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6 Surveillance Radar Detection (SURDET) Program

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Radar Analysis Staff
Radar Division

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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.

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CONTENTS

INTRODUCTION	1
Model Overview	1
Future Growth	2
ROUTINES EXCLUSIVE TO SURDET2D.....	3
SURDET2D Executive Routine	3
Input for SURDET2D	9
Output from SURDET2D	13
Subroutine FXCLT2	15
Subroutine INITAL	18
Subroutine MERDET	21
Subroutine MWDET	23
Subroutine STAB2	33
Subroutine VRCLT2.....	35
ROUTINES EXCLUSIVE TO SURDET3D.....	37
SURDET3D Executive Routine	37
Input for SURDET3D	44
Output from SURDET3D	47
Subroutine ADJDET	49
Subroutine DET3D	51
Subroutine FXCLT3	59
Subroutine INITAL	62
Subroutine INIT3D	66
Subroutine MRDT3D	66
Subroutine STAB3	69
Subroutine VRCLT3.....	71
ROUTINES COMMON TO BOTH VERSIONS OF SURDET ..	74
Function BEAM	74
Subroutine CLTSIG	79
Subroutine ENVIRN	80
Subroutine GAIN	81
Subroutine JAM	83
Subroutine MATCH	90
Subroutine MULPTH	93
Subroutine NEWPOS	99
Subroutine RESOL	106
Subroutine RNGCEN	106

ROUTINES COMMON TO BOTH VERSIONS OF
SURDET — (Continued)

Subroutine SIGNAL	110
Subroutine TARGET	113
Subroutine TARSIG	119
Subroutine UFUN	120
ACKNOWLEDGMENTS	122
REFERENCES	122
APPENDIX A — SURDET3D Threshold Values	123
APPENDIX B — Program Listings of Routines Exclusive to SURDET2D	124
APPENDIX C — Program Listings of Routines Exclusive to SURDET3D	153
APPENDIX D — Program Listings of Routines Common to Both Versions of SURDET	184

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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DAVIS AND TRUNK

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 output produced. The options include no output printed (ANS1 = 0), only the summary 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 IOOUT.

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

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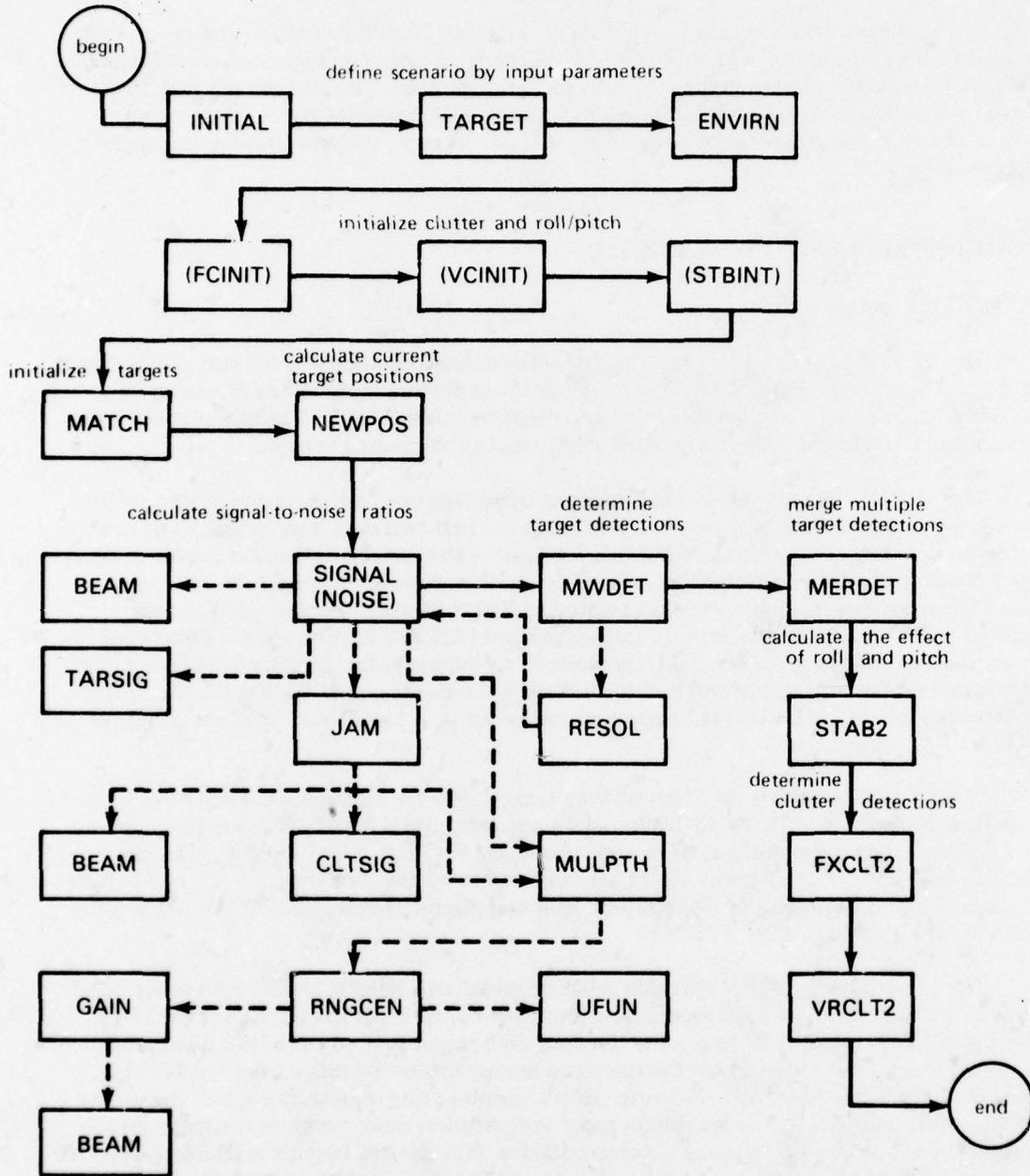


