctuations) for either a previous azimuth or elevation beam position. If F_{ik} needs to be calculated (either the first time for Swerling cases 1 and 3 or every time for Swerling cases 2 and 4), F_{ik} is given for the appropriate Swerling case NSW by the following equations, in which the U_i, $i = 1, ..., M$, are independent random numbers uniformly distributed between 0 and 1. For NSW = 0 (nonfluctuating target)

$$F_{ik} = 1, \qquad i = 1, ..., M. \tag{94}$$

For NSW = 1 (scan-to-scan fluctuations, Rayleigh density)

$$F_{ik} = -\log U_1, \qquad i = 1, ..., M. \tag{95}$$

For NSW = 2 (pulse-to-pulse fluctuations, Rayleigh density)

$$F_{ik} = -\log U_i, \qquad i = 1, ..., M. \tag{96}$$

For NSW = 3 (scan-to-scan fluctuations, chi-square density)

$$F_{ik} = -0.5(\log U_1 + \log U_2), \qquad i = 1, ..., M. \tag{97}$$

For NSW = 4 (pulse-to-pulse fluctuations, chi-square density)

$$F_{ik} = -0.5(\log U_i + \log U_{M+i}), \qquad i = 1, ..., M. \tag{98}$$

The signal is next placed in the appropriate range cell and the adjacent range cells by reducing the returned signal by a $[(\sin x)/x]^2$ pulse shape and a $[(\sin x)/x]^4$ antenna pattern. The return signal from the kth target is centered in range cell K_R:

$$K_R = \text{integer}\,[(R_k - R_S)/\Delta R], \tag{99}$$

where R_k is the range of the kth target. The signal-return reduction F in the adjacent range cell

$$K_T = K_R + I, \qquad I = -1, 0, 1, \tag{100}$$

is given by (because of the (sin x)/x pulse shape)

$$F = [(\sin F_d)/F_d]^2, \tag{101}$$

where

$$F_d = 2.7832(R_k - R_R)/\Delta R \tag{102}$$

and

$$R_T = (K_T + 0.5)\Delta R + R_S. \tag{103}$$

At this time the indicator $I(K_T)$ is set equal to 1.

Similarly the signal reduction G due to the (sin x)/x antenna pattern is

$$G = [(\sin G_d)/G_d]^4, \tag{104}$$

where

$$G_d = 2.7832(A_k - \theta)/\theta_{3dB}, \tag{105}$$

in which A_k is the azimuth of the kth target and θ_{3dB} is the antenna 3-dB azimuth beamwidth. Finally, the signal (normalized by the clutter energy C and noise energy N) due to the kth target in the K_Tth range cell for the azimuth beam position specified by Eq. 88 is

$$S_{i,K_T}(\text{new}) = S_{i,K_T}(\text{old}) + GFF_{i,k}P_k/(C + N), \tag{106}$$

where P_k is the signal energy of the kth interfering target.

The calculation indicated by Eqs. 100 through 106 is first repeated for the adjacent range cells indicated in Eq. 100. Then the calculation indicated by Eqs. 94 through 106 is repeated for all NI targets in the reference cells. Thus at the end of all of these repetitions $S_{i,j}$ is the signal energy in the ith pulse and jth range cell due to all the targets in the reference cells.

Next Rayleigh noise (and possibly correlated clutter) is added to the signal to produce the total video return x_{ij}. The video return is generated (because of computer speed considerations) for three distinct cases: clutter insignificant and no signal present in the range cell, clutter insignificant and signal energy S_{ij} present in the range cell, and clutter significant. The significance of clutter is indicated by the product of clutter and the number of pulses integrated CM being greater than N, and signal present in the jth cell is indicated by $I(j) = 1$. Thus, the ith return in the jth cell x_{ij} is given as follows. For clutter insignificant ($CM \leqslant N$) and no signal in the jth cell ($I(j) = 0$)

$$x_{ij} = (-2 \log U_i)^{1/2}, \qquad i = 1, ..., M, \tag{107}$$

where the U_i are independent uniform random numbers between 0 and 1 different for each j. For clutter insignificant ($CM \leqslant N$) and signal in the jth cell ($I(j) = 1$)

$$x_{ij} = \{[\alpha_i \cos \phi_i + (2S_{ij})^{1/2}]^2 + (\alpha_i \sin \phi_i)^2\}^{1/2}, \tag{108}$$

where

$$\alpha_i = (-2 \log U_i)^{1/2} \tag{109}$$

and

$$\phi_i = 2\pi U_{i+M}. \tag{110}$$

For clutter significant ($CM > N$)

$$x_{ij} = \{[CX_i + \alpha_i \cos \phi_i + (2S_{ij})^{1/2}]^2 + (CY_i + \alpha_i \sin \phi_i)^2\}^{1/2}, \tag{111}$$

where the Rayleigh-noise components $\alpha_i \cos \phi_i$ and $\alpha_i \sin \phi_i$ are given by

$$\alpha_i = N'(-2 \log U_{i+M})^{1/2} \tag{112}$$

and

$$\phi_i = 2\pi U_{i+3M}, \tag{113}$$

with

$$N' = [N/(C+N)]^{1/2}, \tag{114}$$

the clutter is given by

$$CX_i = \rho CX_{i-1} + (1-\rho^2)^{1/2} \alpha_i' \sin \phi_i' \tag{115}$$

and

$$CY_i = \rho CY_{i-1} + (1-\rho^2)^{1/2} \alpha_i' \cos \phi_i', \tag{116}$$

in which

$$\alpha_i' = C'(-2 \log U_i)^{1/2} \tag{117}$$

and

$$\phi_i' = 2\pi U_{i+2M}, \tag{118}$$

with

$$C' = [C/(C+N)]^{1/2}, \tag{119}$$

and the initial clutter values are

$$CX_0 = C'\alpha_0 \cos \phi_0' \tag{120}$$

and

$$CY_0 = C'\alpha_0 \sin \phi_0'. \tag{121}$$

Next a decision is made whether to use linear video (Fortran variable XLOG = 0.0) or log video (XLOG = 1.0), according to the value of XLOG specified at input. Then the M pulses are integrated in each range cell, yielding the values

$$Z_j = \sum_{i=1}^{M} x_{ij}. \tag{122}$$

The detection threshold T_j for the jth range cell (j = 12, 13, and 14) uses either all the reference cells, the half with the minimum mean value, or the half with the maximum mean value. Furthermore, the threshold may be based on either one parameter (the mean) or two parameters (the mean and the variance). Thus the mean is

$$\overline{Z_j} = \frac{1}{2N_R} \sum_{i=1}^{N_R} (Z_{j+1+i} + Z_{j-1-i}), \tag{123a}$$

$$\overline{Z_j} = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j+1+i}, \tag{123b}$$

or

$$\overline{Z_j} = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j-1-i}, \tag{123c}$$

and the corresponding mean squares are

$$\overline{Z_j^2} = \frac{1}{2N_R} \sum_{i=1}^{N_R} (Z_{j+1+i}^2 + Z_{j-1-i}^2), \tag{124a}$$

$$\overline{Z_j^2} = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j+1+i}^2, \tag{124b}$$

and

$$\overline{Z_j^2} = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j-1-i}^2. \tag{124c}$$

The standard deviation is

$$\sigma_j = [\overline{Z_j^2} - (\overline{Z_j})^2]^{1/2}, \tag{125}$$

where $\overline{Z_j^2}$ and $\overline{Z}_j$ use the same reference cells. The two-parameter threshold for either linear or log video is

$$T_j = \overline{Z}_j + F_\sigma \sigma_j, \tag{126}$$

where the parameter F_σ is used to set the false alarm rate. (Appropriate values of F_σ are given in Appendix A.) The two-parameter threshold for log video has dubious meaning, since the threshold can be dominated by the shape of the density function near zero. The one-parameter threshold is

$$T_j = F_\sigma \overline{Z}_j \tag{127}$$

for linear video and

$$T_j = F_\sigma + \overline{Z}_j \tag{128}$$

for log video.

Finally, detections are declared by comparing Z_{12}, Z_{13}, and Z_{14} to T_{12}, T_{13}, and T_{14} respectively. If Z_j is greater than T_j, a detection is declared in the jth range cell, the counter for the number of detections denoted by II is increased by one, and the following detection parameters are saved:

II, the number of detections,
$R_S + (j + 0.5)\Delta R$, the range of the detection,
θ, the azimuth of the detection,
$Z_j(C + N)$, the signal amplitude of the detection, and
Time, the time of the detection.

Also, if any target lies within three range cells and 2.4 azimuth beamwidths of target NTAR, MER3(NTAR) is set to -1, which notes this interfering-target condition.

After the detection tests have been performed for the initial azimuth beam position with IAZ = 1, all calculations are repeated for the other two beam positions. If there are interfering-target conditions and if the target has not been detected on this mode or previous modes of this radar scan, MER3(NTAR) is set to -1. Then control is returned to the executive routine.

Table 10 — DET3D Variables

Fortran Variable	Description
A	Rayleigh random variable (α_i in Eq. 109)
AA	Azimuth of the kth interfering target (A_k in Eq. 105)
AOLDX	Gaussian clutter random variable (CX_i in Eq. 115)
AOLDY	Gaussian clutter random variable (CY_i in Eq. 116)
AZBBP	Azimuth angle between elevation scans (θ_B in Eq. 88)
AZIM	Azimuth of the center of the present beam position (θ in Eq. 88)

Table continues.

Table 10 (Continues) — DET3D Variables

Fortran Variable	Description
AZINIT	Azimuth of first complete elevation scan (θ_I in Eq. 89)
AZ3(I,II,J)	Azimuth of the *II*th detection of the *i*th target by the *j*th mode
A1	Rayleigh random variable (α_i' in Eq. 117)
B	Uniformly distributed phase angle (ϕ_i in Eq. 113)
B1	Uniformly distributed phase angle (ϕ_i' in Eq. 118)
C	Clutter energy (C in Eqs. 106, 114, and 119)
CC	Normalized clutter energy (C' in Eq. 119)
COR	Clutter correlation coefficient (ρ in Eqs. 115 and 116)
D(J)	Detection threshold for the *j*th range cell (T_j in Eqs. 126, 127, and 128)
F	Signal reduction due to pulse shape (F in Eq. 101)
FDIF	Normalized difference between the target range and the center of range cell (F_d in Eq. 102)
FFN	Normalized noise energy (N' in Eq. 114)
FL	Fluctuation amplitude when the amplitude is the same for all pulses
FLUCT(I,J)	Fluctuation amplitude of the *i*th pulse and the *j*th interfering target (F_{ik} in Eqs. 94 and 98)
FN	Noise energy (N in Eqs. 106, 114, and 119)
FSIG	Number of standard deviations used in the calculation of the threshold (F_σ in Eq. 126)
G	Signal reduction due to the antenna pattern (G in Eq. 104)
GDIF	Normalized difference between the target azimuth and the center of the beam (G_d in Eq. 105)
IAZ	Index of the current azimuth beam position (IAZ in Eq. 88)
II	Number of detections (II in text after Eq. 128)
IKEY(NTAR)	Indicator that fluctuation amplitudes have been calculated at least once for target NTAR
IMERGE	Indicator that the interfering target is in the 9th to the 17th range cell
INF(I)	Index of the *i*th interfering target
IS(J)	Indicator that the signal is in the *j*th range cell ($I(j)$ in text preceding Eq. 107)
KAZ	Azimuth beam position closest to the target (K_θ in Eq. 89)
KK	Counter for random numbers
KR	Range cell in which *k*th interfering target lies (K_R in Eq. 99)
KRS	Range cell in which target NTAR lies (K_{RS} in Eq. 91)
KT	Range cell adjacent to the target cell (K_T in Eq. 100)
M	Number of pulses integrated M
M2	Two times the number of pulses integrated
M3	Three times the number of pulses integrated
M4	Four times the number of pulses integrated
MER3(I)	Indicator of an interfering-target problem (a target within three range cells and 2.4 azimuth beamwidths of the *i*th target) for the *i*th target
MODE	Active radar mode

Table continues.

Table 10 (Continues) — DET3D Variables

Fortran Variable	Description
MODEL(I)	Swerling fluctuation index for the ith target (NSW in text preceding Eq. 94)
MS	Number of pulses integrated M
N	Number of targets
NDET3(I,J)	Number of detections of the ith target by the jth radar mode
NF	Last pulse simulated (M in Eqs. 94 through 98)
NI	Number of targets in the reference cells (NI in text after Eq. 106)
NREF	Number of reference cells on each side of the test cell (N_R in Eqs. 123 and 124)
NREF2	Two times NREF ($2N_R$ in Eqs. 123a and 124a)
NRF	Last range cell used (N_L in Eq. 93)
NRS	First range cell used (N_F in Eq. 92)
NS	First pulse simulated (1 in Eqs. 94 through 98)
NSW	Index of the Swerling fluctuation model (NSW in text preceding Eq. 94)
NTAR	Target of interest
N3DB	Number of pulses integrated M
P	Function of the clutter correlation ($(1 - \rho^2)^{1/2}$ in Eqs. 115 and 116)
PARM	Parameter to denote whether the mean (PARM = 1) or the mean and the variance (PARM = 2) should be used to calculate the threshold
R(I)	Uniform random numbers (U_i in Eqs. 96 and 98)
RANGE3(I,II,J)	Range of the IIth detection of the ith target by the jth mode
RES	Range-cell dimension (ΔR in Eq. 90)
RR	Range of the kth interfering target (R_k in Eq. 99)
RS	Range to the first of the 25 range cells (R_S in Eq. 90)
RTEMP	Range to the center of the K_Tth range cell (R_T in Eq. 103)
S	Signal energy S
SM	Normalized signal energy including the effects of the pulse shape
SNDET3(I,II,J)	Signal amplitude of the IIth detection of the ith target by the jth mode
SNINT	Maximum integrated signal-to-noise ratio
SNREF(K)	Signal energy of the kth interfering target (P_k in Eq. 106)
SS(I,J)	Signal energy of the ith pulse and the jth range cell (S_{ij} in Eqs. 108 and 111)
SUM(J)	Integrated sum of the jth range cell (Z_j in Eq. 122)
THRSH	Indicates reference cells to be used
TH3DB	The 3-dB azimuth antenna beamwidth (θ_{3dB} in Eq. 105)
TRGPOS(I,4)	Range of the ith target (R in Eq. 91)
TRGPOS(I,5)	Azimuth of the ith target (A in Eq. 89)
TWOPI	Two times 3.1415926536, or 2π
U	Mean value of the reference cells ($\overline{Z}_j$ in Eq. 123a)
ULOW	Mean value of lower half of the reference cells ($\overline{Z}_j$ in Eq. 123c)
UUP	Mean value of upper half of the reference cells ($\overline{Z}_j$ in Eq. 123b)
X(I,J)	Video return of the ith pulse in the jth cell (x_{ij} in the text preceding Eq. 107)

Table continues.

Table 10 (Concluded) — DET3D Variables

Fortran Variable	Description
XLOG	Denotes the type of video to be used (linear if XLOG = 0 and log if XLOG = 1)
XMS	Mean square of the reference cells ($\overline{Z_j^2}$ in Eq. 124a)
XMSLOW	Mean square of the lower half of the reference cells ($\overline{Z_j^2}$ in Eq. 124c)
XMSUP	Mean square of the upper half of the reference cells ($\overline{Z_j^2}$ in Eq. 124b)

Subroutine FXCLT3

Subroutine FXCLT3 generates fixed clutter points and is called once per scan by the executive routine. The routine is initialized by calling the entry point FCINIT. The initialization section reads in the following nine inputs with a (2I8,7F8.2) format (Table 11):

ISET — initialization number for the random-number generator,
N — number of fixed clutter points,
PROB — probability that a clutter point is detected,
RS — initial range of the clutter area (kft),
RF — final range of the clutter area (kft),
SIGR — standard deviation of the range measurement (fractions of a range cell),
THS — initial azimuth of the clutter area (deg),
THF — final azimuth of the clutter area (deg),
SIGA — standard deviation of the azimuth measurement (fractions of a beamwidth).

The initialization section calculates the range-cell dimension ΔR by

$$\Delta R = c\tau_c/2, \tag{129}$$

where c is the speed of light and τ_c is the compressed pulsewidth. Next the input values are converted to nautical miles and radians for internal use. Finally, N fixed clutter points are generated by

$$R_i = R_S + (R_F - R_S)U_i \tag{130}$$

and

$$\theta_i = \theta_S + (\theta_F - \theta_S)V_i, \tag{131}$$

where R_i and θ_i are the range and azimuth of the clutter points, R_S and R_F are the initial and final range boundaries of the clutter area, θ_S and θ_F are the initial and final azimuth boundaries of the clutter area, and U_i and V_i are independent, uniformly distributed random numbers.

The detected clutter points are generated by calling FXCLT3 once per scan. For each clutter point a uniform random number U is compared to P_r, the probability of detecting the clutter point. If $U \leqslant P_r$, the clutter point is assumed to be detected, Gaussian errors are added in range and azimuth, and the azimuth measurement is corrupted by roll and pitch. The range measurement is

$$R_m = (K + 0.5)\Delta R, \tag{132}$$

where

$$K = \text{integer } \{[R_i + \sigma_R(-2 \log U_i)^{1/2} \cos 2\pi V_i]/\Delta R\}, \tag{133}$$

in which σ_R is the measurement standard deviation and U_i and V_i are uniform random numbers. The errors in azimuth and elevation are

$$\epsilon_a = \sigma_\theta (-2 \log U_i)^{1/2} \sin 2\pi V_i \tag{134}$$

and

$$\epsilon_e = W_i \theta_e / 2, \tag{135}$$

where σ_θ is the standard deviation of the azimuth measurement, θ_e is the elevation beamwidth, and U_i, V_i, and W_i are uniformly distributed random numbers. The angles of roll R and pitch P at time t are

$$R = R_{\max} \sin (2\pi t/T_R + \phi_R) \tag{136}$$

and

$$P = P_{\max} \sin (2\pi t/T_P + \phi_P), \tag{137}$$

where $R_{\max}$ and $P_{\max}$ are the maximum roll and pitch angles, T_R and T_P are the corresponding periods, and ϕ_R and ϕ_P are uniform phase angles between 0 and 2π. The measured azimuth position a_m (in the deck plane) is [3]

$$a_m = \tan^{-1} \left[\frac{\sin a \cos R + (\cos a \sin P + \tan e \cos P) \sin R}{\cos a \cos P - \tan e \sin P}\right] + \epsilon_a, \tag{138}$$

and the measured elevation position e_m is [3]

$$e_m = \sin^{-1} [\cos e \cos a \sin P + \sin e \cos P) \cos R - \cos e \sin a \sin R] + \epsilon_e, \tag{139}$$

where $a = \theta_i$ is the true azimuth, $e = 0$ is the true elevation of the clutter point, and ϵ_a and ϵ_e are the previously calculated azimuth and elevation errors. Finally the measurements a_m and e_m which are relative to the deck plane of the ship can be rotated into a system whose xy plane is the plane of the ocean. These equations are [3]

$$a'_m = \tan^{-1} \left[\frac{-\sin R \sin e_m + \cos R \sin a_m \cos e_m}{\cos P \cos a_m \cos e_m + D \sin P}\right] \tag{140}$$

and

$$e'_m = \sin^{-1} [\sin P \cos a_m \cos e_m + D \cos P], \tag{141}$$

where

$$D = \cos R \sin e_m + \sin R \sin a_m \cos e_m . \tag{142}$$

The detection time T_i is proportional to the azimuth:

$$T_i = T_0 + (\Delta T)\theta_i/2\pi, \tag{143}$$

where T_0 is the time of the start of the scan and ΔT is the scan period.

Table 11 — FXCLT3 Variables

Fortran Variable	Description
A	Azimuth of the clutter point in the deck plane with zero measurement error
AA	True azimuth of the clutter point with respect to the ship (a in Eqs. 138 and 139)
AM	Azimuth measurement (between π and 3π)
AT	Measured azimuth (between 0 and 2π) (a_m in Eq. 138)
ATEMP	Azimuth measurement (between π and 3π)
AZ	True azimuth of the clutter point (θ_i in Eq. 143)
AZOUT	Azimuth measurement (a_m in Eq. 138)
CP	Cosine of the pitch angle
CR	Cosine of the roll angle
E	Elevation of the target in the deck plane
EL	True elevation e of the clutter: $e = 0$
ELOUT	Elevation measurement (e'_m in Eq. 141)
ET	Elevation measurement (e_m in Eq. 139)
IC	Number of fixed clutter points detected this scan
ISET	Initialization number for the random-number generator
K	Range cell of the measurement (K in Eq. 132)
N	Number of fixed clutter points
NC	Index of the clutter point detected
N2	Two times N
N3	Three times N
N4	Four times N
PFAC	Frequency of the pitch cycle
PHASE(1)	Phase angle of the roll (ϕ_R in Eq. 136)
PHASE(2)	Phase angle of the pitch (ϕ_P in Eq. 137)
PMAX	Maximum pitch angle (P_{max} in Eq. 137)
PROB	Probability that the clutter point is detected (P_r in text preceding Eq. 132)

Table continues.

Table 11 (Concluded) — FXCLT3 Variables

Fortran Variable	Description
PTOUT	Pitch at the time of the ith detection (P in Eq. 137)
R	True range of the clutter point (R_i in Eq. 130)
RADIAN	57.29578°, the number of degrees in a radian, or $180/\pi$
PAN	Array of uniform random numbers (U_i in Eqs. 130, 133, and 134)
RAY	Rayleigh random number
RC(4)	Azimuth beamwidth
RC(5)	Elevation beamwidth (θ_e in Eq. 135)
RC(19)	Range-cell dimension (ΔR in Eq. 129)
RES	Range-cell dimension (ΔR in Eq. 132)
RF	Final range of the clutter area (R_F in Eq. 130)
RFAC	Frequency of the roll cycle
RLOUT	Roll at the time of the ith detection (R in Eq. 136)
RMAX	Maximum roll angle (R_{max} in Eq. 136)
RMODE(1,5)	Scan period (ΔT in Eq. 143)
ROUT	Range measurement (R_m in Eq. 132)
RS	Initial range of the clutter area (R_S in Eq. 130)
SHIP(5)	Ship heading
SIGA	Standard deviation of the azimuth measurement (σ_0 in Eq. 134)
SIGR	Standard deviation of the range measurement (σ_R in Eq. 133)
SOUT	Energy of the ith detection
SP	Sine of the pitch angle
SR	Sine of the roll angle
T	Time of the start of the radar scan (T_0 in Eq. 143)
TAU	Compressed pulsewidth (s) (τ_c in Eq. 129)
TE	Tangent of the elevation angle (zero)
TH	Uniform distributed phase angle
THF	Final azimuth of the clutter area (θ_F in Eq. 131)
THS	Initial azimuth of the clutter area (θ_S in Eq. 131)
TIMSCN	Scan period (ΔT in Eq. 143)
TIMZB	Time of the zero-bearing crossing (T_0 in Eq. 143)
TOUT	Detection time (T_i in Eq. 143)
TWOPI	Two times 3.1415926536, or 2π
X	Trigometric function of angles
Y	Trigonometric function of angles

Subroutine INITAL

Subroutine INITAL is called once by the SURDET3D executive routine. Its purpose is to establish constants, to read ship (radar platform) and radar data in kilofeet and seconds, and to convert the units to internal units (nautical miles and hours) for use by other subroutines (Table 12).

The location and heading of the ship or radar platform, which is to remain stationary throughout an engagement, and the antenna height above sea level are specified by four radar-position input parameters read into the SHIP array:

SHIP(1) — x position coordinate (kft),
SHIP(2) — y position coordinate (kft),
SHIP(3) — z position coordinate (antenna height above sea level) (kft),
SHIP(5) — ship heading (deg).

It is often convenient to let the radar platform be located at the origin (0, 0) of the scenario coordinate system.

A radar is described by specifying 11 basic parameters followed by 15 descriptors for each of up to 30 operational radar scan modes and moving-window detector data. Typical radar scan modes include different elevation beams, long-range search, high-angle low-energy search, burnthrough, and horizon scan. The 11 basic radar input parameters, which are stored in the RC array, in NSCAN, and in POLRZ, are:

RC(1) — Radar frequency (MHz),
RC(2) — Antenna-pattern indicator (0 = pencil beam and 1 = cosecant-squared beam),
RC(3) — Receiver noise (dB),
RC(4) — Horizontal 3-dB beamwidth (deg),
RC(5) — Vertical 3-dB beamwidth (deg),
RC(6) — One-way antenna gain (dB),
RC(7) — One-way sidelobe level (dB down from peak),
RC(8) — Receiver line loss (dB),
RC(9) — Transmitter line loss (dB),
NSCAN — Number of scan modes to be defined (a number not to exceed 30),
POLRZ — Linear polarization from 0° to 90° (0° = horizontal and 90° = vertical).

Each radar scan mode J is described by the following 15 input parameters, which are read into the RMODE, IMODE, SUBC, DWL, and SMODE arrays:

RMODE(J,1) — lower 3 dB-point of the elevation-angle coverage (deg),
RMODE(J,2) — upper 3 dB-point of the elevation-angle coverage (deg),
RMODE(J,3) — peak power (MW),
RMODE(J,4) — pulse length (μs),
RMODE(J,5) — interlook period (time between scans) (s)
RMODE(J,6) — scan offset (relative to radar initialization) (s),
RMODE(J,7) — instrumented range (n.mi.),
RMODE(J,8) — mode-dependent loss (dB),
IMODE(J,1) — number of pulses integrated,
RMODE(J,11) — compressed-pulse length (μs),
SUBC(J) — sea-clutter improvement factor (dB),
RMODE(J,12) — intermediate-frequency bandwidth (MHz) (if 0 is entered, the bandwidth is set at 1.0/(compressed-pulse length)
DWL(J) — mode-dependent frequency increment (MHz) (if DWL(J) is nonzero, the effective horizontal and vertical beamwidths and antenna gain for this scan mode are also affected),

SM — blanking time (μs) (if 0 is entered, the blanking time is set at the pulse length),
SMODE(J,2) — rain-clutter improvement factor (dB).

These radar scan modes are numbered in ascending order as they are defined, beginning with 1.

The moving window detector is defined by the following seven input parameters, stored in the RC array:

RC(15) — number of reference cells on each side of the target cell,
RC(16) — clutter correlation coefficient,
RC(17) — number of standard deviations used in the threshold (determines the probability of a false alarm),
RC(18) — azimuth offset between beam positions,
RC(20) — video-type indicator (0 = linear video and 1 = log video),
RC(21) — number of reference cells used for the threshold (0 = all cells used, <0 = half with smaller mean value used, and >0 = half with larger mean value used),
RC(22) — Parameters used to calculate the threshold (1 = mean used and 2 = mean and variance used).

Subroutine INITAL also performs checks on the input data with the result that:

- The number of radar scan modes is limited to 30,
- The interlook period for each mode is set equal to 10 s if its input value is zero or negative,
- The IF bandwidth for each mode is set equal to the reciprocal of the compressed pulse length if its input value is zero or negative, and
- The blanking time for each mode is set equal to the pulse length if its input value is zero.

Table 12 — INITAL Variables

Fortran Variable	Description
DWL(J)	Frequency increment for mode J (MHz)
IMODE(J,1)	Number of pulses integrated for mode J
IMODE(J,2)	max $(B_{IF}\tau_c, 1)$ rounded to the nearest integer for mode J
MILLION	1×10^6
MM	Effective number of pulses integrated
NSCAN	Number of scan modes
PI	3.1415926536, or π
PIOVER2	One half of 3.1415926536, or $\pi/2$

Table continues.

Table 12 (Concluded) — INITAL Variables

Fortran Variable	Description
POLRZ	Linear polarization (0° to 90°, where 0° = horizontal and 90° = vertical)
RADIAN	57.29578°, the number of degrees in a radian, or $180/\pi$
RC(1)	Radar frequency f (MHz)
RC(2)	Indicator of the antenna-pattern function: 0 = pencil beam 1 = $\csc^2$ beam
RC(3)	Receiver noise
RC(4)	Horizontal 3-dB beamwidth (deg to rad)
RC(5)	Vertical 3-dB beamwidth (deg to rad)
RC(6)	One-way antenna gain
RC(7)	One-way sidelobe level
RC(8)	Receiver losses
RC(9)	Transmitter losses
RC(10)	Boltzmann's constant times the system temperature, or kT (J)
RC(15)	Number of reference cells on each side of the target cell used in the moving-window detector
RC(16)	Clutter correlation coefficient
RC(17)	Number of standard deviations used in the detection threshold
RC(18)	Azimuth offset between beam positions (deg to rad)
RC(20)	Detector video type: 0 = linear video 1 = log video
RC(21)	Number of reference cells used to calculate the threshold: 0 = all cells used <0 = half with smaller mean value used >0 = half with larger mean value used
RC(22)	Parameter to denote whether the mean (RC(22) = 1) or the mean and variance (RC(22) = 2) should be used to calculate the threshold
RMODE(J,1)	Lower 3-dB point of the elevation-angle coverage for mode J (deg)
RMODE(J,2)	Upper 3-dB point of the elevation-angle coverage for mode J (deg)
RMODE(J,3)	Peak power for mode J (MW to W)
RMODE(J,4)	Pulse length for mode J (μs to s)
RMODE(J,5)	Interlook period for mode J (s to h)
RMODE(J,6)	Scan offset for mode J (s to h)
RMODE(J,7)	Instrumented range for mode J (n.mi.)
RMODE(J,8)	Mode-dependent loss for mode J
RMODE(J,11)	Compressed-pulse length for mode J (μs)
RMODE(J,12)	Intermediate-frequency bandwidth for mode J (MHz to Hz)
SHIP(1)	x coordinate of the ship position (kft to n.mi.)
SHIP(2)	y coordinate of the ship position (kft to n.mi.)
SHIP(3)	Antenna height (kft to n.mi.)
SHIP(5)	Ship heading (deg to rad)
SM	Blanking time used to calculate SMODE(J,1) (μs)
SMODE(J,1)	Blanking range for mode J (n.mi.)
SMODE(J,2)	Rain-clutter improvement factor for mode J
SUBC(J)	Sea-clutter improvement factor for mode J
TAU(J)	Compressed-pulse length for mode J, or τ_c (s)
TWOPI	Two times 3.1415926536, or 2π

Subroutine INIT3D

The INIT3D subroutine is called at the beginning of each scan of the 3D radar by the executive routine. The main purpose of the routine is to generate an initial azimuth beam position for the start of the first elevation scan. Successive elevation scans are then offset in azimuth by AZBBP, an input variable (Table 13). The initial azimuth AZINIT is uniformly distributed between 0 and AZBBP. A secondary purpose of this routine is to zero three arrays: NDET3(I,J), the number of detections of the *i*th target by the *j*th mode; MER3(I), an indicator of merging problems for the *i*th target; and IKEY(I), an indicator that the fluctuating statistics have already been generated for the appropriate Swerling target models. for the *i*th target.

Table 13 — INIT3D Variables

Fortran Variable	Description
AZBBP	Change in azimuth between successive elevation scans
AZINIT	Azimuth of the initial elevation scan
IKEY(I)	Indicator that target fluctuation statistics have (IKEY(I) = 1) or have not (IKEY(I) = 0) been generated for the *i*th target
MER3(I)	Indicator of an interfering-target problem (a target within three range cells and one azimuth beamwidth of the *i*th target) for the *i*th target: 0 = no merging problem -1 = merging problem and target detected -2 = merging problem and target not detected.
N	Number of targets
NDET3(I,J)	Number of detections of the *i*th target by the *j*th mode
NSCAN	Number of radar modes

Subroutine MRDT3D

Subroutine MRDT3D is called once at the end of the radar scan after all the detections for each target and radar mode have been made. The purpose of the routine is to merge adjacent detections from the 3D radar and estimate the range, azimuth, and elevation of the centroided detection. The number of detections, the range, the azimuth, the elevation, the signal power of the centroided detection, and the detection time are stored in NDET, RANGE, AZ, ELEV, SNDET, and TIME respectively (Table 14).

The merging is accomplished by examining all the detections for each target. If there are no detections of target KTAR by any mode, the number of detections NDET(KTAR) is set equal to 0, and the indicator of interfering targets MER(KTAR) and the detection time TIME(KTAR) are set equal to MER3(KTAR) and TIME3(KTAR) respectively.

If there are detections of target KTAR, the last detection of the lowest (index) radar mode is eliminated, and its parameters (range, azimuth, elevation, and signal power) are stored in DETPAR(1,1), DETPAR(1,2), DETPAR(1,3), and DETPAR(1,4) respectively. The number of adjacent targets K is set equal to 1, and KSTART, the number of adjacent detections of each target and radar mode is set equal to K. Then each ith detection of target KTAR by the jth mode is examined to see whether it is adjacent to any of the previous K adjacent detections; this is accomplished by calling subroutine ADJDET. At the start of the jth mode, the nonadjacent detection counter NEWJJ is initialized to 0, and at the end of examining all detections for the jth mode, NDET(KTAR,J) is set equal to NEWJJ. Thus at the end of the jth mode the NEWJJ nonadjacent detections are stored in the first NEWJJ locations of the detection arrays associated with the Jth mode. The detections of target KTAR by all radar modes are examined in this way. Then if target KTAR has an interfering-target problem (indicated by MER3(KTAR) = -1), all other targets LTAR with interfering-target problems (MER3(LTAR) = -1) are also examined to find other adjacent detections. After all such targets have been examined, KSTART is compared to K. If K is greater than KSTART, KSTART is set equal to K, and the remaining detections for all targets (including target KTAR) are reexamined to find possible new adjacent detections. This procedure is repeated until K = KSTART. Then the target parameters of the centroided detection of target KTAR are estimated using the K adjacent detections.

The estimates of range R, azimuth A, elevation E, and signal power S are

$$R = \sum_{k=1}^{K} S_k R_k \Big/ \sum_{k=1}^{K} S_k, \tag{144}$$

$$A = \sum_{k=1}^{K} S_k A_k \Big/ \sum_{k=1}^{K} S_k, \tag{145}$$

$$E = \sum_{k=1}^{K} S_k E_k \Big/ \sum_{k=1}^{K} S_k, \tag{146}$$

and

$$S = \max\,\{S_1, S_2, ..., S_K\}, \tag{147}$$

where R_k, A_k, E_k, and S_k are the range, azimuth, elevation, and signal power respectively associated with the kth adjacent detection. If E is less than the radar's elevation 3-dB beamwidth, the estimate can be corrupted by multipath propagation, so the following estimate of elevation is used:

$$E = (E_{\mathrm{min}} + E_{\mathrm{max}})/2, \tag{148}$$

where

$$E_{\mathrm{min}} = \min\,\{E_1, E_2, ..., E_K\} \tag{149}$$

and

$$E_{\mathrm{max}} = \max\,\{E_1, E_2, ..., E_K\}. \tag{150}$$

The centroided estimates of range, azimuth, elevation, and signal power are stored in RANGE, AZ, ELEV, and SNDET.

After the centroided estimates are made, target KTAR is reexamined to determine whether there are any unused detections. If there are any unused detections, the last unused detection in the lowest radar mode is used as a starting point, and the entire procedure is repeated. The maximum number of centroided detections for any target is limited to three. After all detections of target KTAR are used, target KTAR + 1 is examined.

Table 14 — MRDT3D Variables

Fortran Variable	Description
AZ(KTAR,I)	Azimuth of the *i*th centroided detection of target KTAR (*A* in Eq. 145)
AZ3(KTAR,I,J)	Azimuth of the *i*th detection of target KTAR by the *j*th radar mode
DETPAR(K,1)	Range of the *k*th adjacent detection (R_k in Eq. 144)
DETPAR(K,2)	Azimuth of the *k*th adjacent detection (A_k in Eq. 145)
DETPAR(K,3)	Elevation of the *k*th adjacent detection (E_k in Eq. 146)
DETPAR(K,4)	Signal power of the *k*th adjacent detection (S_k in Eq. 147)
ELEV(KTAR,I)	Elevation of the *i*th centroided detection of target KTAR (*E* in Eq. 146)
EL3DB	The antenna 3-dB elevation beamwidth
EMAX	Maximum elevation of the adjacent detections (E_{max} in Eqs. 148 and 150)
EMIN	Minimum elevation of the adjacent detections (E_{min} in Eqs. 148 and 149)
I	Index of the detection being tested
II	Number of centroided detections for target KTAR
J	Index of the mode being examined
JJ	Number of detections in the *j*th mode
K	Number of adjacent detections
KTAR	Index of the target being centroided
LTAR	Index of the target being examined to find adjacent detections
MER(I)	Indicator of an interfering target problem (a target within three range cells and 2.4 azimuth beamwidths of the *i*th target) for the *i*th centroided target: 0 = no interfering targets -1 = interfering targets and the *i*th target detected -2 = interfering targets and the *i*th target not detected
MER3(I)	Indicator of an interfering-target problem for the *i*th target
N	Number of targets
NDET(I)	Number of centroided detections for the *i*th target
NDET3(I,J)	Number of detections of the *i*th target by the *j*th mode
NEWJJ	Present number of nonadjacent detections in the previous set of $I - 1$ detections of target KTAR by the *j*th mode
NSCAN	Number of scan modes

Table continues.

Table 14 (Concluded) — MRDT3D Variables

Fortran Variable	Description
RANGE(KTAR,I)	Range of the *i*th centroided detection of target KTAR (*R* in Eq. 144)
RANGE3(KTAR,I,J)	Range of the *i*th detection of target KTAR by the *j*th radar mode
RES	Range-cell dimension
RMODE(J,1)	Elevation angle of the *j*th mode
SNDET(KTAR,I)	Signal power of the *i*th centroided detection of target KTAR (*S* in Eq. 147)
SNDET3(KTAR,I,J)	Signal power of the *i*th detection of target KTAR by the *j*th radar mode
TH3DB	The antenna 3-dB azimuth beamwidth
TIME(I)	Time when the *i*th target is detected
TIME3(I)	Time when the *i*th target is detected

Subroutine STAB3

Subroutine STAB3 generates a new azimuth and elevation position for each target detection because the radar is unstabilized. The routine is initialized by calling the entry point STBINT. The initialization section first reads four input parameters with a 4F8.2 format (Table 15):

RMAX — maximum roll angle (deg),
PMAX — maximum pitch angle (deg),
RPER — roll period (s),
PPER — pitch period (s).

Next, the angles are converted to radians, and the random-number generator is used to generate uniform phase angles for the roll and pitch cycles.

The modified azimuth and elevation positions are generated by calling STAB3 once per scan from the executive routine (after all detections have been obtained). The roll *R* and pitch *P* angles at time *t* are

$$R = R_m \sin(2\pi t/T_R + \phi_R) \tag{151}$$

and

$$P = P_m \sin(2\pi t/T_P + \phi_P), \tag{152}$$

where R_m and P_m are the maximum roll and pitch angles, T_R and T_P are the corresponding periods, and ϕ_R and ϕ_P are uniform phase angles between 0 and 2π. The measured azimuth position a_m (in the deck plane) is [3]

$$a_m = \tan^{-1}\left[\frac{\sin a \cos R + (\cos a \sin P + \tan e \cos P) \sin R}{\cos a \cos P - \tan e \sin P}\right] + \epsilon_a, \qquad (153)$$

and the measured elevation position e_m is [3]

$$e_m = \sin^{-1}\left[(\cos e \cos a \sin P + \sin e \cos P) \cos R - \cos e \sin a \sin R\right] + \epsilon_e, \qquad (154)$$

where a and e are the true azimuth (re ship heading) and elevation angles of the target and ϵ_a and ϵ_e are the previously calculated azimuth and elevation errors.

If one measured only a_m and not e_m, one would have large azimuth errors. For instance, if $R = 10°$, $P = 5°$, and $e = 15°$, the azimuth error can be as large as 5° even though $\sigma_a = 0.5°$. However, if e_m is measured and R and P are known, the measurements a_m and e_m, which are relative to the deck plane of the ship, can be rotated into a system whose xy plane is the plane of the ocean. These equations are [3]

$$a'_m = \tan^{-1}\left[\frac{-\sin R \sin e_m + \cos R \sin a_m \cos e_m}{\cos P \cos a_m \cos e_m + D \sin P}\right] \qquad (155)$$

and

$$e'_m = \sin^{-1}(\sin P \cos a_m \cos e_m + D \cos P), \qquad (156)$$

where

$$D = \cos R \sin e_m + \sin R \sin a_m \cos e_m . \qquad (157)$$

It is assumed that the radar makes the corrections indicated by Eqs. 155 and 156; thus Eqs. 155 and 156 are used as the measured azimuth and elevation respectively.

Table 15 — STAB3 Variables

Fortran Variable	Description
A	Azimuth of the target in the deck plane with zero measured error
AA	True azimuth of target (a in Eqs. 153 and 154)
AM	Corrected azimuth measurement (between π and 3π)
AT	Azimuth measurement (between 0 and 2π) (a_m in Eq. 153)
ATEMP	Azimuth measurement (between π and 3π)
AZ	Corrected azimuth measurement (between 0 and 2π) (a'_m in Eq. 155)
CP	Cosine of the pitch angle
CR	Cosine of the roll angle
E	Elevation of the target in the deck plane with zero measurement error
EL	True elevation of the target (e in Eqs. 153 and 154)

Table continues.

Table 15 (Concluded) — STAB3 Variables

Fortran Variable	Description
ELEV	Corrected elevation measurement (e'_m in Eq. 156)
ET	Elevation measurement (e_m in Eq. 154)
K	Number of detections per target
NDET(I)	Number of detections of the *i*th target
NTARG	Number of targets
PFAC	Frequency of the pitch cycle
PHASE(1)	Phase angle of the roll (ϕ_R in Eq. 151)
PHASE(2)	Phase angle of the pitch (ϕ_P in Eq. 152)
PI	3.1415926536, or π
PITCH	Pitch angle (P in Eq. 152)
PMAX	Maximum pitch angle (P_m in Eq. 152)
PPER	Period of the pitch cycle (T_P in Eq. 152)
RADIAN	57.29578°, the number of degrees in a radian, or $180/\pi$
RFAC	Frequency of the roll cycle
RMAX	Maximum roll angle (R_m in Eq. 151)
ROLL	Roll angle (R in Eq. 151)
RPER	Period of the roll angle (T_R in Eq. 151)
SHIP(5)	Heading of the ship
SP	Sine of the pitch angle
SR	Sine of the roll angle
TE	Tangent of the target elevation
TIME(I)	Time when the *i*th target is detected
TRGPOS(I,5)	Azimuth of the target
TRGPOS(I,6)	Elevation of the target
TWOPI	Two times 3.1415926536, or 2π
X	Trigonometric function of angles
Y	Trigonometric function of angles

Subroutine VRCLT3

Subroutine VRCLT3 generates scan-to-scan independent clutter points in specified areas and is called once per scan by the executive routine after FXCLT3 has been called. The routine is initialized by calling the entry point VCINIT. The initialization section first reads two parameters with a 2I8 format (Table 16):

ISET — initialization number for the random-number generator,
NREG — number of clutter regions,

Next for *each* clutter region (maximum of five regions) seven parameters are specified according to a 7F8.2 format:

FN — average number of detections in the clutter region,
RS — initial range of the clutter region (kft),
RF — final range of the clutter region (kft),

THS — initial azimuth of the clutter region (kft),
THF — final azimuth of the clutter region (kft),
ELS — initial elevation of the clutter region (kft),
ELF — final elevation of the clutter region (kft).

The input parameters are converted to nautical miles and radians for internal use, and the inverse of the density per unit azimuth F_i is generated by

$$F_i = (\theta_F - \theta_S)/N_i, \tag{158}$$

where θ_S and θ_F are the initial and final azimuth boundaries of the ith clutter region and N_i is the average number of detections in the ith region.