Fig. 1 — Subroutine linkage by the SURDET2D executive routine. The solid lines indicate program flow, and the dashed lines indicate subroutines called. The names in parentheses are entry points. The loops for multiple radar modes and multiple targets are not indicated.

NRL REPORT 8228

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.

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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)
ANSI	Printed output control: 0 = no output printed 1 = detection output only printed 2 = detailed output printed
AZ(I,K)	Azimuth of the <i>k</i> th centroided detection of target I
AZOUT(L)	Azimuth of the <i>l</i> 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 <i>k</i> th detection
BUFA(2,K)	Range of the <i>k</i> th detection (n.mi.)
BUFA(3,K)	Azimuth of the <i>k</i> th detection (rad)
BUFA(4,K)	Elevation of the <i>k</i> th detection (rad)
BUFA(5,K)	Time of the <i>k</i> th detection (s)
BUFA(6,K)	Signal energy of the <i>k</i> th detection (dB)
BUFA(7,K)	Roll angle of the <i>k</i> th detection (rad)
BUFA(8,K)	Pitch angle of the <i>k</i> 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.

DAVIS AND TRUNK

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 <i>k</i> th clutter detection
RADIAN	Conversion factor for radians to degrees ($180/\pi$)
RANGE(I,K)	Range of the <i>k</i> th 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 <i>k</i> 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 (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 <i>k</i> 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 <i>k</i> th centroided detection of target I
SNTRUE	Signal energy
SOUT(K)	Signal energy of the <i>k</i> 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 <i>k</i> 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;

DAVIS AND TRUNK

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 = coscant-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 (μ s),
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 (μ s),
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 (μ s) (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,

NRL REPORT 8228

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 (14,7F6.2 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;

DAVIS AND TRUNK

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

NRL REPORT 8228

Data card 17—recycle control parameter (15 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.

DAVIS AND TRUNK

***** SCAN NUMBER 2 TO *****											
TARGET MADE	TIME	RANGE	AZIM	ELEV	SIGMA FACTOR	FSIG	NAMP	HCLT	NJAN	E/N	MER
1	105.3	32.35	102.14	17.56	0.1	-102.	-202.	-298.	-740.	9.59	9.44
1	*DETECTION*	32.19	101.82			42.					-1
2	105.3	37.76	102.22	17.57	0.1	-3.	-202.	-299.	-740.	10.61	2.39
1	*DETECTION*	33.67	102.14			36.					-1
2	*DETECTION*	33.37	102.07			36.					
1	*DETECTION*	33.96	101.86			35.					