The detected clutter points are generated by calling VRCLT3 once per scan. The clutter regions are processed one at a time. For each clutter region the azimuth interval Δ_i between detections is generated by $\Delta_i = -F_i \log U_i$, where U_i is a uniformly distributed random number. If

$$\sum_{j=1}^{i} \Delta_j \leqslant (\theta_F - \theta_S), \tag{159}$$

the new detection is accepted. Its measured azimuth, range, and elevation are

$$\theta = \theta_S + \sum_{j=1}^{i} \Delta_j, \tag{160}$$

$$R = (K + 0.5)\Delta R, \tag{161}$$

and

$$E = E_S + (E_F - E_S)W_i, \tag{162}$$

where ΔR is the range-cell dimension, E_F is the final elevation of the clutter region, E_S is the initial elevation of the clutter region, and

$$K = \text{integer}\ \{[R_S + (R_F - R_S)V_i]/\Delta R\}, \tag{163}$$

in which R_S and R_F are the initial and final range boundaries of the ith clutter region and V_i and W_i are uniformly distributed random numbers. The associated detection time is

$$T_i = T_0 + (\Delta T)\theta/2\pi, \tag{164}$$

where T_0 is the time of the zero-bearing crossing and ΔT is the scan period. The roll and pitch angles at time t are

$$\text{roll} = R_m \sin(2\pi t/T_R + \phi_R) \tag{165}$$

and

$$\text{pitch} = P_m \sin(2\pi t/T_P + \phi_P), \tag{166}$$

where R_m and P_m are the maximum roll and pitch angles, T_R and T_P are the corresponding periods, and ϕ_R and ϕ_P are uniform phase angles between 0 and 2π.

On the other hand, if

$$\sum_{j=1}^{i} \Delta_j > (\theta_F - \theta_S), \tag{167}$$

then the new detection is out of the present clutter region and the next clutter region is considered.

Table 16 — VRCLT3 Variables

Fortran Variable	Description
A	Azimuth of the detection (θ in Eq. 160)
AZOUT	Azimuth of the detection (output) (θ in Eq. 160)
ELF	Final elevation of the clutter region (E_F in Eq. 162)
ELOUT	Elevation of the detection (E in Eq. 162)
ELS	Initial elevation of the clutter region (E_S in Eq. 162)
FLAM	Inverse azimuth density of the clutter points in the ith clutter region (F_i in Eq. 158)
FN	Average number of detections in the region (N_i in Eq. 158)
IC	Number of fixed clutter points detected
IRAN	Random-number counter
ISET	Initialization number for the random-number generator
IV	Total number of clutter detections (fixed plus variable)
K	Range-cell number (K in Eqs. 161 and 163)
NREG	Number of regions (maximum of five)
PFAC	Frequency of the pitch cycle
PHASE(1)	Phase angle of the roll (ϕ_R in Eq. 165)
PHASE(2)	Phase angle of the pitch (ϕ_P in Eq. 166)
PTOUT(I)	Pitch angle at the time of the ith detection
PMAX	Maximum pitch angle (P_m in Eq. 166)
RADIAN	57.29578°, the number of degrees in a radian, or $180/\pi$
RAN	Array of random numbers U_i, V_i, and W_i
RC(19)	Range-cell dimension (ΔR in Eq. 161)
RES	Range-cell dimension (ΔR in Eq. 161)
RF	Final range of the clutter region (R_F in Eq. 163)
RFAC	Frequency of the roll cycle
RLOUT(I)	Roll angle at the time of the ith detection
RMAX	Maximum roll angle (R_m in Eq. 165)
RMODE(1,5)	Scan period (ΔT in Eq. 164)

Table continues.

Table 16 (Concluded) — VRCLT3 Variables

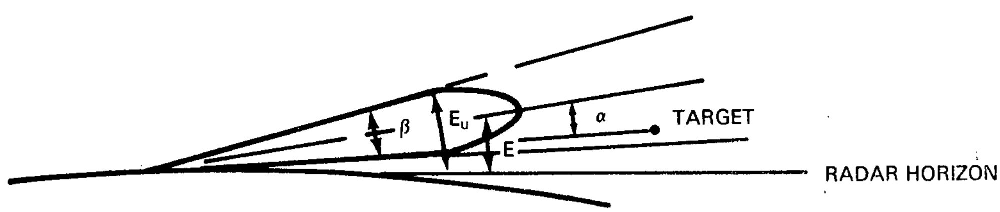
Fortran Variable	Description
ROUT(I)	Range of the ith detection (R in Eq. 161)
RS	Initial range of the clutter region (R_S in Eq. 163)
SOUT(I)	Power of the ith detection
T	Time of the zero-bearing crossing (T_0 in Eq. 164)
THF	Final azimuth of the clutter region (θ_F in Eq. 158)
THS	Initial azimuth of the clutter region (θ_S in Eq. 158)
TIMSCN	Scan period (ΔT in Eq. 164)
TIMZB	Time of the zero-bearing crossing (T_0 in Eq. 164)
TOUT(I)	Time of the ith detection
TWOPI	Two times 3.1415926536, or 2π

ROUTINES COMMON TO BOTH VERSIONS OF SURDET

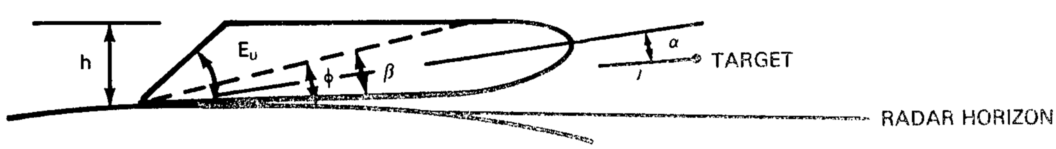
Function BEAM

Function BEAM is used by subroutines JAM, SIGNAL, and GAIN to determine the normalized beam-pattern factor. The function can handle cosecant-squared and pencil-beam patterns.

The function is called with four calling parameters (Table 17): ALPHA, BETA, GAMMA, and KEY1. ALPHA is the angle between the pencil-beam boresight and the target, which in the orientation shown in Fig. 5 is positive clockwise (Fig. 5). For cosecant-squared beams ALPHA is measured from the center of the main beam. BETA is the 3-dB beamwidth. GAMMA is an indicator that specifies whether the beam-pattern factor is being determined horizontally or vertically, and KEY1 is also an indicator that identifies the beam type.



(a) Pencil beam



(b) Cosecant-squared beam

Fig. 5 — Beam patterns

Function BEAM uses a $(\sin x)/x$ curve to represent the horizontal and vertical beam patterns of the pencil beam and the horizontal beam pattern of the cosecant-squared beam. The vertical beam pattern of the cosecant-squared beam is modeled by a main beam with a $(\sin x)/x$ representation and an extended fan above the main beam in which the antenna gain will vary with elevation angle according to R^2/h^2, where R is the slant range to the target and h is the height shown in Fig. 5b.

The first step in the calculation is to normalize the angle α; that is, the beam pattern is assumed to be a $(\sin \kappa\alpha)/\kappa\alpha$ curve with a 3-dB beamwidth given by β, so that the normalized angle θ on a $(\sin x)/x$ curve that corresponds to α is

$$\theta = \frac{2.78}{\beta}\ \alpha, \tag{168}$$

where 2.78 rad is the 3-dB beamwidth on a $(\sin x)/x$ curve.

The next step in the calculation depends on the beam type and its orientation. If the beam is a pencil beam or if the horizontal pattern factor is being determined for a cosecant-squared beam, then the beam-pattern factor (power) is

$$f = \left(\frac{\sin \theta}{\theta}\right)^2 \tag{169}$$

unless $|\theta| < 10^{-6}$ or $|\theta| > \pi$, in which cases

$$f = 1.0, \quad |\theta| < 10^{-6} \tag{170a}$$

and

$$f = f_{SL}, \qquad |\theta| > \pi, \tag{170b}$$

where f_{SL} is the input sidelobe level.

When the beam is a cosecant-squared beam and the vertical beam pattern factor is being determined, the calculation is more complicated. The main beam is pointed at some angle E above the horizon (Fig. 5). This can be expressed as a function of the 3-dB beamwidth β and a constant k:

$$E = \frac{k\beta}{2}\ . \tag{171}$$

The location of the point on the main beam at which the tangent to the beam is horizontal determines the start of the cosecant-squared portion of the beam. If the main beam can be represented by a $(\sin \kappa x)/\kappa x$ curve, this point is found as follows: A point on the curve with elevation angle ϕ has a radius r or normalized power magnitude given by

$$r = \left(\frac{\sin p\theta}{p\theta}\right)^2, \tag{172}$$

where

$$p = \frac{2.78}{\beta} \tag{173}$$

and

$$\theta = \phi - E. \tag{174}$$

Expressing r in rectangular coordinates and differentiating with respect to x yields

$$\frac{x + yy'}{r} = 2p \frac{\sin p\theta}{p\theta} \left[\frac{\cos p\theta}{p\theta} - \frac{\sin p\theta}{(p\theta)^2}\right] \theta', \tag{175}$$

where

$$\theta = \tan^{-1} \frac{y}{x} \tag{176}$$

and

$$\theta' = \frac{1}{1 + y^2/x^2} \left(\frac{y'}{x} - \frac{y}{x^2}\right),$$

$$= \frac{xy' - y}{r^2} . \tag{177}$$

At the angle θ_h where the cosecant-squared beam pattern starts, $y' = 0$. Combining Eqs. 175 and 177 and inserting $y' = 0$ gives

$$\frac{x}{r} = -2p \frac{\sin p\theta_h}{p\theta_h} \left[\frac{\cos p\theta_h}{p\theta_h} - \frac{\sin p\theta_h}{(p\theta_h)^2}\right] \frac{y}{r^2} ,$$

or

$$r = -2p \frac{\sin p\theta_h}{p\theta_h} \left[\frac{\cos p\theta_h}{p\theta_h} - \frac{\sin p\theta_h}{(p\theta_h)^2}\right] \tan \phi_h, \tag{178}$$

where ϕ_h is the elevation angle corresponding to θ_h. Substituting the expression for r from Eq. 172 gives

$$0 = 1 + 2p \left(\cot p\theta_h - \frac{1}{p\theta_h}\right) \tan \phi_h . \tag{179}$$

It is reasonable to assume that ϕ_h and θ_h are small. With this assumption it can be shown that

$$\cot p\theta_h - \frac{1}{p\theta_h} \approx \frac{-p\theta_h}{3} \tag{180}$$

and

$$\tan \phi_h \approx \phi_h . \tag{181}$$

This reduces Eq. 179 to

$$\frac{2p^2 \phi_h \theta_h}{3} = 1 \tag{182}$$

or, by substituting Eq. 174,

$$2p^2 \phi_h (\phi_h - E) = 3, \tag{183}$$

which can be rearranged into the quadratic form

$$\phi_h^2 - \phi_h E - \frac{3}{2p^2} = 0 \tag{184}$$

with the root

$$\phi_h = \frac{E + (E^2 + 6/p^2)^{1/2}}{2} . \tag{185}$$

By use of Eqs. 171 and 173 this can be expressed as a function of β:

$$\phi_h = \frac{1}{2} \left[\frac{k\beta}{2} + \left(\frac{k^2\beta^2}{4} + \frac{6\beta^2}{(2.78)^2} \right)^{1/2} \right]$$

$$= \frac{\beta}{4} \left[k + (k^2 + 3.1)^{1/2} \right]. \tag{186}$$

The normalized beam-pattern factor (power) for the vertical pattern of the cosecant-squared beam can now be determined according to the position of the target. If the target elevation is above ϕ_h, the antenna beam-pattern factor will vary with elevation according to the square of the cosecant:

$$f(\phi) = \frac{K}{\csc^2 \phi}, \tag{187}$$

where K is readily found to be

$$K = f(\phi_h) \csc^2 \phi_h, \tag{188}$$

so that

$$f(\phi) = f(\phi_h) \frac{\csc^2 \phi_h}{\csc^2 \phi}. \tag{189}$$

Table 17 — BEAM Variables

Fortran Variable	Description
ALPHA	Angle between the boresight and the target (rad) (α in Eq. 168)
BETA	The 3-dB beamwidth (rad) (β in Eq. 168)
DBDOWN	First-sidelobe power-level ratio
GAMMA	Beam pattern indicator: 0 = pencil beam 1 = $\csc^2$ beam
HOFK	Elevation angle at which the slope of the $(\sin px)/px$ beam pattern equals zero (rad) (ϕ_h in Eq. 178)
KEY1	Beam-pattern-factor indicator: 0 = horizontal 1 = vertical
PBBS	The elevation of the boresight of the main-beam portion of the $\csc^2$ beam (rad) (E in Eq. 171)
RMODE(J,2)	Upper elevation limit for mode J (rad) (E_u in Fig. 5)
SINC	Normalized beam-pattern factor (power) (f in Eqs. 169, 170, and 191)
THETA	Normalized angular position of the target (rad) (θ in Eqs. 168, 174, and 176)
THETBK	The 3-dB beamwidth (rad) of the main-beam portion of the cosequent-squared beam multiplied by a constant k that sets THETBK equal to twice the elevation of the pencil-beam boresight

If the target elevation is less than or equal to ϕ_h,

$$f(\phi) = \left[\frac{\sin p(\phi - E)}{p(\phi - E)}\right]^2. \tag{190}$$

In summary, the beam-pattern factor for the vertical pattern of the cosecant-squared beam can be expressed as follows:

$$f(\phi) = \left(\left\{\sin \frac{2.78}{\beta[\phi - (k\beta/2)]}\right\} \bigg/ \frac{2.78}{\beta[\phi - (k\beta/2)]}\right)^2, \quad \phi \leqslant \phi_h, \tag{191a}$$

$$= \left(\left\{\sin \frac{2.78 \csc^2 \phi_h}{\beta[\phi_h - (k\beta/2)] \csc^2 \phi}\right\} \bigg/ \frac{2.78 \csc^2 \phi_h}{\beta[\phi_h - (k\beta/2)] \csc^2 \phi}\right)^2, \quad E_u > \phi > \phi_h \tag{191b}$$

$$= \text{first sidelobe level}, \quad \phi > E_u. \tag{191c}$$

This completes the computation, and control of the program is returned to the calling subroutine.

Subroutine CLTSIG

Subroutine CLTSIG is called by subroutine JAM to evaluate the normalized reflectivity σ_0, which corresponds to given values of the radio frequency (Fortran variable XFRE, as listed in Table 18), the Beaufort sea state (XBEAU), the incident angle (XANG), and the angle of linear polarization. The normalized reflectivity represents the observed mean radar cross section from each unit of area in the clutter cell; that is, if σ_0 = - 20 dB, each square meter in the clutter cell will contribute a radar cross section that is 20 dB below a target cross section of 1 m^2.

Values of σ_0 for various radio frequencies I, sea states J, and incidence angles K are stored in two three-dimensional arrays: SIGOH(I,J,K) and SIGOV(I,J,K), corresponding to horizontal and vertical polarization respectively. These values are based on tables that were presented in Ref. 4 and have been extended for greater utility. The values for the various parameters are as follows:

Frequency (MHz) — 500, 1250, 3000, 5600, 9000, 17,000, 35,000,
Beaufort scale — 1, 2, 3, 4, 5, 6,
Incident angle (deg) — 0.1, 0.3, 1, 3, 10

In its current configuration, subroutine CLTSIG considers only linearly polarized radars. For a given set of parameters values of σ_0 are drawn from the SIGOH and SIGOV arrays by a linear interpolation scheme. These values of the normalized reflectivity are for horizontal and vertical polarization respectively. The normalized reflectivity for a given linear polarization angle θ_p is

$$\sigma_0(\theta_p) = [(\sigma_{0_H} \cos \theta_p)^2 + (\sigma_{0_V} \sin \theta_p)^2]^{1/2}. \tag{192}$$

This value of σ_0 is returned to subroutine JAM, thereby completing the process.

Table 18 — CLTSIG Variables

Fortran Variable	Description
ANG	Linear polarization (rad)
INDEX(I,J)	The INDEX (3,2) array identifies the values in the XPAR array that straddle the values of radio frequency, Beaufort scale, and incidence angle that are being considered
NDX(I)	Parameter bookkeeping array: NDX(1) = number of radio frequencies considered NDX(2) = number of Beaufort scales considered NDX(3) = number of incident angles considered
PAR(1)	Parameter 1 is assigned the value of the radio frequency if it is within the boundary values 500 to 35 000 MHz; otherwise it is assigned the boundary value that is closest to the radio frequency
PAR(2)	Similar to parameter 1 but for the Beaufort scale, with a range of 1 to 6
PAR(3)	Similar to parameter 1 but for 10 times the incident angle, with a range of 1 to 100 (0.1° to 10°)
POLRZ	Linear polarization (deg) (0° = horizontal) (θ_p in Eq. 192)
SIGN	Normalizing factor applied to TEMP
SIGOH(I,J,K)	Three-dimensional array relating normalized reflectivity to the radio frequency (I), Beaufort scale (J), and incident angle (K) for horizontal polarization (σ_{0H} in Eq. 192)
SIGOV(I,J,K)	Similar to SIGOH but the vertical polarization (σ_{0V} in Eq. 192)
SIGZ	Normalized reflectivity (dB below a 1-m^2 target cross section/m^2) (σ_0 in Eq. 192)
SIGZP	Normalized reflectivity associated with vertical polarization (dB below a 1-m^2 target cross section/m^2)
TEMP	Weighting function applied to the value of the normalized reflectivity at each vertex of a cube in the SIGOV or SIGOH matrix; the cube surrounds the point defined by PAR(J)
XANG	Incident angle (rad)
XBEAU	Beaufort scale
XFRE	Radio frequency (MHz)

Subroutine ENVIRN

Subroutine ENVIRN is called once by the executive routine. It controls the input of the four environmental parameters (Table 19): windspeed, height of the windspeed measurement, multipath indicator, and rainfall rate. The subroutine also determines the standard deviation of the wave height by the method described below.

Burling [5] suggests that

$$\overline{H}_{1/3} = 4\sigma_h, \tag{193}$$

where $\overline{H}_{1/3}$ is the significant wave height and σ_h is the standard deviation. The significant wave height is related to the windspeed at the sea surface V by

$$\overline{H}_{1/3} = 0.02667\ V^2, \tag{194}$$

where V is in meters per second and $\overline{H}_{1/3}$ is in meters.

Pierson [4] has shown that the windspeed at 10 meters above the surface is related to the speed at greater heights by

$$V_{10} = V_H (10/H)^{0.09682}, \tag{195}$$

where V_H is the windspeed as measured at height H above the sea. Eliminating $\overline{H}_{1/3}$ by combining Eqs. 193 and 194 and substituting for V the expression for V_{10} from Eq. 195 yields

$$\sigma_h = 0.00667\ V_H^2 (H/10)^{-0.19364}. \tag{196}$$

Table 19 — ENVIRN Variables

Fortran Variable	Description
ENVIR(1)	Windspeed at height H (knots) (V_H in Eqs. 195 and 196)
ENVIR(2)	Height of the windspeed measurement (kft) (H in Eqs. 195 and 196)
ENVIR(3)	Multipath indicator: 1 = multipath 0 = no multipath
ENVIR(4)	Rainfall rate (mm/h)
SIGMAH	Standard deviation of the wave height (m) (σ_h in Eqs. 193 and 196)

Subroutine GAIN

Subroutine GAIN is called by subroutines MULPTH and JAM. Its primary function is to determine the field-strength ratio in the direction of direct and reflected rays from target ITAR.

The program is called with the indicator IKEY (Table 20), which specifies which ray is under consideration. If a direct ray is being considered, the field-strength ratio is determined by taking the square root of the beam-pattern function that is calculated in either JAM or MULPTH. Control of the program is then returned to the calling subroutine.

For an indirect ray the difference in azimuth between the target under detection (JTAR) and the target called for (ITAR) is determined and used by the BEAM function to calculate the horizontal beam-pattern factor (f_{PH}). The angle between the direct ray and the reflected ray (Fig. 6) is then

$$\sin \alpha_v = \frac{2R_2 \sin \psi \cos \psi}{R}. \tag{197}$$

Table 20 — GAIN Variables

Fortran Variable	Description
ALFV	Angle between the direct ray and the reflected ray at the antenna (rad) (α_v in Eq. 197)
FH	Horizontal beam-pattern factor (power) (fp_H in Eq. 198)
FHV(K)	Pattern function (total) for target K
FV	Vertical beam-pattern factor (power) (fp_V in Eq. 198)
GAINR	Ratio of the field strength in the direction of a specified ray to the field strength in the beam-maximum direction ($f(\beta)$ in Eq. 199)
IKEY	Indicator in the calling sequence: 0 = direct ray 1 = reflected ray
ITAR	Target under consideration
JTAR	Target under detection
OAH	Horizontal angle between the boresight and the target (rad)
OAV	Vertical angle between the boresight and the target (rad)
RC(2)	Beam-pattern indicator: 0 = pencil beam 1 = $\csc^2$ beam
RC(4)	Horizontal 3-dB beamwidth (rad)
RC(5)	Vertical 3-dB beamwidth (rad)
RC(7)	One-way sidelobe level (dB)
SRTAR	Slant range from the target to the reflection point (m) (R_2 in Eq. 197)
TRGPOS(I,4)	Slant range of target I (m) (R in Eq. 197)
TRGPOS(I,5)	Azimuth of target I (rad)
TRGPOS(I,6)	Elevation of target I with respect to the horizon (rad)

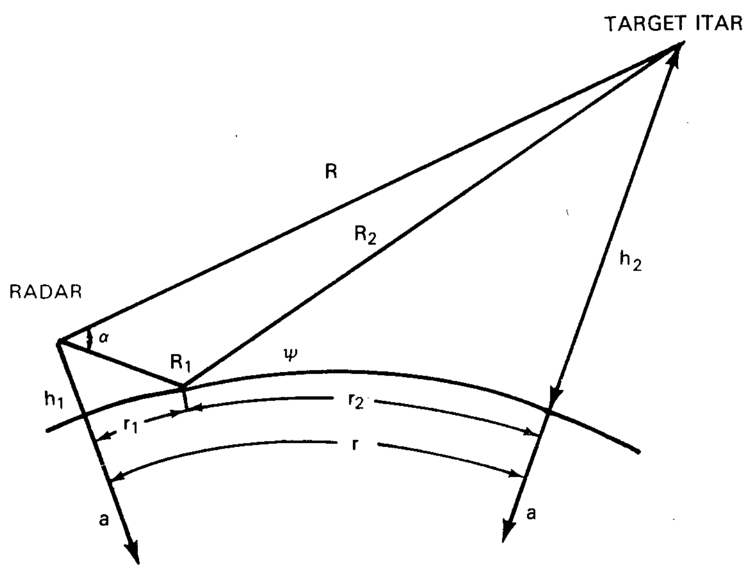


Fig. 6 — Geometrical parameters

This information is used to calculate the vertical angle between the boresight and the target. For the cosecant-squared beam this amounts to the angular difference between the pencil-beam boresight and the target. For the pencil beam the vertical angle between the target under detection (JTAR) and the target under consideration (ITAR) is determined. This information is used by function BEAM to calculate the vertical beam-pattern factor f_{PV}, which is used in turn to calculate the total beam-pattern factor from

$$f_P = f_{P_H} f_{P_V} \tag{198}$$

and the field strength ratio from

$$f(\beta) = f_P^{1/2}. \tag{199}$$

If this value exceeds the sidelobe level, it is retained; otherwise the field-strength ratio is assigned the value of the sidelobe level. The sidelobe level is also assigned to the field-strength ratio if the target is not within the beamwidth in the pencil-beam case.

When the calculation of the field-strength ratio has been completed, control of the program is returned to the calling subroutine.

Subroutine JAM

Subroutine JAM is called by subroutine SIGNAL through its entry NOISE to determine the magnitudes of the received jamming energy EJ and sea clutter energy EC, while the radar is scanning target JTAR (Table 21). Targets with jamming capability (self-screening) as well as any standoff jammers are treated.

After initializing the required variables, the subroutine considers the jamming energy transmitted from each jammer. For each jammer J a beam-pattern factor must be determined to account for the jammer's being off beam center. If the antenna beam pattern has been designated as a pencil beam, the antenna beam pattern (power) is approximated by a $[(\sin kx)/kx]^2$ curve both horizontally and vertically. In this case a check is made to determine whether the jammer is beyond the first null. A jammer that is not inside the first null is assigned a corresponding beam-pattern factor that is equal to the sidelobe level. For the jammer whose angular position places it within the first null, the function BEAM is used to determine a horizontal (f_H) and vertical (f_V) beam pattern factor. The total beam-pattern factor for jammer J is then

$$f_{HV} = f_H f_V. \tag{200}$$

A similar procedure is followed for the alternative cosecant-squared antenna beam.

A free-space jamming energy for jammer J is now found from

$$E_{0J} = \frac{G_r L_r L_m S_J f_{HV} \lambda^2}{(4\pi^2) R^2}, \tag{201}$$

where G_r is the one-way antenna gain, L_r is the receiving antenna loss, L_m is the mode-dependent loss, S_J is the jamming power density, λ is the radar wavelength, and R is the slant range from the radar to the target.

Subroutine MULPTH is called to account for multipath effects. It calculates a one-way amplitude propagation factor F, which is used to determine the jamming energy from jammer J as

$$E_J = E_{0J} F^2. \tag{202}$$

The total jamming energy is

$$E_{TJ} = \sum_{J=1}^{N_J} E_J, \tag{203}$$

where N_J is the total number of jammers, including jamming targets.

The total sea-clutter energy is determined when all jammers have been considered. The first step in the determination of sea-clutter energy is the computation of the normalized mean backscatter σ_0. This is performed by subroutine CLTSIG, which evaluates σ_0 as a function of radio frequency, Beaufort sea state, incidence angle, and polarization orientation. The Beaufort sea state is calculated from the input wind velocity and the height at which the velocity is assumed to be measured [4]. An equivalent wind speed at a height of 10 m is found from

$$V_{10} = V_H \left(\frac{7.5}{H}\right)^{0.09682}. \tag{204}$$

The Beaufort sea state is

$$B_{SS} = 0.6077(V_{10})^{0.7186}. \tag{205}$$

The other parameters required by CLTSIG (radio frequency and incidence angle) are inputs to subroutine JAM.

When the normalized mean backscatter has been evaluated, a differential clutter element of area $rd\phi dr$ is considered (Fig. 7). The energy received (dE) from this element is

$$dE = C \frac{G^2}{r^4} rd\phi dr, \tag{206}$$

where

$$C = \frac{P_T \lambda^2 L_r L_t L_m \sigma_0}{4\pi^3} \tag{207}$$

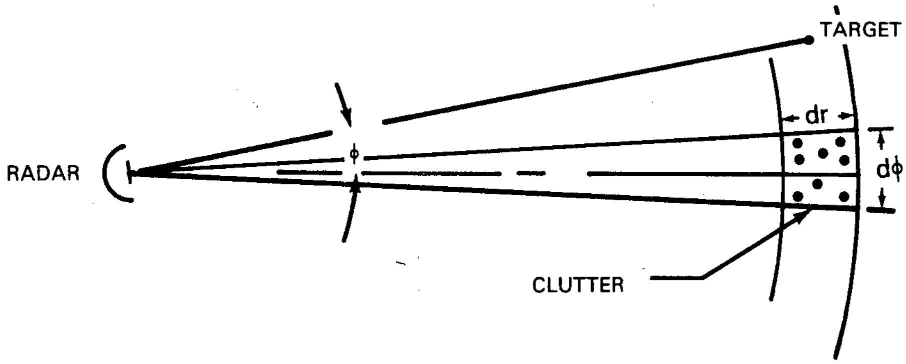


Fig. 7 — Differential clutter element

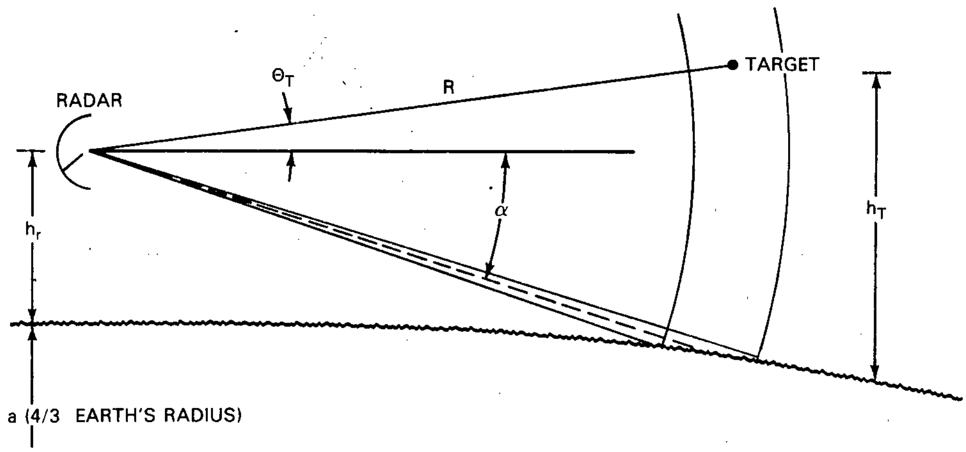


Fig. 8 — Geometry of a clutter element

and G, the antenna directional gain, is a function of the horizontal and vertical angular displacement of the clutter cell with respect to the beam center:

$$G = G(\theta_T + \alpha, \phi). \tag{208}$$

Here θ_T is the angle between the local horizontal and the target or beam center, that is (Fig. 8)

$$\theta_T \approx \sin^{-1}\left(\frac{h_T - h_r}{R} - \frac{R}{2a}\right), \tag{209}$$

α is the angle between the local horizontal and the reflected ray, given to a first-order approximation by

$$\alpha \approx \sin^{-1}\left(\frac{h_r}{R} - \frac{R}{2a}\right), \tag{210}$$

and ϕ is the azimuth of the clutter element with respect to the beam center.

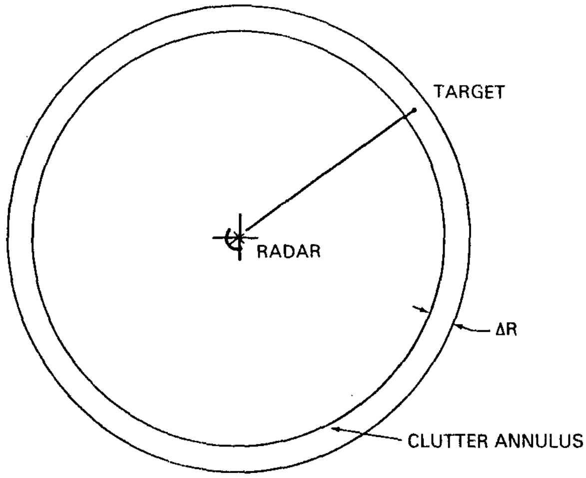


Fig. 9 — Annulus of total sea clutter

The total sea-clutter energy is now considered to be the energy that is reflected from an annulus of width ΔR (Fig. 9) given by

$$\Delta R = \frac{1}{2} c\tau \sec \psi, \tag{211}$$

where τ is the pulse width and ψ is the grazing angle. The total sea-clutter energy is

$$E = C \int_0^{2\pi} \int_{\min(\sqrt{2ah},R)}^{\min(\sqrt{2ah},R+\Delta R)} \frac{[G(\theta,\phi)]^2}{r^3} \, dr d\phi, \tag{212}$$

where $\theta = \theta_T + \alpha$, or

$$\theta = \theta_T + \sin^{-1}\left(\frac{h}{r} - \frac{r}{2a}\right), \tag{213}$$

and r is the range to the differential sea-clutter element.

Equation 212 can be rewritten in a simplified form through the use of a unit gate function $U_r(R_1, R_2)$:

$$E = C \int_0^{2\pi} \int_0^{\infty} \frac{G^2}{r^3} U_r(R_1, R_2) \, dr d\phi, \tag{214}$$

where

$$R_1 = \min(R, \sqrt{2ah}) \tag{215}$$

and

$$R_2 = \min(R + \Delta R, \sqrt{2ah}). \tag{216}$$

Essentially this procedure restricts consideration of the sea-clutter return to that from within the horizon range; that is, if the target range is greater than the horizon range, there is no clutter return. The sea-clutter return is now considered as coming from two distinct areas: the surface area that is within the 3-dB beamwidth and the area of the annulus that is outside the 3-dB beamwidth. The return from the area within the 3-dB beamwidth can now be expressed as

$$E_1 = \int_0^{2\pi} \int_0^{\infty} \frac{1}{r^3} U_\theta \left(-\frac{\theta_B}{2}, \frac{\theta_B}{2}\right) U_\phi \left(-\frac{\phi_B}{2}, \frac{\phi_B}{2}\right) U_r(R_1, R_2)\, dr d\phi, \tag{217}$$

where ϕ_B and θ_B represent the horizontal and vertical 3-dB beamwidths respectively and G has been assigned the value of unity (corresponding to the beam center).

Equation 217 can be simplified by carrying out the integration on ϕ:

$$E_1 = C\phi_B \int_0^{\infty} \frac{1}{r^3} U_\theta \left(-\frac{\theta_B}{2}, \frac{\theta_B}{2}\right) U_r(R_1, R_2)\, dr. \tag{218}$$

From Eq. 213 it is possible to express r as a function of θ:

$$r(\theta) = \frac{2h}{\sin(\theta - \theta_T) + [\sin^2(\theta - \theta_T) - (2h/a)]^{1/2}} . \tag{219}$$

Thus the integral of Eq. 218 can be expressed entirely as a function of r:

$$\begin{aligned} E_1 &= C\phi_B . \int_0^{\infty} \frac{1}{r^3} U_r \left[r\left(-\frac{\theta_B}{2}\right), r\left(\frac{\theta_B}{2}\right)\right] U_r(R_1, R_2)\, dr \\ &= C\phi_B \int_0^{\infty} \frac{1}{r^3} U_r \left\{ \max\left[R_1, r\left(-\frac{\theta_B}{2}\right)\right], \min\left[R_2, r\left(\frac{\theta_B}{2}\right)\right]\right\} dr. \end{aligned} \tag{220}$$

The notation can be simplified with the definitions

$$S_1 \equiv \max\left[R_1, r\left(-\frac{\theta_B}{2}\right)\right] \tag{221a}$$

and

$$S_2 \equiv \min\left[R_2, r\left(\frac{\theta_B}{2}\right)\right] , \tag{221b}$$

so that Eq. 220 can be written as

$$E_1 = C\phi_B \int_0^{\infty} \frac{1}{r^3} \; U_r(S_1, S_2)\, dr. \tag{222}$$

Integration of Eq. 222 yields

$$E_1 = \frac{1}{2} \; C\phi_B \left(\frac{1}{S_1^2} - \frac{1}{S_2^2}\right). \tag{223}$$

Similarly the energy from the remainder of the annulus can be expressed as

$$E_2 = CS\left[\pi\left(\frac{1}{R_1^2} - \frac{1}{R_2^2}\right) - H\right], \tag{224}$$

where S represents a constant value assigned to the antenna directional gain (usually the sidelobe level) and

$$H = \frac{1}{2} \; \phi_B \left(\frac{1}{S_1^2} - \frac{1}{S_2^2}\right). \tag{225}$$

The total sea-clutter energy can now be expressed as

$$E = E_1 + E_2 = C\left[5\pi\left(\frac{1}{R_1^2} - \frac{1}{R_2^2}\right) - H(S - 1)\right], \tag{226}$$

which is then reduced by the input sea-clutter improvement factor I_c:

$$E_c = EI_c. \tag{227}$$

Table 21 — JAM Variables

Fortran Variable	Description
ALPHA	Grazing angle of the clutter cell (rad) (α in Fig. 8)
ALPHAD	Grazing angle of the clutter cell (deg) (α in Fig. 8)
ACON	Constant used in the sea-state calculation
BEAUS	Beaufort sea state
BETA	Constant used in the sea-state calculation
DBDOWN	One-way sidelobe level
DC	Distance to the clutter cell (on a 4/3 earth's radius) (m)
DSTAR	Distance to the radar horizon (n.mi.)
DWL(K)	Incremental change to the radio frequency for mode K

Table continues.

Table 21 (Continued) — JAM Variables

Fortran Variable	Description
EC	Total sea-clutter energy adjusted by the improvement factor (J) (E_c in Eq. 227)
EJ	Total jamming energy (J) (E_{TJ} in Eq. 203)
ENVIR(1)	Windspeed (knots)
ENVIR(2)	Height of the wind-speed measurement (kft) (V_H in Eq. 204)
FH	Normalized horizontal beam pattern factor (power) (f_H in Eq. 200)
FHV(J)	Total normalized beam-pattern factor for jammer J (power) (f_{HV} in Eq. 200)
FOPISQ	Four times the square of 3.1415926536, or $4\pi^2$
FV	Normalized vertical beam pattern factor (power) (f_V in Eq. 200)
HR	Height of the radar (m) (h_r in Fig. 8 and Eqs. 209 and 210)
HT	Height of target JTAR (m) (h_T in Fig. 8 and Eq. 209)
JTAR	Target under detection
NUMTGT	Total number of targets and jammers (N_J in Eq. 203)
OAH	Horizontal angle between target JTAR and the jamming target (rad)
OAV	Vertical angle between JTAR and the jamming target (rad)
PBBS	Pencil-beam boresight elevation with respect to the horizon (rad)
PHIB	Horizontal 3-dB beamwidth (rad) (ϕ_B in Eq. 217)
PJ	Jamming power density (W/Hz) (S_J in Eq. 201)
POLRZ	Linear polarization (deg)
R1	min(slant range, horizontal range) (R_1 in Eqs. 214 and 215)
R2	max(slant range plus pulse width, horizontal range) (R_2 in Eqs. 214 and 216)
RC(1)	Basic radar frequency (MHz)
RC(2)	Indicator of the antenna-pattern function: 0 = pencil beam 1 = $\csc^2$ beam
RC(4)	Horizontal 3-dB beamwidth (rad) (ϕ_B in Eq. 217)
RC(5)	Vertical 3-dB beamwidth (rad) (θ_B in Eq. 217)
RC(6)	One-way antenna gain (dB) (G_r in Eq. 201)
RC(8)	Receiver antenna loss (dB) (L_r in Eq. 201)
RC(9)	Losses between the transmitter output and free space (dB) (L_t in Eq. 201)
RPTB	Range corresponding to $\theta_B/2$ (m), or $r(\theta_B/2)$
RE	4/3 of the earth's radius (m) (a)
RMODE(K,2)	Upper boundary of elevation-angle coverage (rad) for mode K
RMODE(K,8)	Mode-dependent losses for scan mode K (L_m)
RMTB	Range corresponding to $-\theta_B/2$ (m), or $r(-\theta_B/2)$
SIGC	Total sea-clutter energy adjusted by the improvement factor (J) (E_c in Eq. 227)
SIGJAM	Jamming power density (W/Hz) (S_J in Eq. 201)
SIGZ	Normalized mean backscatter (m^2/m^2) (σ_0 in Eq. 207)
SINALF	Sine of the grazing angle at the clutter cell, or $\sin \alpha$ (Eq. 210)

Table continues.

Table 21 (Concluded) — JAM Variables

Fortran Variable	Description
SR	Slant range of target JTAR (m) (R in Eq. 201)
SUBC(K)	Clutter improvement factor for mode K (I_c in Eq. 227)
TEMPWR	Signal energy with the target at the center of the beam
THETB	Vertical 3-dB beamwidth (rad) (θ_B in Eq. 217)
THETT	Target elevation with respect to the local horizontal (rad) (θ_T in Eq. 209)
TRGPOS(J,3)	Height of jammer J (n.mi.)
TRGPOS(J,4)	Slant range of jammer J (n.mi.)
TRGPOS(J,5)	Azimuth angle of jammer J (rad)
TRGPOS(J,6)	Elevation angle of jammer J (rad)
V	Range extent of the clutter cell (m) (ΔR in Eq. 211)
WVL	Wavelength (m) (λ in Eq. 201)
WS	Intermediate parameter (H in Eq. 225)
XFRE	Radio frequency of the scan mode under consideration (MHz)
XJAMFA	Jamming energy from the jth jammer (J) (E_J in Eq. 202)
XJAMN	Total jamming energy (J)

Subroutine MATCH

Subroutine MATCH is called once by the executive routine. For each target defined the subroutine calculates the time at which each radar scan mode first scans the target once it has come within the radar mode's instrumented range RMODE(J,7) (Table 22). These times are then considered by the executive routine when it determines the time at which to initialize the radar.

For a target of type 0, which is a target that traverses a straight-line path, the components of vectors **A** and **B** (Fig. 10) are first calculated from the input initial and final positions of the target and the position coordinates of the ship. The distance d is then calculated according to

$$d^2 = \left|\frac{\mathbf{A} \cdot \mathbf{B}}{B}\right| - (A^2 - R_{\text{ins}}^2), \tag{228}$$

where R_{ins} is the radar's instrumented range. The ratio $x/|\mathbf{B}|$, defined as

$$\frac{x}{|\mathbf{B}|} = \frac{\text{distance from the initial point to a range of } R_{\text{ins}}}{\text{distance from the initial point to the final point}}, \tag{229}$$

is given by

$$\frac{x}{|\mathbf{B}|} = -\frac{1}{|\mathbf{B}|}\left(\frac{\mathbf{A} \cdot \mathbf{B}}{|\mathbf{B}|} + d\right). \tag{230}$$

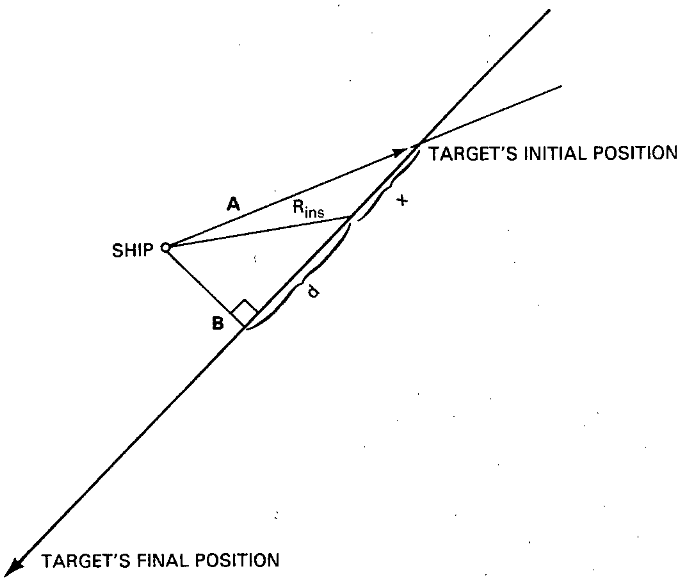


Fig. 10 — Target-and-ship geometry

This ratio is used to determine t_R, the time required for the target to travel from its initial point to the point where it comes within instrumented range:

$$t_R = t_i + \frac{x}{|B|} (t_f - t_i), \tag{231}$$

where t_i and t_f represent respectively the initial and final times of the target's trajectory.

The starting time $t_i(J)$ for mode J with respect to target I is defined as the initial target time plus the mode offset time if the radar is initially scanning in mode 1 and pointing at the target.

The quantity

$$N(J) = \text{integer part} \left[\frac{t_R - t_i(J)}{\Delta t(J)} \right], \tag{232}$$

where $\Delta t(J)$ is the interlook period for mode J, represents the number of scans made by mode J during the time interval in which the target is covering the distance from its initial point to a range of R_{ins}. The time at which mode J first scans target I after it has come within the radar's instrumented range can now be determined as

$$t_{scan}(J) = t_i(J) + [N(J) + 1] \Delta t(J). \tag{233}$$

For a target of type 1, which traverses a piecewise linear trajectory consisting of from two to four altitude legs, the calculations are performed for each leg in succession until an initial scan time is determined for each radar scan mode.

In the case of a target of type 2, which traverses a constant-altitude trajectory consisting of a straight-line segment, a maneuver (turn), and another straight-line segment, the linear flight leg defined by the target's starting point and the point at which the target's maneuver begins is used to determine initial scan times for each radar mode as above. If the target is never within a radar mode's instrumented range prior to its maneuver, then the initial scan time for that mode is set to correspond to the projected last scan preceding the start of the maneuver.

If a nonmaneuvering target fails to enter a radar scan mode's instrumented range during the course of its trajectory, the initial scan time for that mode and target is set to a large default value. The target is thereby removed from further consideration by that radar mode.

Table 22 — MATCH Variables

Fortran Variable	Description
A(K)	The kth component of the vector **A** (n.mi.)
ADOTB	Dot product of vectors **A** and **B** ($\mathbf{A} \cdot \mathbf{B}$ in Eqs. 228 and 230)
ADOTB2	Dot product squared: $(\mathbf{A} \cdot \mathbf{B})^2$
AMAG2	Magnitude of **A** squared ($\lvert\mathbf{A}\rvert^2$, or A^2, in Eq. 228)
B(K)	The kth component of the vector **B** (n.mi.)
BMAG2	Magnitude of **B** squared, or $\lvert\mathbf{B}\rvert^2$
DISC	Quantity used in simplifying the calculations: B^2d^2
ISTAT(I)	Status indicator for target I at the current time T: 0 = inactive 1 = active
ITYPE(I)	Target type for target I
NSCAN	Number of scan modes
NTARG	Number of targets
RMODE(J,5)	Interlook period for mode J (h) ($\Delta t(J)$ in Eqs. 232 and 233)
RMODE(J,6)	Time offset for mode J (h)
RMODE(J,7)	Instrumented range for mode J (n.mi.) (R_{ins} in Eq. 228)
RMODE(J,9)	The earliest time at which mode J first scans any target within the instrumented range
SHIP(K)	Position coordinates of the ship (n.mi.)
TALT(I,L)	Altitude of the trajectory of a type-1 target I on leg L (n.mi.)
TERM	Square root of DISC: $\sqrt{B^2d^2} = \lvert Bd\rvert$
TMANI(I)	Time a type-2 target I begins its maneuver (h)
TSCAN(I,J)	Time at which mode J first scans target I after it has come within the instrumented range (h) ($t_{scan}(J)$ in Eq. 233)
UMINUS	Ratio used to calculate XSCAN ($x/\lvert\mathbf{B}\rvert$ in Eq. 231)
XN	The number of scans made by mode J while the target is going from its initial point to the instrumented range ($N(J)$ in Eq. 232)
XYZF(I,K)	Final position coordinates of target I (n.mi.)
XYZI(I,K)	Initial position coordinates of target I (n.mi.)
XSCAN	Target travel time from its initial position to the radar mode's instructed range (t_R in Eq. 231)

Once an initial scan time TSCAN(I,J) for each target I and radar mode J has been calculated, the earliest time each mode J sees any target is determined:

$$\mathrm{RMODE}(J,9) = \min[\mathrm{TSCAN}(I,J), I = 1, ..., \mathrm{NTARG}], \tag{234}$$

where NTARG is the number of targets. Also, the target-status indicator ISTAT(I) (0 = inactive and 1 = active) is initialized to 0 for each target I.

Subroutine MULPTH

Subroutine MULPTH is called by subroutines SIGNAL and JAM. Its purpose is to calculate the pattern-propagation factor FAC for a specified target ITAR, while the radar is scanning target JTAR (Table 24).

For computational purposes the atmosphere is divided into three regions: the interference region, the intermediate region, and the diffraction region (Fig. 11). The propagation factor is determined for targets only above the horizon, that is, in the interference region and in part of the intermediate region. This can be readily accomplished for targets in the interference region and diffraction regions, but there are no numerical methods that are easily applicable to field-strength determination in the intermediate region. Consequently the pattern-propagation factor for targets in the intermediate region is found by interpolating between the interference region and the diffraction region. In other words, the field strength is determined for points in the interference and diffraction regions at the altitude of the target under consideration, and this information is then used to determine the field strength in the intermediate region by a curve-fitting process.

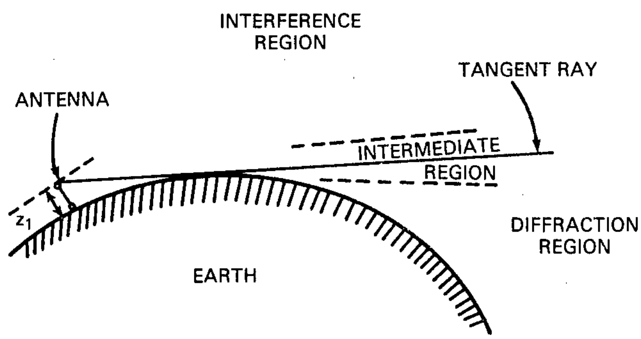


Fig. 11 — Interference, intermediate, and diffraction regions

The initial step in the calculation, which is carried out for each new frequency mode, is the determination of the complex dielectric constant

$$\epsilon_c = \epsilon_1 - i60\lambda\sigma \tag{235}$$

where ϵ_1 is the ordinary dielectric constant, λ is the wavelength, and σ is the conductivity. Values of ϵ_1 and σ as a function of frequency are given in Refs. 6 and 7. The values used in MULPTH are given in Table 23. Linear interpolation is used for intermediate values.

Table 23 — Values of the Frequency, Dielectric Constant, and Conductivity Used in MULPTH

f (MHz)	ϵ_1	σ (mhos/m)
<1500	80	4.3
1500 to 3000	80 - [0.00733 (f - 1500)]	4.3 + [0.00148 (f - 1500)]
3000 to 10000	69 - [0.0005714 (f - 3000)]	6.52 + [0.001354 (f - 3000)]

The next step in the calculation is the determination of factors that will be used in calculating the value of the pattern-propagation factor for a target in the diffraction region. The propagation factor in the diffraction region is [7]

$$F = 2\sqrt{\pi X}\, e^{-C_1 X} |U_1(Z_1) U_1(Z_2)|, \tag{236}$$

where X is the target ground range in natural units,

$$X = \frac{r}{L}, \tag{237}$$

in which r is in meters and L is the natural unit of range,

$$L = 2\left(\frac{4k_0}{a^2}\right)^{-1/3}, \tag{238}$$

with a being the earth's effective radius and k_0 being the radar wavenumber $k = 2\pi/\lambda$ multiplied by the index of refraction n_0 at the earth's surface. In Eq. 236 U_1 and U_2 are calculated by subroutine UFUN. Only the factors that are target independent, namely, C_1 and $U_1(Z_1)$, are calculated on the initial pass for a new frequency mode. The term C_1 is the imaginary part of the parameter A_1, which is used also in evaluating $U_1(Z_1)$ in subroutine UFUN. The parameter A_1 is [7]

$$A_1 = 2.3381\, e^{2\pi i/3} + \frac{1}{Hp}, \tag{239}$$

where H is the natural unit of height,

$$H = \left(\frac{2k_0^2}{a}\right)^{-1/3}, \tag{240}$$

and

$$p = ik_0(\epsilon_c - 1)^{1/2}\left(\cos\theta + \frac{\sin\theta}{\epsilon_c}\right), \tag{241}$$

in which θ is the linear polarization.

The location of the reflection point and the determination of the grazing angle is the next step in the calculation. The ground range of the reflection point r_1 is a function of target height h_2, antenna height h_1, and target ground range r (Fig. 6). This relationship is

$$2r_1^3 - 3rr_1^2 + [r^2 - 2a(H_1 + H_2)]r_1 + 2aH_1 r = 0, \tag{242}$$

where

$$H_i = h_i\left(1 - \frac{h_i}{a}\right), \qquad i = 1, 2. \tag{243}$$

Equation 242 has the solution

$$r_1 = \frac{r}{2} + \operatorname{sgn}(H_1 - H_2)P\cos\left(\frac{\phi + \pi}{3}\right), \tag{244}$$

where

$$P = \left\{\frac{4}{3}\left[a(H_1 + H_2) + \left(\frac{r}{2}\right)^2\right]\right\}^{1/2} \tag{245}$$

and

$$\phi = \cos^{-1}\left(\frac{2ar|H_1 - H_2|}{P^3}\right). \tag{246}$$

The grazing angle ψ is then found from the approximation

$$\tan\psi \approx \frac{h_1}{r_1}\left(1 - \frac{h_1}{a}\right) - \frac{r_1}{2a}\ . \tag{247}$$

If the grazing angle is found to be less than or equal to 0, the pattern-propagation factor is set to 1×10^{-20}, and control of the program is returned to the calling subroutine. If ψ is greater than 0, the divergence factor D and the path-length difference ΔR are calculated according to

$$D = \left\{\left(1 - \frac{h_1 + h_2}{a}\right)\left[\frac{(R_1 + R_2)^2 a \sin\psi\cos\psi}{(R_1 + R_2)a\sin\psi + 2R_1R_2}\right]\left(\frac{1}{r}\right)\right\}^{1/2} \tag{248}$$

and

$$\Delta R = \frac{(R_1 + R_2)G}{1 + (1 - G)^{1/2}}\ , \tag{249}$$

where

$$G = \left(\frac{2 \sin \psi}{R_1 + R_2}\right)^2 R_1 R_2 \tag{250}$$

and R_1 and R_2 are slant ranges from the antenna and target respectively to the reflection point.

Equation 248 is a simplified version of Eq. 16 in Ref. 7, and Eq. 249 is readily derived from basic trigonometric relationships.

The path-length difference is now compared to $\lambda/4$, since this is the generally accepted limit of validity for the analytical method applied to the interference region. If $\Delta R < \lambda/4$, the target is assumed to be in the intermediate region, and the preliminary step in the interpolation process is carried out. This consists of finding the location of a point that has the altitude of the target under consideration but with a path-length difference of $\lambda/4$. The method used will be discussed in the subsection on subroutine RNGCEN. This information is used in the interpolation scheme for determining the pattern-propagation factor in the intermediate region.

The next step in the calculation is the computation of the complex reflection coefficient. The reflection coefficient is related to the linear polarization, and the equations for the horizontal polarization and vertical polarization reflection coefficients are

$$\Gamma_v = \rho_v e^{-i\phi_v} = \frac{\epsilon_c \sin \psi - (\epsilon_c - \cos^2 \psi)^{1/2}}{\epsilon_c \sin \psi + (\epsilon_c - \cos^2 \psi)^{1/2}} \tag{251a}$$

and

$$\Gamma_h = \rho_h e^{-i\phi_h} = \frac{\sin \psi - (\epsilon_c - \cos^2 \psi)^{1/2}}{\sin \psi + (\epsilon_c - \cos^2 \psi)^{1/2}} , \tag{251b}$$

where ρ_v and ρ_h are the intrinsic reflection coefficients and ϕ_v and ϕ_h are the phase changes for seawater. For other than vertical or horizontal polarization the reflection coefficient is the vector sum of the horizontal and vertical components:

$$\Gamma = \rho_0 e^{-i\phi} = [(\Gamma_h \cos \theta)^2 + (\Gamma_v \sin \theta)^2]^{1/2} . \tag{252}$$

The two remaining parameters that contribute to the pattern-propagation factor are the roughness factor and the directional field-strength ratio. The roughness factor is [6]

$$r_s = e^{-2[(2 - H \sin \psi)/\lambda]^2} . \tag{253}$$

Equation 253 was developed under the assumption that the sea surface has a Gaussian height distribution with standard deviation H_s. For a sea surface with approximately sinusoidal waves and amplitude a,

$$H_s = \frac{a}{2\sqrt{2}} \; . \tag{254}$$

The field-strength ratios $f(\theta_1)$ and $f(\theta_2)$ for the direct and reflected rays are computed in subroutine GAIN.

It is now possible to compute the pattern-propagation factor for the point in question according to

$$F = \left| 1 + \frac{f(\theta_2)}{f(\theta_1)} \; \rho_0 D r_s e^{-i(k_0 \Delta R + \phi)} \right| . \tag{255}$$

The point in question will be the target position if the target is in the interference region or the point corresponding to a path-length difference of $\lambda/4$ if the target is above the horizon and in the intermediate region.

For targets in the interference region the calculation is now complete, and control of the program is returned to the calling routine.

For targets in the intermediate region additional computation is required. The pattern-propagation factor must be found for a point in the diffraction region that will be used as the lower bound in the interpolation. A point that is twice the horizon distance from the antenna is chosen as being representative of the diffraction region. Subroutine UFUN is now called to determine the value of the parameter $U_1(Z_2)$ for this point, and the pattern-propagation factor is calculated according to Eq. 236. The upper bound for the interpolation is the value of the pattern-propagation factor that was calculated from the point with a path-length difference of $\lambda/4$ (Eq. 255). The lower and upper bound values of the pattern-propagation factor are presented to subroutine INTER, which carries out the interpolation to determine the pattern-propagation factor at the target. This completes the calculation, and control of the program is returned to the calling routine.

Table 24 — MULPTH Variables

Fortran Variable	Description
CA	Function of the complex dielectric constant and polarization used in subroutine UFUN (A_1 in Eq. 239)
CGAM	Reflection coefficient (Γ in Eq. 252)
CGAMH	Horizontal polarization reflection coefficient (Γ_h in Eq. 251b)
CGAMV	Vertical polarization reflection coefficient (Γ_v in Eq. 251a)
CTEMY	Complex dielectric coefficient (ϵ_c in Eq. 235)

Table continues.

Table 24 (Concluded) — MULPTH Variables

Fortran Variable	Description
CU1	Parameter (calculated in subroutine UFUN) used in evaluating F ($U_1(Z_1)$ in Eq. 236)
DISP	Divergence factor (D in Eq. 248)
EPSI	Ordinary dielectric constant (ϵ_1 in Eq. 235)
FAC	Pattern-propagation factor (F in Eq. 236)
FAC1	Pattern-propagation factor (F in Eq. 236)
GD	Field-strength ratio for the direct ray ($f(\theta_1)$ in Eq. 255)
GRRAD	Ground range from the radar to the reflection point (m) (r_1 in Eq. 242)
GRRT	Ground range to target (m) (r in Eq. 242)
GRTAR	Ground range from the target to the reflection point (m) (r_2 in Fig. 6)
GV	Field-strength ratio for the reflected ray ($f(\theta_2)$ in Eq. 255)
H	Natural unit of height (H in Eq. 240)
HR	Height of the antenna (m) (h_1 in Eq. 243)
HT	Height of the target (m) (h_2 in Eq. 243)
ITAR	Target under consideration
ISWIT	Mode indicator: 0 = initial pass or a new mode 1 = same mode as the preceding pass
JTAR	Target currently being scanned by the radar
L	Natural unit of length (L in Eq. 238)
PHIREF	Reflection-coefficient phase angle (rad) (ϕ in Eqs. 244 and 246)
POLRZ	Linear polarization (deg) (0° = horizontal and 90° = vertical) (θ in Eqs. 241 and 252)
PTHDIF	Path-length difference (m) (ΔR in Eq. 249)
RE	4/3 of the earth's radius, or a (m)
RHOREF	Intrinsic reflection coefficient (ρ_0 in Eq. 252)
SIG1	Conductivity (mhos/m) (σ in Eq. 235)
SRRAD	Slant range from the radar to the reflection point (m) (R_1 in Eqs. 248, 249, and 250)
SRTAR	Slant range from the target to the reflection point (m) (R_2 in Eqs. 248, 249, and 250)
TANPSI	Tangent of the grazing angle ($\tan \psi$ in Eq. 247)
WVL	Wavelength λ (m)
XFRE	Frequency of the next mode to be considered (MHz)
XIMCA	Imaginary part of CA
XKPAR	Wavenumber $k = 2\pi/\lambda$
XKZERO	Product kn_0 of the radar wavenumber and the index of refraction at the earth's surface (k_0 in Eqs. 238, 240, and 241)
XMUR	Roughness factor (r_s in Eqs. 253 and 255)
XNAT	Ground range to the target in natural units (X in Eq. 237)
XNAT1	Range corresponding to $\Delta R = \lambda/4$ in natural units
XNAT2	Twice the horizon range in natural units, or $2r_H/L$
XNZERO	Index of refraction of the earth's surface (n_0 in text after Eq. 238)
Z1	Antenna height in natural units (Z_1 in Eq. 236)
Z2	Target height in natural units (Z_2 in Eq. 236)

Subroutine NEWPOS

Subroutine NEWPOS is called by the executive routine to calculate the position of all targets and jammers for game time T. It is assumed that the radar beam is positioned at 0 degrees azimuth at time T. The position and azimuth (relative to 0 degrees) of each target is first determined at time T. Then a corrected position for each target is calculated, corresponding to its location at time $T + dT$, where dT is the time it takes the radar to scan the azimuth angle of the target.

For each target or jammer J, the target status at game time T is determined. If

$$t_i \leqslant T \leqslant t_f, \tag{256}$$

where T is the current game time, t_i is the time target J leaves its initial position, and t_f is the time target J arrives at its final position, then the target is active and the target-status indicator ISTAT(J) is set to 1 (Table 25). Otherwise, ISTAT(J) is set to 0 to indicate an inactive target, and the subroutine proceeds to the next target.

If target J is of type 0, with a straight-line trajectory, or of type 1, with from two to four altitude legs, the subroutine first determines the ratio of the elapsed time to the total target time according to

$$\Delta T = \frac{T - t_i}{t_f - t_i} . \tag{257}$$

The target's position coordinates with respect to the designated origin at time T are

$$x_T = x_i + \Delta T(x_f - x_i), \tag{258}$$

$$y_T = y_i + \Delta T(y_f - y_i), \tag{259}$$

and, for target type 0,

$$z_T = z_i + \Delta T(z_f - z_i), \tag{260}$$

where (x_i, y_i, z_i) and (x_f, y_f, z_f) are the initial and final position coordinates respectively for target J.

If target J is of type 1 let k be the kth altitude point, so that

$$t_a(k - 1) < T \leqslant t_a(k), \tag{261}$$

where $t_a(k)$ is the time when target J reaches the kth altitude point and where

$$t_a(1) = t_i \tag{262}$$

and

$$t_a(N) = t_f, \tag{263}$$

with N being the number of altitude points (NALT + 2), where NALT is defined for target J in subroutine TARGET. If ΔT is redefined so that

$$\Delta T = \frac{T - t_a(k-1)}{t_a(k) - t_a(k-1)}, \tag{264}$$

the z coordinate for target J of type 1 at time T is

$$z_T = z_a(k-1) + \Delta T[z_a(k) - z_a(k-1)], \tag{265}$$

where $z_a(k)$ is the designated altitude of target J at node k at time $t(k)$. The z component z_v and the magnitude d_v of the direction vector for target J originally calculated in subroutine MATCH are also updated:

$$z_v = z_T - z_a(k-1) \tag{266}$$

and

$$d_v^2 = x_v^2 + y_v^2 + z_v^2. \tag{267}$$

If target J is of type 2, a maneuvering target, then if

$$T \leqslant t_m, \tag{268}$$

where t_m is the time when target J begins its maneuver (constant-altitude turn), the target is on a linear path segment and the distance traveled by time T is

$$d = v(T - t_i), \tag{269}$$

so that

$$x_T = x_i + d\cos(\theta_i) \tag{270}$$

and

$$y_T = y_i + d\sin(\theta_i), \tag{271}$$

where v is the speed of target J and θ_i is the initial heading of target J. Similarly, if

$$T > t_n, \tag{272}$$

where t_n is the time when target J terminates its maneuver, the target is on its final linear leg and the distance traveled on this leg by time T is

$$d = v(T - t_n), \tag{273}$$

so that

$$x_T = x_n + d \cos \theta_f \tag{274}$$

and

$$y_T = y_n + d \sin \theta_f, \tag{275}$$

where (x_n, y_n) are the coordinates of the point where target J terminates its maneuver and θ_f is its final heading. If

$$t_m < T \leqslant t_n, \tag{276}$$

then the target is performing its maneuver, so that if

$$\Delta = v(T - t_m)/r_m \tag{277}$$

and

$$\phi = \theta_i + \text{TURN}(\Delta - \pi/2), \tag{278}$$

then

$$x_T = x_c + r_m \cos \phi, \tag{279}$$

$$y_T = y_c + r_m \sin \phi, \tag{280}$$

and

$$z_T = z_i, \tag{281}$$

where r_m is the radius of the maneuver circle for target J, TURN is the maneuver direction indicator (1 for counterclockwise and -1 for clockwise), and x_c and y_c are the x and y coordinates of the center of the maneuver circle for target J. The components of the target direction vector are also corrected to

$$x_v = \cos (\phi + \text{TURN}\pi/2), \tag{282}$$

$$y_v = \sin (\phi + \text{TURN}\pi/2), \tag{283}$$

and

$$d_v^2 = x_v^2 + y_v^2, \tag{284}$$

since a target of type 2 moves at a constant altitude.

Once the target's coordinates (x_T, y_T, z_T) with respect to the designated origin at time T are calculated, they are transformed to a radar-centered coordinate system by

$$dx_T = x_T - x_r, \tag{285}$$

$$dy_T = y_T - y_r, \tag{286}$$

and

$$dz_T = z_T - z_r, \tag{287}$$

where (x_r, y_r, z_r) is the stationary position of the radar. The target azimuth θ is

$$\theta = \tan^{-1} (dy_T/dx_T). \tag{288}$$

Once the target azimuth at time T has been computed for target J, the corrected target positions $(x_{T+dT}, y_{T+dT}, z_{T+dT})$ and $(dx_{T+dT}, dy_{T+dT}, dz_{T+dT})$ with respect to the designated origin and the radar respectively and a corrected azimuth θ_{T+dT} are obtained by repeating the preceding sequences of calculations with time T replaced by $T + dT$, where

$$dT = s\theta_T/2\pi, \tag{289}$$

in which s is the radar scan period and θ_T is the target-I azimuth at game time T.

The elevation α of target J with respect to the horizon is determined from approximations made to the geometry of Fig. 12. The distance D can be found from

$$D = (dx^2_{T+dT} + dy^2_{T+dT})^{1/2}. \tag{290}$$

This can be approximated by

$$D = (2a_0h_1)^{1/2} + (2a_0h_a)^{1/2}, \tag{291}$$

where a_0 is 4/3 of the earth's radius. Equation 291 can now be solved for h_1 to yield

$$h_1 = \left[\frac{D}{95.2} - (h_a)^{1/2}\right]^2, \tag{292}$$

where h_1 is in nautical miles. If it is assumed that triangle ABT is a right triangle, then

$$\tan \alpha = \frac{h_T - h_1}{D}$$

$$= \frac{h_T}{D} - \left(\frac{D^{1/2}}{95.2} - \frac{h_a^{1/2}}{D^{1/2}}\right)^2. \tag{293}$$

This completes the computational procedure in NEWPOS, and program control is returned to the executive routine.

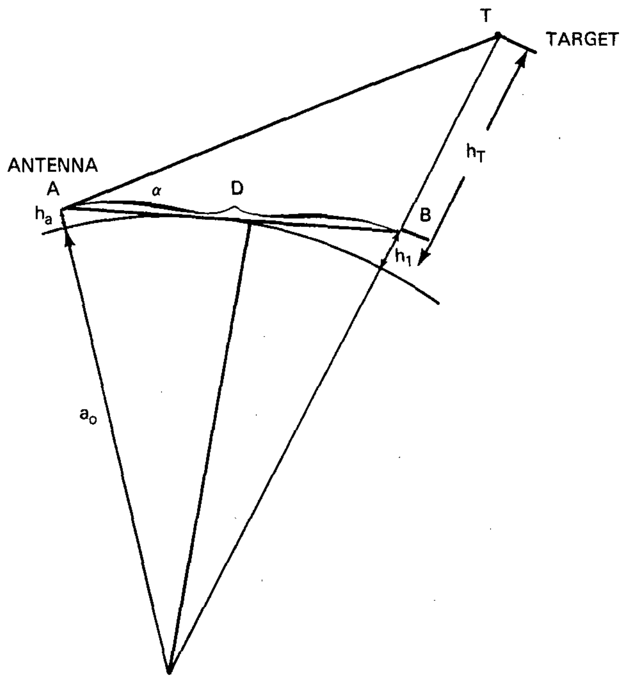


Fig. 12 — Geometry of target elevation

Table 25 — NEWPOS Variables

Fortran Variable	Description
ALT(J,I)	Altitude of profile node I of target J with ITYPE = 1 (n.mi.)
BPRIME	Tangent of the elevation of target J measured from the horizon (tan α in Eq. 295)
CM(J,1)	Position coordinate x of the center of the maneuver circle for target J with ITYPE(J) = 2 (n.mi.) (x_c in Eq. 279)
CM(J,2)	Position coordinate y of the center of the maneuver circle for target J with ITYPE(J) = 2 (n.mi.) (y_c in Eq. 280)
D	Ground range from the radar to target J at time $T + dT$ (n.mi.) (D in Eqs. 292 through 295)
DEL(1)	Coordinate x of target J with respect to the radar at time T and then corrected to time $T + dT$ (n.mi.) (dx_T in Eq. 285 and dx_{T+dT} in Eq. 290)
DEL(2)	Coordinate y of target J with respect to the radar at time T and then corrected to time $T + dT$ (n.mi.) (dy_T in Eq. 286 and dy_{T+dT} in Eq. 290)
DEL(3)	Coordinate z of target J with respect to the radar at times T and then corrected to time $T + dT$ (n.mi.) (dz_T in Eq. 287 and dz_{T+dT})
DELT	Distance target J has traveled on the current segment of the profile with ITYPE(J) = 2 (n.mi.) (d in Eqs. 269 and 273)

Table continues.

Table 25 (Continues) — NEWPOS Variables

Fortran Variable	Description
DOTP	Normalized dot product of the vectors defined by VEL and DEL (cosine of the angle between the vectors)
DSTAR	Distance from the radar to the horizon (n.mi.)
DT	Ratio of the elapsed time in flight to the total flight time for target J (ΔT in Eq. 257)
DX	Coordinate x of target J with respect to the radar at time T and then corrected to time $T + dT$ (n.mi.) (dx_T in Eq. 285 and dx_{T+dT} in Eq. 290)
DY	Coordinate y of target J with respect to the radar at time T and then corrected to time $T + dT$ (n.mi.) (dy_T in Eq. 286 and dy_{T+dT} in Eq. 290)
DZ	Coordinate z of target J with respect to the radar at times T and then corrected to time $T + dT$ (n.mi.) (dz_T in Eq. 287 and dz_{T+dT})
HEADF(J)	Final heading of target J with ITYPE(J) = 2 (θ_f in Eqs. 274 and 275)
HEADI(J)	Initial heading of target J with ITYPE(J) = 2 (θ_i in Eqs. 270 and 271)
IFLAG	Flag to indicate if calculations are being performed with respect to T (IFLAG = 1) or $T + dT$ (IFLAG = 2)
ISTAT(J)	Status indicator for target J: 0 = inactive 1 = active
ITYPE(J)	Type of target profile for target J: 0 = straight-line trajectory 1 = altitude legs 2 = maneuver
NALT(J)	Number of altitude nodes for target J with ITYPE(J) = 1
NUMTGT	Total number of targets plus jammers
PIOVR2	One half of 3.1415926536, or $\pi/2$
RADM(J)	Radius of the circle of maneuver by target J with ITYPE(J) = 2 (n.mi.) (r_m in Eqs. 276, 279, and 280)
SHIP(1)	Coordinate x of the radar position (n.mi.) (x_r in Eq. 285)
SHIP(2)	Coordinate y of the radar position (n.mi.) (y_r in Eq. 286)
SHIP(3)	Radar antenna height (n.mi.) (h_a in Eqs. 291 through 293)
SHIP(4)	Square root of the antenna height ((n.mi.)$^{1/2}$) ($h_a^{1/2}$ in Eqs. 291 through 293)
SPEED(J)	Speed of target J with ITYPE(J) = 2 (n.mi./h) (v in Eqs. 269 and 273)
T	Current game time (h) (T in Eq. 256)
TALT(J,1)	Time when target J arrives at altitude node I with ITYPE(J) = 1 (h) ($t_a(k)$ in Eq. 261)
TIME3(J)	Time when the radar scans target J (s) ($T + dT$ in sentence containing Eq. 289)
TMANF(J)	Time when target J with ITYPE(J) = 2 terminates its maneuver (t_n in Eq. 272)

Table continues.

Table 25 (Concluded) — NEWPOS Variables

Fortran Variable	Description
TMANI(J)	Time when target J with ITYPE(J) = 2 begins its maneuver (t_m in Eq. 268)
TRGPOS(J,1)	Coordinate x of target J at time T and then corrected to time $T + dT$ (n.mi.) (x_T in Eq. 258 and x_{T+dT})
TRGPOS(J,2)	Coordinate y of target J at time T and then corrected to time $T + dT$ (n.mi.) (y_T in Eq. 259 and y_{T+dT})
TRGPOS(J,3)	Coordinate z of target J at time T and then corrected to time $T + dT$ (n.mi.) (z_T in Eqs. 260, 265, and 281 and z_{T+dT})
TRGPOS(J,4)	Slant range R to target J (n.mi.)
TRGPOS(J,5)	Azimuth of target J at time T and then corrected to time $T + dT$ (rad) (θ_T in Eq. 289 and θ_{T+dT})
TRGPOS(J,6)	Elevation of target J measured from the horizon (rad) (α in Eq. 293)
TRGPOS(J,7)	Ground range from the radar to target J (n.mi.) (D in Eq. 293)
TT	Times T and $T + dT$ when position calculations are being performed, depending on the value of IFLAG
TURN(J)	Indicator for the target-J maneuver with ITYPE(J) = 2: 1 = counterclockwise —1 = clockwise
VEL(J,1)	Target-J direction-vector x component (x_v in Eqs. 267, 282, and 284)
VEL(J,2)	Target-J direction-vector y component (y_v in Eqs. 267, 283, and 284)
VEL(J,3)	Target-J direction-vector z component (z_v in Eqs. 266 and 267)
VELMAG2	Magnitude of vector VEL
XMANF(J,1)	Coordinate x for the point where target J with ITYPE = 2 terminates its maneuver (x_n in Eq. 274)
XMANF(J,2)	Coordinate y for the point where target J with ITYPE = 2 terminates its maneuver (y_n in Eq. 275)
XMANI(J,1)	Coordinate x for the point where target J with ITYPE = 2 begins its maneuver
XMANI(J,2)	Coordinate y for the point where target J with ITYPE = 2 begins its maneuver
XYZF(J,1)	Final coordinate x for target J (n.mi.) (x_f in Eq. 258)
XYZF(J,2)	Final coordinate y for target J (n.mi.) (y_f in Eq. 259)
XYZF(J,3)	Final coordinate z for target J (n.mi.) (z_f in Eq. 260)
XYZF(J,4)	Final time for target J (t_f in Eq. 256)
XYZI(J,1)	Initial coordinate x for target J (n.mi.) (x_i in Eq. 258)
XYZI(J,2)	Initial coordinate y for target J (y_i in Eq. 258)
XYZI(J,3)	Initial coordinate z for target J (z_i in Eq. 260)
XYZI(J,4)	Initial time for target J (t_i in Eq. 256)

Subroutine RESOL

Subroutine RESOL is called by subroutines DET3D and MWDET. The purpose of this routine is to identify the targets whose return signal lies within the reference cells of the *i*th target (target NTAR, the target of interest). The number of targets (including the *i*th target) within the reference cells is NI. The specific NI targets are listed in array INF, and the signal energy of the NI targets is calculated and stored in the array SNREF (Table 26).

The *j*th target lies within the reference cells of the *i*th target if

$$|R_J - R_I| \leqslant \Delta D = (N_R + 2)\Delta R \tag{294}$$

and

$$|A_J - A_I| \leqslant 2.4\ \theta, \tag{295}$$

where R is the target range and A is the target azimuth, N_R is the number of reference cells on each side of the *i*th target cell, ΔR is the range-cell dimension, and θ is the 3-dB antenna beamwidth. The signal energy for the *j*th target is found by calling subroutine SIGNAL.

Table 26 — RESOL Variables

Fortran Variable	Description
DELR	Range interval used to determine whether the target lies with the reference cells of the *i*th target (ΔD in Eq. 294)
INF(K)	Target number of the *k*th interfering target
N	Number of targets
NI	Number of interfering targets
NREF	Number of reference cells on each side which are used to calculate the detection threshold (N_R in Eq. 294)
NTAR	Target I of interest
RES	Dimension of the range-resolution cell (ΔR in Eq. 294)
SNREF(K)	Signal power of the *k*th interfering target
TH3DB	Antenna 3-dB azimuth beamwidth (θ in Eq. 295)
TRGPOS(I,4)	Range of the *i*th target (R_I in Eq. 294)
TRGPOS(I,5)	Azimuth of the *i*th target (A_I in Eq. 295)

Subroutine RNGCEN

Subroutine RNGCEN is called by subroutine MULPTH. Its function is to determine the location of the reflection point on a surface with a radius of 4/3 of the earth's radius, corresponding to a path-length difference of $\lambda/4$. This information is used in evaluating the propagation factor in the intermediate region.

The subroutine is entered with a value of sin ψ that corresponds to the flat-earth solution to the problem

$$\sin \psi = 2\left(\frac{\lambda}{4}\right) \frac{h_r + h_t}{(\lambda/4)^2 + 4h_r h_t}, \qquad (296)$$

where $\lambda/4$ represents the path-length difference and h_r, h_t, and ψ are defined in Fig. 13. This value of sin ψ is used to calculate the path-length difference Δ from the following equation, whose development will be discussed in the next paragraph using the spherical-earth geometry shown in Fig. 14:

$$\Delta = \frac{4 \sin \psi}{\dfrac{1 + [1 + (2h_r/a \sin^2 \psi)]^{1/2}}{h_r} + \dfrac{1 + [1 + (2h_t/a \sin^2 \psi)]^{1/2}}{h_t}}, \qquad (297)$$

where a is 4/3 of the earth's radius. The function f, defined as

$$f = \Delta - \frac{\lambda}{4}, \qquad (298)$$

is evaluated, and its absolute value is compared to $\lambda/40$. If $|f| \geqslant \lambda/40$, the derivative of f with respect to sin ψ is determined and used to calculate a new value of sin ψ:

$$\sin \psi_{new} = \sin \psi_{old} - f\left[\frac{1}{df/d(\sin \psi)}\right]. \qquad (299)$$

A new value of Δ is then computed using sin ψ_{new}, and this process is continued until the convergence criterion $|f| < \lambda/40$ is satisfied. When this occurs, the corresponding values of r_1, r_2, R_1, and R_2 (Fig. 13) are calculated (Fortran variables SR1, SR2, R1, and R2, Table 27) and control of the program is returned to MULPTH.

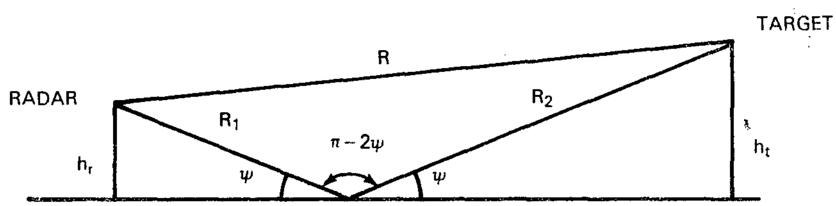


Fig. 13 — Flat-earth geometry

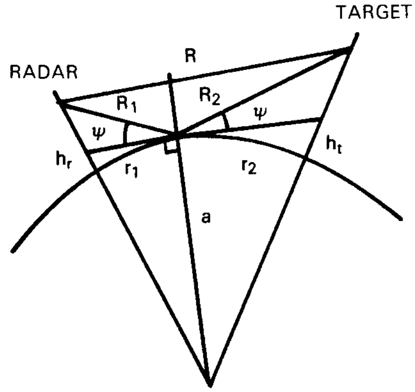


Fig. 14 — Spherical-earth geometry

Equation 297 is developed as follows: From Fig. 13 or Fig. 14

$$R = (R_1^2 + R_2^2 + 2R_1R_2 \cos 2\psi)^{1/2}$$
$$= [(R_1 + R_2)^2 - 2R_1R_2(1 - \cos 2\psi)]^{1/2}$$
$$= [(R_1 + R_2)^2 - 4R_1R_2 \sin^2 \psi]^{1/2}. \tag{300}$$

Equation 300 can be rewritten as

$$R = (R_1 + R_2)\left[1 - \frac{4R_1R_2 \sin^2 \psi}{(R_1 + R_2)^2}\right]^{1/2}, \tag{301}$$

and, since $\Delta = R - (R_1 + R_2)$,

$$\Delta = (R_1 + R_2)\left\{-1 + \left[1 - \frac{4R_1R_2 \sin^2 \psi}{(R_1 + R_2)^2}\right]^{1/2}\right\},$$
$$= (R_1 + R_2) \frac{(4R_1R_2 \sin^2 \psi)/(R_1 + R_2)^2}{\left\{1 - \left[(4R_1R_2 \sin^2 \psi)/(R_1 + R_2)^2\right]\right\}^{1/2} + 1}. \tag{302}$$

When the path-length difference is close to $\lambda/4$, $\sin \psi \approx 0$; consequently Eq. 302 can be simplified to

$$\Delta = \frac{2R_1R_2}{R_1 + R_2} \sin^2 \psi = \frac{2}{R_1^{-1} + R_2^{-1}} \sin^2 \psi. \tag{303}$$

To reduce Eq. 303 to Eq. 297, R_1 and R_2 must be expressed in terms of h_r, h_t, and sin ψ, which is accomplished as follows: From Fig. 14

$$\sin \psi = \frac{h_r^2 - R_1^2 + 2ah_r}{2R_1 a} = \frac{h_r}{R_1}\left(\frac{h_r}{2a} + 1\right) - \frac{R_1}{2a} . \tag{304}$$

Neglecting $h_r/2a$ gives

$$\sin \psi = \frac{h_r}{R_1} - \frac{R_1}{2a} . \tag{305}$$

Applying the quadratic formula to Eq. 305 yields

$$R_1 = \frac{2h_r}{\sin \psi + [\sin^2 \psi + (2h_r/a)]^{1/2}} . \tag{306}$$

Similarly

$$R_2 = \frac{2h_t}{\sin \psi + [\sin^2 \psi + (2h_t/a)]^{1/2}} . \tag{307}$$

Substitutions of Eqs. 306 and 307 reduce Eq. 303 to Eq. 297.

Table 27 — RNGCEN Variables

Fortran Variable	Description
DELT	Wavelength divided by 4 (m) ($\lambda/4$ in Eq. 296)
HR	Height of the antenna (m) (h_r in Eqs. 296 and 297)
HT	Height of the target (m) (h_t in Eqs. 296 and 297)
R1	Slant range from the radar to reflection point (m) (R_1 in Eq. 300)
R2	Slant range from the reflection point to target (m) (R_2 in Eq. 300)
RE	4/3 of the earth's radius (m) (a in Eqs. 299 and 306 through 307)
S	Sine of the grazing angle (sin ψ in Eqs. 298, 299, 301, and 305 through 307)
SR1	Ground range from the radar to the reflection point (m) (r_1 in text after Eq. 299)
SR2	Ground range from the reflection point to the target (m) (r_2 in text after Eq. 299)

Subroutine SIGNAL

Subroutine SIGNAL is called by the executive routine every scan for each target and radar mode. For a given target JTAR, the subroutine computes the free-space returning signal power PWR and the total received signal energy SIGEN, the latter taking into account the effects of multipath propagation and rain attenuation (Table 28). A second entry point NOISE calculates the noise energy (including jamming) EN and clutter energy EC associated with the target JTAR.

Subroutine SIGNAL first calls subroutine TARSIG to compute target JTAR's radar cross section σ as a function of aspect angle. This is then used to determine the free-space returning signal power at the beam maximum according to

$$P_r = \frac{P_T G^2 \lambda^2 \sigma L_R L_T L_M}{R^4 (4\pi)^3}, \tag{308}$$

where P_T is the peak power (W), G is the one-way antenna gain (with respect to the omnidirectional case), λ is the radar wavelength (m), σ is the target cross section (m^2), L_r is the receiver antenna loss, L_T is the loss between the transmitter output and free space, L_M is the mode-dependent loss, and R is the target range (m). The received signal energy for a pulse of duration τ is then

$$S_0 = P_r \tau. \tag{309}$$

While the target is assumed to be in the center of the azimuth beam, the signal energy must be adjusted for target JTAR being off the elevation beam center. This is accomplished through the use of the BEAM function, which determines a one-way beam-shape factor $f(\theta)$ that is applied to the received-signal energy according to

$$S_1 = S_0 [f(\theta)]^2. \tag{310}$$

Rain is modeled by a large number of independent scatterers, each of cross section σ_i and located within the radar resolution cell. This method is suggested by Skolnik [8]. Accordingly the total rain cross section is

$$\sigma_R = V_m \sum \sigma_i, \tag{311}$$

where V_m is the volume of the radar resolution cell:

$$V_m = \left(\frac{\pi}{4}\right) R^2 \theta_B \phi_B \left(\frac{c\tau_c}{2}\right), \tag{312}$$

where θ_B and ϕ_B are respectively the horizontal and vertical 3-dB beamwidths in radians, c is the speed of light, and τ_c is the compressed-pulse length in seconds.

It can be shown that if the raindrop diameter D is small in comparison to λ, then σ_i can be represented by

$$\sigma_i = \frac{\pi^5}{\lambda^4} |K|^2 D^6, \tag{313}$$

where K depends on the dielectric constant of the scatterer and K^2 is approximately 0.93 for water at 10°C when λ = 10 cm. Since the drop diameter is not a convenient parameter, an expression has been developed that relates drop diameter to rainfall rate r (in millimeters per hour):

$$\sum_i D^6 = 200 r^{1.6}. \tag{314}$$

Substituting Eqs. 312, 313, and 314 into Eq. 311 and using a value of 0.93 for K^2 gives the total rain cross section σ_R in the resolution cell as

$$\sigma_R = 6.706 \times 10^{-6}\, \tau_c \theta_B \phi_B R^2 r^{1.6} \lambda^{-4}. \tag{315}$$

This expression for σ_R is used to determine the rain's contribution to the total noise.

The two-way rain attenuation is calculated by fitting a curve to data published by Nathanson [9]. The data show a logarithmic relationship between attenuation and frequency that can be expressed algebraically as

$$2\alpha = 1.753 \times 10^{-3} f^{1.87}, \tag{316}$$

where 2α is the two-way attenuation in decibels per nautical mile per millimeter per hour and f is the frequency in gigahertz. The two-way attenuation A_r (absolute) for a given rainfall rate r, range R (meters), and wavelength λ (meters) is

$$\log_{10} A_r = -10^{-8} R r \lambda^{-1.87}. \tag{317}$$

Before the rain-attenuated signal energy can be computed, it is necessary to consider multipath effects. This is carried out in subroutine MULPTH, which calculates the propagation factor F. The rain-attenuated signal energy for IF bandwidth B_{IF} is then

$$S = S_1 F^4 A_r [\min (B_{IF} \tau_c, 1)], \tag{318}$$

where the bandwidth adjustment is consistent with matched-filter analysis.

The four components that are considered to be contributory to noise—thermal noise, jamming, sea clutter, and rain backscatter—are calculated through entry NOISE.

Thermal noise energy is determined from

$$N_T = F_n k T_0, \tag{319}$$

where F_n is the receiver noise figure, k is Boltzmann's constant, and T_0 is the system temperature in degrees Kelvin.

Jamming energy E_J and sea clutter E_c are calculated by subroutine JAM and are modified by A_r to include the effects of rain attenuation.

Rain backscatter energy is computed according to

$$E_R = \frac{6\sigma_R S I_c \tau}{\sigma F^4 f^2(\theta)}, \tag{320}$$

where I_c is the rain-clutter improvement factor and the factor 6 represents the effect of averaging returns for rain in the resolution cell over many multipath fade and reinforcement regions in radar modes affected by multipath propagation.

The noise energy E_N, including jamming and rain backscatter but not sea clutter, is

$$E_N = (N_T + E_J + E_R) \max (B_{\mathrm{IF}} \tau_c, 1), \tag{321}$$

where the adjustment to the total energy allows for increased noise due to an unmatched IF bandwidth. The sea-clutter energy E_c is also adjusted to allow for an unmatched IF bandwidth and returned separately.