9	SCAN NUMBERS	30.	TIME	103.92	NJ.	DETECTIONS	18.	RADAR	ICR	2063.	HEADING	1.57	NO.	TARGETS	2.
10	DETECTION NUM	1.	5.2935	1.7399	0.0000	105.2814	42.0651	30.4567	0.0000	0.0676	0.0676	0.0676	0.0676	0.0676	0.0676
11	DETECTION NUM	101.	5.0021	1.5260	0.0000	105.0925	34.8937	30.4567	0.0000	0.0574	0.0574	0.0574	0.0574	0.0574	0.0574
12	DETECTION NUM	103.	8.5950	3.8884	0.0000	106.8808	34.8937	30.4567	0.0000	0.3252	0.3252	0.3252	0.3252	0.3252	0.3252
13	DETECTION NUM	104.	10.4414	2.8289	0.0000	106.0810	34.8937	30.4567	0.0000	0.3377	0.3377	0.3377	0.3377	0.3377	0.3377
14	DETECTION NUM	105.	22.2911	4.9394	0.0000	107.6911	34.8937	30.4567	0.0000	0.3307	0.3307	0.3307	0.3307	0.3307	0.3307
15	DETECTION NUM	107.	18.5830	3.1371	0.0000	106.3174	34.8937	30.4567	0.0000	0.2401	0.2401	0.2401	0.2401	0.2401	0.2401
16	DETECTION NUM	108.	21.2227	1.2672	0.0000	104.8901	34.8937	30.4567	0.0000	0.1121	0.1121	0.1121	0.1121	0.1121	0.1121
17	DETECTION NUM	110.	21.4169	1.0450	0.0000	108.7230	34.8937	30.4567	0.0000	0.2117	0.2117	0.2117	0.2117	0.2117	0.2117
18	DETECTION NUM	200.	21.7083	0.9722	0.0000	108.6625	30.4567	30.4567	0.0000	0.2219	0.2219	0.2219	0.2219	0.2219	0.2219
19	DETECTION NUM	200.	24.3308	4.0485	0.0000	107.0126	30.4567	30.4567	0.0000	0.2401	0.2401	0.2401	0.2401	0.2401	0.2401
20	DETECTION NUM	200.	A.1103	4.9819	0.0000	107.7272	30.4567	30.4567	0.0000	0.3252	0.3252	0.3252	0.3252	0.3252	0.3252
21	DETECTION NUM	200.	23.9823	5.2301	0.0000	107.9132	30.4567	30.4567	0.0000	0.3377	0.3377	0.3377	0.3377	0.3377	0.3377
22	DETECTION NUM	200.	13.0638	6.2413	0.0000	108.6878	30.4567	30.4567	0.0000	0.3307	0.3307	0.3307	0.3307	0.3307	0.3307
23	DETECTION NUM	200.	24.3308	1.0967	0.0000	104.7576	30.4567	30.4567	0.0000	0.2058	0.2058	0.2058	0.2058	0.2058	0.2058
24	DETECTION NUM	200.	22.4853	1.1298	0.0000	104.7828	30.4567	30.4567	0.0000	0.0717	0.0717	0.0717	0.0717	0.0717	0.0717
25	DETECTION NUM	200.	21.0244	1.1409	0.0000	104.7988	30.4567	30.4567	0.0000	0.1993	0.1993	0.1993	0.1993	0.1993	0.1993
26	DETECTION NUM	200.	23.4566	1.1409	0.0000	104.7982	30.4567	30.4567	0.0000	0.0722	0.0722	0.0722	0.0722	0.0722	0.0722
27	DETECTION NUM	200.	23.2624	1.1882	0.0000	104.8275	30.4567	30.4567	0.0000	0.1934	0.1934	0.1934	0.1934	0.1934	0.1934

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):

ISSET	—	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 beam-width).

The initialization section calculates the range-cell dimension ΔR by

$$\Delta R = c\tau_c/2, \quad (1)$$

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

$$R_i = R_S + (R_F - R_S)U_i \quad (2)$$

and

$$\theta_i = \theta_S + (\theta_F - \theta_S)V_i, \quad (3)$$

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 $U \leq P_r$, 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

$$R_m = (K + 0.5)\Delta R, \quad (4)$$

where

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

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

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

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

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

and

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

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]

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

and the measured elevation position e_m is

$$e_m = 0, \quad (10)$$

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:

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

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 i th 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 i th 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 i th 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),

NRL REPORT 8228

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 (μ s),
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 (μ s),
SUBC(J) — sea-clutter improvement factor (dB),
RMODE(J,12) — intermediate-frequency bandwidth (MHz) (if 0 is entered, the bandwidth is set at $1.0/(\text{compressed-pulse length})$),
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 (μ s) (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,

DAVIS AND TRUNK

- 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 — INITIAL 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) -- INITIAL 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 (μ s 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 (μ s)
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) (μ s)
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 i th target, A_{ij} be the initial azimuth, F_{ij} be the final azimuth, and R_{ij} be the range of the j th detection of the i th 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

$$A_1 \leq A_2 \leq A_3 \leq \dots \leq A_{M-1} \leq A_M. \quad (12)$$

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

DAVIS AND TRUNK

$$A_j < A_i, \quad (13a)$$

$$|R_j - R_i| \leq \Delta R, \quad (14a)$$

and

$$F_i \leq F_j + \Delta A, \quad (15a)$$

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

$$A_k < A_i, \quad (13b)$$

$$|R_i - R_k| \leq \Delta R, \quad (14b)$$

and

$$F_i \leq F_k, \quad (15b)$$

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 j th 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