Table 28 — SIGNAL Variables

Fortran Variable	Description
AMBN	Thermal noise energy (J) (N_T in Eq. 319)
EC	Sea-clutter energy (J) (E_c in text between Eqs. 319 and 320)
EJ	Jamming energy (J) (E_J in Eq. 321)
EN	Noise energy (J), including thermal noise, jamming, and rain backscatter, but excluding sea clutter (E_N in Eq. 321)
ENVIR(4)	Rainfall rate (mm/h) (r in Eq. 314)
ES	Signal energy (J) (S in Eqs. 318 and 320)
FAC	Propagation factor (F in Eq. 318)
FHV(1)	Beam-pattern factor (power) ($f(\theta)$ in Eq. 310)
IMODE(J,1)	Number of pulses integrated
IMODE(J,2)	max $(B_{\mathrm{IF}}\tau_c, 1)$ for mode J (rounded to the nearest integer) (Eq. 321)
PWR	Power received (W) (P_r in Eq. 309)
R	Range R (n.mi.)
RA	Two-way rain attenuation (A_r in Eq. 317)
RC(3)	Receiver noise figure (F_n in Eq. 319)
RC(4)	Horizontal 3-dB beamwidth (rad) (θ_B in Eqs. 312 and 315)
RC(5)	Vertical 3-dB beamwidth (rad) (ϕ_B in Eqs. 312 and 315)
RC(6)	Antenna gain one way with respect to the omnidirectional case (G in Eq. 308)
RC(8)	Receive antenna loss (dB) (L_R in Eq. 308)
RC(9)	Loss between the transmitter output and free space (L_T in Eq. 308)

Table continues.

Table 28 (Concluded) — SIGNAL Variables

Fortran Variable	Description
RC(10)	Boltzmann's constant times the system temperature (kT_0 in Eq. 319)
RM	Range (m) (R in Eqs. 312, 315, and 317)
RMODE(J,3)	Peak power (W) for mode J (P_t in Eq. 308)
RMODE(J,4)	Pulse length for mode J (τ in Eq. 309)
RMODE(J,8)	Mode-dependent loss for mode J (L_M in Eq. 308)
RMODE(J,12)	Intermediate-frequency bandwidth (Hz) (B_{IF} in Eqs. 318 and 321)
RMT	Range to the fourth power (m^4) (R^4 in Eq. 308)
RNCS	Rain cross section for rain in the resolution cell (m^2) (σ_R in Eqs. 311 and 315)
SIGEN	Signal energy (J), same as ES (S in Eqs. 318 and 320)
SMODE(J,2)	Rain-clutter improvement factor (I_c in Eq. 320)
TARCS	Target cross section (m^2) (σ in Eq. 308)
TAU(NEXT)	Compressed pulse length (s) (τ_c in Eqs. 312, 315, 318, and 321)
WVL	Wavelength (m) (λ in Eqs. 308, 313, 315, and 317)
XNMTOM	Conversion factor (nautical miles to meters)

Subroutine TARGET

Subroutine TARGET is called once by the executive routine. Its purpose is to read in target and jammer characteristics and trajectory data, which it converts from kilofeet, seconds, and watts per megahertz to internal units (nautical miles, hours, and watts per hertz) for use by other subroutines. In addition, preliminary calculations are performed for maneuvering targets, and the coefficient array for computations of target radar cross sections is determined.

A maximum of 20 targets (to be detected) and jammers (additional sources of jamming radiation) in any combination may be defined. The first input card read by subroutine TARGET specifies the number of targets NTARG and then the number of jammers NJAM. Each target or jammer is defined by a pair of cards; the NTARG pairs of cards immediately following the first input card define the targets, and the next NJAM pairs of cards define the jammers (Table 29).

The initial card (of the pair) for a target (or jammer) contains the following data:

XYZI — Initial position coordinates and time $(x, y, z, t)_i$ (kft and s),
XYZF — Final position coordinates and time $(x, y, z, t)_f$ (kft and s), with t_f being ignored for a maneuvering target (ITYPE = 2),
SIGTAR — Head-on, broadside, and minimum radar reflective areas (m^2),
SIGJAM — Jamming power density (W/MHz),
MODEL — Marcum-Swerling cross-section model number.

The contents of the second card varies according to the value of its first parameter ITYPE, which specifies which of the three defined types of flight profiles the target will follow. Target profile type 0 (ITYPE = 0) consists of a straight-line trajectory from the initial position to the final position. The target's constant speed is determined from the initial and final times specified for these positions. Therefore the second card for a target of type 0 is blank (but cannot be omitted).

Target profile type 1 (ITYPE = 1) is defined as a piecewise linear trajectory consisting of from two to four altitude legs. These legs are determined by specifying from one to three altitude nodes and corresponding arrival times. Therefore the complete trajectory consists of straight-line segments between altitude nodes, with the projection of the profile on the xy plane being a straight line between the initial and final positions. The second card for a type-1 target contains the following data:

ITYPE(J) — Target profile type (1),
NALT(J) — Number of altitude nodes,
ALT(J,1) — First altitude (node) (kft),
TALT(J,1) — Time of arrival at the first altitude (s),
ALT(J,2) — Second altitude (node) (kft),
TALT(J,2) — Time of arrival at the second altitude (s),
ALT(J,3) — Third altitude (node) (kft),
TALT(J,3) — Time of arrival at the third altitude (s).

Target profile type 2 (ITYPE = 2) is defined at a constant altitude and consists of a straight-line trajectory from the initial position at the defined speed and heading to a specified time when the maneuver begins. The maneuver (turn) occurs in the horizontal plane according to the specified g capability. The maneuver terminates when the target is heading toward its final position, at which time the profile returns to a straight-line trajectory to the target's endpoint.

The second card for a type 2 target contains the following data:

ITYPE(J) — Target profile type (2),
SPEED(J) — Target speed (kft/s),
HEADI(J) — Initial target heading (deg),
TMANI(J) — Time at which the maneuver begins (s),
GTURN(J) — Radial acceleration of the maneuver (g's).

For each target defined with a type-2 trajectory the calculations that follow are performed in addition to the scaling of parameters.

Let Δ denote the distance traveled by the target from its initial position to the point of maneuver:

$$\Delta = v(t_m - t_i), \tag{322}$$

where v is the speed of the target, t_m is the time the target starts its maneuver, and t_i is the time the target leaves its initial position. The coordinates of the point (x_m, y_m) where the maneuver begins are

$$x_m = x_i + \Delta \cos(h_i) \tag{323a}$$

and

$$y_m = y_i + \Delta \sin (h_i), \tag{323b}$$

where x_i is the x coordinate of the target's initial position, y_i is the y coordinate of the target's initial position, and h_i is the initial heading of the target. To determine if the maneuver is clockwise or counterclockwise (looking into the xy plane), the heading of the vector defined from the point of maneuver to the target's final position is computed:

$$h_m = \cos^{-1} \left([x_f - x_m]/[(x_f - x_m)^2 + (y_f - y_m)^2]^{1/2}\right), \tag{324}$$

where x_f is the x coordinate of the target's final position and y_f is the y coordinate of target's final position. If $h_i < \pi$ and either $h_m < h_i$ or $h_m \geqslant h_i + \pi$, or if $h_i \geqslant \pi$ and both $h_m < h_i$ and $h_m \geqslant h_i - \pi$ (the point (x_f, y_f) lies to the right of the initial heading vector), then the maneuver is clockwise and flagged by TURN = -1. Otherwise the maneuver is counterclockwise with TURN = 1.

The radius of the maneuver circle is

$$r_m = v^2/g, \tag{325}$$

where v is the target speed and g is the radial acceleration of the target maneuver.

The center (x_c, y_c) of the maneuver circle is

$$x_c = x_m + r_m \cos (h_i + \text{TURN}\ \pi/2) \tag{326a}$$

and

$$y_c = y_m + r_m \sin (h_i + \text{TURN}\ \pi/2). \tag{326b}$$

If

$$d = [(x_f - x_c)^2 + (y_f - y_c)^2]^{1/2} < r_m, \tag{327}$$

then the target's final position lies inside the maneuver circle, so the maneuver is impossible, and the target is deleted from further consideration.

Let α and β be defined by

$$\alpha = \cos^{-1} [(x_f - x_c)/d] \tag{328}$$

and

$$\beta = \sin^{-1} [r_m/d]. \tag{329}$$

The heading h_f of the target as it terminates its maneuver and begins its final leg is then

$$h_f = \alpha + \text{TURN}\ \beta, \qquad \sin\alpha \geqslant 0, \tag{330a}$$

$$= 2\pi - \alpha + \text{TURN}\ \beta, \qquad \sin\alpha < 0. \tag{330b}$$

The point (x_n, y_n) where the target terminates its maneuver is

$$x_n = x_c + r_m \cos(h_f - \text{TURN } \pi/2) \tag{331a}$$

and

$$y_n = y_c + r_m \sin(h_f - \text{TURN } \pi/2), \tag{331b}$$

and the time t_n the target reaches (x_n, y_n) is

$$t_n = t_m + v(\Delta h)/g, \tag{332}$$

where

$$\Delta h = h_f - h_i, \qquad (h_f - h_i) \geqslant 0, \tag{333a}$$

$$= h_f - h_i + 2\pi, \qquad (h_f - h_i) < 0. \tag{333b}$$

The time t_f the target arrives at its final position is

$$t_f = t_n + [(x_f - x_n)^2 + (y_f - y_n)^2]^{1/2}/v. \tag{324}$$

(The final time specified as input for a type-2 target is ignored and may be omitted.)

The concluding calculations performed in subroutine TARGET are those to determine the coefficient array $[A]$ for radar cross sections of a target. It is assumed that a target's radar cross section, as viewed circumferentially, generates a lobing structure and that this structure can be represented by a linear combination of the functions $\cos 2\theta$, $\cos 4\theta$, and $\cos 8\theta$, where θ is the angle between the line of sight to the target and the target's broadside axis (Fig. 15). Thus

$$\alpha(\theta) = A_1 \cos 2\theta + A_2 \cos 4\theta + A_3 \cos 8\theta + A_4. \tag{335}$$

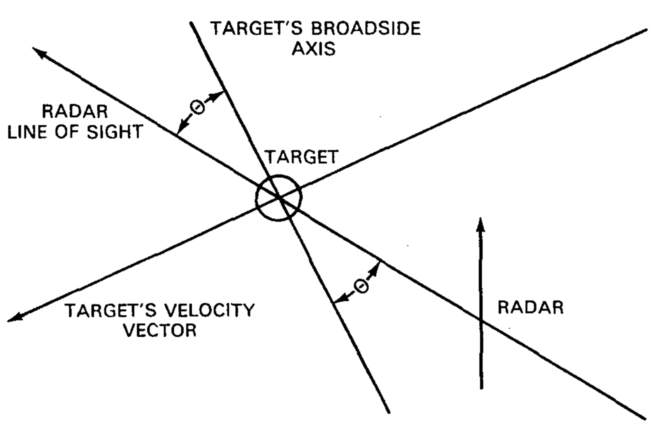


Fig. 15 — Geometry used in determining radar cross section of a target

Expressions for the coefficients A_i as functions of the broadside, head-on, and minimum cross sections are developed as follows. First the expression for $\alpha(\theta)$ is differentiated and expressed in terms of $\cos\theta$ and $\sin 2\theta$:

$$\alpha'(\theta) = 2A_1 \sin 2\theta + 8A_2(2\cos^2\theta - 1)\sin 2\theta$$
$$+ 32A_3(16\cos^6\theta - 24\cos^4\theta + 10\cos^2\theta - 1)\sin 2\theta. \quad (336)$$

It is now assumed that the minimum radar cross section occurs at $\theta = \pi/3$, or 60° off broadside. (This is consistent with measurements made on the type of aircraft that is normally encountered in applications.) Setting $a' = 0$ and $\cos\theta = -1/2$ in Eq. 336 yields

$$4A_3 - 2A_2 + A_1 = 0. \quad (337)$$

For $\theta = 0$ the radar cross section is given by the input value for the broadside cross section B. These values together with Eq. 337 reduce Eq. 335 to

$$\alpha(0) = 3A_2 - 3A_3 + 4A_2 = B. \quad (338)$$

For $\theta = \pi/2$ the radar cross section is given by the input value for the normal cross section N; hence

$$-A_2 + 5A_3 + A_4 = N. \quad (339)$$

For $\theta = \pi/3$ the radar cross section is given by the input minimum value M. This yields

$$-3A_2 + 3A_3 - 2A_4 = 2M. \quad (340)$$

Solving Eqs. 337 through 340 for A_1, A_2, A_3, and A_4 gives the results

$$A_4 = \frac{B + 2M}{2}, \quad (341a)$$

$$A_3 = \frac{B + 3N - 4A_4}{12}, \quad (341b)$$

$$A_2 = 5A_3 - N + A_4, \quad (341c)$$

and

$$A_1 = 2A_2 - 4A_3. \quad (341d)$$

A set of four such coefficients is calculated for each target.

Table 29 — TARGET Variables

Fortran Variable	Description
A(J,I)	Coefficients calculated for use in determining target-I radar cross sections (A_1, A_2, A_3, and A_4 in Eqs. 335 and 341)
ALT(J,I)	Altitude of profile node I of target J with ITYPE(J) = 1
CARD(I)	Temporary storage for the input parameters from the second data card for the target
CM(J,1)	Coordinate x of the center of the maneuver circle for target J with ITYPE(J) = 2 (x_c in Eq. 326a)
CM(J,2)	Coordinate y of the center of the maneuver circle for target J with ITYPE(J) = 2 (y_c in Eq. 326b)
DELR	Distance from the center of the maneuver circle to the final position for target J with ITYPE(J) = 2 (d in Eq. 327)
GTURN(J)	Radial acceleration for the maneuver by target J with ITYPE = 2 (g in Eq. 325)
HEADF(J)	Final heading of target J with ITYPE(J) = 2 (h_f in Eqs. 330)
HEADI(J)	Initial heading of target J with ITYPE(J) = 2 (h_i in Eqs. 323)
ITYPE(J)	Type of target profile for target J: 0 = straight-line trajectory 1 = altitude legs 2 = maneuver
MODEL(J)	Indicator of the Marcum-Swerling cross-section model for target J
NALT(J)	Number of altitude nodes for target J with ITYPE(J) = 1
NJAM	Number of jammers
NTARG	Number of targets
NUMTGT	Total number of targets plus jammers
RADM(J)	Radius of the maneuver circle of target J with ITYPE = 2
SIGJAM(J)	Jamming power for target J (W/MHz to W/Hz)
SIGTAR(J,1)	Head-on radar cross section for target J (m^2) (N in Eq. 339)
SIGTAR(J,2)	Broadside radar cross section for target J (m^2) (B in Eq. 338)
SIGTAR(J,3)	Minimum radar cross section for target J (m^2) (M in Eq. 340)
SPEED(J)	Speed of target J with ITYPE(J) = 2 (v in Eq. 325)
TALT(J,I)	Time when target J with ITYPE(J) = 1 arrives at altitude node I
TMANF(J)	Time when target J with ITYPE(J) = 2 terminates its maneuver (t_n in Eqs. 332 and 334)
TMANI(J)	Time when target J with ITYPE(J) = 2 begins its maneuver (t_m in Eq. 322)
TURN(J)	Indicator for a counterclockwise (1) or clockwise (- 1) maneuver for target J with ITYPE(J) = 2
XHEAD	Heading of the vector defined from the point the maneuver begins to the final position of target J with ITYPE(J) = 2 (h_m in Eq. 324)
XMANF(J,1)	Coordinate x for the point where target J with ITYPE(J) = 2 terminates its maneuver (x_n in Eqs. 331a and 334)
XMANF(J,2)	Coordinate y for the point where target J with ITYPE(J) = 2 terminates its maneuver (y_n in Eqs. 331b and 334)

Table continues.

Table 29 (Concluded) — TARGET Variables

Fortran Variable	Description
XMANI(J,1)	Coordinate x for the point where target J with ITYPE(J) = 2 begins its maneuver (x_m in Eq. 323a)
XMANI(J,2)	Coordinate y for the point where target J with ITYPE(J) = 2 begins its maneuver (y_m in Eq. 323b)
XYZF(J,1)	Final coordinate x for target J (kft to n.mi.) (x_f in Eqs. 324 and 334)
XYZF(J,2)	Final coordinate y for target J (kft to n.mi.) (y_f in Eqs. 324 and 334)
XYZF(J,3)	Final coordinate z for target J (kft to n.mi.)
XYZF(J,4)	Final time for target J (s to h) (t_f in Eq. 334)
XYZI(J,1)	Initial coordinate x for target J (kft to n.mi.) (x_i in Eq. 323a)
XYZI(J,2)	Initial coordinate y for target J (kft to n.mi.) (y_i in Eq. 323b)
XYZI(J,3)	Initial coordinate z for target J (kft to n.mi.)
XYZI(J,4)	Initial time for target J (s to h) (t_i in Eq. 322)

Subroutine TARSIG

Subroutine TARSIG is called by subroutine SIGNAL to calculate the radar cross section of target JTAR at a given aspect angle θ (Table 30). It is assumed that the target's radar cross section σ generates a lobing structure which can be represented by a linear combination of functions of the form $\cos 2k\theta$, so that

$$\sigma(\theta) = A_1 \cos 2\theta + A_2 \cos 4\theta + A_3 \cos 8\theta + A_4, \tag{342}$$

where θ is the angle between the line of sight from the radar to the target and the target's broadside axis (Fig. 15). The coefficients A_i are functions of the target's head-on and broadside radar-cross-section input values and of the minimum radar cross section encountered over the anticipated range of aspect angles, also an input value. A set of these weighting factors A_i is calculated for each target in subroutine TARGET.

Table 30 — TARSIG Variables

Fortran Variable	Description
A(JTAR,I)	Coefficients for target JTAR calculated in subroutine TARGET (A_i in Eq. 342)
DOTP(JTAR)	Cosine of the angle $(\pi/2) - \theta$ between the line of sight from the radar to the target and the target's velocity vector (Fig. 15)
TARCS	Target cross section (m^2) ($\sigma(\theta)$ in Eq. 342)
TEMP(2)	$-\cos 2\theta$
TEMP(3)	$\cos 4\theta$
TEMP(4)	$\cos 8\theta$

Subroutine UFUN

Subroutine UFUN is called by subroutine MULPTH to calculate the U functions that are used in determining the pattern-propagation factor F in the diffraction region. The equation as given by Kerr [7] for the pattern-propagation factor in the diffraction region is

$$F = 2(\pi X)^{1/2} e^{-C_1 X} |U_1(Z_1)U_1(Z_2)|, \tag{343}$$

and UFUN evaluates the function $U_1(Z_j)$ for the values of Z_j given in its calling sequence. The term Z_j is alternatively assigned the height of the radar (Z_1) and the height of the target (Z_2) in the so-called natural units discussed in the subsection on subroutine MULPTH.

The rationale followed in evaluating $U_1(Z_j)$ is as follows: The term $U_1(Z_j)$ can be expressed in terms of the function $h_2(x)$. This is found [7, p. 109] to be

$$U_1(Z_j) = i \frac{h_2(Z_j + A_1)}{h_2'(A_1)} . \tag{344}$$

The quantity A_1 is calculated in MULPTH and corresponds to CA in the calling sequence (Table 31), and h_2' indicates the derivative of h_2.

The function $h_2(x)$ can in turn be expressed in terms of Airy functions:

$$h_2(x) = i 2^{4/3} 3^{1/6} Ai(x e^{i\pi/3}). \tag{345}$$

Expressions for evaluating the Airy functions are found in Ref. 10. The Airy function is

$$Ai(z) = c_1 f(z) - c_2 g(z), \tag{346}$$

where $f(z)$ and $g(z)$ are given by power series for small values of $|z|$:

$$f(z) = 1 + \frac{1}{3!} z^3 + \frac{1 \cdot 4}{6!} z^6 + \frac{1 \cdot 4 \cdot 7}{9!} z^9 + \ldots \tag{347a}$$

and

$$g(z) = z + \frac{2}{4!} z^4 + \frac{2 \cdot 5}{7!} z^7 + \frac{2 \cdot 5 \cdot 8}{10!} z^{10} + \ldots. \tag{347b}$$

For values of $|z| > 3$, $Ai(z)$ is approximated by an asymptotic expansion:

$$Ai(z) \approx \frac{1}{2} \pi^{-1/2} z^{-1/4} e^{-\mu} \sum_{k=0}^{\infty} (-1)^k n_k \mu^{-k}, \tag{348}$$

Table 31 — UFUN Variables

Fortran Variable	Description
CA	Function of the complex dielectric constant and polarization, evaluated in MULPTH (A_1 in Eq. 344)
CA1	$A_1 e^{i\pi/3}$ (An Airy-function argument in Eq. 345, represented by z in Eqs. 346 through 349)
CA13	$(A_1 e^{i\pi/3})^3$ (z^3 in Eq. 347a)
CA14	$(A_1 e^{i\pi/3})^{-1/4}$ ($z^{-1/4}$ in Eq. 348)
CAIR	The kth term of the asymptotic expansion of the Airy function (Eq. 348) with argument $(Z_i + A_1)e^{i\pi/3}$
CAIRP	The kth term of the asymptotic expansion of the derivative of the Airy function with argument $A_1 e^{i\pi/3}$
CANS	Function used to determine the propagation factor in the diffraction region (U_1 in Eqs. 343 and 344)
CC	$(1/2)\pi^{-1/2}(CZ)^{-1/4}e^{-\mu}$ (factor in Eq. 348)
CCP	$-(1/2)\pi^{-1/2}(CAI)^{1/4}e^{-\mu}$ (factor in Eq. 348)
CDA	$2/3(A_1 e^{i\pi/3})^{3/2}$ (right-hand side of Eq. 349)
CDZ	$2/3[(Z_i + A_1)e^{i\pi/3}]^{3/2}$ (right-hand side of Eq. 349)
CFI	$f[(Z_i + A_1)e^{i\pi/3}]$ summed to the kth term ($f(z)$ in Eq. 347a)
CFIP	$f'(A_1 e^{i\pi/3})$ summed to the kth term
CGI	$g[(Z_i + A_1)e^{i\pi/3}]$ summed to the kth term ($g(z)$ in Eq. 347b)
CGIP	$g'(A_1 e^{i\pi/3})$ summed to the kth term
CH2	h function used in determining U_1 ($h_2(Z_1 + A_1)$ in Eq. 344)
CH2P	Derivative of the h function ($h_2'(A_1)$ in Eq. 344)
CI	$\sqrt{-1}$ (i in Eqs. 344 and 345)
COLDA	Previous value of CANS
CXP3	$e^{i\pi/3}$ (Eq. 345)
CZ	$(Z_2 + A_1)e^{i\pi/3}$ (an Airy-function argument z)
CZ3	$[(Z_i + A_1)e^{i\pi/3}]^3$ (z^3 in Eq. 347a)
CZ4	$[(Z_i + A_1)e^{i\pi/3}]^{-1/4}$ ($z^{-1/4}$ in Eq. 348)
I	Counter k indicating which term of the power series (Eqs. 347) or the asymptotic expansion (Eq. 348) is under consideration
IKEY	Indicator that determines which expansion to use for the Airy functions: 0 = $\lvert CZ \rvert$ and $\lvert CA1 \rvert \leq 3$ 1 = $\lvert CZ \rvert > 3$ 2 = $\lvert CA1 \rvert > 3$ 3 = $\lvert CZ \rvert$ and $\lvert CA1 \rvert > 3$
ISWIT	Indicator: 0 = initial pass or new mode 1 = same mode as previous pass
OLDZ	Value of Z_j on the previous entry to UFUN
RTPI	$\sqrt{\pi}$
XC1	Constant used in evaluating the Airy function (c_1 in Eq. 346)
XC2	Constant used in evaluating the Airy function (c_2 in Eq. 346)
XMUL1	Coefficient of the kth term of the power series for $f(z)$ (Eq. 347a)
XMUL2	Coefficient of the kth term of the power series for $g(z)$ (Eq. 347b)
Z	Height of the point in space under consideration (Z_j in Eq. 344)

where

$$\mu = \frac{2z^{3/2}}{3}, \tag{349}$$

$$n_0 = 1, \tag{350}$$

and

$$n_k = \frac{\Gamma(3k + 1/2)}{54^k k!\Gamma(k + 1/2)} \tag{351}$$

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Appendix A

THRESHOLD VALUES

This appendix is a guide in setting the threshold required as an input value to SURDET2D and SURDET3D (data card 7, described on pages 10 and 45). It will be assumed that the noise is Rayleigh and that enough reference cells are used so that there is no error in the estimate of the noise power. Then, for linear video and a two-parameter threshold of the form (Eqs. 62 and 126)

$$T = \hat{\mu} + F_2 \hat{\sigma} \tag{A1}$$

the appropriate value of F_2 can be found in Robertson*. For linear video and a one-parameter threshold of the form (Eqs. 63 and 127)

$$T = F_1 \hat{\mu}, \tag{A2}$$

the appropriate value of F_1 can be found from

$$F_1 = 1 + F_2 \sqrt{\frac{4 - \pi}{M\pi}} , \tag{A3}$$

where M is the number of pulses integrated. For log video and a threshold of the form (Eqs. 64 and 128)

$$T = \hat{\mu} + F_3 \tag{A4}$$

the appropriate value of F_3 can be found by Monte Carlo techniques employing importance-sampling techniques.

For a probability of false alarm equal to 10^{-6} the appropriate values of F_i are given in Table A1.

Table A1 — Threshold Values for F_1, F_2, and F_3

Type of Video	Threshold Type	Threshold Value for a Given Number of Samples							
		1	2	4	8	16	32	64	128
Linear	$T = F_1 \hat{\mu}$	6.10	5.85	5.62	5.40	5.25	5.12	5.04	4.96
Linear	$T = \hat{\mu} + F_2 \hat{\sigma}$	4.19	3.16	2.47	2.00	1.69	1.47	1.33	1.23
Log	$T = \hat{\mu} + F_3$	1.59	2.63	4.24	6.55	9.78	15.0	22.3	32.0

*G.H. Robertson, "Operating Characteristics for a Linear Detector of CW Signals in Narrow-band Gaussian Noise," *Bell Syst. Tech. J.* 46, 755-774 (Apr. 1967).

Appendix B

PROGRAM LISTINGS OF ROUTINES EXCLUSIVE TO SURDET2D

```
0001          PROGRAM SURDET
        C
        C     THIS IS THE SURDET2D EXECUTIVE ROUTINE
        C
        CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        C
        C
        C                         DESCRIPTION OF DATA CARDS
        C
        C        DATA CARD NO. 1
        C
        C                DETAILED OUTPUT CONTROL INTEGER   (I5 FORMAT)
        C                      0 = NO OUTPUT TO BE PRINTED
        C                      1 = DETECTION OUTPUT TO BE PRINTED
        C                      2 = DETAILED OUTPUT TO BE PRINTED
        C
        C
        C
        C        DATA CARD NO. 2
        C
        C                TITLE CARD  -  RUN IDENTIFICATION  (I4,19A4 FORMAT)
        C                   1 RADAR ID NUMBER FOR TARGET DETECTION OUTPUT FILES
        C                2-20 ALPHANUMERIC DESCRIPTIVE TITLE
        C
        C
        C
        C        DATA CARD NO. 3
        C
        C                SHIP (RADAR) POSITION  (4F8.2 FORMAT)
        C                 1-3 POSITION COORDINATES (X,Y,Z) IN KFT
        C                   4 SHIP HEADING IN DEGREES
        C
        C
        C
        C        DATA CARD NO. 4
        C
        C                11 BASIC RADAR PARAMETERS   (9F8.2,I2,F6.2 FORMAT)
        C                   1 RADAR FREQUENCY IN MHZ
        C                   2 ANTENNA PATTERN FUNCTION INDICATOR
        C                          0 = PENCIL BEAM
        C                          1 = COSECANT SQUARE BEAM
        C                   3 RECEIVER NOISE IN DB
        C                   4 HORIZONTAL 3DB BEAMWIDTH IN DEGREES
        C                   5 VERTICAL 3DB BEAMWIDTH IN DEGREES
        C                   6 ONE-WAY ANTENNA GAIN IN DB
        C                   7 ONE-WAY SIDELOBE LEVEL IN DB DOWN
        C                   8 RECEIVER LOSS IN DB
        C                   9 TRANSMITTER LOSS IN DB
        C                  10 NUMBER OF SCAN MODES
        C                  11 LINEAR POLARIZATION IN DEGREES
```

```
C                        0 = HORIZONTAL
C                       90 = VERTICAL
C
C
C       DATA CARDS NO. 5 AND 6      (ONE SET FOR EACH RADAR SCAN MODE)
C
C              15 PARAMETERS FOR EACH SCAN MODE    (10F8.2/5F8.2 FORMAT)
C                 1 LOWER BOUNDARY ELEVATION ANGLE COVERAGE IN DEGREES
C                 2 UPPER BOUNDARY ELEVATION ANGLE COVERAGE IN DEGREES
C                 3 PEAK POWER IN MW
C                 4 PULSE LENGTH IN MICROSECONDS
C                 5 INTERLOOK PERIOD IN SECONDS
C                 6 SCAN OFFSET IN SECONDS
C                 7 INSTRUMENTED RANGE IN NMI
C                 8 MODE DEPENDENT LOSS IN DB
C                 9 NUMBER OF PULSES INTEGRATED
C                10 COMPRESSED PULSE LENGTH IN MICROSECONDS
C                11 SEA CLUTTER IMPROVEMENT FACTOR IN DB
C                12 I.F. BANDWIDTH IN MHZ. IF 0, BANDWIDTH WILL BE SET
C                        AT 1.0/(COMPRESSED PULSE LENGTH)
C                13 MODE DEPENDENT FREQUENCY INCREMENT IN MHZ
C                14 BLANKING TIME IN MICROSECONDS.  IF 0, SET AT
C                        PULSE LENGTH
C                15 RAIN CLUTTER IMPROVEMENT FACTOR IN DB
C
C
C       DATA CARD NO. 7
C
C              7 PARAMETERS FOR MOVING WINDOW DETECTOR   (7F8.2 FORMAT)
C                 1 NO. OF REFERENCE CELLS ON EACH SIDE OF TARGET CELL
C                 2 CLUTTER CORRELATION COEFFICIENT
C                 3 NO. OF STANDARD DEVIATIONS USED IN THRESHOLD
C                 4 NO. OF DETECTIONS THAT CAN BE MISSED AND DETECTIONS
C                   STILL MERGED INTO A SINGLE DETECTION
C                 5 VIDEO TYPE INDICATOR
C                        0 = LINEAR VIDEO
C                        1 = LOG VIDEO
C                 6 NO. OF REFERENCE CELLS USED FOR THRESHOLD
C                        0 = ALL CELLS USED
C                       <0 = SMALLER HALF USED
C                       >0 = LARGER HALF USED
C                 7 PARAMETERS USED TO CALCULATE THRESHOLD
C                        1 = MEAN USED
C                        2 = MEAN AND VARIANCE USED
C
C
C
C       DATA CARD NO. 8
C
C              NUMBER OF TARGETS AND JAMMERS    (2I5 FORMAT)
```

```
C                 1 NO. OF TARGETS
C                 2 NO. OF JAMMERS
C
C
C       DATA CARDS NO. 9 AND 10   (ONE SET FOR EACH TARGET AND JAMMER)
C
C              CARD 9    13 TARGET PARAMETERS    (12F6.2,I3 FORMAT)
C              TARGET TRAJECTORY SHOULD NOT CROSS 0 DEGREES IN AZIMUTH
C               1-4 INITIAL COORDINATES  (X,Y,Z,T) IN KFT AND SECONDS
C               5-8 TERMINAL COORDINATES  (X,Y,Z,T) IN KFT AND SECONDS
C              9-11 RADAR REFLECTIVE AREAS FOR HEAD-ON,
C                        BROAD-SIDE, AND MINIMUM IN SQ. METERS
C                12 JAMMING POWER DENSITY IN W/MHZ
C                13 MARCUM SWERLING CROSS SECTION MODEL
C
C              CARD 10   TARGET PROFILE PARAMETERS    (I4,7F6.2 FORMAT)
C                 1 TARGET PROFILE TYPE
C                         0 = STRAIGHT LINE TRAJECTORY
C                         1 = 2-4 ALTITUDE LEGS
C                         2 = G-MANEUVER AT CONSTANT ALTITUDE
C              REMAINING PROFILE PARAMETERS BY TARGET TYPE
C               IF TARGET TYPE = 0
C               2-8 IGNORED
C               IF TARGET TYPE = 1
C                 2 = NO. OF ALTITUDE NODES
C                 3 = FIRST ALTITUDE NODE IN KFT
C                 4 = TIME OF ARRIVAL AT FIRST NODE IN SEC
C                 5 = SECOND ALTITUDE NODE IN KFT
C                 6 = TIME OF ARRIVAL AT SECOND NODE IN SEC
C                 7 = THIRD ALTITUDE NODE IN KFT
C                 8 = TIME OF ARRIVAL AT THIRD NODE IN SEC
C               IF TARGET TYPE = 2
C                 2 = TARGET SPEED IN KFT/SEC
C                 3 = INITIAL HEADING IN DEGREES
C                 4 = TIME MANEUVER BEGINS IN SEC
C                 5 = TARGET MANEUVER RADIAL ACCELERATION IN G'S
C
C
C
C       DATA CARD NO. 11
C
C              4 ENVIRONMENTAL PARAMETERS    (4F8.2 FORMAT)
C                 1 WIND SPEED IN KNOTS
C                 2 HEIGHT OF WIND SPEED MEASUREMENT IN KFT
C                 3 MULTIPATH INDICATOR
C                        1 = MULTIPATH
C                        0 = NO MULTIPATH
C                 4 RAINFALL RATE IN MM/HR
C
C
```

```
C
C       DATA CARD NO. 12
C
C               9 FIXED CLUTTER PARAMETERS    (2I8,7F8.2 FORMAT)
C                  1 INITIALIZATION FOR RANDOM NUMBER GENERATOR FOR
C                    GENERATION OF FIXED CLUTTER POINTS
C                  2 NO. OF FIXED CLUTTER POINTS
C                  3 PROBABILITY THAT CLUTTER POINT IS DETECTED
C                  4 INITIAL RANGE OF CLUTTER AREA IN KFT
C                  5 FINAL RANGE OF CLUTTER AREA IN KFT
C                  6 STANDARD DEVIATION OF RANGE MEASUREMENT
C                    AS A PERCENTAGE OF RANGE RESOLUTION CELL SIZE
C                  7 INITIAL AZIMUTH OF CLUTTER AREA IN DEGREES
C                  8 FINAL AZIMUTH OF CLUTTER AREA IN DEGREES
C                  9 STANDARD DEVIATION OF AZIMUTH MEASUREMENT
C                    AS A PERCENTAGE OF HORIZONTAL 3DB BEAMWIDTH
C
C
C
C       DATA CARD NO. 13
C
C               2 BASIC VARIABLE CLUTTER PARAMETERS    (2I8 FORMAT)
C                  1 INITIALIZATION FOR RANDOM NUMBER GENERATOR FOR
C                    GENERATION OF VARIABLE CLUTTER POINTS
C                  2 NO. OF CLUTTER REGIONS
C
C
C       DATA CARD NO. 14      (ONE CARD FOR EACH CLUTTER REGION)
C
C               5 PARAMETERS FOR EACH CLUTTER REGION    (5F8.2 FORMAT)
C                  1 AVERAGE NUMBER OF CLUTTER POINTS IN REGION
C                  2 INITIAL RANGE OF CLUTTER AREA IN KFT
C                  3 FINAL RANGE OF CLUTTER AREA IN KFT
C                  4 INITIAL AZIMUTH OF CLUTTER AREA IN DEGREES
C                  5 FINAL AZIMUTH OF CLUTTER AREA IN DEGREES
C
C
C
C       DATA CARD NO. 15
C
C               4 ROLL AND PITCH PARAMETERS    (4F8.2)
C                  1 MAXIMUM ROLL ANGLE IN DEGREES
C                  2 MAXIMUM PITCH ANGLE IN DEGREES
C                  3 ROLL PERIOD IN SECONDS
C                  4 PITCH PERIOD IN SECONDS
C
C
C
C       DATA CARD NO. 16
C
```

```
      C                  TIME PARAMETER (F8.2)
      C                     GAME TIME (IN SEC) BY WHICH RADAR IS TO BEGIN SCANS
      C
      C
      C
      C         DATA CARD NO. 17
      C
      C                  RECYCLE CONTROL PARAMETER    (I5 FORMAT)
      C                               1 = NEW SHIP   IN WHICH CASE
      C                                         THE NEXT DATA CARD IS NO. 1
      C                               2 = NEW TARGETS
      C                               3 = NEW ENVIROMENT
      C                               4 = RUN COMPLETED
      C
      C
      C
      CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      C
      C
0002        COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
           1       ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
           2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
           3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
           4       ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
0003        COMMON/B/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACON,BETA,
           *        DOTP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPIQB,FOPISQ
0004        COMMON/D/ ALPHAD,SIGZ,V,AR1,AR2,SIGC,SIG
0005        COMMON/H/FAC4,AMBN,XJAMN,IKEYJG,XXXXX
0006        COMMON/I/ PBBS,HOFK,THETBK,DBDOWN,THH,THV,GN
0007        COMMON/TM/NTARG,NJAM,SPEED(20),HEADI(20),HEADF(20),TMANI(20),
           1          TMANF(20),XMANI(20,3),XMANF(20,3),GTURN(20),TURN(20),
           2         CM(20,2),RADM(20),ITYPE(20),ALT(20,5),TALT(20,5),NALT(20)
0008        COMMON/TS/ISTAT(20),TSCAN(20,30)
0009        COMMON /CLTOUT/ ROUT(201),AZOUT(201),ELOUT(201),TOUT(201),
           1 RLOUT(201),PTOUT(201),SOUT(201),NC(100),IC,IV
0010        COMMON /DET/ NDET(20),MER(20),RANGE(20,3),AZ(20,6),SNDET(20,3),
           1             ELEV(20,3),TIME(20)
0011        COMMON /STAB/ ROLL(20),PITCH(20)
0012        DIMENSION ITITLE(20)
0013        DIMENSION BUFA(8,300),BUF(10)
0014        DIMENSION BUFB(5,20)
0015        INTEGER ANS1
0016        CALL R$STOP
0017        IOUT = 10
0018        CONV=4.342944819
0019        RE=8392375.04
0020        CNM=161883.5474
0021        CCM=30000000000.
0022        BETA =.718565021
0023        ACON= .607701593
```

```
      XKTØMS =.514444444
      XNMTØM =1852.
      FØPISQ =157.9136706
      FØPIQB =1984.401711
    5 ØFR = 0
      READ 52,ANS1
   52 FØRMAT(16I5)
      READ 500,ITITLE
  500 FØRMAT(I4,19A4)
      PRINT 501,ITITLE
  501 FØRMAT(1H1,I4,5X,19A4)
      CALL INITAL
   10 CALL TARGET
   11 CALL ENVIRN
C
C     INITIALIZE CLUTTER FØR TRACKING
      CALL FCINIT
      CALL VCINIT
C
C     INITIALIZE RØLL AND PITCH
      CALL STBINT
C
C     READ IN TIME BY WHICH RADAR MUST BE INITIALIZED
      READ 59, RINIT
   59 FØRMAT(F8.2)
      PRINT 590, RINIT
  590 FØRMAT(1H0,' GAME INITIALIZATIØN BY ',F8.2)
C
C     ADD SCAN ØFFSET (FRØM MØDE 1) TØ MAX RADAR INITIALIZATIØN TIME
      RINIT = RINIT/3600. + RMØDE(1,6)
      ISC=0
      IKEYF=0
C     DETERMINE TIMES EACH TARGET CØMES WITHIN INSTRUMENTED RANGE
C        ØF EACH RADAR MØDE
      CALL MATCH
C
C     DETERMINE INITIAL AND FINAL GAME TIMES
C
      T = RMØDE(1,9)
      ENDTIM = XYZF(1,4)
C     SET TARGETS INITIALLY TØ ØVER-THE-HØRIZØN
      TRGPØS(1,4) = -1.
      IF(NSCAN .LT. 2) GØ TØ 17
C     DETERMINE INITIAL TIME FRØM MATCH
      DØ 15 J = 2,NSCAN
      IF(RMØDE(J,9) .LT. T) T = RMØDE(J,9)
   15 CØNTINUE
   17 IF(NTARG .LT. 2) GØ TØ 19
C     DETERMINE END GAME TIME
      DØ 18 I = 1,NTARG
```

```
          TRGPOS(I,4) = -1.
          IF(XYZF(I,4) .GT. ENDTIM) ENDTIM = XYZF(I,4)
       18 CONTINUE
       19 CONTINUE
C         SET INITIAL TIME FROM MATCH 30 SEC. EARLIER FOR CLUTTER SAMPLES
          T = T - 3./360.
C         SET INITIAL GAME TIME
          T = AMIN1(T,RINIT)
C         WRITE ID ON DETECTION OUTPUT FILE
          TEMP = 2
          TEMPB = RMODE(1,5)*3600.
          WRITE (IOUT) ITITLE(1),TEMP,TEMPB
C
          IF (ANS1.EQ.0) GO TO 20
          MUL=ENVIR(3)
          IF ( MUL .NE. 0 )  PRINT 506
          IF ( MUL .EQ. 0 )  PRINT 505
      506 FORMAT(/,'           $$$$$  WITH MULTIPATH  $$$$$',/)
      505 FORMAT(//,60X,'     $$$$$  NO MULTIPATH  $$$$$',/)
C
C         NEW SCAN
       20 ISC = ISC + 1
          ICNT = 0
          BUF(3) = 0
C         SET SCAN PRINT FLAG
          IPFLAG = 0
C         DETERMINE TARGET AND JAMMER POSITIONS AT SCAN TIME T
          CALL NEWPOS
C
          DO 75 J = 1,NSCAN
          NEXT = J
C         ZERO ARRAYS
          DO 25 I = 1,NTARG
          NDET(I) = 0
       25 MER(I) = 0
          DO 70 I = 1,NTARG
C         CHECK IF TARGET ACTIVE
          IF(ISTAT(I) .NE. 1) GO TO 70
C         CHECK IF TARGET WITHIN DETECTION RANGE OF THIS MODE
          IF(TSCAN(I,J) .GT. T) GO TO 70
          TEMP = RMODE(J,1) - 0.63*RC(5)
          TEMP2 = RMODE(J,2) + 0.63*RC(5)
          IF(TRGPOS(I,6) .GE. TEMP .AND. TRGPOS(I,6) .LE.
         1   TEMP2       .AND. TRGPOS(I,4) .LE. RMODE(J,7)
         2   .AND. TRGPOS(I,4) .GT. SMODE(J,1)) GO TO 30
C         TARGET CANNOT BE DETECTED BY MODE J
          GO TO 70
       30 IF(RC(1) + DWL(NEXT) .NE. OFR) ISWIT = 0
          OFR=RC(1)+DWL(NEXT)
          RFR=RC(1)/OFR
```

```
      RC(6)=GN/RFR**2
      RC(4)=THH*RFR
      RC(5)=THV*RFR
      PBBS = RMODE(NEXT,1) + RC(5)/2.
C
      ALPHAD = 0
      SIGC = 0
      SIG = 0
      AR1 = 0
      AR2 = 0
      V = 0
C     CHECK FOR PRINT
      IF( IPFLAG .NE. 0) GO TO 35
      IPFLAG = 1
      IF( ANS1.EQ.0 ) GO TO 35
C     PRINT SCAN NUMBER
      PRINT 507,ISC
  507 FORMAT (////,30X,'+++++++  SCAN NUMBER = ',I4,'  +++++++',/)
      IF( ANS1.NE.2 ) GO TO 35
C     PRINT HEADING
      PRINT 40
C     COMPUTE SIGNAL ENERGY AND NOISE AND CLUTTER ENERGIES FOR TARGET I
   35 CALL SIGNAL(I,RC(11),RC(12))
      CALL NOISE(I,RC(13),RC(14))
      TCRSS = TARCS
C     DETERMINE TARGET DETECTIONS IN MODE J
      NREF = RC(15)
      NCONZ = RC(18)
      CALL MWDET(RC(12),RC(13),RC(14),IMODE(J,1),RC(16),RC(17),NREF,
     1            RC(19),I,NTARG,RC(4),NCONZ, ACONZ,RC(20),RC(21),RC(22),
     2            SNTRUE)
      IF (ANS1.NE.2) GO TO 65
      BHDEG=TRGPOS(I,5)*RADIAN
      BVDEG = TRGPOS(I,6)*RADIAN
      DBE=CONV*ALOG(RC(12))
      DBN=CONV*ALOG(RC(14))
      SN=DBE-DBN
      TRGP = TRGPOS(I,4)*6.0802
      AMBNDB = CONV*ALOG(AMAX1(AMBN,1.0E-74))
      XJAMDB  = CONV*ALOG(AMAX1(XJAMN,1.0E-74))
      SCDB = CONV*ALOG(AMAX1(SIGC,1.0E-74))
      SFAC4=CONV*ALOG(AMAX1(FAC4,1.0E-74))
      SNTRUE = 10.*ALOG10(SNTRUE)
      PRINT 50,I,J,TIME(I),TRGP,BHDEG,BVDEG,TCRSS,SFAC4,DBE,AMBNDB
     1        ,SCDB,XJAMDB,SN,SNTRUE,MER(I)
      KNUM = NDET(I)
      IF (KNUM.EQ.0) GO TO 65
      DO 61 K=1,KNUM
      RRRR = RANGE(I,K)*6.0802
      AAAA = AZ(I,K)*RADIAN
```

```
      IF( MER(I).NE.0 ) AAAA = .5*(AZ(I,2*K) + AZ(I,2*K-1))*RADIAN
      SSSS = SNDET(I,K)
      SSSS = 20.*ALOG10(SSSS)
      PRINT 55,RRRR,AAAA,SSSS
   55 FORMAT(5X,'*DETECTION*',4X,F12.2,F10.2,19X,F10.0)
  61  CONTINUE
  65  CONTINUE
   70 CONTINUE
C
C     MERGE DETECTIONS FOR THIS MODE
      CALL MERDET(RC(19),NTARG,ACONZ)
C     CALCULATE ROLL AND PITCH
      CALL STAB2
C
C     SET UP DETECTIONS FOR OUTPUT
      DO 74 I = 1,NTARG
      NCT = NDET(I)
      IF(NCT .EQ. 0) GO TO 74
      BUF(3) = BUF(3) + NCT
      DO 73 K = 1,NCT
      ICNT = ICNT+1
      BUFA(1,ICNT) = I
      BUFA(2,ICNT) = RANGE(I,K)
      BUFA(3,ICNT) = AZ(I,K)
      BUFA(4,ICNT) = ELEV(I,K)
      BUFA(5,ICNT) = TIME(I)
      BUFA(6,ICNT) = SNDET(I,K)
      BUFA(6,ICNT)=20.*ALOG10(BUFA(6,ICNT))
      BUFA(7,ICNT) = ROLL(I)
      BUFA(8,ICNT) = PITCH(I)
   73 CONTINUE
   74 CONTINUE
   75 CONTINUE
C
C     CLUTTER OUTPUT FOR TRACKING
      CALL FXCLT2
      CALL VRCLT2
C
C     SCAN OUTPUT
      BUF(1) = ISC
      BUF(2) =    T*3600.
      BUF(3) = BUF(3) + IV
      BUF(4) = 2000+ITITLE(1)
      BUF(5) = SHIP(5)
      BUF(6) = NTARG
      WRITE (IOUT) (BUF(I),I=1,6)
      IF(ANS1.EQ.0) GO TO 220
      IF( BUF(3).EQ.0 ) GO TO 220
      PRINT 56, (BUF(I),I=1,6)
   56 FORMAT(1H0/'  SCAN NUMBER=',F5.0,'    TIME=',F9.2,'    NO. DETECTI
```

```
     1ONS=',F5.0,'    RADAR ID=',F6.0,'    HEADING=',F7.2,'    NO. TARGE
     2TS=',F4.0/)
      PRINT 58
   58 FORMAT(18X,'ID',6X,'RANGE',5X,'AZIM',6X,'ELEV',6X,'TIME',6X,'ESIG'
     1,6X,'ROLL',5X,'PITCH')
  220 CONTINUE
      DO 250 I = 1,NTARG
      BUFB(1,I) = I
      BUFB(2,I) = TRGPOS(I,4)
      BUFB(3,I) = TRGPOS(I,5)
      BUFB(4,I) = TRGPOS(I,6)
      BUFB(5,I) = TIME(I)
  250 CONTINUE
      IF(IV.EQ.0) GO TO 270
      DO 260 I = 1,IV
      ICNT = ICNT+1
      BUFA(1,ICNT) = 200
      IF(I.LE.IC)
     1BUFA(1,ICNT) = 100 + NC(I)
      BUFA(2,ICNT) = ROUT(I)
      BUFA(3,ICNT) = AZOUT(I)
      BUFA(4,ICNT) = ELOUT(I)
      BUFA(5,ICNT) = TOUT(I)
      BUFA(6,ICNT) = SOUT(I)
      BUFA(6,ICNT)=20.*ALOG10(BUFA(6,ICNT))
      BUFA(7,ICNT) = RLOUT(I)
      BUFA(8,ICNT) = PTOUT(I)
  260 CONTINUE
  270 CONTINUE
      DO 275 J = 1,NTARG
      WRITE (IOUT)  (BUFB(I,J),I=1,5)
  275 CONTINUE
      IF(ICNT.EQ.0) GO TO 290
      DO 277 J = 1,ICNT
      WRITE(IOUT)  (BUFA(I,J),I = 1,8)
  277 CONTINUE
      IF(ANS1.EQ.0) GO TO 290
      DO 280 J = 1,ICNT
      PRINT 57,(BUFA(I,J),I = 1,8)
   57 FORMAT('  DETECTION NUM ',F5.0,7F10.4)
  280 CONTINUE
  290 CONTINUE
C
C     NEW SCAN
      T = T + RMODE(1,5)
      IF(T .GT. ENDTIM) GO TO 110
      GO TO 20
C
   80 CONTINUE
      IF (ISTEP.LE.4000) GO TO 20
```

```
  110 ISTEP=ISTEP-1
  301 CONTINUE
      XJAMN=0.
C     READ IN RECYCLE CONTROL PARAMETER
C     IANS=1(SHIP),=2(TARGET),=3(ENVIRONMENT),=4(FINISHED)
      READ 52, IANS
      GO TO (5,10,11,140),IANS
  140 CONTINUE
  130 CONTINUE
  40  FORMAT (//,7X,'MODE',42X,'SIGMA',/,' TARGET',9X,'TIME       RANGE
     1,6X,'AZIM       ELEV       FACTOR   ESIG    NAMB    NCLT    NJAM
     2    E/N       MER ')
   50 FORMAT(1X,2I4,F11.1,F12.2,F10.2,F10.2,F5.1,F5.0,F9.0,3F8.0,F9.2
     1,F7.2,I5)
   60 FORMAT (1X,I4/(1X,5(F7.1,F7.5)))
      END
```

```
      SUBROUTINE FXCLT2
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1      ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2      ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3    ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4      ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON /FCIN/ N,PROB,RS,RF,THS,THF,SIGA,SIGR,ISET
      COMMON /FCPT/ R(100),AZ(100),RAN(400),N2,N3,N4
      COMMON /CLTOUT/ ROUT(201),AZOUT(201),ELOUT(201),TOUT(201),
     1 RLOUT(201),PTOUT(201),SOUT(201),NC(100),IC,IV
      COMMON /STABIN/ RMAX,PMAX,RFAC,PFAC,PHASE(2)
C
      IC=0
      IF (N.EQ.0) GO TO 15
C     TIMZB IS THE TIME OF THE ZERO BEARING CROSSING
      TIMZB=T*3600.
C     TIMSCN IS THE SCAN TIME OF THE RADAR
      TIMSCN=RMODE(1,5)*3600.
C     RES IS THE RANGE GATE SIZE
      RES=RC(19)
      CALL SETVR(ISET)
      CALL VRANF(RAN,N4)
      ISET = 2147483647.*RAN(1)
      ISET = 2*(ISET/2) + 1
      DO 20 I=1,N
      IF (RAN(I).GT.PROB) GO TO 20
      IC=IC+1
      NC(IC)=I
      TH=RAN(I+N)*TWOPI
      RAY=SQRT(-2.*ALOG(RAN(I+N2)))
      K=(R(I)+SIGR*RAY*COS(TH))/RES
      ROUT(IC)=(K+0.5)*RES
      TOUT(IC)=TIMZB+TIMSCN*AZ(I)/TWOPI
C
C     GENERATION OF ROLL AND PITCH
C
      RLOUT(IC)=RMAX*SIN(TOUT(IC)*RFAC+PHASE(1))
      PTOUT(IC)=PMAX*SIN(TOUT(IC)*PFAC+PHASE(2))
      CR=COS(RLOUT(IC))
      SR=SIN(RLOUT(IC))
      CP=COS(PTOUT(IC))
      SP=SIN(PTOUT(IC))
      AA=AZ(I)-SHIP(5)
      TE=0.
      X=SIN(AA)*CR+(COS(AA)*SP+TE*CP)*SR
      Y=COS(AA)*CP-TE*SP
      A=ATAN2(X,Y)+TWOPI
C
C     GENERATION OF MEASURED ANGLES
C
```

```
      AM    =A+SIGA*RAY*SIN(TH)+SHIP(5)
      ELOUT(IC)=0.0
      AZOUT(IC)=AMOD(AM,TWOPI)
C     ********** NEED TO GENERATE OUTPUT POWER   **************
      SOUT(IC)=55.55
   20 CONTINUE
      RETURN
C
C     INITIALIZATION OF THE CLUTTER ROUTINE
C
      ENTRY FCINIT
      READ 50,ISET,N,PROB,RS,RF,SIGR,THS,THF,SIGA
   50 FORMAT (2I8,7F8.2)
C
C     ISET IS TNE INITIALIZATION NUMBER FOR THE RANDOM NUMBER GENERATOR
C     N IS THE NUMBER OF FIXED CLUTTER POINTS
C     PROB IS THE PBOBABILITY THAT THE CLUTTER POINT IS DETECTED
C     RS IS THE INITIAL RANGE OF THE CLUTTER AREA
C     RF IS THE FINAL RANGE OF THE CLUTTER AREA
C     SIGR IS THE STANDARD DEVIATION OF THE RANGE MEASUREMENT
C          AS A PERCENTAGE OF RANGE RESOLUTION CELL SIZE
C     THS IS THE INITIAL AZIMUTH OF THE CLUTTER AREA
C     THF IS THE FINAL AZIMUTH OF THE CLUTTER AREA
C     SIGA IS THE STANDARD DEVIATION OF THE AZIMUTH MEASUREMENT
C          AS A PERCENTAGE OF HORIZONTAL 3DB BEAMWIDTH
C
      PRINT 55,ISET,N,PROB,RS,RF,SIGR,THS,THF,SIGA
   55 FORMAT (1H0,' FIXED CLUTTER ',2I8,7F8.3)
      CALL SETVR(ISET)
C
C     CALCULATION OF RANGE CELL DIMENSION
C
      RES=TAU(1)*300000./2.
      RES=RES*3.2808/6.08
C     RC(19) = RES    = RANGE RESOLUTION CELL SIZE
      RC(19)=RES
      IF (N.EQ.0) GO TO 15
      RS=RS/6.0802
      RF=RF/6.0802
      THS=THS/RADIAN
      THF=THF/RADIAN
      SIGA=SIGA*RC(4)
      SIGR=SIGR*RES
      IF (N.GT.100) N=100
      N2=2*N
      N3=3*N
      N4=4*N
      CALL VRANF(RAN,N2)
      ISET = 2147483647.*RAN(1)
      ISET = 2*(ISET/2) + 1
      DO 10 I=1,N
      R(I)=RS+(RF-RS)*RAN(I)
   10 AZ(I)=THS+(THF-THS)*RAN(I+N)
   15 RETURN
      END
```

```
0001        SUBROUTINE INITAL
0002        DIMENSION AMODE(30,2)
0003        COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
           1       ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
           2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
           3    ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
           4       ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
0004        COMMON/B/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACON,BETA,
           *       DATP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPIOB,FOPISO
0005        COMMON/I/ PBOS,HOFK,THETBK,DBDOWN,THH,THV,GN
0006        RC(10)=290.0*1.38*10.0**(-23)
      C     X Y Z SHIP COORDINATES
0007        READ 50, (SHIP(I),I=1,3), SHIP(5)
0008     50 FORMAT(9F8.2,I2,F6.2)
0009        PRINT 500, (SHIP(I),I=1,3), SHIP(5)
0010    500 FORMAT(/,' SHIP X,Y,Z, COORDINATES ARE ',3F8.3,8X,'HEADING IS',
           1       F8.3)
0011         MILION=1.0E+6
0012        DO 30 I=1,3
0013     30 SHIP(I)=SHIP(I)/6.0802
0014        PI=3.1415926536
0015        TWOPI=PI*2.0
0016        PIOVR2 =PI/2.0
0017        RADIAN=57.29578
0018        SHIP(4)=SQRT(SHIP(3))
0019        SHIP(5) = SHIP(5)/RADIAN
0020        READ 50,(RC(I),I=1,9),NSCAN,POLRZ
0021        IF(NSCAN.LE. 30) GO TO 10
0022        NSCAN = 30
0023     10 CONTINUE
0024        PRINT 501,(RC(I),I=1,9),NSCAN,POLRZ
0025    501 FORMAT(/' 11 BASIC RADAR PARAMETERS ARE ',9F8.2,I4,F6.2)
0026        RC(4)=RC(4)/RADIAN
0027        RC(5)=RC(5)/RADIAN
0028        THH=RC(4)
0029        THV=RC(5)
0030        RC(6)=10.**(RC(6)/10.)
0031        GN=RC(6)
0032        RC(3)=10.**(RC(3)/10.)
0033        RC(7)=10.**(-RC(7)/20.)
0034        RC(8)=10.**(-RC(8)/10.)
0035        RC(9)=10.**(-RC(9)/10.)
0036        DBDOWN = RC(7)*RC(7)
0037        DO 60 J = 1,NSCAN
      C     RMODE(1,5) IS USED AS RADAR SCAN RATE FOR ALL MODES
0038        READ 51,(RMODE(J,I),I=1,8),AMODE(J,1),RMODE(J,11),SUBC(J)
           *       ,RMODE(J,12),DWL(J),SM,SMODE(J,2)
0039     51 FORMAT(10F8.2)
0040        IMODE(J,1)=AMODE(J,1)
0041        PRINT 511,J,(RMODE(J,I),I=1,8),IMODE(J,1),RMODE(J,11),SUBC(J)
```

```
     *              ,RMODE(J,12),DWL(J),SM,SMODE(J,2)
  511 FORMAT(/,' 16 MODE ',I2,' PARAMETERS ARE ',8F9.3,I8,/,50X,6F9.3)
      IF (RMODE(J,5).GT.0.0) GO TO 55
      RMODE(J,5)=10.0
   55 RMODE(J,1)=RMODE(J,1)/RADIAN
      RMODE(J,2)=RMODE(J,2)/RADIAN
      IF(SM.EQ.0)SM=RMODE(J,4)
      SMODE(J,1)=150.*SM/XNMTOM
      SMODE(J,2) = 10.**(-SMODE(J,2)/10.)
      RMODE(J,5)=RMODE(J,5)/3600.0
      RMODE(J,6)=RMODE(J,6)/3600.0
      RMODE(J,4)=RMODE(J,4)/MILION
      RMODE(J,8)=10.**(-RMODE(J,8)/10.)
      RMODE(J,3)=RMODE(J,3)*MILION
      TAU(J) = RMODE(J,11)/MILION
      IF(RMODE(J,12).LE.0) RMODE(J,12) = 1.0/RMODE(J,11)
      RMODE(J,12) = RMODE(J,12)*MILION
      IMODE(J,2)=MAX1(RMODE(J,12)*RMODE(J,11)/MILION +0.5,1.0)
      RMODE(J,11) = 10.**(-PMF)
      SUBC(J) = 10.**(-SUBC(J)/10.)
   60 CONTINUE
C
C     READ IN PARAMETERS FOR MOVING WINDOW DETECTOR
C     RC(15) = NREF   = NO. REFERENCE CELLS ON EACH SIDE OF TARGET CELL
C     RC(16) = COR    = CLUTTER CORRELATION COEFFICIENT
C     RC(17) = FSIG   = NO. STANDARD DEVIATIONS USED IN THRESHOLD
C     RC(18) = NCONZ = NO. OF DETECTIONS THAT CAN BE MISSED AND
C                       DETECTIONS STILL MERGED INTO A SINGLE DETECTION
C     RC(19) = RESOLUTION CELL SIZE  (CALCULATED)
C     RC(20) = XLOG = VIDEO TYPE
C                      0   LINEAR VIDEO
C                      1   LOG VIDEO
C     RC(21) = THRSH = NO. OF REFERENCE CELLS USED
C                       0   ALL CELLS USED
C                       < 0   SMALLER HALF USED
C                       > 0   LARGER HALF USED
C     RC(22) = PARM = PARAMETERS USED TO CALCULATE THRESHOLD
C                      1   MEAN USED
C                      2   MEAN AND VARIANCE USED
C
      READ 70, (RC(I),I=15,18), (RC(I),I=20,22)
   70 FORMAT(10F8.2)
      PRINT 700, (RC(I),I=15,18), (RC(I),I=20,22)
  700 FORMAT(1H0,'   ADDITIONAL RADAR PARAMETERS ARE ',7F9.3/)
      RETURN
      END
```

```
      SUBROUTINE MERDET (RES,N,ACONZ)
      COMMON /DET/ NDET(20),MER(20),RANGE(20,3),AZ(20,6),SNDET(20,3),
     1             ELEV(20,3),TIME(20)
      DIMENSION KTAR(60),KDET(60),KTRR(60),KDTT(60)
C
C     RES IS THE RANGE RESOLUTION
C     N IS THE NUMBER OF TARGETS
C     ACONZ IS THE ANGLE IN WHICH TARGETS ARE MERGED
C
      K=0
      DO 30  I=1,N
      IF (MER(I).NE.-1) GO TO 30
C     HAVE A MERGE PLOBLEM AND AM ORDERING DETECTIONS IN AZIMUTH
      II=NDET(I)
      IF (II.EQ.0) GO TO 30
      DO 25 J=1,II
      IF (K.GT.0) GO TO 10
      K=1
      KTAR(1)=I
      KDET(1)=J
      GO TO 20
   10 A=AZ(I,2*J-1)
      DO 15 KK=1,K
      IF (A.GT.AZ(KTAR(KK),2*KDET(KK)-1)) GO TO 15
      KC=0
      DO 12 JJ=KK,K
      KC=KC+1
      KTAR(K+2-KC)=KTAR(K+1-KC)
      KDET(K+2-KC)=KDET(K+1-KC)
   12 CONTINUE
      KTAR(KK)=I
      KDET(KK)=J
      GO TO 18
   15 CONTINUE
      KTAR(K+1)=I
      KDET(K+1)=J
   18 K=K+1
   20 CONTINUE
   25 CONTINUE
   30 CONTINUE
      IF (K.GT.1) GO TO 40
      IF (K.EQ.0) GO TO 35
      I=KTAR(1)
      AZ(I,1)=(AZ(I,2)+AZ(I,1))/2.
   35 RETURN
   40 CONTINUE
C
C     DECISION MADE ON THE PROPER DETECTIONS
C
      KK=1
```

```
      KC=0
      DO 100 JJ=2,K
      I=KTAR(JJ)
      J=KDET(JJ)
      DO 60 L=1,KK
      IF (ABS(RANGE(I,J)-RANGE(KTAR(L),KDET(L))).GT.1.5*RES) GO TO 60
      IF (AZ(KTAR(L),2*KDET(L))+ACONZ.LT.AZ(I,2*J)) GO TO 60
      GO TO 80
   60 CONTINUE
      IF (KC.EQ.0) GO TO 75
      DO 70 L=1,KC
      IF (ABS(RANGE(I,J)-RANGE(KTRR(L),KDTT(L))).GT.1.5*RES) GO TO 70
      IF (AZ(KTRR(L),2*KDTT(L))       .LT.AZ(I,2*J)) GO TO 70
      GO TO 80
   70 CONTINUE
   75 KK=KK+1
      KTAR(KK)=KTAR(JJ)
      KDET(KK)=KDET(JJ)
      GO TO 100
   80 KC=KC+1
      KTRR(KC)=KTAR(JJ)
      KDTT(KC)=KDET(JJ)
  100 CONTINUE
C
C     CORRECTION OF OUTPUT ARRAYS
C
      DO 110 I=1,N
      IF (MER(I).EQ.-1) NDET(I)=0
  110 CONTINUE
      DO 150 K=1,KK
      I=KTAR(K)
      J=KDET(K)
      II=NDET(I)+1
      NDET(I)=II
      RANGE(I,II)=RANGE(I,J)
      SNDET(I,II)=SNDET(I,J)
      AZ(I,II)=(AZ(I,2*J)+AZ(I,2*J-1))/2.
  150 CONTINUE
      RETURN
      END
```

```
0001          SUBROUTINE MWDET (S,C,FN,N3DB,COR,FSIG,NREF,RES,NTAR,N,TH3DB,
             1    NCONZ,ACONZ,XLOG,THRSH,PARM,SNTRUE)
0002          COMMON /DET/ NDET(20),MER(20),RANGE(20,3),AZ(20,6),SNDET(20,3),
             1             ELEV(20,3),TIME(20)
0003          COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
             1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
             2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
             3      ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
             4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
0004          COMMON /MOD/ MODEL(20)
0005          DIMENSION FLUCT(401)
0006          DIMENSION SNREF(20),INF(20)
0007          DIMENSION X(401,25),SS(401,25),SUM(25),IS(25),R(1204),ID(3)
0008          DIMENSION D(14),IC(14),XFIRST(14),XLAST(14),IDET(14),SN(14)
        C
        C     S IS THE SIGNAL POWER
        C     C IS THE CLUTTER POWER
        C     FN IS THE NOISE POWER
        C     N3DB IS THE NUMBER OF PULSES BETWEEN THE 3-DB ANTENNA POINTS
        C     COR IS THE CORRELATION COEFFICIENT OF CLUTTER
        C     FSIG NUMBER OF STANDARD DEVIATIONS USED IN CALCULATION OF THE TH
        C     NREF IS THE NUMBER OF REFERENCE CELLS ON EACH SIDE
        C     RES IS THE RANGE RESOLUTION CELL SIZE
        C     NTAR IS THE TARGET OF INTEREST
        C     N IS THE NUMBER OF TARGETS
        C     TH3DB IS THE ANTENNA 3-DB BEAMWIDTH
        C     NCONZ NUMBER OF DETECTION THAT CAN BE MISSED AND DETECTIONS STILL
        C      MERGED INTO A SINGLE DETECTION
        C     ACONZ IS THE MERGE DISTANCE(NCONZ) IN ANGLE
        C     XLOG DENOTES WHETHER LINEAR(XLOG=0.0) OR LOG(XLOG=1.0) VIDEO IS USED
        C     THRSH DENOTES WHETHER ALL THE REFERENCE CELLS(THRSH=0.0) , THE
        C            SMALLER HALF(THRSH<0), OR THE LARGER HALF(THRSH>0) SHOULD BE USED
        C     PARM DENOTES WHETHER THE MEAN AND VARIANCE(PARM=2.) OR JUST THE
        C          MEAN(PARM=1.) SHOULD BE USED TO CALCULATE THE THRESHOLD
        C     SNTRUE RETURNS TRUE SIGNAL/NOISE RATIO USED
        C
0009          IF (N3DB.LE. 99.AND.NREF.LE.10) GO TO 3
0010          PRINT 50
0011       50 FORMAT (1H1,' EITHER N3DB OR NREF ARE TOO LARGE')
0012          STOP
0013        3 IF (ABS(COR).LT.1.0) GO TO 4
0014          PRINT 51
0015       51 FORMAT (1H1,' CORRELATION COEFFICIENT IS GREATER OR EQUAL TO 1')
0016          STOP
0017        4 CONTINUE
        C
        C     TEST TO SEE IF THERE IS ANY CHANCE OF A TARGET DETECTION
        C
0018          SNINT=N3DB*S/(C+FN)
```

```
      IF (SNINT.GT.2) GO TO 5
      NDET(NTAR)=0
      SNTRUE = 10.**(-9.9)
      RETURN
    5 SNREF(1)=S
      INF(1)=NTAR
      NREF2=2*NREF
      CALL RESOL(NREF,RES,NTAR,SNREF,INF,NI,TH3DB,N)
      CALL VRANF(R,1)
      DEL=TH3DB/(N3DB+1)
      ACONZ=DEL*NCONZ
      AZIM=TRGPOS(NTAR,5)+(R(1)-.5)*DEL
      AZIMS=AZIM-201.*DEL
      KRS=TRGPOS(NTAR,4)/RES
      RS=RES*KRS-13.*RES
C
C     +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C     GENERATION OF SIGNAL VALUES
C
C     +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
      NS=201-2*N3DB-2
      NF=201+2*N3DB
      NRS=13-NREF-2
      NRF=13+NREF+2
      DO  7 I=NRS,NRF
      IS(I)=0
      DO  7 J=NS,NF
    7 SS(J,I)=0.
      IMERGE=0
      DO 40 K=1,NI
      RR=TRGPOS(INF(K),4)
      KR=(RR-RS)/RES
      IF (K.EQ.1.OR.KR.GT.16.OR.KR.LT.10) GO TO 8
      IMERGE=1
C
C     FLUCTUATING SIGNAL
C
    8 NSW=MODEL(INF(K))
      IF (NSW.GT.0) GO TO 11
      FL=1.0
    9 DO 10 J=NS,NF
   10 FLUCT(J)=FL
      GO TO 171
   11 GO TO (12,13,15,16),NSW
   12 CALL VRANF (R,1)
      FL =-ALOG(R(1))
      GO TO 9
   13 M=NF+1-NS
```

```
      CALL VRANF (R,M)
      KK=0
      DO 14 J=NS,NF
      KK=KK+1
   14 FLUCT(J)=-ALOG(R(KK))
      GO TO 171
   15 CALL VRANF (R,2)
      FL=-.5*(ALOG(R(1))+ALOG(R(2)))
      GO TO 9
   16 M=NF+1-NS
      M2=2*M
      CALL VRANF (R,M2)
      KK=0
      DO 17 J=NS,NF
      KK=KK+1
   17 FLUCT(J)=-.5*(ALOG(R(KK))+ALOG(R(KK+M)))
  171 CONTINUE
      DO 35 I=1,3
      KT=KR+I-2
      IF (KT.LT.NRS.OR.KT.GT.NRF) GO TO 35
      IS(KT)=1
C
C     MODULATION OF SIN(X)/X PULSE SHAPE
C
      RTEMP = KT*RES+RES/2.+RS
      FDIF=2.7832*(RR-RTEMP)/RES
      F=1.
      IF (FDIF.EQ.0) GO TO 18
      F=SIN(FDIF)/FDIF
   18 F=F*F
      SM=F*SNREF(  K    )/(C+FN)
C
      AA=TRGPOS(INF(K),5)
      NC=(AA-AZIM)/DEL+201
      NRED=MAX0(1,N3DB/10)
      IF (I.EQ.2) NRED=0
      NNS=MAX0(NS,NC-N3DB+NRED)
      NNF=MIN0(NF,NC+N3DB-NRED)
C
C     MODULATION OF SIN(X)/X ANTENNA PATTERN
C
      DO 20 J=NNS,NNF
      GDIF=2.7832*(J*DEL+AZIMS-AA)/TH3DB
      G=1.
      IF (GDIF.EQ.0) GO TO 19
      G=SIN(GDIF)/GDIF
   19 G=G**4
C
C     ***** NOTE , TARGETS ARE ADDED NONCOHERENTLY ********
C
```

```
      SS(J,KT)=SS(J,KT)+SM*G*FLUCT(J)
   20 CONTINUE
   35 CONTINUE
   40 CONTINUE
      SNTRUE = 0.
      NSS = 201 - (N3DB-1)/2
      NSF = 201 + N3DB/2
      DO 402 J = NSS,NSF
  402 SNTRUE = SNTRUE + SS(J,13)/N3DB
      DO 41 I=NRS,NRF
      IF (IS(I).EQ.0) GO TO 41
   41 CONTINUE
C
C     ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C     GENERATION OF NOISE SAMPLES
C
C     ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
      M=NF+1-NS
      M2=2*M
      M3=3*M
      M4=4*M
      IF (N3DB*C     .GT.FN) GO TO 100
C
C     CLUTTER IS NOT A FACTOR
C
      DO 90 I=NRS,NRF
      IF (IS(I).EQ.1) GO TO 75
C
C     NO SIGNAL PRESENT IN THIS CELL
C
      CALL VRANF (R,M)
      K=0
      DO 60 J=NS,NF
      K=K+1
      X(J,I)=SQRT(-2.*ALOG(R(K)))
   60 CONTINUE
      GO TO 90
C
C     SIGNAL PRESENT IN THIS CELL
C
   75 CALL VRANF (R,M2)
      K=0
      DO 80 J=NS,NF
      K=K+1
      A=SQRT(-2.*ALOG(R(K)))
      B=TWOPI*R(K+M)
      X(J,I)=SQRT((A*COS(B)+SQRT(SS(J,I))*1.414)**2+ (A*SIN(B))**2)
   80 CONTINUE
```

```
   90 CONTINUE
      GO TO 200
C
C     CLUTTER IS A FACTOR
C
  100 AOLDX=SQRT(C/(C+FN))
      CC=AOLDX
      FFN=SQRT(FN/(C+FN))
      P=SQRT(1.-COR*COR)
      DO 150 I=NRS,NRF
      CALL VRANF (R,2)
      AOLDY=   CC*SIN(TWOPI*R(1))*SQRT(-2.*ALOG(R(2)))
      AOLDX=   CC*COS(TWOPI*R(1))*SQRT(-2.*ALOG(R(2)))
      CALL VRANF (R,M4)
      K=0
      DO 120 J=NS,NF
      K=K+1
      A =SQRT(-2.*ALOG(R(K)))*CC
      A1=SQRT(-2.*ALOG(R(K+M)))*FFN
      B =TWOPI*R(K+M2)
      B1=TWOPI*R(K+M3)
      AOLDX=COR*AOLDX+P*A*COS(B)
      AOLDY=COR*AOLDY+P*A*SIN(B)
      X(J,I)=SQRT((AOLDX+A1*COS(B1)+SQRT(SS(J,I))*1.414)**2 +
     1           (AOLDY+A1*SIN(B1))**2)
  120 CONTINUE
  150 CONTINUE
C
C     ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C     GENERATION OF MOVING WINDOW
C
C     ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
  200 MS=NS+N3DB-1
      IF (XLOG.LT.0.0001) GO TO 210
C
C     USE LOG VIDEO
C
      DO 205 J=NS,NF
      DO 205 I=NRS,NRF
  205 X(J,I)=ALOG(X(J,I))
  210 CONTINUE
      DO 241 I=NRS,NRF
  241 CONTINUE
      DO 220 I=NRS,NRF
      SUM(I)=0.
      DO 220 J=NS,MS
  220 SUM(I)=SUM(I)+X(J,I)
      MS=MS+1
```

```
      II=0
      DO 285 J=MS,NF
      DO 225 I=NRS,NRF
  225 SUM(I)=SUM(I)+X(J,I)-X(J-N3DB,I)
C
C     GENERATION OF THE DETECTION THRESHOLDS
C
      DO 250 L=12,14
      ULOW=0.
      UUP=0.0
      XMSLOW=0.0
      XMSUP=0.0
      DO 230 I=1,NREF
      ULOW=ULOW+SUM(L-I-1)
      UUP=UUP+SUM(L+I+1)
      XMSLOW=XMSLOW+SUM(L-I-1)**2
  230 XMSUP=XMSUP+SUM(L+I+1)**2
      IF (THRSH.NE.0.0) GO TO 235
C
C     USE ALL REFERENCE CELLS
C
      U=ULOW+UUP
      XMS=XMSLOW+XMSUP
      D(L)=U/NREF2+FSIG*SQRT(XMS/NREF2-(U/NREF2)**2)
      IF (PARM.GT.1.5) GO TO 250
      D(L)=FSIG*U/NREF2
      IF (XLOG.LT.0.0001) GO TO 250
      D(L)=FSIG+U/NREF2
      GO TO 250
C
C     USE EITHER MIN(THRSH<0) OR MAX(THRSH>0) REFERENCE CELLS
C
  235 IF (THRSH.LT.0.0.AND.ULOW.LT.UUP) GO TO 240
      IF (THRSH.LT.0.0.AND.ULOW.GE.UUP) GO TO 245
      IF (THRSH.GT.0.0.AND.ULOW.LT.UUP) GO TO 245
      IF (THRSH.GT.0.0.AND.ULOW.GE.UUP) GO TO 240
  240 U=ULOW
      XMS=XMSLOW
      GO TO 248
  245 U=UUP
      XMS=XMSUP
  248 D(L)=U/NREF+FSIG*SQRT(XMS/NREF-(U/NREF)**2)
      IF (PARM .GT.1.5) GO TO 250
      D(L)=FSIG*U/NREF
      IF (XLOG.LT.0.0001) GO TO 250
      D(L)=FSIG+U/NREF
  250 CONTINUE
      IF (J.GT.MS) GO TO 249
  249 CONTINUE
C
```

```
      C     DO LOOP FOR DETECTION AND GENERATION OF CENTER PULSES
      C
            DO 280 I=12,14
            IF (J.GT.MS) GO TO 255
            IDET(I)=1
            IC(I)=0
            IF (SUM(I).LT.D(I)) GO TO 280
            IDET(I)=3
            IC(I)=NCONZ
            GO TO 280
        255 K=IDET(I)
            GO TO (260,270,275,280),K
      C
      C     CHECK FOR INITIAL DETECTION
      C
        260 IF (SUM(I).LT.D(I)) GO TO 280
            II=II+1
            ID(II)=I
            XFIRST(I)=J
            XLAST(I)=J
            SN(I)=SUM(I)
            IC(I)=NCONZ
            IDET(I)=2
            GO TO 280
      C
      C     CHECK FOR FINAL DETECTION
      C
        270 IF (SUM(I).LT.D(I)) GO TO 273
            XLAST(I)=J
            IC(I)=NCONZ
            IF (SUM(I).LT.SN(I)) GO TO 280
            SN(I)=SUM(I)
            GO TO 280
      C
      C     CHECK TO SEE IF DETECTION ENDED
      C
        273 IC(I)=IC(I)-1
            IF (IC(I).EQ.0) IDET(I)=4
            GO TO 280
      C
      C     CHECK TO SEE IF DETECTION FROM ANOTHER TARGET ENDED
      C
        275 IF (SUM(I).GE.D(I)) IC(I)=NCONZ+1
            IC(I)=IC(I)-1
            IF (IC(I).GT.0) GO TO 280
            IDET(I)=1
        280 CONTINUE
        285 CONTINUE
      C
      C     ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

```
C
C      CHECK FOR DETECTIONS
C
C      +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
       IF (II.GT.0) GO TO 300
       NDET(NTAR)=0
       MER(NTAR)=0
       IF (IMERGE.EQ.1) MER(NTAR)=-2
       RETURN
C
C      MERGING OF MULTIPLE THRESHOLD CROSSINGS
C
  300  IF (IMERGE.EQ.1) GO TO 400
C
C      NO MULTI TARGET RESOLUTION PROPLEMS
C
       GO TO (310,320,330), II
C      ONLY 1 THRESHOLD CROSSING
  310  NDET(NTAR)=II
       MER(NTAR)=0
  312  DO 315 I=1,II
       RANGE(NTAR,I)=RS+(ID(I)+.5)*RES
       SNDET(NTAR,I)=SN(ID(I))
       IF (XLOG.GT.0.0001) SNDET(NTAR,I)=N3DB*EXP(SNDET(NTAR,I)/N3DB)
       AZ(NTAR,I)=AZIMS+(XLAST(ID(I))+XFIRST(ID(I))-N3DB)*DEL/2.
  315  CONTINUE
       RETURN
C
C      TWO CROSSINGS OF THE THRESHOLD
C
  320  IF (IDET( 13).EQ.1.OR.IDET(13).EQ.3) GO TO 310
C
C      THERE ARE TWO ADJACENT THRESHOLD CROSSINGS
C
  325  IF (XLAST(ID(1))+NCONZ.LT.XLAST(ID(2))) GO TO 310
       II=1
       GO TO 310
C
C      THERE ARE THREE ADJACENT THRESHOLD CROSSINGS
C
  330  K=1
       IF (IABS(ID(1)-ID(2)).EQ.2.OR.
     1          XLAST(ID(1))+NCONZ.LT.XLAST(ID(2))) K=2
       GO TO (340,350),K
  340  IF (IABS(ID(1)-ID(3)).EQ.2.AND.
     1          XLAST(ID(2))        .LT.XLAST(ID(3))) GO TO 345
       II=1
       GO TO 310
  345  II=2
```

```
          ID(2)=ID(3)
          GO TO 310
      350 IF (IABS(ID(1)-ID(3)).EQ.2.OR.
         1          XLAST(ID(1))+NCONZ.LT.XLAST(ID(3))) GO TO 355
          II=2
          GO TO 310
      355 IF (IABS(ID(2)-ID(3)).EQ.2.OR.
         1          XLAST(ID(2))+NCONZ.LT.XLAST(ID(3))) GO TO 310
          II=2
          GO TO 310
C
C         +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C         MERGING PROPLEM WITH ANOTHER TARGET ,PROBLEM SOLVED IN SUB. MERDET
C
C         +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
      400 NDET(NTAR)=II
          MER(NTAR)=-1
          DO 415 I=1,II
          RANGE(NTAR,I)=RS+(ID(I)+.5)*RES
          SNDET(NTAR,I)=SN(ID(I))
          IF (XLOG.GT.0.0001) SNDFT(NTAR,I)=N3DB*EXP(SNDET(NTAR,I)/N3DB)
          AZ(NTAR,2*I-1)=AZIMS+XFIRST(ID(I))*DEL-N3DB*DEL/2.
          AZ(NTAR,2*I  )=AZIMS+XLAST (ID(I))*DEL-N3DB*DEL/2.
      415 CONTINUE
          RETURN
          END
```

```
      SUBROUTINE STAB2
      COMMON/TM/NTARG,NJAM,SPEED(20),HEADI(20),HEADF(20),TMANI(20),
     1          TMANF(20),XMANI(20,3),XMANF(20,3),GTURN(20),TURN(20),
     2        CM(20,2),RADM(20),ITYPE(20),ALT(20,5),TALT(20,5),NALT(20)
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1       ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4       ,SHIP(4),RC(30),RMODE(30,12),IMODE(30,2),RES
      COMMON /DET/ NDET(20),MER(20),RANGE(20,3),AZ(20,6),SNDET(20,3),
     1             ELEV(20,3),TIME(20)
      COMMON /STAB/ ROLL(20),PITCH(20)
      COMMON /STABIN/ RMAX,PMAX,RFAC,PFAC,PHASE(2)
      DO 30 I=1,NTARG
      IF (NDET(I).EQ.0) GO TO 30
      K=NDET(I)
      ROLL(I) =RMAX*SIN(TIME(I)*RFAC+PHASE(1))
      PITCH(I)=PMAX*SIN(TIME(I)*PFAC+PHASE(2))
      CR=COS(ROLL(I))
      SR=SIN(ROLL(I))
      CP=COS(PITCH(I))
      SP=SIN(PITCH(I))
      AA=TRGPOS(I,5)-SHIP(5)
      TE=TAN(TRGPOS(I,6))
      X=SIN(AA)*CR+(COS(AA)*SP+TE*CP)*SR
      Y=COS(AA)*CP-TE*SP
      A=ATAN2(X,Y)+TWOPI
   20 DO 25 J=1,K
      ATEMP=AZ(I,J)+A-AA
   25 AZ(I,J)=AMOD(ATEMP,TWOPI)
   30 CONTINUE
      RETURN
C
C     INITIALIZATION
C
      ENTRY STBINT
      READ 50,RMAX,PMAX,RPER,PPER
   50 FORMAT (4F8.2)
      PRINT 55,RMAX,PMAX,RPER,PPER
   55 FORMAT (1H0,' ROLL AND PITCH  ',4F8.2)
      RMAX=RMAX/RADIAN
      PMAX=PMAX/RADIAN
      RFAC=TWOPI/RPER
      PFAC=TWOPI/PPER
      CALL VRANF(PHASE,2)
      PHASE(1)=TWOPI*PHASE(1)
      PHASE(2)=TWOPI*PHASE(2)
      RETURN
      END
```

```
      SUBROUTINE VRCLT2
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1       ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3    ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4       ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON /VCIN/ NREG,FN(5),RS(5),RF(5),THS(5),THF(5),ELS(5),ELF(5),
     1    ISET
      COMMON /VCLT/ PI2,RAN(305),FLAM(5)
      COMMON /CLTOUT/ ROUT(201),AZOUT(201),ELOUT(201),TOUT(201),
     1 RLOUT(201),PTOUT(201),SOUT(201),NC(100),IC,IV
      COMMON /STABIN/ RMAX,PMAX,RFAC,PFAC,PHASE(2)
C
      IV=IC
      IF (NREG.EQ.0) GO TO 95
      CALL SETVR(ISET)
      CALL VRANF(RAN,305)
      ISET = 2147483647.*RAN(305)
      ISET = 2*(ISET/2) + 1
C     TIMZB IS THE TIME OF THE ZERO BEARING CROSSING
      TIMZB=T*3600.
C     TIMSCN IS THE SCAN TIME OF THE RADAR
      TIMSCN=RMODE(1,5)*3600.
C     RES IS THE RANGE GATE SIZE
      RES=RC(19)
      IRAN=0
      DO 20 I=1,NREG
      IRAN=IRAN+1
      IF (IRAN.GT.302) GO TO 30
      A = THS(I)-FLAM(I)*ALOG(RAN(IRAN))
   15 IF (A.GT.THF(I)) GO TO 20
      IV=IV+1
      AZOUT(IV)=A
      K=(RS(I) + (RF(I)-RS(I))*RAN(IRAN+1))/RES
      ROUT(IV)=(K+0.5)*RES
      ELOUT(IV)=0.0
      TOUT(IV)=TIMZB+TIMSCN*A/TWOPI
      RLOUT(IV)=RMAX*SIN(TOUT(IV)*RFAC+PHASE(1))
      PTOUT(IV)=PMAX*SIN(TOUT(IV)*PFAC+PHASE(2))
      SOUT(IV)=33.33
      IRAN=IRAN+3
      IF (IRAN.GT.302) GO TO 30
      A=A-FLAM(I)*ALOG(RAN(IRAN))
      GO TO 15
   20 CONTINUE
   30 RETURN
C
C     INITIALIZATION
C
      ENTRY VCINIT
```

```
      READ 50,ISET,NREG
   50 FØRMAT(2I8)
C
C     ISET IS THE INITIALIZATIØN NUMBER ØF THE RANDØM NUMBER GENERATØR
C     NREG IS THE NUMBER ØF CLUTTER REGIØNS
C
      PRINT 55,ISET,NREG
   55 FØRMAT (1H0,' VARIABLE CLUTTER ',2I8)
      IF (NREG.EQ.0) GØ TØ 95
      IF (NREG.GT.5) NREG=5
      DØ 5 I=1,NREG
      READ 51,FN(I),RS(I),RF(I),THS(I),THF(I)
   51 FØRMAT (7F8.2)
C
C     FN IS THE AVERAGE NUMBER ØF CLUTTER PØINT PER REGIØN
C     RS IS THE INITIAL RANGE ØF THE CLUTTER AREA
C     RF IS THE FINAL RANGE ØF THE CLUTTER AREA
C     THS IS THE INITIAL AZIMUTH ØF THE CLUTTER AREA
C     THF IS THE FINAL AZIMUTH ØF THE CLUTTER AREA
C
      PRINT 56,FN(I),RS(I),RF(I),THS(I),THF(I)
   56 FØRMAT (25X,7F9.3)
      RS(I)=RS(I)/6.0802
      RF(I)=RF(I)/6.0802
      THS(I)=THS(I)/RADIAN
      THF(I)=THF(I)/RADIAN
    5 CØNTINUE
      DØ 10 I=1,NREG
   10 FLAM(I)=(THF(I)-THS(I))/FN(I)
   95 RETURN
      END
```

Appendix C

PROGRAM LISTINGS OF ROUTINES EXCLUSIVE TO SURDET3D

```
0001          PROGRAM SURDET
      C
      C       THIS IS THE SURDET3D EXECUTIVE ROUTINE
      C
      CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      C
      C
      C                           DESCRIPTION OF DATA CARDS
      C
      C       DATA CARD NO. 1
      C
      C               DETAILED OUTPUT CONTROL INTEGER    (I5 FORMAT)
      C                    0 = NO OUTPUT TO BE PRINTED
      C                    1 = DETECTION OUTPUT TO BE PRINTED
      C                    2 = DETAILED OUTPUT TO BE PRINTED
      C
      C
      C
      C       DATA CARD NO. 2
      C
      C               TITLE CARD  -  RUN IDENTIFICATION  (I4,19A4 FORMAT)
      C                  1 RADAR ID NUMBER FOR TARGET DETECTION OUTPUT FILES
      C               2-20 ALPHANUMERIC DESCRIPTIVE TITLE
      C
      C
      C
      C       DATA CARD NO. 3
      C
      C               SHIP (RADAR) POSITION  (4F8.2 FORMAT)
      C                1-3 POSITION COORDINATES (X,Y,Z) IN KFT
      C                  4 SHIP HEADING IN DEGREES
      C
      C
      C
      C       DATA CARD NO. 4
      C
      C               11 BASIC RADAR PARAMETERS    (9F8.2,I2,F6.2 FORMAT)
      C                  1 RADAR FREQUENCY IN MHZ
      C                  2 ANTENNA PATTERN FUNCTION INDICATOR
      C                         0 = PENCIL BEAM
      C                         1 = COSECANT SQUARE BEAM
      C                  3 RECEIVER NOISE IN DB
      C                  4 HORIZONTAL 3DB BEAMWIDTH IN DEGREES
      C                  5 VERTICAL 3DB BEAMWIDTH IN DEGREES
      C                  6 ONE-WAY ANTENNA GAIN IN DB
      C                  7 ONE-WAY SIDELOBE LEVEL IN DB DOWN
      C                  8 RECEIVER LOSS IN DB
      C                  9 TRANSMITTER LOSS IN DB
      C                 10 NUMBER OF SCAN MODES
      C                 11 LINEAR POLARIZATION IN DEGREES
```

```
C                      0 = HORIZONTAL
C                     90 = VERTICAL
C
C
C        DATA CARDS NO. 5 AND 6     (ONE SET FOR EACH RADAR SCAN MODE)
C
C               15 PARAMETERS FOR EACH SCAN MODE   (10F8.2/5F8.2 FORMAT)
C                  1 LOWER BOUNDARY ELEVATION ANGLE COVERAGE IN DEGREES
C                  2 UPPER BOUNDARY ELEVATION ANGLE COVERAGE IN DEGREES
C                  3 PEAK POWER IN MW
C                  4 PULSE LENGTH IN MICROSECONDS
C                  5 INTERLOOK PERIOD IN SECONDS
C                  6 SCAN OFFSET IN SECONDS
C                  7 INSTRUMENTED RANGE IN NMI
C                  8 MODE DEPENDENT LOSS IN DB
C                  9 NUMBER OF PULSES INTEGRATED
C                 10 COMPRESSED PULSE LENGTH IN MICROSECONDS
C                 11 SEA CLUTTER IMPROVEMENT FACTOR IN DB
C                 12 I.F. BANDWIDTH IN MHZ. IF 0, BANDWIDTH WILL BE SET
C                        AT 1.0/(COMPRESSED PULSE LENGTH)
C                 13 MODE DEPENDENT FREQUENCY INCREMENT IN MHZ
C                 14 BLANKING TIME IN MICROSECONDS.  IF 0, SET AT
C                        PULSE LENGTH
C                 15 RAIN CLUTTER IMPROVEMENT FACTOR IN DB
C
C
C        DATA CARD NO. 7
C
C               7 PARAMETERS FOR MOVING WINDOW DETECTOR   (7F8.2 FORMAT)
C                  1 NO. OF REFERENCE CELLS ON EACH SIDE OF TARGET CELL
C                  2 CLUTTER CORRELATION COEFFICIENT
C                  3 NO. OF STANDARD DEVIATIONS USED IN THRESHOLD
C                  4 AZIMUTH OFFSET BETWEEN BEAM POSITIONS IN DEGREES
C                  5 VIDEO TYPE INDICATOR
C                        0 = LINEAR VIDEO
C                        1 = LOG VIDEO
C                  6 NO. OF REFERENCE CELLS USED FOR THRESHOLD
C                        0 = ALL CELLS USED
C                       <0 = SMALLER HALF USED
C                       >0 = LARGER HALF USED
C                  7 PARAMETERS USED TO CALCULATE THRESHOLD
C                        1 = MEAN USED
C                        2 = MEAN AND VARIANCE USED
C
C
C
C        DATA CARD NO. 8
C
C               NUMBER OF TARGETS AND JAMMERS    (2I5 FORMAT)
C                  1 NO. OF TARGETS
```

UNCLASSIFIED

```
C             2 NO. OF JAMMERS
C
C
C      DATA CARDS NO. 9 AND 10   (ONE SET FOR EACH TARGET AND JAMMER)
C
C             CARD 9    13 TARGET PARAMETERS    (12F6.2,I3 FORMAT)
C             TARGET TRAJECTORY SHOULD NOT CROSS 0 DEGREES IN AZIMUTH
C              1-4 INITIAL COORDINATES  (X,Y,Z,T) IN KFT AND SECONDS
C              5-8 TERMINAL COORDINATES  (X,Y,Z,T) IN KFT AND SECONDS
C             9-11 RADAR REFLECTIVE AREAS FOR HEAD-ON,
C                       BROAD-SIDE, AND MINIMUM IN SQ. METERS
C               12 JAMMING POWER DENSITY IN W/MHZ
C               13 MARCUM SWERLING CROSS SECTION MODEL
C
C             CARD 10   TARGET PROFILE PARAMETERS    (I4,7F6.2 FORMAT)
C                1 TARGET PROFILE TYPE
C                       0 = STRAIGHT LINE TRAJECTORY
C                       1 = 2-4 ALTITUDE LEGS
C                       2 = G-MANEUVER AT CONSTANT ALTITUDE
C             REMAINING PROFILE PARAMETERS BY TARGET TYPE
C              IF TARGET TYPE = 0
C              2-8 IGNORED
C              IF TARGET TYPE = 1
C                2 = NO. OF ALTITUDE NODES
C                3 = FIRST ALTITUDE NODE IN KFT
C                4 = TIME OF ARRIVAL AT FIRST NODE IN SEC
C                5 = SECOND ALTITUDE NODE IN KFT
C                6 = TIME OF ARRIVAL AT SECOND NODE IN SEC
C                7 = THIRD ALTITUDE NODE IN KFT
C                8 = TIME OF ARRIVAL AT THIRD NODE IN SEC
C              IF TARGET TYPE = 2
C                2 = TARGET SPEED IN KFT/SEC
C                3 = INITIAL HEADING IN DEGREES
C                4 = TIME MANEUVER BEGINS IN SEC
C                5 = TARGET MANEUVER RADIAL ACCELERATION IN G'S
C
C
C
C      DATA CARD NO. 11
C
C             4 ENVIRONMENTAL PARAMETERS   (4F8.2 FORMAT)
C                1 WIND SPEED IN KNOTS
C                2 HEIGHT OF WIND SPEED MEASUREMENT IN KFT
C                3 MULTIPATH INDICATOR
C                       1 = MULTIPATH
C                       0 = NO MULTIPATH
C                4 RAINFALL RATE IN MM/HR
C
C
C
```

```
C         DATA CARD NO. 12
C
C                9 FIXED CLUTTER PARAMETERS    (2I8,7F8.2 FORMAT)
C                   1 INITIALIZATION FOR RANDOM NUMBER GENERATOR FOR
C                     GENERATION OF FIXED CLUTTER POINTS
C                   2 NO. OF FIXED CLUTTER POINTS
C                   3 PROBABILITY THAT CLUTTER POINT IS DETECTED
C                   4 INITIAL RANGE OF CLUTTER AREA IN KFT
C                   5 FINAL RANGE OF CLUTTER AREA IN KFT
C                   6 STANDARD DEVIATION OF RANGE MEASUREMENT
C                     AS A PERCENTAGE OF RANGE RESOLUTION CELL SIZE
C                   7 INITIAL AZIMUTH OF CLUTTER AREA IN DEGREES
C                   8 FINAL AZIMUTH OF CLUTTER AREA IN DEGREES
C                   9 STANDARD DEVIATION OF AZIMUTH MEASUREMENT
C                     AS A PERCENTAGE OF HORIZONTAL 3DB BEAMWIDTH
C
C
C
C         DATA CARD NO. 13
C
C                2 BASIC VARIABLE CLUTTER PARAMETERS    (2I8 FORMAT)
C                   1 INITIALIZATION FOR RANDOM NUMBER GENERATOR FOR
C                     GENERATION OF VARIABLE CLUTTER POINTS
C                   2 NO. OF CLUTTER REGIONS
C
C
C         DATA CARD NO. 14      (ONE CARD FOR EACH CLUTTER REGION)
C
C                7 PARAMETERS FOR EACH CLUTTER REGION    (7F8.2 FORMAT)
C                   1 AVERAGE NUMBER OF CLUTTER POINTS IN REGION
C                   2 INITIAL RANGE OF CLUTTER AREA IN KFT
C                   3 FINAL RANGE OF CLUTTER AREA IN KFT
C                   4 INITIAL AZIMUTH OF CLUTTER AREA IN DEGREES
C                   5 FINAL AZIMUTH OF CLUTTER AREA IN DEGREES
C                   6 INITIAL ELEVATION OF CLUTTER AREA IN DEGREES
C                   7 FINAL ELEVATION OF CLUTTER AREA IN DEGREES
C
C
C
C         DATA CARD NO. 15
C
C                4 ROLL AND PITCH PARAMETERS    (4F8.2)
C                   1 MAXIMUM ROLL ANGLE IN DEGREES
C                   2 MAXIMUM PITCH ANGLE IN DEGREES
C                   3 ROLL PERIOD IN SECONDS
C                   4 PITCH PERIOD IN SECONDS
C
C
C
C         DATA CARD NO. 16
```

UNCLASSIFIED

```
C
C                  TIME PARAMETER (F8.2)
C                     GAME TIME (IN SEC) BY WHICH RADAR IS TO BEGIN SCANS
C
C
C
C          DATA CARD NO. 17
C
C                  RECYCLE CONTROL PARAMETER    (I5 FORMAT)
C                                 1 = NEW SHIP   IN WHICH CASE
C                                          THE NEXT DATA CARD IS NO. 1
C                                 2 = NEW TARGETS
C                                 3 = NEW ENVIRONMENT
C                                 4 = RUN COMPLETED
C
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4        ,SHIP(9),PC(30),RMODE(30,12),IMODE(30,2)
      COMMON/B/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACON,BETA,
     *        DATP(20),POLRZ,TKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPTQB,FOPISG
      COMMON/D/ ALPHAD,SIGZ,V,AR1,AR2,SIGC,SIG
      COMMON/H/FAC4,AMBN,XJAMN,IKEYJG,XXXXX
      COMMON/I/ PBBS,HOFK,THETBK,DRDOWN,THH,THV,GN
      COMMON/TM/NTARG,NJAM,SPEED(20),HEADI(20),HEADF(20),TMANI(20),
     1           TMANF(20),XMANI(20,3),XMANF(20,3),GTURN(20),TURN(20),
     2          CM(20,2),RADM(20),ITYPE(20),ALT(20,5),TALT(20,5),NALT(20)
      COMMON/TS/ISTAT(20),TSCAN(20,30)
      COMMON /CLTOUT/ ROUT(201),AZOUT(201),ELOUT(201),TOUT(201),
     1 RLOUT(201),PTOUT(201),SOUT(201),NC(100),IC,IV
      COMMON /DET/ NDET(20),MER(20),RANGE(20,3),AZ(20,6),SNDET(20,3),
     1             ELEV(20,3),TIME(20)
      COMMON /DET3/ NDET3(20,30),MER3(20),RANGE3(20,9,30),AZ3(20,9,30),
     1   SNDET3(20,9,30)           ,TIME3(20),IKEY(20)
      COMMON /STAB/ ROLL(20),PITCH(20)
      DIMENSION ITITLE(20)
      DIMENSION BUFA(8,300),BUF(10)
      DIMENSION BUFB(5,20)
      INTEGER ANS1
      CALL RSSTOP
      IOUT = 10
      CONV=4.342944819
      RE=8392375.04
      CNM=161883.5474
```

```
      CCM=30000000000.
      BETA =.718565021
      ACON= .607701593
      XKTOMS =.514444444
      XNMTOM =1852.
      FOPISQ =157.9136706
      FOPIOB =1984.401711
    5 OFR = 0
      READ 52,ANS1
   52 FORMAT(16I5)
      READ 500,ITITLE
  500 FORMAT(I4,19A4)
      PRINT 501,ITITLE
  501 FORMAT(1H1,I4,5X,19A4)
      CALL INITAL
   10 CALL TARGET
   11 CALL ENVIRN
C
C     INITIALIZE CLUTTER FOR TRACKING
      CALL FCINIT
      CALL VCINIT
C
C     INITIALIZE ROLL AND PITCH
      CALL STRINT
C
C     READ IN TIME BY WHICH RADAR MUST BE INITIALIZED
      READ 59, RINIT
   59 FORMAT(F8.2)
      PRINT 590, RINIT
  590 FORMAT(1H0,' GAME INITIALIZATION BY ',F8.2)
C
C     ADD SCAN OFFSET (FROM MODE 1) TO MAX RADAR INITIALIZATION TIME
      RINIT = RINIT/3600. + RMODE(1,6)
      ISC=0
      IKEYF=0
C     DETERMINE TIMES EACH TARGET COMES WITHIN INSTRUMENTED RANGE
C        OF EACH RADAR MODE
      CALL MATCH
C
C     DETERMINE INITIAL AND FINAL GAME TIMES
C
      T = RMODE(1,9)
      ENDTIM = XYZF(1,4)
C     SET TARGETS INITIALLY TO OVER-THE-HORIZON
      TRGPOS(1,4) = -1.
      IF(NSCAN .LT. 2) GO TO 17
C     DETERMINE INITIAL TIME FROM MATCH
      DO 15 J = 2,NSCAN
      IF(RMODE(J,9) .LT. T) T = RMODE(J,9)
   15 CONTINUE
```

```
   17 IF(NTARG .LT. 2) GO TO 19
C     DETERMINE END GAME TIME
      DO 18 I = 1,NTARG
      TRGPOS(I,4) = -1.
      IF(XYZF(I,4) .GT. ENDTIM) ENDTIM = XYZF(I,4)
   18 CONTINUE
   19 CONTINUE
C     SET INITIAL TIME FROM MATCH 30 SEC. EARLIER FOR CLUTTER SAMPLES
      T = T - 3./360.
C     SET INITIAL GAME TIME
      T = AMIN1(T,RINIT)
      TEMP = 3
      TEMPB = RMODE(1,5)*3600.
      WRITE (IOUT) ITITLE(1),TEMP,TEMPB
C
      IF (ANS1.EQ.0) GO TO 20
      MUL=ENVIR(3)
      IF ( MUL .NE. 0 )  PRINT 506
      IF ( MUL .EQ. 0 )  PRINT 505
  506 FORMAT(/,'            $$$$$  WITH MULTIPATH  $$$$$',/)
  505 FORMAT(//,60X,'     $$$$$  NO MULTIPATH  $$$$$',/)
C
C     GENERATE INITIAL AZIMUTH BEAM POSITION
   20 CALL INIT3D(NTARG,AZINIT)
      ISC=ISC+1
C     INITIALIZE SCAN PRINT FLAG
      IPFLAG = 0
C     DETERMINE TARGET AND JAMMER POSITIONS AT SCAN TIME T
      CALL NEWPOS
C     PERFORM ELEVATION SCAN FOR EACH ACTIVE TARGET
      DO 75 I = 1,NTARG
C     CHECK IF TARGET ACTIVE
      IF(ISTAT(I) .NE. 1) GO TO 75
      DO 70 J = 1,NSCAN
      NEXT = J
C     CHECK IF TARGET WITHIN DETECTION RANGE OF THIS MODE
      IF(TSCAN(I,J) .GT. T) GO TO 70
      TEMP = RMODE(J,1) - 0.63*RC(5)
      TEMP2 = RMODE(J,2) + 0.63*RC(5)
      IF(TRGPOS(I,6) .GE. TEMP .AND. TRGPOS(I,6) .LE.
     1   TEMP2       .AND. TRGPOS(I,4) .LE. RMODE(J,7)
     2   .AND. TRGPOS(I,4) .GT. SMODE(J,1)) GO TO 30
C     TARGET CANNOT BE DETECTED BY MODE J
      GO TO 70
   30 IF(RC(1) + DWL(NEXT) .NE. OFF) ISWIT = 0
      OFR=RC(1)+DWL(NEXT)
      RFR=RC(1)/OFR
      RC(6)=GN/RFR**2
      RC(4)=THH*RFR
      RC(5)=THV*RFR
```

```
            PBPS = RMODE(NEXT,1) + RC(5)/2.
      C
      C     COMPARE TARGET ELEVATION ANGLE TO ELEVATION BEAM CENTER
            IF(ABS(PBPS - TRGPOS(I,6)) .GE. RC(5)) GO TO 70
            ALPHAD = 0
            SIGC = 0
            SIG = 0
            AR1 = 0
            AR2 = 0
            V = 0
      C     CHECK FOR PRINT
            IF(ANS1 .EQ. 0) GO TO 35
            IF( IPFLAG .NE. 0) GO TO 35
            IPFLAG = 1
      C     PRINT SCAN NUMBER
            PRINT 507,ISC
        507 FORMAT (////,30X,'+++++++  SCAN NUMBER = ',I4,'  +++++++',/)
            IF( ANS1.NE.2 ) GO TO 35
      C     PRINT HEADING
            PRINT 40
      C     COMPUTE SIGNAL ENERGY AND NOISE AND CLUTTER ENERGIES FOR TARGET I
         35 CALL SIGNAL(I,RC(11),RC(12))
            CALL NOISE(I,RC(13),RC(14))
            TCRSS = TARCS
      C     DETERMINE TARGET DETECTIONS IN MODE J
            NREF = RC(15)
            CALL DET3D(RC(12),RC(13),RC(14),IMODE(J,1),RC(16),RC(17),NREF,
           1          RC(19),I,NTARG,RC(4),J,AZINIT,RC(18),RC(20),RC(21),
           2          RC(22),SNTRUE)
            IF (ANS1.NE.2) GO TO 65
            BHDEG=TRGPOS(I,5)*RADIAN
            BVDEG = TRGPOS(I,6)*RADIAN
            DBE=CONV*ALOG(RC(12))
            DBN=CONV*ALOG(RC(14))
            SN=DBE-DBN
            TRGP = TRGPOS(I,4)*6.0802
            AMBNDB = CONV*ALOG(AMAX1(AMBN,1.0E-74))
            XJAMDB  = CONV*ALOG(AMAX1(XJAMN,1.0E-74))
            SCDB = CONV*ALOG(AMAX1(SIGC,1.0E-74))
            SFAC4=CONV*ALOG(AMAX1(FAC4,1.0E-74))
            SNTRUE = 10.*ALOG10(SNTRUE)
            PRINT 50,I,J,TIME3(I),TRGP,BHDEG,BVDEG,TCRSS,SFAC4,DBE,AMBNDB
           1        ,SCDB,XJAMDB,SN,SNTRUE,MER3(I)
            KNUM=NDET3(I,J)
            IF (KNUM.EQ.0) GO TO 65
            DO 61 K=1,KNUM
            RRRR=RANGE3(I,K,J)*6.0802
            AAAA=AZ3(I,K,J)*RADIAN
            SSSS=SNDET3(I,K,J)
            SSSS = 20.*ALOG10(SSSS)
```

```
      PRINT 55,RRRR,AAAA,SSSS
   55 FORMAT(5X,'*DETECTION*',4X,F12.2,F10.2,19X,F10.0)
   61 CONTINUE
   65 CONTINUE
   70 CONTINUE
   75 CONTINUE
C
C     MERGE DETECTIONS
      CALL MRDT3D(RC(19),NTARG,RC(4),RC(5))
C
C     CALCULATE ROLL AND PITCH
      CALL STAB3
C     CLUTTER OUTPUT FOR TRACKING
      CALL FXCLT3
      CALL VRCLT3
C
C     NEW OUTPUT
      BUF(1) = ISC
      BUF(2) =   T*3600.
      BUF(3) = IV
      DO 200 I = 1,NTARG
      BUF(3) = BUF(3)+NDET(I)
  200 CONTINUE
      BUF(4) = 3000+ITITLE(1)
      BUF(5) = SHIP(5)
      BUF(6) = NTARG
      WRITE (IOUT) (BUF(I),I=1,6)
      IF(ANS1.EQ.0) GO TO 220
      IF(BUF(3) .EQ. 0) GO TO 220
      PRINT 56, (BUF(I),I=1,6)
   56 FORMAT(1H0/'  SCAN NUMBER=',F5.0,'    TIME=',F9.2,'    NO. DETECTI
     1ONS=',F5.0,'    RADAR ID=',F6.0,'    HEADING=',F7.2,'    NO. TARGE
     2TS=',F4.0/)
   57 FORMAT('  DETECTION NUM ',F5.0,7F10.4)
      PRINT 58
   58 FORMAT(18X,'ID',6X,'RANGE',5X,'AZIM',6X,'ELEV',6X,'TIME',6X,'ESIG'
     1,6X,'ROLL',5X,'PITCH')
  220 CONTINUE
      ICNT = 0
      DO 250 I = 1,NTARG
      BUFB(1,I) = I
      BUFB(2,I) = TRGPOS(I,4)
      BUFB(3,I) = TRGPOS(I,5)
      BUFB(4,I) = TRGPOS(I,6)
      BUFB(5,I) = TIME3(I)
      NCT = NDET(I)
      IF(NCT.EQ.0) GO TO 250
      DO 240 J = 1,NCT
      ICNT = ICNT+1
      BUFA(1,ICNT) = I
```

```
          BUFA(2,ICNT) = RANGE(I,J)
          BUFA(3,ICNT) = AZ(I,J)
          BUFA(4,ICNT) = ELEV(I,J)
          BUFA(5,ICNT) = TIME(I)
          BUFA(6,ICNT) = SNORT(I,J)
          BUFA(6,ICNT)=20.*ALOG10(BUFA(6,ICNT))
          BUFA(7,ICNT) = ROLL(I)
          BUFA(8,ICNT) = PITCH(I)
  240 CONTINUE
  250 CONTINUE
      IF(IV.EQ.0) GO TO 270
      DO 260 I = 1,IV
      ICNT = ICNT+1
      BUFA(1,ICNT) = 200
      IF(I.LE.IC)
     1BUFA(1,ICNT) = 100 + NC(I)
      BUFA(2,ICNT) = ROUT(I)
      BUFA(3,ICNT) = AZOUT(I)
      BUFA(4,ICNT) = ELOUT(I)
      BUFA(5,ICNT) = TOUT(I)
      BUFA(6,ICNT) = SOUT(I)
      BUFA(6,ICNT)=20.*ALOG10(BUFA(6,ICNT))
      BUFA(7,ICNT) = RLOUT(I)
      BUFA(8,ICNT) = PTOUT(I)
  260 CONTINUE
  270 CONTINUE
      DO 275 J = 1,NTARG
      WRITE (IOUT)  (BUFB(I,J),I=1,5)
  275 CONTINUE
      IF(ICNT.EQ.0) GO TO 290
      DO 277 J = 1,ICNT
      WRITE(IOUT)  (BUFA(I,J),I = 1,8)
  277 CONTINUE
      IF(ANS1.EQ.0) GO TO 290
      DO 280 J = 1,ICNT
      PRINT 57,(BUFA(I,J),I = 1,8)
  280 CONTINUE
  290 CONTINUE
C
C     NEW SCAN
      T = T + RMODE(1,5)
      IF(T .GT. ENDTIM) GO TO 110
      GO TO 20
C
   80 CONTINUE
      IF (ISTEP.LE.4000) GO TO 20
  110 ISTEP=ISTEP-1
  301 CONTINUE
      XJAMN=0.
C     READ IN RECYCLE CONTROL PARAMETER
```

```
C       IANS=1(SHIP),=2(TARGET),=3(ENVIRONMENT),=4(FINISHED)
        READ 52, IANS
        GO TO (5,10,11,140),IANS
  140 CONTINUE
  130 CONTINUE
  40  FORMAT (//,7X,'MODE',42X,'SIGMA',/,' TARGET',9X,'TIME         RANGE'
     1,6X,'AZIM        ELEV        FACTOR    ESIG     NAMB     NCLT     NJAM
     2    E/N         MER3')
   50 FORMAT(1X,2I4,F11.1,F12.2,F10.2,F10.2,F5.1,F5.0,F9.0,3F8.0,F9.2
     1,F7.2,I5)
   60 FORMAT (1X,I4/(1X,5(F7.1,F7.5)))
      END
```

```
      SUBROUTINE ADJDET (RES,TH3DB,EL3DB,K,NEWJJ,KTAR,I,J)
C
C     THIS ROUTINE DETERMINES WHETHER THE PRESENT DETECTION OF THE
C     KTAR-TH TARGET IN THE J-TH MODE IS ADJACENT TO THE PREVIOUS DETECTIONS
C
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1       ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4       ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON /MERSET/ DETPAR(100,4)
      COMMON /DET3/ NDET3(20,30),MER3(20),RANGE3(20,9,30),AZ3(20,9,30),
     1   SNDET3(20,9,30)                TIME3(20),IKEY(20)
C
C     RES IS THE RANGE RESOLUTION CELL SIZE
C     TH3DB IS THE 3-DB AZIMUTH ANTENNA BEAMWIDTH
C     EL3DB IS THE ELEVATION 3-DB BEAMWIDTH
C     K IS THE PRESENT NUMBER OF ADJACENT DETECTIONS
C     NEWJJ IS THE PRESENT NUMBER OF NONADJACENT DETECTIONS
C     KTAR IS THE INDEX OF THE PRESENT TARGET
C     I IS THE INDEX OF THE PRESENT DETECTION
C     J IS THE INDEX OF THE PRESENT MODE
C
      R=RANGE3(KTAR,I,J)
      A =  AZ3(KTAR,I,J)
      E = RMODE(J,1) + RC(5)/2.
C
C     TEST TO LOCATE ADJACENT DETECTIONS
C
      DO 10 IK=1,K
      IF (ABS(R-DETPAR(IK,1)).LT.1.2*RES.AND.
     1    ABS(A-DETPAR(IK,2)).LT.0.1*TH3DB.AND.
     2    ABS(E-DETPAR(IK,3)).LT.0.1*EL3DB) GO TO 20
      IF (ABS(R-DETPAR(IK,1)).LT.0.1*RES.AND.
     1    ABS(A-DETPAR(IK,2)).LT.1.2*TH3DB.AND.
     2    ABS(E-DETPAR(IK,3)).LT.0.1*EL3DB) GO TO 20
      IF (ABS(R-DETPAR(IK,1)).LT.0.1*RES.AND.
     1    ABS(A-DETPAR(IK,2)).LT.0.1*TH3DB.AND.
     2    ABS(E-DETPAR(IK,3)).LT.1.2*EL3DB) GO TO 20
   10 CONTINUE
      NEWJJ=NEWJJ+1
      RANGE3(KTAR,NEWJJ,J)=R
        AZ3(KTAR,NEWJJ,J)=A
      SNDET3(KTAR,NEWJJ,J)=SNDET3(KTAR,I,J)
      RETURN
   20 K=K+1
      DETPAR(K,1)=R
      DETPAR(K,2)=A
      DETPAR(K,3)=E
      DETPAR(K,4)=SNDET3(KTAR,I,J)
      RETURN
      END
```

```
0001          SUBROUTINE DET3D (S,C,FN,N3DB,COR,FSIG,NREF,RES,NTAR,N,TH3DB,
             1    MODE,AZINIT,AZBBP,XLOG,THRSH,PARM,SNTRUE)
        C
        C     THIS ROUTINE PERFORMS THE DETECTION CALCULATION FOR THE NTAR TARGET
        C     AND FOR  A SPECIFIED ELEVATION MODE. THE  CALCULATION IS PERFORMED
        C     IN THE ADJACENT RANGE AND AZIMUTH BEAMS. THE JAMMING AND CLUTTER
        C     ARE ASSUMED TO REMAIN CONSTANT. THE TARGET POWER CHANGES WITH THE
        C     ANTENNA POSITION.
        C
0002          COMMON /DET3/ NDET3(20,30),MER3(20),RANGE3(20,9,30),AZ3(20,9,30),
             1    SNDET3(20,9,30)             ,TIME3(20),IKEY(20)
0003          COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
             1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
             2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
             3      ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
             4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
0004          COMMON /MOD/ MODEL(20)
0005          COMMON /FLUC/ FLUCT(32,20)
0006          DIMENSION SNREF(20),INF(20)
0007          DIMENSION X(32,25),SS(32,25),SUM(25),IS(25),R(128),D(14)
        C
        C     S IS THE SIGNAL POWER
        C     C IS THE CLUTTER POWER
        C     FN IS THE NOISE POWER
        C     N3DB IS THE NUMBER OF PULSES BETWEEN THE 3-DB ANTENNA POINTS
        C     COR IS THE CORRELATION COEFFICIENT OF CLUTTER
        C     FSIG NUMBER OF STANDARD DEVIATIONS USED IN CALCULATION OF THE TH
        C     NREF IS THE NUMBER OF REFERENCE CELLS ON EACH SIDE
        C     RES IS THE RANGE RESOLUTION CELL SIZE
        C     NTAR IS THE TARGET OF INTEREST
        C     N IS THE NUMBER OF TARGETS
        C     TH3DB IS THE ANTENNA 3-DB BEAMWIDTH
        C     MODE IS THE INDEX OF THE ACTIVE RADAR MODE(I.E. BEAM POSITION)
        C     AZINIT IS THE INITIAL BEAM POSITION FOR THIS SCAN
        C     AZBBP IS THE AZIMUTH OFF SET BETWEEN AZIMUTH BEAM POSITIONS
        C     XLOG DENOTES WHETHER LINEAR(XLOG=0.0) OR LOG(XLOG=1.0) VIDEO IS USED
        C     THRSH DENOTES WHETHER ALL THE REFERENCE CELLS(THRSH=0.0) , THE
        C           SMALLER HALF(THRSH<0), OR THE LARGER HALF(THRSH>0) SHOULD BE USED
        C     PARM DENOTES WHETHER THE MEAN AND VARIANCE(PARM=2.) OR JUST THE
        C          MEAN(PARM=1.) SHOULD BE USED TO CALCULATE THE THRESHOLD
        C
        C    ******* NOTE, DETECTION TIME IS SET EQUAL TO T *****************
0008          IF (N3DB.LE. 32.AND.NREF.LE.10) GO TO 3
0009          PRINT 50
0010      50  FORMAT (1H1,' EITHER N3DB OR NREF ARE TOO LARGE')
0011          STOP
0012       3  IF (ABS(COR).LT.1.0) GO TO 4
0013          PRINT 51
0014      51  FORMAT (1H1,' CORRELATION COEFFICIENT IS GREATER OR EQUAL TO 1')
```

```
      STOP
    4 CONTINUE
C
C     TEST TO SEE IF THERE IS ANY CHANCE OF A TARGET DETECTION
C
   99 FORMAT(1H0,2X,'DET',I5,3E15.8)
      SNINT=N3DB*S/(C+FN)
      IF (SNINT.GT.2) GO TO 5
      NDET3(NTAR,MODE)=0
      SNTRUE = 10.**(-9.9)
      RETURN
    5 SNREF(1)=S
      INF(1)=NTAR
      NREF2=2*NREF
      CALL RESOL(NREF,RES,NTAR,SNREF,INF,NI,TH3DB,N)
  502 FORMAT (1H0,' TARGETS ARE',10I5)
      KAZ=(TRGPOS(NTAR,5) -AZINIT)/AZBBP+.5
      II=0
C
C     DO LOOP FOR THE THREE AZIMUTH BEAM POSITIONS
C
      IAZ=0
  285 IAZ=IAZ+1
      AZIM=AZBBP*(KAZ+IAZ-2)+AZINIT
      KRS=TRGPOS(NTAR,4)/RES
      RS=RES*KRS-13.*RES
C
C     ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C     GENERATION OF SIGNAL VALUES
C
C     ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
      NS=1
      NF=N3DB
      NRS=13-NREF-2
      NRF=13+NREF+2
      DO  7 I=NRS,NRF
      IS(I)=0
      DO  7 J=NS,NF
    7 SS(J,I)=0.
      IMERGE=0
      DO 40 K=1,NI
      RR=TRGPOS(INF(K),4)
      KR=(RR-RS)/RES
      IF (K.EQ.1.OR.KR.GT.16.OR.KR.LT.10) GO TO 8
      IMERGE=1
C
C     FLUCTUATING SIGNAL
C
```

```
      8 NSW=MODEL(INF(K))
        IF (NSW.GT.0) GO TO 11
        FL=1.0
      9 DO 10 J=NS,NF
     10 FLUCT(J,K)=FL
        GO TO 171
     11 GO TO (12,13,15,16),NSW
     12 IF (IKEY(NTAR).GT.0) GO TO 171
        CALL VRANF(R,1)
        FL =-ALOG(R(1))
        GO TO 9
     13 M=NF+1-NS
        CALL VRANF(R,M)
        KK=0
        DO 14 J=NS,NF
        KK=KK+1
     14 FLUCT(J,K)=-ALOG(R(KK))
        GO TO 171
     15 IF (IKEY(NTAR).GT.0) GO TO 171
        CALL VRANF(R,2)
        FL=-.5*(ALOG(R(1))+ALOG(R(2)))
        GO TO 9
     16 M=NF+1-NS
        M2=2*M
        CALL VRANF(R,M2)
        KK=0
        DO 17 J=NS,NF
        KK=KK+1
     17 FLUCT(J,K)=  (ALOG(R(KK))+ALOG(R(KK+M)))*(-.5)
    171 CONTINUE
    512 FORMAT (1H0,' MERGING PROBLEM (K,KP,IMERGE) = ',3I10)
        DO 35 I=1,3
        KT=KR+I-2
        IF (KT.LT.NRS.OR.KT.GT.NRF) GO TO 35
        IS(KT)=1
C
C       MODULATION OF SIN(X)/X PULSE SHAPE
C
        RTEMP = KT*RES+RES/2.+RS
        FDIF=2.7832*(RR-RTEMP)/RES
        F=1.
        IF (FDIF.EQ.0) GO TO 18
        F=SIN(FDIF)/FDIF
     18 F=F*F
        SM=F*SNREF(  K    )/(C+FN)
    503 FORMAT (1H0,' KT,RS,RTEMP,RR,FDIF,F,SM = ',I5,6F12.4)
        AA=TRGPOS(INF(K),5)
C
C       MODULATION OF SIN(X)/X ANTENNA PATTERN
C
```

```
      GDIF=2.7832*(AZIM      -  AA)/TH3DB
  519 FORMAT(1H0,'  GDIF,AZIM,AA,AZINIT = ',4F12.6)
      G=1.
      IF (GDIF.EQ.0) GO TO 19
      G=SIN(GDIF)/GDIF
   19 G=G**4
      DO 20 J=NS,NF
C
C     ***** NOTE , TARGETS ARE ADDED NONCOHERENTLY ********
C
      SS(J,KT)=SS(J,KT)+SM*G*FLUCT(J,K)
   20 CONTINUE
   35 CONTINUE
   40 CONTINUE
      IF(IAZ .NE. 2) GO TO 405
      SNTRUE = 0.
      DO 402 J = NS,NF
  402 SNTRUE = SNTRUE + SS(J,13)/N3DP
  405 CONTINUE
      DO 41 I=NRS,NRF
      IF (IS(I).EQ.0) GO TO 41
  501 FORMAT (1H0,' I,NS,NF = ',3I5,25(/,10F12.4))
   41 CONTINUE
      IKEY(NTAP)=1
C
C     +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C     GENERATION OF NOISE SAMPLES
C
C     +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
      M=NF+1-NS
      M2=2*M
      M3=3*M
      M4=4*M
      IF (N3DB*C     .GT.FN) GO TO 100
C
C     CLUTTER IS NOT A FACTOR
C
      DO 90 I=NRS,NRF
      IF (IS(I).EQ.1) GO TO 75
C
C     NO SIGNAL PRESENT IN THIS CELL
C
      CALL VRANF(R,M)
      K=0
      DO 60 J=NS,NF
      K=K+1
      X(J,I)=SQRT(-2.*ALOG(R(K)))
   60 CONTINUE
```

```
            GO TO 90
      C
      C     SIGNAL PRESENT IN THIS CELL
      C
         75 CALL VRANF(R,M2)
            K=0
            DO 80 J=NS,NF
            K=K+1
            A=SQRT(-2.*ALOG(R(K)))
            B=TWOPI*R(K+M)
            X(J,I)=SQRT((A*COS(B)+SQRT(SS(J,I))*1.414)**2+ (A*SIN(B))**2)
         80 CONTINUE
         90 CONTINUE
            GO TO 200
      C
      C     CLUTTER IS A FACTOR
      C
        100 AOLDX=SQRT(C/(C+FN))
            CC=AOLDX
            FFN=SQRT(FN/(C+FN))
            P=SQRT(1.-COR*COR)
            DO 150 I=NRS,NRF
            CALL VRANF(R,2)
            AOLDY=   CC*SIN(TWOPI*R(1))*SQRT(-2.*ALOG(R(2)))
            AOLDX=   CC*COS(TWOPI*R(1))*SQRT(-2.*ALOG(R(2)))
            CALL VRANF(R,M4)
            K=0
            DO 120 J=NS,NF
            K=K+I
            A =SQRT(-2.*ALOG(R(K)))*CC
            A1=SQRT(-2.*ALOG(R(K+M)))*FFN
            B =TWOPI*R(K+M2)
            B1=TWOPI*R(K+M3)
            AOLDX=COR*AOLDX+P*A*COS(B)
            AOLDY=COR*AOLDY+P*A*SIN(B)
            X(J,I)=SQRT((AOLDX+A1*COS(B1)+SQRT(SS(J,I))*1.414)**2 +
           1            (AOLDY+A1*SIN(B1))**2)
        120 CONTINUE
        150 CONTINUE
      C
      C     GENERATION OF SUM
      C
        200 MS=NS+N3DB-1
            IF (XLOG.LT.0.0001) GO TO 210
      C
      C     USE LOG VIDEO
      C
            DO 205 J=NS,MS
            DO 205 I=NRS,NRF
        205 X(J,I)=ALOG(X(J,I))
```

```
  210  CØNTINUE
       DØ 241 I=NRS,NRF
  241  CØNTINUE
       DØ 220 I=NRS,NRF
       SUM(I)=0.
       DØ 220 J=NS,MS
  220  SUM(I)=SUM(I)+X(J,I)
C
C      GENERATIØN ØF THE DETECTIØN THRESHØLDS
C
       DØ 250 J=12,14
       ULØW=0.
       UUP=0.0
       XMSLØW=0.0
       XMSUP=0.0
       DØ 230 I=1,NREF
       ULØW=ULØW+SUM(J-I-1)
       UUP=UUP+SUM(J+I+1)
       XMSLØW=XMSLØW+SUM(J-I-1)**2
  230  XMSUP=XMSUP+SUM(J+I+1)**2
       IF (THRSH.NE.0.0) GØ TØ 235
C
C      USE ALL REFERENCE CELLS
C
       U=ULØW+UUP
       XMS=XMSLØW+XMSUP
       D(J)=U/NREF2+FSIG*SQRT(XMS/NREF2-(U/NREF2)**2)
       IF (PARM.GT.1.5) GØ TØ 250
       D(J)=FSIG*U/NREF2
       IF (XLØG.LT.0.0001) GØ TØ 250
       D(J)=FSIG+U/NREF2
       GØ TØ 250
C
C      USE EITHER MIN(THRSH<0) ØR MAX(THRSH>0) REFERENCE CELLS
C
  235  IF (THRSH.LT.0.0.AND.ULØW.LT.UUP) GØ TØ 240
       IF (THRSH.LT.0.0.AND.ULØW.GE.UUP) GØ TØ 245
       IF (THRSH.GT.0.0.AND.ULØW.LT.UUP) GØ TØ 245
       IF (THRSH.GT.0.0.AND.ULØW.GE.UUP) GØ TØ 240
  240  U=ULØW
       XMS=XMSLØW
       GØ TØ 248
  245  U=UUP
       XMS=XMSUP
  248  D(J)=U/NREF+FSIG*SQRT(XMS/NREF-(U/NREF)**2)
       IF (PARM .GT.1.5) GØ TØ 250
       D(J)=FSIG*U/NREF
       IF (XLØG.LT.0.0001) GØ TØ 250
       D(J)=FSIG+U/NREF
  250  CØNTINUE
```

```
  505 FORMAT (1H0,10F12.4)
C
C     DO LOOP FOR DETECTION OF CENTER PULSES
C
      DO 280 I=12,14
  260 IF (SUM(I).LT.D(I)) GO TO 280
      II=II+1
      NDET3(NTAR,MODE)=II
      IF (IMERGE.EQ.1) MER3(NTAR)=-1
      RANGE3(NTAR,II,MODE)=RS+(I+.5)*RES
      AZ3   (NTAR,II,MODE)=AZIM
      SNDET3(NTAR,II,MODE)=SUM(I)
      IF (XLOG.GT.0.0001) SNDET3(NTAR,II,MODE)=N3DB*EXP(SUM(I)/N3DB)
  280 CONTINUE
 5280 FORMAT(1H0,' SUM AND THRESHOLD = ',5X,6F12.4)
      IF (IAZ.LT.3) GO TO 285
C
C     CHECK FOR DETECTIONS
C
      IF (II.GT.0.OR.MER3(NTAR).EQ.-1) GO TO 300
      IF (IMERGE.EQ.1) MER3(NTAR)=-2
  300 RETURN
      END
```

```
      SUBROUTINE FXCLT3
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON /FCIN/ N,PROB,RS,RF,THS,THF,SIGA,SIGR,ISET
      COMMON /FCPT/ R(100),AZ(100),RAN(400),N2,N3,N4
      COMMON /CLTOUT/ ROUT(201),AZOUT(201),ELOUT(201),TOUT(201),
     1 RLOUT(201),PTOUT(201),SOUT(201),NC(100),IC,IV
      COMMON /STABIN/ RMAX,PMAX,RFAC,PFAC,PHASE(2)
C
      IC=0
      IF (N.EQ.0) GO TO 15
C     TIMZB IS THE TIME OF THE ZERO BEARING CROSSING
      TIMZB=T*3600.
C     TIMSCN IS THE SCAN TIME OF THE RADAR
      TIMSCN=RMODE(1,5)*3600.
C     RES IS THE RANGE GATE SIZE
      RES=RC(19)
      CALL SETVR(ISET)
      CALL VRANF(RAN,N4)
      ISET = 2147483647.*RAN(1)
      ISET = 2*(ISET/2) + 1
      DO 20 I=1,N
      IF (RAN(I).GT.PROB) GO TO 20
      IC=IC+1
      NC(IC)=I
      TH=RAN(I+N)*TWOPI
      RAY=SQRT(-2.*ALOG(RAN(I+N2)))
      K=(R(I)+SIGR*RAY*COS(TH))/RES
      ROUT(IC)=(K+0.5)*RES
      TOUT(IC)=TIMZB+TIMSCN*AZ(I)/TWOPI
C
C     GENERATION OF ROLL AND PITCH
C
      RLOUT(IC)=RMAX*SIN(TOUT(IC)*RFAC+PHASE(1))
      PTOUT(IC)=PMAX*SIN(TOUT(IC)*PFAC+PHASE(2))
      CR=COS(RLOUT(IC))
      SR=SIN(RLOUT(IC))
      CP=COS(PTOUT(IC))
      SP=SIN(PTOUT(IC))
      AA=AZ(I)-SHIP(5)
      EL=0.
      TE=0.
      X=SIN(AA)*CR+(COS(AA)*SP+TE*CP)*SR
      Y=COS(AA)*CP-TE*SP
      A=ATAN2(X,Y)+TWOPI
      E=ARSIN(CR*(COS(EL)*COS(AA)*SP+SIN(EL)*CP)-COS(EL)*SIN(AA)*SR)
C
```

```
      C     GENERATION OF MEASURED ANGLES
      C
            ATEMP=A+SIGA*RAY*SIN(TH)
            AT=AMOD(ATEMP,TWOPI)
            ET=E+0.5*RC(5)*RAN(I+N3)
      C
      C    CORRECTION OF ANGLE MEASUREMENTS WITH ROLL AND PITCH
      C
            D=CR*SIN(ET)+SP*SIN(AT)*COS(ET)
            X=-SR*SIN(ET)+CR*SIN(AT)*COS(ET)
            Y=CP*COS(AT)*COS(ET)+SP*D
            AM=ATAN2(X,Y)+TWOPI+SHIP(5)
            AZOUT(IC)=AMOD(AM,TWOPI)
            ELOUT(IC)=ARSIN(-SP*COS(AT)*COS(ET)+CP*D)
      C     ********** NEED TO GENERATE OUTPUT POWER    **************
            SOUT(IC)=55.55
         20 CONTINUE
            RETURN
      C
      C     INITIALIZATION OF THE CLUTTER ROUTINE
      C
            ENTRY FCINIT
            READ 50,ISET,N,PROB,RS,RF,SIGR,THS,THF,SIGA
         50 FORMAT (2I8,7F8.2)
      C
      C     ISET IS THE INITIALIZATION NUMBER FOR THE RANDOM NUMBER GENERATOR
      C     N IS THE NUMBER OF FIXED CLUTTER POINTS
      C     PROB IS THE PROBABILITY THAT THE CLUTTER POINT IS DETECTED
      C     RS IS THE INITIAL RANGE OF THE CLUTTER AREA
      C     RF IS THE FINAL RANGE OF THE CLUTTER AREA
      C     SIGR IS THE STANDARD DEVIATION OF THE RANGE MEASUREMENT
      C          AS A PERCENTAGE OF RANGE RESOLUTION CELL SIZE
      C     THS IS THE INITIAL AZIMUTH OF THE CLUTTER AREA
      C     THF IS THE FINAL AZIMUTH OF THE CLUTTER AREA
      C     SIGA IS THE STANDARD DEVIATION OF THE AZIMUTH MEASUREMENT
      C          AS A PERCENTAGE OF HORIZONTAL 3DB BEAMWIDTH
      C
            PRINT 55,ISET,N,PROB,RS,RF,SIGR,THS,THF,SIGA
         55 FORMAT (1H0,' FIXED CLUTTER ',2I8,7F8.3)
            CALL SETVR(ISET)
      C
      C     CALCULATION OF RANGE CELL DIMENSION
      C
            RES=TAU(1)*300000./2.
            RES=RES*3.2808/6.08
      C     RC(19) = RES     = RANGE RESOLUTION CELL SIZE
            RC(19)=RES
            IF (N.EQ.0) GO TO 15
            RS=RS/6.0802
            RF=RF/6.0802
```

```
      THS=THS/RADIAN
      THF=THF/RADIAN
      SIGA=SIGA*RC(4)
      SIGR=SIGR*RES
      IF (N.GT.100) N=100
      N2=2*N
      N3=3*N
      N4=4*N
      CALL VFANF(RAN,N2)
      ISET = 2147483647.*RAN(1)
      ISET = 2*(ISET/2) + 1
      DO 10 I=1,N
      R(I)=RS+(RF-RS)*RAN(I)
   10 AZ(I)=THS+(THF-THS)*RAN(I+N)
   15 RETURN
      END
```

```
      SUBROUTINE INITAL
      DIMENSION AMODE(30,2)
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3      ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/B/ ENVIR(10),SURC(30),RE,CNM,CCM,ACON,BETA,
     *        DOTP(20),POLRZ,IKEYF,XKTONS,XNMTOM,TARCS,WVL,FOPIOB,FOPISO
      COMMON/I/ PBBS,HOFK,THETEK,DBDOWN,THH,THV,GN
      RC(10)=290.0*1.38*10.0**(-23)
C     X Y Z SHIP COORDINATES
      READ 50, (SHIP(I),I=1,3), SHIP(5)
   50 FORMAT(9F8.2,I2,F6.2)
      PRINT 500, (SHIP(I),I=1,3), SHIP(5)
  500 FORMAT(/,' SHIP X,Y,Z, COORDINATES ARE ',3F8.3,8X,'HEADING IS',
     1        F8.3)
       MILION=1.0E+6
      DO 30 I=1,3
   30 SHIP(I)=SHIP(I)/6.0802
      PI=3.1415926536
      TWOPI=PI*2.0
      PIOVR2 =PI/2.0
      RADIAN=57.29578
      SHIP(4)=SQRT(SHIP(3))
      SHIP(5) = SHIP(5)/RADIAN
      READ 50,(RC(I),I=1,9),NSCAN,POLRZ
      IF(NSCAN.LE. 30) GO TO 10
      NSCAN = 30
   10 CONTINUE
      PRINT 501,(RC(I),I=1,9),NSCAN,POLRZ
  501 FORMAT(/' 11 BASIC RADAR PARAMETERS ARE ',9F8.2,I4,F6.2)
      RC(4)=RC(4)/RADIAN
      RC(5)=RC(5)/RADIAN
      THH=RC(4)
      THV=RC(5)
      RC(6)=10.**(RC(6)/10.)
      GN=RC(6)
      RC(3)=10.**(RC(3)/10.)
      RC(7)=10.**(-RC(7)/20.)
      RC(8)=10.**(-RC(8)/10.)
      RC(9)=10.**(-RC(9)/10.)
      DBDOWN = RC(7)*RC(7)
      DO 60 J = 1,NSCAN
C     RMODE(1,5) IS USED AS RADAR SCAN RATE FOR ALL MODES
      READ 51,(RMODE(J,I),I=1,8),AMODE(J,1),RMODE(J,11),SURC(J)
     *        ,RMODE(J,12),DWL(J),SM,SMODE(J,2)
   51 FORMAT(10F8.2)
      IMODE(J,1)=AMODE(J,1)
```

```
      MPF=PMF
      PRINT 511,J,(RMODE(J,I),I=1,8),IMODE(J,1),RMODE(J,11),SURC(J)
     *           ,RMODE(J,12),DWL(J),SM,SMODE(J,2)
  511 FORMAT(/,' 16 MODE ',I2,' PARAMETERS ARE ',8F9.3,I8,/,50X,6F9.3)
      IF (RMODE(J,5).GT.0.0) GO TO 55
      RMODE(J,5)=10.0
   55 RMODE(J,1)=RMODE(J,1)/RADIAN
      RMODE(J,2)=RMODE(J,2)/RADIAN
      IF(SM.EQ.0)SM=RMODE(J,4)
      SMODE(J,1)=150.*SM/XNMTOM
      SMODE(J,2) = 10.**(-SMODE(J,2)/10.)
      SMODE(J,3) = PMF
      RMODE(J,5)=RMODE(J,5)/3600.0
      RMODE(J,6)=RMODE(J,6)/3600.0
      RMODE(J,4)=RMODE(J,4)/MILION
      RMODE(J,8)=10.**(-RMODE(J,8)/10.)
      RMODE(J,3)=RMODE(J,3)*MILION
      TAU(J) = RMODE(J,11)/MILION
      IF(RMODE(J,12).LE.0) RMODE(J,12) = 1.0/RMODE(J,11)
      RMODE(J,12) = RMODE(J,12)*MILION
      IMODE(J,2)=MAX1(RMODE(J,12)*RMODE(J,11)/MILION +0.5,1.0)
      RMODE(J,11) = 10.**(-PMF)
      SUBC(J) = 10.**(-SUBC(J)/10.)
   60 CONTINUE
C
C     READ IN PARAMETERS FOR MOVING WINDOW DETECTOR
C     RC(15) = NREF   = NO. REFERENCE CELLS ON EACH SIDE OF TARGET CELL
C     RC(16) = COR    = CLUTTER CORRELATION COEFFICIENT
C     RC(17) = FSIG   = NO. STANDARD DEVIATIONS USED IN THRESHOLD
C     RC(18) = AZBBP = AZIMUTH OFFSET BETWEEN BEAM POSITIONS
C     RC(19) = RESOLUTION CELL SIZE  (CALCULATED)
C     RC(20) = XLOG = VIDEO TYPE
C                     0   LINEAR VIDEO
C                     1   LOG VIDEO
C     RC(21) = THRSH = NO. OF REFERENCE CELLS USED
C                      0   ALL CELLS USED
C                      < 0   SMALLER HALF USED
C                      > 0   LARGER HALF USED
C     RC(22) = PARM = PARAMETERS USED TO CALCULATE THRESHOLD
C                     1   MEAN USED
C                     2   MEAN AND VARIANCE USED
C
      READ 70, (RC(I),I=15,18), (RC(I),I=20,22)
   70 FORMAT(10F8.2)
      PRINT 700, (RC(I),I=15,18), (RC(I),I=20,22)
  700 FORMAT(1H0,'   ADDITIONAL RADAR PARAMETERS ARE ',7F9.3/)
C     AZIMUTH OFFSET FROM DEGREES TO RADIANS
      RC(18) = RC(18)/RADIAN
      RETURN
      END
```

```
      SUBROUTINE INIT3D(N,AZINIT)
C
C     THIS ROUTINE SHOULD BE CALLED AT THE BEGINNING OF EACH AND EVERY
C     SCAN, IT CALCULATES THE INITIAL BEAM POSITION AND ZEROS THE
C     FOLLOWING ARRAYS: MER3, IKEY, AND NDET3
C
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1       ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4       ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON /DET3/ NDET3(20,30),MER3(20),RANGE3(20,9,30),AZ3(20,9,30),
     1   SNDET3(20,9,30)              ,TIME3(20),IKEY(20)
C
C     N IS THE NUMBER OF TARGETS
C     AZINIT IS THE INITIAL BEAM POSITION FOR THIS SCAN
C     AZBBP IS THE AZIMUTH OFF SET BETWEEN AZIMUTH BEAM POSITIONS
C
      AZBBP = RC(18)
      CALL VRANF(AZINIT,1)
      AZINIT = AZINIT*AZBBP
      DO 10 I=1,N
      MER3(I)=0
      IKEY(I)=0
      DO 10 J=1,NSCAN
   10 NDET3(I,J)=0
      RETURN
      END
```

```
      SUBROUTINE MRDT3D (RES,N,TH3DB,EL3DB)
      COMMON NSCAN,NEXT,NUMTGT,T,BLDT,ENDTIM ,SMODE(30,20)
     1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,TSWIT,TEMPWR
     4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON /MERSET/ DETPAR(100,4)
      COMMON /DET3/ NDET3(20,30),MER3(20),RANGE3(20,9,30),AZ3(20,9,30),
     1   SNDET3(20,9,30)            ,TIME3(20),IKEY(20)
      COMMON /DET/ NDET(20),MER(20),RANGE(20,3),AZ(20,6),SNDET(20,3),
     1             ELEV(20,3),TIME(20)
C
C     RES IS THE RANGE RESOLUTION
C     N IS THE NUMBER OF TARGETS
C     TH3DB IS THE AZIMUTH 3-DB ANTENNA BEAMWIDTH
C     EL3DB IS THE ELEVATION 3-DB ANTENNA BEAMWIDTH
C
C     THIS ROUTINE RESOLVES ALL MERGING PROBLEMS AND MAKES THE POSITION
C     ESTIMMATES FOR THE 3-D RADAR. THE APL SYS-1-D LOGIC IS USED.
C     SPECIFICALLY, THERE MUST BE A GAP IN EITHER RANGE, AZIMUTH, OR
C     ELEVATION FOR A SECOND DETECTION TO BE DECLARED
C
C
      DO 1000 KTAR=1,N
C
C     FIND FIRST UNUSED DETECTION FOR TARGET # KTAR
C
      DO 10 J=1,NSCAN
      IF (NDET3(KTAR,J).GT.0) GO TO 15
   10 CONTINUE
      NDET(KTAR)=0
      MER(KTAR)=MER3(KTAR)
      TIME(KTAR)=TIME3(KTAR)
      GO TO 1000
   15 II=0
   20 K=1
      JJ=NDET3(KTAR,J)
      DETPAR(K,1)=RANGE3(KTAR,JJ,J)
      DETPAR(K,2)=   AZ3(KTAR,JJ,J)
      DETPAR(K,3) = RMODE(J,1) + RC(5)/2.
      DETPAR(K,4)=SNDET3(KTAR,JJ,J)
      NDET3(KTAR,J)=JJ-1
   25 KSTART=K
C
C     FIND ALL ADJACENT DETECTIONS
C
      DO 100 LTAR=KTAR,N
      IF (LTAR.EQ.KTAR) GO TO 30
      IF (MER3(KTAR).NE.-1) GO TO 100
      IF (MER3(LTAR).NE.-1) GO TO 100
```

```
   30 DO 45 J=1,NSCAN
      JJ=NDET3(LTAR,J)
      IF (JJ.EQ.0) GO TO 45
      NEWJJ=0
      DO 40 I=1,JJ
      CALL ADJDET(RES,TH3DB,EL3DB,K,NEWJJ,LTAR,I,J)
   40 CONTINUE
      NDET3(LTAR,J)=NEWJJ
   45 CONTINUE
  100 CONTINUE
      IF (K.GT.KSTART) GO TO 25
C
C     ESTIMATE OF POSITION
C
      II=II+1
      IF (II.GT.3) GO TO 400
      NDET(KTAR)=II
      TIME(KTAR)=TIME3(KTAR)
      MER(KTAR)=MER3(KTAR)
      SN=0
      SR=0
      SA=0
      SE=0
      SMAX=0
      EMIN=100000.
      EMAX=-100000.
      DO 200 I=1,K
      SR=SR+DETPAR(I,1)*DETPAR(I,4)
      SA=SA+DETPAR(I,2)*DETPAR(I,4)
      SE=SE+DETPAR(I,3)*DETPAR(I,4)
      SN=SN+DETPAR(I,4)
      EMIN=AMIN1(EMIN,DETPAR(I,3))
      EMAX=AMAX1(EMAX,DETPAR(I,3))
      SMAX=AMAX1(SMAX,DETPAR(I,4))
  200 CONTINUE
      RANGE(KTAR,II)=SR/SN
         AZ(KTAR,II)=SA/SN
      SNDET(KTAR,II)=SMAX
       ELEV(KTAR,II)=SE/SN
      IF (SE/SN.GT.EL3DB) GO TO 210
      ELEV(KTAR,II)=(EMAX+EMIN)/2.
  210 DO 220 J=1,NSCAN
      IF (NDET3(KTAR,J).GT.0) GO TO 20
  220 CONTINUE
      GO TO 1000
  400 PRINT 50,II,KTAR
   50 FORMAT (1H0,'  THERE ARE TOO MANY DETECTIONS!',I5,'DETECTIONS FOR
     1TARGET # ',I3)
 1000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE STAB3
      COMMON/TM/NTARG,NJAM,SPEED(20),HEADI(20),HEADF(20),TMANI(20),
     1          TMANF(20),XMANI(20,3),XMANF(20,3),GTURN(20),TURN(20),
     2         CM(20,2),RADM(20),ITYPE(20),ALT(20,5),TALT(20,5),NALT(20)
      COMMON NSCAN,NEXT,NUMTGT,T,BLDT,ENDTIM ,SMODE(30,20)
     1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON /DET/ NDET(20),MER(20),RANGE(20,3),AZ(20,6),SNDET(20,3),
     1              ELEV(20,3),TIME(20)
      COMMON /STAB/ ROLL(20),PITCH(20)
      COMMON /STABIN/ RMAX,PMAX,RFAC,PFAC,PHASE(2)
      DO 30 I=1,NTARG
      IF (NDET(I).EQ.0) GO TO 30
      K=NDET(I)
      ROLL(I) =RMAX*SIN(TIME(I)*RFAC+PHASE(1))
      PITCH(I)=PMAX*SIN(TIME(I)*PFAC+PHASE(2))
      CR=COS(ROLL(I))
      SR=SIN(ROLL(I))
      CP=COS(PITCH(I))
      SP=SIN(PITCH(I))
      AA=TRGPOS(I,5)-SHIP(5)
      EL=TRGPOS(I,6)
      TE=TAN(TRGPOS(I,6))
      X=SIN(AA)*CR+(COS(AA)*SP+TE*CP)*SR
      Y=COS(AA)*CP-TE*SP
      A=ATAN2(X,Y)+TWOPI
      E=ARSIN(CR*(COS(EL)*COS(AA)*SP+SIN(EL)*CP)-COS(EL)*SIN(AA)*SR)
   20 DO 25 J=1,K
C
C     GENERATION OF MEASURED ANGLES
C
      ATEMP=AZ(I,J)+A-TRGPOS(I,5)
      AT=AMOD(ATEMP,TWOPI)
      ET    =ELEV(I,J)+E-EL
C
C    CORRECTION OF ANGLE MEASUREMENTS WITH ROLL AND PITCH
C
      D=CR*SIN(ET)+SR*SIN(AT)*COS(ET)
      X=-SR*SIN(ET)+CR*SIN(AT)*COS(ET)
      Y=CP*COS(AT)*COS(ET)+SP*D
      AM=ATAN2(X,Y)+TWOPI+SHIP(5)
      AZ(I,J)=AMOD(AM,TWOPI)
      ELEV(I,J)=ARSIN(-SP*COS(AT)*COS(ET)+CP*D)
   25 CONTINUE
   30 CONTINUE
      RETURN
C
```

```
      C
      C      INITIALIZATION
      C
             ENTRY STRINT
      C
      C      RMAX IS THE MAXIMUM ROLL ANGLE
      C      PMAX IS THE MAXIMUM PITCH ANGLE
      C      RPER IS THE ROLL PERIOD
      C      PPER IS THE PITCH PERIOD
      C
             READ 50,RMAX,PMAX,RPER,PPER
          50 FORMAT (4F8.2)
             PRINT 55,RMAX,PMAX,RPER,PPER
          55 FORMAT (1H0,'  ROLL AND PITCH  ',4F8.2)
             RMAX=RMAX/RADIAN
             PMAX=PMAX/RADIAN
             RFAC=TWOPI/RPER
             PFAC=TWOPI/PPER
             CALL VRANF(PHASE,2)
             PHASE(1)=TWOPI*PHASE(1)
             PHASE(2)=TWOPI*PHASE(2)
             RETURN
             END
```

```
      SUBROUTINE VPCLT3
      COMMON NSCAN,NEXT,NUMTGT,T,DLDT,ENDTIM ,SMODE(30,20)
     1       ,PI,PIOVR2 ,T*OPI,RADIAN,TAU(30),OSTAP,DWL(30)
     2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4       ,SHIP(9),PC(30),RMODE(30,12),IMODE(30,2)
      COMMON /VCIN/ NREG,FN(5),RS(5),RF(5),THS(5),THF(5),ELS(5),ELF(5),
     1    ISET
      COMMON /VCLT/ PI2,RAN(305),FLAM(5)
      COMMON /CLTOUT/ ROUT(201),AZOUT(201),ELOUT(201),TOUT(201),
     1 RLOUT(201),PTOUT(201),SOUT(201),NC(100),IC,IV
      COMMON /STABIN/ RMAX,PMAX,RFAC,PFAC,PHASE(2)
C
      IV=IC
      IF (NREG.EQ.0) GO TO 95
      CALL SETVP(ISET)
      CALL VRANF(RAN,305)
      ISET = 2147483647.*RAN(305)
      ISET = 2*(ISET/2) + 1
C     TIMZB IS THE TIME OF THE ZERO BEARING CROSSING
      TIMZB=T*3600.
C     TIMSCN IS THE SCAN TIME OF THE RADAR
      TIMSCN=RMODE(1,5)*3600.
C     RES IS THE RANGE GATE SIZE
      RES=PC(19)
      IRAN=0
      DO 20 I=1,NREG
      IRAN=IRAN+1
      IF (IRAN.GT.302) GO TO 30
      A = THS(I)-FLAM(I)*ALOG(RAN(IRAN))
   15 IF (A.GT.THF(I)) GO TO 20
      IV=IV+1
      AZOUT(IV)=A
      K=(RS(I) + (RF(I)-RS(I))*RAN(IRAN+1))/RES
      ROUT(IV)=(K+0.5)*RES
      ELOUT(IV)=ELS(I)+(ELF(I)-ELS(I))*RAN(IRAN+2)
      TOUT(IV)=TIMZB+TIMSCN*A/TWOPI
      RLOUT(IV)=RMAX*SIN(TOUT(IV)*RFAC+PHASE(1))
      PTOUT(IV)=PMAX*SIN(TOUT(IV)*PFAC+PHASE(2))
      SOUT(IV)=33.33
      IRAN=IRAN+3
      IF (IRAN.GT.302) GO TO 30
      A=A-FLAM(I)*ALOG(RAN(IRAN))
      GO TO 15
   20 CONTINUE
   30 RETURN
C
C     INITIALIZATION
C
      ENTRY VCINIT
```

```
          READ 50,ISET,NREG
     50   FORMAT(2I8)
C
C         ISET IS THE INITIALIZATION NUMBER OF THE RANDOM NUMBER GENERATOR
C         NREG IS THE NUMBER OF CLUTTER REGIONS
C
          PRINT 55,ISET,NREG
     55   FORMAT (1H0,' VARIABLE CLUTTER ',2I8)
          IF (NREG.EQ.0) GO TO 95
          IF (NREG.GT.5) NREG=5
          DO 5 I=1,NREG
          READ 51,FN(I),RS(I),RF(I),THS(I),THF(I),ELS(I),ELF(I)
     51   FORMAT (7F8.2)
C
C         FN IS THE AVERAGE NUMBER OF CLUTTER POINT PER REGION
C         RS IS THE INITIAL RANGE OF THE CLUTTER AREA
C         RF IS THE FINAL RANGE OF THE CLUTTER AREA
C         THS IS THE INITIAL AZIMUTH OF THE CLUTTER AREA
C         THF IS THE FINAL AZIMUTH OF THE CLUTTER AREA
C         ELS IS THE INITIAL ELEVATION OF THE CLUTTER AREA
C         ELF IS THE FINAL ELEVATION OF THE CLUTTER AREA
C
          PRINT 56,FN(I),RS(I),RF(I),THS(I),THF(I),ELS(I),ELF(I)
     56   FORMAT (25X,7F9.3)
          RS(I)=RS(I)/6.0802
          RF(I)=RF(I)/6.0802
          THS(I)=THS(I)/RADIAN
          THF(I)=THF(I)/RADIAN
          ELS(I)=ELS(I)/RADIAN
          ELF(I)=ELF(I)/RADIAN
      5   CONTINUE
          DO 10 I=1,NREG
     10   FLAM(I)=(THF(I)-THS(I))/FN(I)
     95   RETURN
          END
```

Appendix D

PROGRAM LISTINGS OF ROUTINES COMMON TO BOTH VERSIONS OF SURDET

```
      FUNCTION BEAM(ALPHA,BETA,GAMMA,KEY1)
      COMMON NSCAN,NEXT,NUMTGT,T,SLDT,ENDTIM ,SMODE(30,20)
     1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2        ,XYZT(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/I/ PORS,HOFK,THETBK,DBDOWN,THH,THV,GN
      THETA=2.78*ALPHA/BETA
      IF(GAMMA.EQ.1..AND.KEY1.EQ.1) GO TO 40
      IF (THETA.GT.1.0E-6) GO TO 20
      SINC=1.0
      GO TO 30
   20 SINC = (SIN(THETA)/THETA)**2
      SINC=AMAX1(DBDOWN,SINC)
      IF(ABS(THETA).GT.3.14159)SINC=DBDOWN
      GO TO 30
   40 CONTINUE
      THETBK = 2.*PORS
      HOFK = .25*(THETBK+SQRT(THETBK*THETBK+3.1*RC(5)*RC(5)))
      IF(PORS-ALPHA.GT.HOFK) GO TO 50
      IF(ABS(THETA).GT.1.E-6) GO TO 55
      SINC = 1.
      GO TO 30
   55 SINC = (SIN(THETA)/THETA)**2
      GO TO 30
   50 CONTINUE
      IF(PORS-ALPHA .LT. RMODE(NEXT,2)) GO TO 60
      SINC = DBDOWN
      GO TO 30
   60 CONTINUE
      THETA = 2.783*(HOFK-PORS)/BETA
      SINC = (SIN(THETA)/THETA*SIN(HOFK)/SIN(PORS-ALPHA))**2
   30 BEAM = SINC
   65 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CLTSIG (XFRE,XBEAM,XANG,SIGZ,POLRZ)
      COMMON/A/ SIGOH(7,6,5),SIGOV(7,6,5),XPAR(3,7)
      DIMENSION ILIM(2,6,5),INDEX(3,2),NDX(3)
      DIMENSION HOGIS(7,6,2),VOGIS(7,6,2)
      DIMENSION PAR(3)
      EQUIVALENCE (VOGIS,SIGOV(1,1,4))
      EQUIVALENCE (HOGIS,SIGOH(1,1,4))
      DATA OLDANG,OLDPOL,OLDBRW,OLDFRE / 4*0.0 /
      DATA NDX / 7,6,5/
      DATA XPAR / 500.,1.,1.,1250.,2.,3.,3000.,3.,10.,5600.,4.,30.,
     *            9000.,5.,100.,17000.,6.,0.,35000.,0.,0./
      DATA SIGOH/
     *          -100.,-100.,-90.,-87.,-84.,-84.,-84.,
     *          -94.,-94.,-88.,-78.,-72.,-72.,-72.,
     *          -95.,-90.,-75.,-68.,-63.,-63.,-63.,
     *          -90.,-82.,-68.,-62.,-55.,-55.,-55.,
     *          -75.,-75.,-58.,-55.,-48.,-48.,-48.,
     *          -65.,-65.,-53.,-48.,-42.,-42.,-42.,
     *          -90.,-90.,-85.,-79.,-74.,-74.,-74.,
     *          -84.,-84.,-76.,-72.,-68.,-68.,-68.,
     *          -87.,-78.,-66.,-61.,-57.,-57.,-57.,
     *          -72.,-72.,-58.,-50.,-46.,-46.,-46.,
     *          -67.,-67.,-48.,-44.,-42.,-39.,-39.,
     *          -62.,-62.,-44.,-41.,-39.,-39.,-39.,
     *          -86.,-80.,-73.,-70.,-66.,-66.,-66.,
     *          -84.,-73.,-65.,-56.,-49.,-43.,-41.,
     *          -82.,-65.,-55.,-48.,-44.,-40.,-39.,
     *          -78.,-62.,-48.,-43.,-40.,-37.,-36.,
     *          -67.,-58.,-42.,-39.,-36.,-34.,-32.,
     *          -65.,-53.,-40.,-35.,-33.,-31.,-30./
      DATA HOGIS/
     1           -75.,-72.,-68.,-63.,-58.,-55.,-53.,
     1           -70.,-66.,-59.,-54.,-48.,-45.,-43.,
     1           -66.,-61.,-53.,-48.,-42.,-41.,-40.,
     1           -61.,-58.,-46.,-42.,-39.,-37.,-37.,
     1           -56.,-50.,-41.,-38.,-35.,-35.,-35.,
     1           -53.,-46.,-38.,-34.,-32.,-31.,-31.,
     1           -60.,-60.,-66.,-57.,-56.,-48.,-45.,
     1           -58.,-58.,-59.5,-53.,-51.,-42.,-34.,
     1           -55.,-55.,-51.,-46.,-43.,-35.,-33.,
     1           -50.,-48.,-46.,-40.,-37.,-33.,-31.,
     1           -48.,-45.,-38.5,-37.,-33.,-31.,-29.,
     1           -47.,-43.,-36.,-33.,-31.,-29.,-27./
      DATA SIGOV/
     *          -96.,-96.,-86.,-83.,-80.,-80.,-80.,
     *          -91.,-91.,-85.,-74.,-65.,-65.,-65.,
     *          -90.,-87.,-72.,-64.,-56.,-56.,-56.,
     *          -85.,-79.,-65.,-56.,-51.,-51.,-51.,
     *          -72.,-72.,-55.,-53.,-48.,-48.,-48.,
```

```
     *              -63.,-63.,-50.,-46.,-44.,-44.,-44.,
     *              -80.,-80.,-71.,-69.,-64.,-64.,-64.,
     *              -76.,-76.,-62.,-60.,-58.,-58.,-58.,
     *              -80.,-71.,-59.,-55.,-52.,-52.,-52.,
     *              -66.,-66.,-55.,-48.,-45.,-45.,-45.,
     *              -61.,-61.,-54.,-46.,-43.,-39.,-39.,
     *              -57.,-57.,-50.,-44.,-39.,-39.,-39.,
     *              -75.,-68.,-64.,-62.,-60.,-60.,-60.,
     *              -70.,-65.,-56.,-53.,-50.,-47.,-40.,
     *              -63.,-58.,-53.,-47.,-44.,-42.,-38.,
     *              -58.,-54.,-48.,-43.,-39.,-37.,-34.,
     *              -55.,-45.,-42.,-39.,-37.,-34.,-32.,
     *              -52.,-43.,-38.,-35.,-33.,-32.,-31./
0014  DATA VOGIS/
     1               -65.,-64.,-64.,-60.,-56.,-52.,-48.,
     1               -60.,-53.,-52.,-49.,-45.,-43.,-41.,
     1               -55.,-53.,-49.,-45.,-41.,-39.,-37.,
     1               -43.,-43.,-43.,-40.,-38.,-36.,-34.,
     1               -38.,-38.,-38.,-36.,-35.,-33.,-31.,
     1               -38.,-38.,-35.,-33.,-31.,-31.,-30.,
     1               -45.,-45.,-47.,-48.,-49.,-45.,-44.,
     1               -40.,-40.,-42.,-44.,-42.,-40.,-38.,
     1               -35.,-37.,-38.,-39.,-36.,-34.,-33.,
     1               -34.,-34.,-34.,-34.,-32.,-32.,-31.,
     1               -30.,-31.,-31.,-32.,-31.,-29.,-29.,
     1               -25.,-28.,-28.,-28.,-26.,-26.,-26./
0015  DATA ILIM / 2,5,2,5,1,5,1,5,2,5,2,5,
     *   2,5,2,5,1,5,2,5,2,6,2,6,
     *   1,5,1,7,1,7,1,7,1,7,1,7,
     *   1,7,1,7,1,7,1,7,1,7,1,7,
     *   2,7,2,7,1,7,1,7,1,7,1,7/
0016  IF(XFRE.EQ.OLDFRE.AND.XBEAU.EQ.OLDBOW.AND.POLRZ.EQ.OLDPOL.
     *AND.(XANG-OLDANG).LE.0.01) GO TO 65
0017  ANG = POLRZ*3.14159265/180.
0018  PAR(1) = AMAX1(500.,AMIN1(XFRE,35000.))
0019  PAR(2) = AMAX1(1.,AMIN1(XBEAU,6.))
0020  PAR(3) = AMAX1(1.,AMIN1(10.*XANG,100.))
0021  DO 10 I = 1,3
0022  ND = NDX(I)
0023  DO 30 K = 1,ND
0024  IF(PAR(I).GT.XPAR(I,K)) GO TO 30
0025  INDEX(I,1) = MAX0(K-1,1)
0026  INDEX(I,2) = K
0027  GO TO 9
0028  30 CONTINUE
0029  9 IF(INDEX(I,2).NE.1) GO TO 10
0030  INDEX(I,2) = 2
0031  10 CONTINUE
C
C     CHECK FOR NONEXISTENT DATA
```

```
C
C
C      CALCULATE SIGMA ZERO
C
       IF(INDEX(1,1).EQ.INDEX(1,2).AND.INDEX(2,1 ).EQ.INDEX(2,2)
      *.AND.INDEX(3,1).EQ.INDEX(3,2)) GO TO 50
       SIGZ = 0
       SIGZP = 0
       DO 40 I = 1,2
       DO 40 J = 1,2
       DO 40 K = 1,2
       IT1 = INDEX(1,I)
       IT2 = INDEX(2,J)
       IT3 = INDEX(3,K)
       IT1P = INDEX(1,3-I)
       IT2P = INDEX(2,3-J)
       IT3P = INDEX(3,3-K)
       SIGZP = SIGZP + SIGOV(IT1,IT2,IT3)*
      *         ABS(XPAR(1,IT1P)-PAR(1))*
      *         ABS(XPAR(2,IT2P)-PAR(2))*
      *         ABS(XPAR(3,IT3P)-PAR(3))
    40 SIGZ = SIGZ+ SIGOH(IT1,IT2,IT3)*
      *         ABS(XPAR(1,IT1P)-PAR(1))*
      *         ABS(XPAR(2,IT2P)-PAR(2))*
      *         ABS(XPAR(3,IT3P)-PAR(3))
       SIGN = 1.
       DO 80 I=1,3
       IT1 = INDEX(I,1)
       IT2 = INDEX(I,2)
       IF(XPAR(I,IT1).EQ.XPAR(I,IT2)) GO TO 80
       SIGN = SIGN*(XPAR(I,IT2)-XPAR(I,IT1))
    80 CONTINUE
       SIGZ = SIGZ/SIGN
       SIGZP = SIGZP/SIGN
       GO TO 60
    50 CONTINUE
       IT1 = INDEX(1,1)
       IT2 = INDEX(2,1)
       IT3 = INDEX(3,1)
       SIGZ = SIGOH(IT1,IT2,IT3)
       SIGZP = SIGOV(IT1,IT2,IT3)
    60 CONTINUE
       SIGZP = 10.**(SIGZP/10.)
       SIGZ = 10.**(SIGZ/10.)
       SIGZ = SQRT((SIGZ*COS(ANG))**2 + (SIGZP*SIN(ANG))**2)
       OLDANG=XANG
       OLDPOL=POLRZ
       OLDBOW=XHEAU
       OLDFRE=XFRE
    65 RETURN
       END
```

```
      SUBROUTINE ENVIRN
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1       ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3    ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4       ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/B/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACON,BETA,
     *       DOTP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPIOR,FOPISQ
      COMMON/H/FAC4,AMBN,XJAMN,IKEYJG,XXXXX
      READ 50,(ENVIR(I),I=1,4)
50    FORMAT (4F8.2)
      PRINT 500,(ENVIR(I),I=1,4)
500   FORMAT(/,' 4 ENVIROMENTAL PARAMETERS ARE ',4F8.2)
      FAC4=1.
      ENVIR(2) = ENVIR(2)/6.0802
      SIGMAH = .00666667*(XKTOMS*ENVIR(1))**2*(XNMTOM*ENVIR(2)/10.)
     *           **(-.19364)
      RETURN
      END
```

```
      SUBROUTINE GAIN(IKEY,JTAR,ITAR,GAINR)
C
C     JTAR = TARGET UNDER DETECTION
C     ITAR = TARGET FOR WHICH FIELD STRENGTH RATIO IS TO BE DETERMINED
C
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1      ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2      ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3    ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4      ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/B/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACON,BETA,
     *      DOTP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPIOE,FOPISQ
      COMMON/G/ SRTAR,SINPSI,COSPSI
      COMMON/I/ PBBS,HOFK,THETRK,DRDOWN,THH,THV,GN
      IF(IKEY.EQ.1) GO TO 10
      GAINR = SQRT(FHV(ITAR))
      RETURN
   10 CONTINUE
      OAH = SMLANG(TRGPOS(JTAR,5)-TRGPOS(ITAR,5))
      ALFV = (2.*SRTAR*SINPSI*COSPSI/(TRGPOS(ITAR,4)*XNMTOM))
      IF(ALFV.LE.1.)GO TO 30
      IF(ALFV.LE.1.01)GO TO 40
   40 ALFV=1.
   30 CONTINUE
      ALFV = ARSIN(ALFV)
      ALFV = TRGPOS(ITAR,6)-ALFV
      OAV = SMLANG(TRGPOS(JTAR,6)-ALFV)
      IF(RC(2).EQ.1.) OAV = (PBBS-ALFV)
      IF(RC(2).EQ.1.) GO TO 20
      IF(OAH.LE.(1.13*RC(4)).AND.OAV.LE.(1.13*RC(5))) GO TO 20
      GAINR = RC(7)
      RETURN
   20 FH = BEAM(OAH,RC(4),RC(2),0)
      FV = BEAM(OAV,RC(5),RC(2),1)
      GAINR = FH*FV
      GAINR = AMAX1(RC(7),SQRT(GAINR))
      RETURN
      END
```

```
      SUBROUTINE JAM(JTAR,EJ,EC)
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1       ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4       ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/B/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACON,BETA,
     *       DOTP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPIOB,FOPISQ
      COMMON/D/ ALPHAD,SIGZ,V,AR1,AR2,SIGC,SIG
      COMMON/H/FAC4,AMBN,XJAMN,IKEYJG,XXXXX
      COMMON/I/ PBBS,HOFK,THETBK,DBDOWN,THH,THV,GN
      COMMON/TS/ISTAT(20),TSCAN(20,30)
      EJ=0.0
      FACTOR= WVL*WVL/FOPISQ*RC(6)*RC(8)*RMODE(NEXT,8)
      HR = SHIP(3)*XNMTOM
      HT = TRGPOS(JTAR,3)*XNMTOM
      SL = DBDOWN*DBDOWN
      AGAIN = 1
      THETB = RC(5)
      PHIB = RC(4)
      DO 20 J=1,NUMTGT
C     CHECK IF TARGET ACTIVE
      IF(ISTAT(J) .NE. 1) GO TO 20
      PJ=SIGJAM(J)
      SR = TRGPOS(J,4)*XNMTOM
      IF((PJ.LE.(0.).AND.J.EQ.JTAR).OR.SR.LE.(0.)) GO TO 20
      OAH=SMLANG(TRGPOS(JTAR,5)-TRGPOS(J,5))
      OAV=SMLANG(TRGPOS(JTAR,6)-TRGPOS(J,6))
      IF(RC(2).EQ.1.) OAV = (PBBS-TRGPOS(J,6))
      IF(RC(2).EQ.1.) GO TO 10
      IF (OAH.LE.(1.13*RC(4)).AND.OAV.LE.(1.13*RC(5))) GO TO 10
      FHV(J)=DBDOWN
      GO TO 15
   10 FH = BEAM(OAH,RC(4),RC(2),0)
      FV = BEAM(OAV,RC(5),RC(2),1)
      FHV(J)=FH*FV
      IF(RC(2) .EQ. 1.0 .AND. TRGPOS(J,6) .LT. RMODE(NEXT,2) .AND. FH
     * .GT. DBDOWN) GO TO 15
      FHV(J)=AMAX1(DBDOWN,FHV(J))
   15 XJAMFA = FACTOR*PJ*FHV(J)/(SR*SR)
      CALL MULPTH(JTAR,J,FAC)
      XJAMFA = XJAMFA*FAC*FAC
      EJ = EJ + XJAMFA
      XJAMN = EJ
   20 CONTINUE
C     CALCULATE THE EFFECT OF CLUTTER
      EC = 0.
   25 SR = TRGPOS(JTAR,4)*XNMTOM
      IF(ENVIR(1).LT.0) GO TO 30
      DC = (1.-HR/(2.*RE))*SQRT(SR*SR - HR*HR)
```

```
      IF(DC.GE.DSTAR*XNMTOM) GO TO 30
      SINALF = HR/SR -SR/(2.*RE)
      IF(SINALF.LT.0) GO TO 30
      ALPHA = ARSIN(SINALF)
      ALPHAD = ALPHA*RADIAN
      TEMP = ENVIR(1)*XKTOMS*(7.5/(ENVIR(2)*XNMTOM))**.09682
      BEAUS = ACON*(TEMP/XKTOMS)**BETA
      XFRE=RC(1)+DWL(NEXT)
      CALL CLTSIG (XFRE,BEAUS,ALPHAD,SIGZ,POLRZ)
      V = TAU(NEXT)*CNM/(2.*COS(ALPHA))*XNMTOM
      THETT =ARSIN((HT-HR)/SR - SR/(2.*RE))
      IF(RC(2).EQ.1.) THETT = PBBS-DSTAR*XNMTOM/RE
      SMTB = -SIN(THETB/2.+THETT)
      SPTB = SIN(THETB/2.-THETT)
      RADM2 = SMTB*SMTB-2.*HR/RE
      RADP2 = SPTB*SPTB-2.*HR/RE
      IF(RADM2.LT.0) GO TO 26
      RMTB = 2.*HR/(SMTB+SQRT(RADM2))
      GO TO 27
   26 RMTB = 1.E+35
   27 IF(RADP2.LT.0) GO TO 28
      RPTB = 2.*HR/(SPTB+SQRT(RADP2))
      IF(RPTB.LT.0) RPTB = 1.E+35
      GO TO 29
   28 RPTB = 1.E+35
   29 CONTINUE
      R1 = AMIN1(SR,DSTAR*XNMTOM)
      R2 = AMIN1(SR+V,DSTAR*XNMTOM)
      IF(RMTB.LT.0) RMTB = 1.E+35
      S1 = AMAX1(R1,RPTB)
      S2 = AMIN1(R2,RMTB)
      WS = .5*PHIB *(1./(S1*S1)-1./(S2*S2))
      WR = PI*(1./(R1*R1)-1./(R2*R2))
      WS = AMAX1(0.0,WS)
      AR1 = WR
      AR2 = WS
      C = TEMPWR*SR**4*SIGZ/TARCS
      SIG = C
      SIGC = C*((AGAIN-SL)*WS+SL*WR)*SUBC(NEXT)
      EC = SIGC
   30 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MATCH
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1         ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2         ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3      ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4         ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/B/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACON,BETA,
     *        ORTP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPIOB,FOPISO
      COMMON/C/A(3),B(20,3),BMAG2(20)
      COMMON/TM/NTARG,NJAM,SPEED(20),HEADI(20),HEADF(20),TMANI(20),
     1            TMANF(20),XMANI(20,3),XMANF(20,3),GTURN(20),TURN(20),
     2          CM(20,2),RADM(20),ITYPE(20),ALT(20,5),TALT(20,5),NALT(20)
      COMMON/TS/ISTAT(20),TSCAN(20,30)
C
C     MATCH SCANTIME VALUES WITH TIMES EACH TARGET COMES WITHIN SCOPE
C     LIMITS
C     TSCAN(J,I) IS TIME MODE I FIRST SCANS TARGET J AFTER TARGET J HAS
C     COME WITHIN RADAR INSTRUMENTED RANGE
C
      TMAX = 1.E38
      DO 90 J = 1,NTARG
C     INITIALIZE ISTAT VECTOR
C     ISTAT = 0   TARGET NOT ACTIVATED
C     STAT = 1   TARGET ACTIVE
      ISTAT(J) = 0
      DO 10 K=1,3
      A(K)=XYZI(J,K)-SHIP(K)
   10 CONTINUE
      AMAG2=A(1)*A(1)+A(2)*A(2)+A(3)*A(3)
      IF (ITYPE(J) .EQ. 2) GO TO 25
C
C     NO MANEUVER
      B(J,1) = XYZF(J,1) - XYZI(J,1)
      B(J,2) = XYZF(J,2) - XYZI(J,2)
      TEMP = XYZF(J,3)
      IF (ITYPE(J) .EQ. 0) GO TO 18
      TEMP = ALT(J,2)
   18 B(J,3) = TEMP - XYZI(J,3)
   20 BMAG2(J) = B(J,1)*B(J,1) + B(J,2)*B(J,2) + B(J,3)*B(J,3)
      GO TO 22
C
C     MANEUVER
   25 B(J,1) = COS(HEADI(J))
      B(J,2) = SIN(HEADI(J))
      BMAG2(J) = B(J,1)*B(J,1) + B(J,2)*B(J,2)
      B(J,3) = 0.
   22 ADOTB = A(1)*B(J,1) + A(2)*B(J,2) + A(3)*B(J,3)
      ADOTB2=ADOTB*ADOTB
      K = ITYPE(J)+1
```

```
      IF(K .NE. 2) GO TO 27
C     STORE CRITICAL VALUES FOR TARGET TYPE 1 TO REINITIATE NEW MODE
      XAB = ADOTB
       XAB2 = ADOTB2
      XBMAG2 = BMAG2(J)
      XAMAG2 = AMAG2
      LEG = 1
C
   27 DO 80 I = 1,NSCAN
   29 TSCAN(J,I) = RMODE(I,6) + XYZI(J,4)
      R2=RMODE(I,7)*RMODE(I,7)
      DISC = ADOTB2 - BMAG2(J)*(AMAG2 - R2)
      GO TO (30,40,55), K
   30 IF(DISC .GE. 0.0) GO TO 60
C
C     TARGET NEVER WITHIN RANGE
   35 TSCAN(J,I) = TMAX
      GO TO 80
C
C     ALTITUDE LEGS
   40 IF(LEG .EQ. 1) GO TO 42
C     RESET VALUES FOR INITIAL LEG
      ADOTB = XAB
      ADOTB2 = XAB2
      BMAG2(J) = XBMAG2
      AMAG2 = XAMAG2
      LEG = 1
   42 IF (DISC .LT. 0.0) GO TO 45
      TEM1 =  TALT(J,LEG)
      TEM2 =  TALT(J,LEG+1)
      TERM = SQRT(DISC)
      UMINUS = -1.0*(ADOTB + TERM)/BMAG2(J)
      UPLUS = (TERM - ADOTB)/BMAG2(J)
      WMINUS=AMAX1(UMINUS,0.0)
      WPLUS=AMIN1(UPLUS,1.0)
      IF (WMINUS .GT. WPLUS) GO TO 45
      XSCAN = TEM1 + WMINUS*(TEM2 - TEM1)
      IF((XSCAN .GE. TEM1) .AND. (XSCAN .LE. TEM2)) GO TO 75
C
C     TARGET NEVER WITHIN RANGE ON THIS LEG  -  LOOK AT NEXT LEG
   45 LEG = LEG+1
      IF (LEG .GE. NALT(J)) GO TO 35
      B(J,3) = ALT(J,LEG+1) - ALT(J,LEG)
      DT = (TALT(J,LEG)-XYZI(J,4))/(XYZF(J,4)-XYZI(J,4))
      A(1) = XYZI(J,1) + DT*(XYZF(J,1) - XYZI(J,1)) - SHIP(1)
      A(2) = XYZI(J,2) + DT*(XYZF(J,2) - XYZI(J,2)) - SHIP(2)
      A(3) = ALT(J,LEG) - SHIP(3)
      AMAG2=A(1)*A(1)+A(2)*A(2)+A(3)*A(3)
      BMAG2(J) = B(J,1)*B(J,1) + B(J,2)*B(J,2) + B(J,3)*B(J,3)
      ADOTB = A(1)*B(J,1) + A(2)*B(J,2) + A(3)*B(J,3)
```

```
      ADOTB2=ADOTB*ADOTB
      DISC = ADOTB2 - BMAG2(J)*(AMAG2 - R2)
      GO TO 42
C
C     MANEUVER
   55 TEM1 = TMANI(J)
      IF(DISC .GE. 0.0) GO TO 65
C
C     TARGET NOT WITHIN RANGE PRIOR TO MANEUVER
C     DEFAULT TO BEGINNING OF MANEUVER
   58 XSCAN = TMANI(J)
      GO TO 75
C
   60 TEM1 = XYZF(J,4)
   65 TERM=SQRT(DISC)
      UMINUS=-1.0*(ADOTB+TERM)/BMAG2(J)
      UPLUS=(TERM-ADOTB)/BMAG2(J)
      WMINUS=AMAX1(UMINUS,0.0)
      WPLUS=AMIN1(UPLUS,1.0)
      IF(WMINUS .GT. WPLUS) GO TO (35,35,58), K
      XSCAN = XYZI(J,4) + WMINUS*(TEM1 - XYZI(J,4))
   75 IF (TSCAN(J,I) .GE. XSCAN) GO TO 80
      XN = AINT((XSCAN - TSCAN(J,I))/RMODE(I,5))
      TSCAN(J,I) = TSCAN(J,I) + XN*RMODE(I,5)
      IF(XSCAN .EQ. TSCAN(J,I)) GO TO 80
      TSCAN(J,I) = TSCAN(J,I) + RMODE(I,5)
   80 CONTINUE
   90 CONTINUE
C     DETERMINE EARLIEST TIME EACH MODE SEES A TARGET
      DO 95 I = 1,NSCAN
      TMIN = TMAX
      DO 92 J = 1,NTARG
      TSCAN(J,I) = TSCAN(J,I) - RMODE(I,5)*1.1
      IF(TSCAN(J,I) .GE. TMIN) GO TO 92
      TMIN = TSCAN(J,I)
   92 CONTINUE
      RMODE(I,9) = TMIN
   95 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MULPTH(JTAR,ITAR,FAC)
C
C     JTAR = TARGET UNDER DETECTION  (DIRECTION OF RADAR)
C     ITAR = TARGET FOR WHICH PATTERN PROPAGATION FACTOR IS BEING CALC
C
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1       ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3    ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4       ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/B/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACON,BETA,
     *       OBTP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPIOB,FOPISQ
      COMMON/F/ HR,HT
      COMMON/G/SRTAP,SINPSI,COSPSI
      COMPLEX CI,CTEMY,CP,CA,CU1,CU2,CTEMW,CGAMV,CGAMH
     *    ,CGAM
      FAC = 1.
      IF(ENVIR(3) .EQ. 0.) RETURN
C     CHECK FOR NEW SCAN MODE
      IF(ISWIT.EQ.1) GO TO 5
C     RADAR MODE DEPENDENT CALCULATIONS
      XNZERO = 1.000313
      HR = SHIP(3)*XNMTOM
      RAR = HR/RE
      CHR = HR*(1.-RAR)
      XKPAR = 2.*PI/WVL
      XFRE=RC(1)+DWL(NEXT)
      IF(XFRE.GT.1500.) GO TO 6
      EPS1 = 80.
      SIG1 = 4.3
      GO TO 8
    6 IF(XFRE.GT.3000.) GO TO 7
      EPS1 = 80.-0.00733*(XFRE-1500.)
      SIG1 = 4.3+0.00148*(XFRE-1500.)
      GO TO 8
    7 EPS1 = 69-0.0005714*(XFRE-3000.)
      SIG1 = 6.52+0.001314*(XFRE-3000.)
    8 CONTINUE
      CI = (0.0,1.)
      CTEMY = CMPLX(EPS1,-60.*WVL*SIG1)
      XKZERO = XKPAR*XNZERO
      H = (2.*XKZERO*XKZERO/RE)**(-1./3.)
      XL = 2.*(4.*XKZERO/(RE*RE))**(-1./3.)
      Z1 =HR/H
      CP = CI*XKZERO*CSQRT(CTEMY-1.)*(COS(POLRZ/RADIAN)
     *     + SIN(POLRZ/RADIAN)/CTEMY)
      CA = 2.3381*CEXP(CI*2.*PI/3.) + 1./(H*CP)
      XIMCA = AIMAG(CA)
      CALL UFUN(Z1,CA,CU1)
```

```
      ISWIT = 1
    5 CONTINUE
      IKEY = -1
      GRRT = TRGPOS(ITAR,7)*XNMTOM
   20 CONTINUE
      HT = TRGPOS(ITAR,3)*XNMTOM
      HSUM = HR+HT
      RAT = HT/RE
      CHT = HT*(1.-RAT)
      TEMP = SQRT(4./3.*(RE*(CHR+CHT)+GRRT*GRRT/4.))
      TEMPHI =ARCOS(2.*RE*GRRT*ABS(CHR-CHT)/(TEMP*TEMP*TEMP))
      GRRAD = GRRT/2.+SIGN(1.,CHR-CHT)*TEMP*COS((TEMPHI+PI)/3.)
      GRTAR = GRRT-GRRAD
      SRRAD = SQRT(HR*HR+(1.+RAR)*GRRAD*GRRAD)
      SRTAR = SQRT(HT*HT+(1.+RAT)*GRTAR*GRTAR)
      TANPSI = CHR/GRRAD - GRRAD/(2.*RE)
      IF(TANPSI.LE.0) GO TO 40
      COSPSI = GRRAD/SRRAD*(1.+RAR)
      SINPSI = GRRAD/SRRAD*(TANPSI+HR/GRRAD*RAR)
   50 CONTINUE
      RREF = SRRAD+SRTAR
      PRREF = SRRAD*SRTAR
      TEMW = 2.*PRREF/RREF
      DISP = SQRT((1.-HSUM/RE)*RREF/GRRT
     *       *COSPSI/(1.+TEMW/(RE*SINPSI)))
      TEMG = (2.*SINPSI/RREF)**2*PRREF
      PTHDIF = RREF*TEMG/(1.+SQRT(1.-TEMG))
      IF(IKEY.EQ.1) GO TO 30
      IF(PTHDIF.GE.WVL/4.) GO TO 30
      IKEY = 1
      CRITR = GRRT
      XNAT = CRITR/XL
      SINPSI = 2.*WVL/4.*HSUM/(WVL/4.*WVL/4.+4.*HR*HT)
      CALL RNGCEN(WVL/4.,GRRAD,GRTAR,SRRAD,SRTAR,SINPSI)
      CRITR = GRRAD+GRTAR
       GRRT = GRRAD+GRTAR
      COSPSI = SQRT(1.-SINPSI*SINPSI)
      XNAT1 = CRITR/XL
      GO TO 50
   30 CONTINUE
      CTEMW = CSQRT(CTEMY-COSPSI*COSPSI)
      CGAMV = (CTEMY*SINPSI-CTEMW)/(CTEMY*SINPSI+CTEMW)
      CGAMH = (SINPSI-CTEMW)/(SINPSI+CTEMW)
      CGAM =        .5*CLOG((CGAMH*COS(POLRZ/RADIAN))**2
     *        +(CGAMV*SIN(POLRZ/RADIAN))**2)
      CGAMI=AIMAG(CGAM)
      IF ( CGAMI .GT. 0.0 ) GOTO 51
      CGAM=CMPLX( REAL(CGAM),3.1416+CGAMI)
   51 CGAM=CEXP( CGAM )
      RHOREF = CABS(CGAM)
```

```
      PHIREF = AIMAG(CLOG(CGAM))
      TEMG1 = (2.*XKPAR*SIGMAH*SINPSI)**2
      XMUR = EXP(-TEMG1/2.)
      CALL GAIN(1,JTAR,ITAR,GV)
      CALL GAIN(0,JTAR,ITAR,GD)
      FAC1 = CABS(1.+GV/GD*RHOREF*DISP*XMUR*CEXP(CI*(-XKZERO*
     *     PTHDIF-PHIREF)))
      IF(IKEY.EQ.-1) GO TO 10
      Z2 = HT/H
      XNAT2 = 2.*(SQRT(2.*RE*CHT) + SQRT(2.*RE*CHR))/XL
      CALL UFUN(Z2,CA,CU2)
      FAC2 = 2.*SQRT(PT*XNAT2)*EXP(-XIMCA*XNAT2)*CABS(CU1*CU2)
      CALL INTER(0,FAC1,XNAT1,FAC2,XNAT2,FAC,XNAT)
      RETURN
   10 FAC = FAC1
      RETURN
   40 CONTINUE
      FAC = 1.E-20
      RETURN
      END
```

```
      SUBROUTINE NEWPOS
C
C     CURRENT TIME T REPRESENTS TIME OF CURRENT SCAN WITH BEAM AT ZERO
C       DEGREES AZIMUTH.
C     TARGET POSITIONS ARE FIRST CALCULATED AT TIME T.
C     THE AZIMUTH OF EACH TARGET AT TIME T IS DETERMINED (RELATIVE TO
C       ZERO DEGREES).
C     A CORRECTED POSITION FOR EACH TARGET I IS CALCULATED, WHICH IS
C       ITS POSITION AT TIME T+DELTI, WHERE DELTI IS THE TIME IT TAKES
C       THE RADAR BEAM TO SCAN AZIMUTH OF TARGET I.
C
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/B/ ENVIR(10),SUAC(30),RE,CNM,CCM,ACON,BETA,
     *        DOTP(20),POLRZ,IKEYF,XKTONS,XNMTOM,TARCS,WVL,FOPIOB,FOPISQ
      COMMON/C/ DEL(3),VEL(20,3),VELMG2(20)
      COMMON/TM/NTARG,NJAM,SPEED(20),HEADI(20),HEADF(20),TMANI(20),
     1           TMANF(20),XMANI(20,3),XMANF(20,3),GTURN(20),TURN(20),
     2         CM(20,2),RADM(20),ITYPE(20),ALT(20,5),TALT(20,5),NALT(20)
      COMMON /DET3/ NDET3(20,30),MER3(20),RANGE3(20,9,30),AZ3(20,9,30),
     1                 SNDET3(20,9,30),TIME3(20),IKEY(20)
      DIMENSION TAZ(20)
      COMMON/TS/ISTAT(20),TSCAN(20,30)
C
C
C     SET FLAG FOR POSITION CALCULATION AT TIME T
      IFLAG = 1
    5 DO 90 J = 1,NUMTGT
C     J = TARGET NUMBER
      TT = T
C     DETERMINE TARGET STATUS
C     ISTAT = 0   TARGET INACTIVE
C     ISTAT = 1   TARGET ACTIVE
      ISTAT(J) = 0
      IF((TT .LT. XYZI(J,4)) .OR. (TT .GT. XYZF(J,4))) GO TO 90
      ISTAT(J) = 1
C     CHECK FOR AZIMUTH CORRECTIONS
C     SCAN RATE TAKEN FROM RMODE(1,5) FOR ALL MODES
      IF(IFLAG .EQ. 2) TT = TT + (TAZ(J)/TWOPI)*RMODE(1,5)
C
C     DETERMINE TARGET TYPE
      IF (ITYPE(J) .EQ. 2) GO TO 11
C     NO MANEUVER
      DT = (TT - XYZI(J,4))/(XYZF(J,4) - XYZI(J,4))
      DO 7 I = 1,2
         TRGPOS(J,I) = XYZI(J,I) + DT*(XYZF(J,I) - XYZI(J,I))
```

```
      7 CONTINUE
C
        IF (ITYPE(J) .EQ. 1) GO TO 8
        TRGPOS(J,3) = XYZI(J,3) + DT*(XYZF(J,3) - XYZI(J,3))
        GO TO 20
C       DETERMINE ALTITUDE LEG
      8 N = NALT(J)
        DO 9 I = 1,N
           IF(TT  .LE. TALT(J,I)) GO TO 10
      9 CONTINUE
C       TARGET ON LEG I-1
C       TIME EXCEEDS TARGET FINAL TIME
        TS = TT*3600.
        TSS = TALT(J,N)*3600.
        PRINT 400, TS, TSS, J
    400 FORMAT(1H0/5X,'CURRENT TIME',F10.2,'  EXCEEDS FINAL TARGET TIME',
       1        F10.2,'  IN NEWPOS FOR TARGET',I5/)
        I = N
     10 DT = (TT - TALT(J,I-1))/(TALT(J,I) - TALT(J,I-1))
        TRGPOS(J,3) = ALT(J,I-1) + DT*(ALT(J,I) - ALT(J,I-1))
C       CORRECT ALTITUDE COMPONENT OF TARGET DIRECTION VECTOR
        VEL(J,3) = TRGPOS(J,3) - ALT(J,I-1)
        VELMG2(J) = VEL(J,1)*VEL(J,1)+VEL(J,2)*VEL(J,2)+VEL(J,3)*VEL(J,3)
        GO TO 20
C
C       MANEUVERING TARGET
C       TARGET AT CONSTANT ALTITUDE    (TRGPOS(J,3) SET IN TARGET)
     11 IF(TT .LE. TMANF(J)) GO TO 12
C       TARGET BEYOND MANEUVER
        DELT = (TT - TMANF(J))*SPEED(J)
        VEL(J,1) = COS(HEADF(J))
        VEL(J,2) = SIN(HEADF(J))
        TRGPOS(J,1) = XMANF(J,1) + DELT*VEL(J,1)
        TRGPOS(J,2) = XMANF(J,2) + DELT*VEL(J,2)
        GO TO 18
C
     12 IF(TT .GT. TMANI(J)) GO TO 15
C
C       TARGET PRIOR TO MANEUVER
        DELT = (TT - XYZI(J,4))*SPEED(J)
        VEL(J,1) = COS(HEADI(J))
        VEL(J,2) = SIN(HEADI(J))
        TRGPOS(J,1) = XYZI(J,1) + DELT*VEL(J,1)
        TRGPOS(J,2) = XYZI(J,2) + DELT*VEL(J,2)
        GO TO 18
C
C       TARGET WITHIN MANEUVER
     15 DELT = (TT - TMANI(J))*SPEED(J)/RADM(J)
        ANG = HEADI(J) + TURN(J)*(DELT - PIOVR2)
        TRGPOS(J,1) = CM(J,1) + RADM(J)*COS(ANG)
```

```
            TRGPOS(J,2) = CM(J,2) + RADM(J)*SIN(ANG)
            ANG = ANG + TURN(J)*PIOVR2
            VEL(I,1) = COS(ANG)
            VEL(J,2) = SIN(ANG)
         18 VELMG2(J) = VEL(J,1)*VEL(J,1)+VEL(J,2)*VEL(J,2)
         20 DO 22 I = 1,3
            DEL(I)=TRGPOS(J,I)-SHIP(I)
         22 CONTINUE
            DSTAR=95.2*SHIP(4)
            DX=DEL(1)
            DY=DEL(2)
            DZ=DEL(3)
      C       NOW COMPUTE THE TARGET HORIZONTAL ANGLE (CCW FROM EAST)
         28 IF (ABS(DX).GT.0.000001) GO TO 30
      C          THE TARGET IS AT PLUS OR MINUS PI/2
            RTEMP = PIOVR2
            IF (DY.GE.0.0) GO TO 40
            RTEMP = -PIOVR2
            GO TO 40
         30 RTEMP = ATAN(DY/DX)
            IF (DX.GE.0.0) GO TO 40
            RTEMP = RTEMP+PI
         40 IF (RTEMP.GE.0.0) GO TO 50
            RTEMP = RTEMP+TWOPI
         50 TRGPOS(J,5)=RTEMP
            IF(IFLAG .EQ. 2) GO TO 52
      C     STORE AZIMUTH
            TAZ(J) = TRGPOS(J,5)
            GO TO 90
         52 D = SQRT(DX*DX + DY*DY)
            DHALF=SQRT(D)
            TRGPOS(J,4)=SQRT(DX*DX+DY*DY+DZ*DZ)
      C     TIME3 AND TIME ARRAYS IN SECONDS
            TIME3(J) = TT*3600.
            TRGPOS(J,7) = D
            IF(J .GT. NTARG) GO TO 24
      C     DSTP USED FOR TARGET CROSSSECTION CALCULATION IN TARSIG
            DSTP(J) = (DEL(1)*VEL(J,1)+DEL(2)*VEL(J,2)+DEL(3)*VEL(J,3))/
           1           (SQRT(VELMG2(J))*TRGPOS(J,4))
         24 IF (D.GT.0.000001) GO TO 55
      C            THE TARGET IS NOW DIRECTLY OVERHEAD
            TRGPOS(J,6)=PIOVR2
            GO TO 90
         55 B=DHALF/95.2-SHIP(4)/DHALF
            BPRIME=TRGPOS(J,3)/D-B*B
            TRGPOS(J,6) = ATAN(BPRIME)
            IF (BPRIME.LT.0.0.AND.D.GT.DSTAR) GO TO 80
      C       THE TARGET HAS NOW BEEN FOUND TO BE IN SIGHT
            GO TO 90
      C      THE FOLLOWING APPLIES TO AN OUT OF SIGHT TARGET
         80 TRGPOS(J,4)=-TRGPOS(J,4)
            ISTAT(J) = 0
         90 CONTINUE
      C
      C     CHECK FOR AZIMUTH CORRECTION
            IF(IFLAG .EQ. 2) RETURN
            IFLAG = 2
            GO TO 5
            END
```

```
      SUBROUTINE RESOL (NREF,RES,NTAR,SNREF,INF,NI,TH3DB,N)
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1      ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2      ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3    ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4      ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      DIMENSION SNREF(20),INF(20)
C
C     NREF IS THE NUMBER OF REFERENCE CELLS ON EACH SIDE
C     RES IS THE RANGE RESOLUTION CELL DIMENSION
C     NTAR IS THE TARGET OF INTEREST
C     NI IS THE NUMBER OF INTERFERING TARGETS IN THE REFERENCE CELLS
C     INF( ) IS AN ARRAY OF INTERFERING TARGET NUMBERS
C     SNREF( ) IS THE SIGNAL POWER  OF THE INTERFERING TARGET
C     TH3DB IS THE ANTENNA 3-DB BEAMWIDTH
C     N IS THE NUMBER OF TARGETS
C
      NI=1
      DELR=(NREF+2)*RES
      DO 20 I=1,N
      IF (I.EQ.NTAR) GO TO 20
      IF (ABS(TRGPOS(I,4)-TRGPOS(NTAR,4)).GT.DELR) GO TO 20
      IF (ABS(TRGPOS(I,5)-TRGPOS(NTAR,5)).GT.2.4*TH3DB) GO TO 20
      NI=NI+1
      INF(NI)=I
C     CALCULATE SIGNAL ENERGY FOR INTERFERING TARGET
C
      CALL SIGNAL(I,PWR,SNREF(NI))
C
   20 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RNGCEN(DELT,SR1,SR2,R1,R2,S)
      COMMON NSCAN,NEXT,NUMTGT,T,BLDT,ENDTIM ,SMODE(30,20)
     1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPKR
     4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/B/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACON,BETA,
     *        DSTP(20),BBLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPIOB,FOPISO
      COMMON/F/HR,HT
      I = 0
   10 CONTINUE
      ASS = RE*S*S
      V1 = SQRT(1.+2.*HR/ASS)
      V2 = SQRT(1.+2.*HT/ASS)
      V = (1.+V1)/HR + (1.+V2)/HT
      F = 4.*S/V - DELT
      FP = 4.*V + 8./ASS * (1./V1+1./V2)
      FP = FP/(V*V)
      S = S-F/FP
      IF(ABS(F).LT.DELT/10.) GO TO 20
      IF(I.GT.10) GO TO 20
      I = I+1
      GO TO 10
   20 CONTINUE
      ASS = RE*S*S
      TEMP = 2.*HR
      R1 = TEMP/(S+SQRT((ASS+TEMP)/RE))
      TEMP = 2.*HT
      R2 = TEMP/(S+SQRT((ASS+TEMP)/RE))
      SR1 = SQRT((R1*R1-HR*HR)/(1.+HR/RE))
      SR2 = SQRT((R2*R2-HT*HT)/(1.+HT/RE))
      RETURN
      END
```

```
      SUBROUTINE SIGNAL(JTAR,PWR,SIGEN)
C     JTAR = TARGET UNDER CONSIDERATION
C     PWR = POWER RECEIVED
C     SIGEN = SIGNAL ENERGY
      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
     1       ,PI,PIOVR2 ,TWOPI,RADTAN,TAU(30),DSTAR,DWL(30)
     2       ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4       ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/B/ ENVIR(10),SURC(30),RE,CNM,CCM,ACON,BETA,
     *       DOTP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPIOB,FOPISQ
      COMMON/H/FAC4,AMRN,XJAMN,IKEYJG,XXXXX
      COMMON/I/ PRBS,HOFK,THETBK,DBDOWN,THH,THV,GN
      COMMON/MOD/MODEL(20)
      COMMON/SIG/RM,RA,ES
C     COMPUTE SIGNAL ENERGY FOR TARGET JTAR
      CALL TARSIG(JTAR)
      WVL=300./(RC(1)+DWL(NEXT))
      S = RMODE(NEXT,3)*RC(6)*RC(6)*WVL*WVL*TARCS
      R = TRGPOS(JTAR,4)
      RM = R*XNMTOM
      R=R*R
      R=R*R
      RMT = R*XNMTOM*XNMTOM*XNMTOM*XNMTOM
      PWR    = S*RC(8)*RC(9)*RMODE(NEXT,8)/(RMT*FOPIOB)
      FHV(JTAR) = 1.
      IF(RC(2).NE.1.) GO TO 50
      FH = 1.
      OAV = (PRBS - TRGPOS(JTAR,6))
      FV = BEAM(OAV,RC(5),RC(2),1)
      FHV(JTAR) = FH*FV
      IF(TRGPOS(JTAR,6) .LT. RMODE(NEXT,2)) GO TO 50
      FHV(JTAR) = AMAX1(FHV(JTAR),DBDOWN)
   50 CONTINUE
      ES = PWR*RMODE(NEXT,4)
      TEMPWR = ES
      ES = ES*FHV(JTAR)*FHV(JTAR)
      CALL MULPTH(JTAR,JTAR,FAC)
      FAC4 = FAC*FAC*FAC*FAC
C     COMPUTE TWO WAY RAIN ATTENUATION
      RA = 10.**(-1.E-8*RM*ENVIR(4)*WVL**(-1.87))
C     COMPUTE SIGNAL ENERGY
      ES = ES*FAC4*AMIN1(RMODE(NEXT,12)*TAU(NEXT),1.)*RA
      SIGEN = ES
      RETURN
      ENTRY NOISE(JTAR,EC,EN)
C
C     JTAR = TARGET UNDER CONSIDERATION
C     EC = CLUTTER ENERGY
```

```
      C      EN = NOISE ENERGY (INCLUDING JAMMING)
      C
             EN = RC(3)*RC(10)
             AMRN = EN
      C      CALCULATE JAMMING (EJ) AND CLUTTER (EC) ENERGIES
             CALL JAM(JTAR,EJ,EC)
      C      COMPUTE RAIN CROSS SECTION
             RNCS = 6.706E-6*TAU(NEXT)*RC(4)*RC(5)*RM *RM **VL**(-4)
            **ENVIR(4)**1.6
      C      CALCULATE RAIN BACKSCATTER
             ER = ES*RNCS/(TARCS*FAC4*FHV(JTAR)*FHV(JTAR))*SMODE(NEXT,2)
             TEMP = PRBS - RC(5)/4.
             IF( TEMP.GE.0 ) GO TO 60
      C      INCLUDE MULTIPATH AVERAGING FACTOR
             ER = 6.*ER
      C      COMPUTE NOISE ENERGY TO INCLUDE RAIN BACKSCATTER AND RAIN-
      C         ATTENUATED JAMMING ENERGY
          60 EN = (EN + ER + EJ*RA/2.)*FLOAT(IMODE(NEXT,2))
      C      COMPUTE RAIN ATTENUATED CLUTTER
             EC = EC*RA*FLOAT(IMODE(NEXT,2))
             RETURN
             END
```

```
      SUBROUTINE TARGET
C
C     TYPES OF TARGET FLIGHT PROFILES
C     ITYPE = 0     PROFILE CONSISTS OF STRAIGHT LINE TRAJECTORY FROM
C                   INITIAL POSITION TO FINAL POSITION.  CONSTANT SPEED
C                   IS DETERMINED FROM TIMES SPECIFIED FOR THESE
C                   POSITIONS.
C
C     ITYPE = 1     IN ADDITION TO INITIAL AND FINAL TIMES AND POSITIONS,
C                   FROM 2 TO 4 ALTITUDE LEGS ARE DEFINED BY SPECIFYING
C                   1 TO 3 ALTITUDE NODES AND CORRESPONDING ARRIVAL
C                   TIMES.  PROFILE CONSISTS OF STRAIGHT LINE
C                   TRAJECTORIES BETWEEN NODES, WITH PROJECTION OF THE
C                   PROFILE ON THE X-Y PLANE A STRAIGHT LINE BETWEEN THE
C                   INITIAL AND FINAL POSITIONS.
C
C     ITYPE = 2     PROFILE IS DEFINED AT A CONSTANT ALTITUDE AND
C                   CONSISTS OF A STRAIGHT LINE TRAJECTORY FROM THE
C                   INITIAL POSITION WITH THE DEFINED SPEED AND HEADING
C                   TO A SPECIFIED POINT IN TIME AT WHICH THE MANEUVER
C                   BEGINS.  THE MANEUVER OCCURS IN THE HORIZONTAL PLANE
C                   ACCORDING TO THE SPECIFIED G-CAPABILITY.  THE
C                   MANEUVER TERMINATES WHEN THE TARGET IS HEADING TOWARD
C                   ITS FINAL POSITION, AND THEN PROCEEDS IN A STRAIGHT
C                   LINE TRAJECTORY.
C
C
      COMMON NSCAN,NEXT,NUMTGT,T,ALOT,ENDTIM ,SMODE(30,20)
     1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
     2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
     3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
     4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
      COMMON/P/ ENVIR(10),SURC(30),RE,CNM,CCM,ACON,BETA,
     *        DETP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,KVL,FOPIGR,FOPISO
      COMMON/F/A(20,4)
      COMMON/MOD/MODEL(20)
      COMMON/TM/NTARG,NJAM,SPEED(20),HEADI(20),HEADF(20),TMANI(20),
     1         TMANF(20),XMANI(20,3),XMANF(20,3),GTURN(20),TURN(20),
     2        CM(20,2),RADM(20),ITYPE(20),ALT(20,5),TALT(20,5),NALT(20)
      DIMENSION CARD(10),DEL(3)
      READ 2, NTARG, NJAM
    2 FORMAT(2I5)
      PRINT 500, NTARG,NJAM
  500 FORMAT(/' NUMBER OF TARGETS = ',I2,5X,' NUMBER OF JAMMERS = ',I2)
      NUMTGT = NTARG + NJAM
      J = 0
    5 DO 90 K = 1,NUMTGT
      J = J + 1
      READ 6, (XYZI(J,I),I=1,4),
     1        (XYZF(J,I),I=1,4),(SIGTAR(J,I),I=1,3),SIGJAM(J),MODEL(J)
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      6 FORMAT(12F6.2,I3)
        PRINT 600, J,(XYZI(J,I),I=1,4),(XYZF(J,I),I=1,4),
     1             (SIGTAR(J,I),I=1,3),SIGJAM(J),MODEL(J)
    600 FORMAT(/,' INPUT PARAMETERS FOR TARGET ',I2,' ARE',4F10.2,/,40X,
     1         4F10.2,4F8.2,I5)
C       SCALE INPUT TO NAUTICAL MILES, HOURS, AND RADIANS FOR INTERNAL
C       CALCULATIONS
        DO 7 I = 1,3
        XYZI(J,I) = XYZI(J,I)/6.0802
        XYZF(J,I) = XYZF(J,I)/6.0802
      7 CONTINUE
        XYZI(J,4)=XYZI(J,4)/3600.
        XYZF(J,4)=XYZF(J,4)/3600.
        SIGJAM(J) = SIGJAM(J)/1.0E+6
        READ 8, ITYPE(J), (CARD(I),I=1,7)
      8 FORMAT(I4,7F6.2)
C       CHECK FOR TYPE OF TARGET PROFILE
        IF (ITYPE(J) .EQ. 0) GO TO 90
        PRINT 800, ITYPE(J), (CARD(I),I=1,7)
    800 FORMAT(/1X,I4,5X,7F10.2)
        IF (ITYPE(J) .NE. 1) GO TO 10
C       ALTITUDE LEGS
        NALT(J) = CARD(1)
        N = NALT(J)
        IF (N .GT. 3) N = 3
C       NALT UPDATED TO CONTAIN NO. OF ALTITUDE NODES PLUS TWO  (FOR
C           INITIAL AND FINAL ALTITUDES)
        NALT(J) = N + 2
        ALT(J,1) = XYZI(J,3)
        TALT(J,1) = XYZI(J,4)
        ALT(J,NALT(J)) = XYZF(J,3)
        TALT(J,NALT(J)) = XYZF(J,4)
C       STORE INTERMEDIATE ALTITUDE NODES
        DO 9  I=1,N
           ALT(J,I+1) = CARD(2*I)/6.0802
        TALT(J,I+1) = CARD(2*I+1)/3600.
      9 CONTINUE
        GO TO 90
C       MANEUVER
     10 IF (ITYPE(J) .EQ. 2) GO TO 15
        PRINT 100, J, ITYPE(J)
    100 FORMAT(1H0,5X,'TARGET',I3,' HAS UNDEFINED TARGET TYPE',I3,
     1         '     TARGET DELETED'/)
        J = J - 1
        IF(K .LE. NTARG) NTARG = NTARG - 1
        IF(K .GT. NTARG) NJAM = NJAM - 1
        GO TO 90
     15 SPEED(J) = CARD(1)*3600./6.0802
        HEADI(J) = CARD(2)/RADIAN
        TMANI(J) = CARD(3)/3600.
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            GTURN(J) = CARD(4)*32.17*3600.*3600./6080.2
            TRGPOS(J,3) = XYZI(J,3)
C
C     SCALE INPUT TO NAUTICAL MILES, HOURS, AND RADIANS FOR INTERNAL
C     CALCULATIONS
C     TARGET MANEUVER PARAMETERS
C     CALCULATE TARGET BEGIN AND END MANEUVER POSITIONS IN X-Y PLANE
C     TARGET ENDS MANEUVER ON HEADING TOWARDS FINAL POSITION
C     TARGET POSITION AT BEGINNING OF MANEUVER
            DELT = (TMANI(J) - XYZI(J,4))*SPEED(J)
            XMANI(J,1) = XYZI(J,1) + DELT*COS(HEADI(J))
            XMANI(J,2) = XYZI(J,2) + DELT*SIN(HEADI(J))
C     DETERMINE DIRECTION OF MANEUVER
C     TURN = 1 CCW MANEUVER
C     TURN = -1 CW MANEUVER
C     COMPUTE HEADING OF VECTOR FROM TARGET POSITION XMANI TO XYZF
            DEL(1) = XYZF(J,1) - XMANI(J,1)
            DEL(2) = XYZF(J,2) - XMANI(J,2)
            XHEAD = ARCOS(DEL(1)/SQRT(DEL(1)*DEL(1)+DEL(2)*DEL(2)))
            IF(DEL(2) .LT. 0.0) XHEAD = TWOPI - XHEAD
            TURN(J) = 1.
C     RIGHT HAND TURN ASSUMED FOR 180 DEGREE TURN
            HTEST = HEADI(J) + PI
            IF(HTEST .GE. TWOPI) GO TO 25
            IF((XHEAD .LT. HEADI(J)) .OR. (XHEAD .GE. HTEST))
     1          TURN(J) = -1.*TURN(J)
            GO TO 30
         25 HTEST = HTEST - TWOPI
            IF((XHEAD .LT. HEADI(J)) .AND. (XHEAD .GE. HTEST))
     1          TURN(J) = -1.*TURN(J)
         30 CONTINUE
C
C     CALCULATE CENTER AND RADIUS OF MANEUVER CIRCLE
            RADM(J) = SPEED(J)*SPEED(J)/GTURN(J)
            CM(J,1) = XMANI(J,1) + RADM(J)*COS(HEADI(J)+TURN(J)*PIOVR2)
            CM(J,2) = XMANI(J,2) + RADM(J)*SIN(HEADI(J)+TURN(J)*PIOVR2)
C     DETERMINE IF MANEUVER POSSIBLE
C     COMPUTE DISTANCE FROM CM TO XYZF
            DEL(1) = XYZF(J,1) - CM(J,1)
            DEL(2) = XYZF(J,2) - CM(J,2)
            DELR = SQRT(DEL(1)*DEL(1) + DEL(2)*DEL(2))
            IF (DELR .GE. RADM(J)) GO TO 75
C     IMPOSSIBLE MANEUVER
            PRINT 400, J
        400 FORMAT(1H0,5X,'MANEUVER IMPOSSIBLE FOR TARGET',I3,
     1        '     TARGET DELETED'/)
            J = J - 1
            IF(K .LE. NTARG) NTARG = NTARG - 1
            IF(K .GT. NTARG) NJAM = NJAM - 1
            GO TO 90
```

```
C
C      DETERMINE TARGET POSITION AT END OF MANEUVER
C
    75 STNB = RADM(J)/DELR
       COSA = DEL(1)/DELR
       SINA = DEL(2)/DELR
       ANA = ARCOS(COSA)
       ANB = ARSIN(STNB)
C      DETERMINE QUADRANT OF XYZF RELATIVE TO CM
    80 IF(SINA .GE. 0.) GO TO 85
C      QUADRANTS 3 AND 4
       HEADF(J) = TWOPI - ANA + TURN(J)*ANB
       GO TO 88
C      QUADRANTS 1 AND 2
    85 HEADF(J) = ANA + TURN(J)*ANB
    88 DHEAD = TURN(J)*(HEADF(J) - HEADI(J))
    89 IF(DHEAD .LT. 0.) DHEAD = DHEAD + TWOPI
       XMANF(J,1) = CM(J,1) + RADM(J)*COS(HEADF(J) - TURN(J)*PIOVR2)
       XMANF(J,2) = CM(J,2) + RADM(J)*SIN(HEADF(J) - TURN(J)*PIOVR2)
       TMANF(J) = TMANI(J) + DHEAD*SPEED(J)/GTURN(J)
C
C      CALCULATE TIME TARGET ARRIVES AT FINAL POSITION
       DEL(1) = XYZF(J,1) - XMANF(J,1)
       DEL(2) = XYZF(J,2) - XMANF(J,2)
       DELR = SQRT(DEL(1)*DEL(1) + DEL(2)*DEL(2))
       XYZF(J,4) = DELR/SPEED(J) + TMANF(J)
    90 CONTINUE
       NUMTGT = NTARG + NJAM
C      SET UP ARRAY FOR TARGET CROSS SECTION CALCULATIONS
       DO 95 J = 1,NTARG
       A(J,4) = (2.*SIGTAR(J,3) + SIGTAR(J,2))/3.
       A(J,3) = (3.*SIGTAR(J,1) + SIGTAR(J,2) - 4.*A(J,4))/12.
       A(J,2) = 5.*A(J,3) - SIGTAR(J,1) + A(J,4)
       A(J,1) = 2.*A(J,2) - 4.*A(J,3)
    95 CONTINUE
       RETURN
       END
```

```
0001          SUBROUTINE TARSIG(JTAR)
        C
        C      JTAR = TARGET NUMBER
        C
0002          COMMON NSCAN,NEXT,NUMTGT,T,PLOT,ENDTIM ,SMODE(30,20)
             1        ,PI,PIOVR2 ,THRPT,RADIAN,TAU(30),DSTAR,DWL(30)
             2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
             3      ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
             4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
0003          COMMON/B/ ENVIR(10),SURC(30),PE,CNM,CCM,ACPN,BETA,
             *        DOTP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,HVL,FOPTOH,FORISS
0004          COMMON/F/A(20,4)
0005          DIMENSION TEMP(4)
0006          TEMP(1) = DOTP(JTAR)
0007          DO 10  I = 2,4
0008       10 TEMP(I) = 2.*TEMP(I-1)**2-1.
0009          TARCS = A(JTAR,4) + A(JTAR,3)*TEMP(4) + A(JTAR,2)*TEMP(3)
             1         - A(JTAR,1)*TEMP(2)
0010          RETURN
0011          END
```

```
              SUBROUTINE UFUN(Z,CA,CANS)
              COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
             1        ,PI,PIOVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
             2        ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
             3      ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
             4        ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
              COMMON/B/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACON,BETA,
             *        DRTP(20),POLRZ,IKEYF,XKTOMS,XNMTOM,TARCS,WVL,FOPIOB,FOPISQ
              COMPLEX CA,CANS,CI,CXP3,CZ,CA1,CZ3,CA13,CFI,CFIP,CGI,CGIP
             *      ,CF,CFP,CG,CGP,CH2,CH2P,CDZ,CDA,CZ4,CA14,CCE,CCEA
             *      ,CC,CCP,CAIR,CAIRP,CFM,CFPM,CGM,CGPM,COLDA
              IF(ISWIT.EQ.1) GO TO 5
              CI = (0.,0,1.)
              XC1 = .3550280539
              XC2 = .2588194038
              RTPI = SQRT(PI)
              CXP3 = CEXP(CI*PI/3.)
              CA1 = CA*CXP3
              OLDZ = 0
            5 CONTINUE
              IF(Z.EQ.OLDZ) GO TO 80
              OLDZ = Z
              CZ = (Z+CA)*CXP3
              IKEY = 0
              IF(CABS(CZ).GT.3.) IKEY = IKEY+1
              IF(CABS(CA1).GT.3.) IKEY = IKEY+2
              IF(IKEY.EQ.3) GO TO 10
              IF(ISWIT.EQ.1.AND.IKEY.EQ.1) GO TO 10
              CZ3 = CZ*CZ*CZ
              CA13 = CA1*CA1*CA1
              CFI = 1
              CFIP = 0
              CGI = CA1
              CGIP = 1.
              CFM = 1.
              CFPM = 1./CA1
              CGM = CZ
              CGPM = 1
              XMUL1 = 1
              XMUL2 = 1
              I = 0
           20 I = I+1
              XMUL1 = XMUL1/(3*I*(3*I-1))
              XMUL2 = XMUL2/((3*I+1)*3*I)
              CFM = CFM*CZ3
              CFPM = CFPM*CA13*(3*I)/(MAX0(1,3*I-3))
              CGM = CGM*CZ3
              CGPM = CGPM*CA13*(3*I+1)/(3*I-2)
              CF = XMUL1*CFM
```

```
      CFP = XMUL1*CFPM
      CG = XMUL2*CGM
      CGP = XMUL2*CGPM
      CFI = CFI+CF
      CFIP = CFIP+CFP
      CGI = CGI+CG
      CGIP = CGIP+CGP
      IKEY1 = IKEY+1
      GO TO (22,23,24), IKEY1
   22 IF(CABS(XC1*CF-XC2*CG).LT..005*CABS(XC1*CFI-XC2*CGI).AND.
     *     CABS(XC1*CFP-XC2*CGP).LT..005*CABS(XC1*CFIP-XC2*CGIP))
     *     GO TO 21
      GO TO 20
   23 IF(CABS(XC1*CFP-XC2*CGP).LT..005*CABS(XC1*CFIP-XC2*CGIP))
     *     GO TO 21
      GO TO 20
   24 IF(CABS(XC1*CF-XC2*CG).LT..005*CABS(XC1*CFI-XC2*CGI))
     *     GO TO 21
      GO TO 20
   21 CONTINUE
      IF(IKEY.EQ.1) GO TO 25
      CH2 = CI*3.02617*(XC1*CFI-XC2*CGI)
   25 IF(IKEY.LT.2) CH2P = CI*3.02617*(XC1*CFIP-XC2*CGIP)*CXP3
      IF(IKEY.EQ.0) GO TO 70
      IF(ISWIT.EQ.1.AND.IKEY.EQ.2) GO TO 70
   10 CONTINUE
      CDZ = 2./3.*CEXP(1.5*CLOG(CZ))
      CDA = 2./3.*CEXP(1.5*CLOG(CA1))
      CZ4 = 1./CSQRT(CSQRT(CZ))
      CA14 = CSQRT(CSQRT(CA1))
      CCE = CEXP(-CDZ)
      CCEA = CEXP(-CDA)
      CC = .5*CZ4*CCE/RTPI
      CCP = -.5*CA14*CCEA/RTPI
      XMUL1 = 1.
      CAIR = 1
      CFM = 1.
      CAIPP = 1
      CFPM = 1.
      I = 0
   40 I = I+1
      K = 6*I-1
      DO 50 J = 1,3
      XMUL1 = XMUL1*K
      K = K-2
   50 CONTINUE
      XMUL1 = XMUL1/(216*I*(2*I-1))
      CFM = CFM/CDZ
      CF = XMUL1*CFM
      CFPM = CFPM*((6*I+1)/(1-6*I))/CDA
```

```
      CFP = XMUL1*CFPM
      CAIR = CAIR+(-1)**I*CF
      CAIRP = CAIRP+(-1)**I*CFP
      GO TO (51,52,53), IKEY
   51 IF(CABS(CF).LT..002) GO TO 60
      GO TO 40
   52 IF(CABS(CFP).LT..002) GO TO 60
      GO TO 40
   53 IF(CABS(CF).LT..002.AND.CABS(CFP).LT..002) GO TO 60
      GO TO 40
   60 CONTINUE
      IF(IKEY.NE.2) CH2 = CI*3.02617*CC*CAIR
      IF(IKEY.GE.2) CH2P = CI*3.02617*CCP*CAIRP*CXP3
   70 CONTINUE
      CANS = CI*CH2/CH2P
      COLDA = CANS
      RETURN
   80 CANS = COLDA
      RETURN
      END
```