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

Table 4 — MERDET Variables

Fortran Variable	Description
A	Initial azimuth of the j th detection of the i th target (ΔA in Eq. 15)
ACONZ	Azimuth interval used to inhibit detection (ΔA in Eq. 15)
AZ(I,2J-1)	Initial azimuth of the j th detection of the i th target which has a target close by (A_k in Eq. 16)
AZ(I,2J)	Final azimuth of the j th detection of the i th target which has a target close by (F_k in Eq. 16)
AZ(I,J)	Azimuth of the j th detection of the i th 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 i th ordered azimuth
KDIT(I)	Detection index of the i th 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>i</i> th ordered azimuth
KTRR(I)	Target index of the <i>i</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>i</i> th target, or <i>N_i</i>
RANGE(I,J)	Range of the <i>j</i> th detection of the <i>i</i> th target
RES	Range-cell dimension (ΔR in Eqs. 14a and 14b)
SNDET(I,J)	Signal amplitude of the <i>j</i> th detection of the <i>i</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

$$\theta = A + (U - 0.5)\Delta\theta, \quad (17)$$

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

DAVIS AND TRUNK

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

$$\theta_0 = \theta - 201\Delta\theta, \quad (18)$$

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

$$NS = 201 - 2M, \quad (19)$$

and the final pulse generated is

$$NF = 201 + 2M. \quad (20)$$

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

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

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

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

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

$$N_F = 11 - N_R, \quad (23)$$

and the index of the last range cell is

$$N_L = 15 + N_R. \quad (24)$$

Thus, if $N_R = 10$, signal must be placed in all 25 range cells. The signal return for the i th pulse and the j th range cell S_{ij} and an indicator of signal in the j th 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 k th target this is accomplished by first generating the appropriate fluctuating amplitudes F_i for the i th pulse. For Swerling case NSW, F_i is given by the following equations, in which the U_i , $i = 1, \dots, M$, are independent random numbers uniformly distributed between 0 and 1. For NSW = 0 (nonfluctuating target)

$$F_i = 1, \quad i = 1, \dots, M. \quad (25)$$

NRL REPORT 8228

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

$$F_i = -\log U_1, \quad i = 1, \dots, M. \quad (26)$$

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

$$F_i = -\log U_i, \quad i = 1, \dots, M. \quad (27)$$

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

$$F_i = -0.5(\log U_1 + \log U_2), \quad i = 1, \dots, M. \quad (28)$$

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

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

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 k th target is centered in range cell K_R :

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

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

$$K_T = K_R + I, \quad I = -1, 0, 1, \quad (31)$$

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

$$F = [(\sin F_d)/F_d]^2, \quad (32)$$

where

$$F_d = 2.7832(R_k - R_T)/\Delta R, \quad (33)$$

in which

$$R_T = (K_T + 0.5)\Delta R + R_S. \quad (34)$$

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

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

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

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

$$NNS = \max \{NS, NC - M\} \quad (36)$$

to

$$NNF = \min \{NF, NC + M\}. \quad (37)$$

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

$$G = [(\sin G_d)/G_d]^4, \quad (38)$$

where

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

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_T th range cell (for the i th pulse) is

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

where P_k is the signal energy of the k th 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 i th pulse and j th 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 j th cell is indicated by $I(j) = 1$. Thus, the i th return in the j th cell x_{ij} is given as follows. For clutter insignificant ($CM \leq N$) and no signal in the j th cell ($I(j) = 0$)

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

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

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

where

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

and

$$\phi_i = 2\pi U_{i+M}. \quad (44)$$

NRL REPORT 8228

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

$$\phi'_i = 2\pi U_{i+2M}, \quad (52)$$

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:

DAVIS AND TRUNK

$$Z_j = \sum_{i=NS}^{MS} x_{ij}, \quad j = N_F, \dots, N_L, \quad (56)$$

where

$$MS = NS + M - 1. \quad (57)$$

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

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

The detection threshold T_j for the j th range cell ($j = 12, 13, \text{ and } 14$) 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

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

$$\bar{Z}_j = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j+1+i}, \quad (59b)$$

or

$$\bar{Z}_j = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j-1-i}, \quad (59c)$$

and the corresponding mean squares are

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

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

and

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

The standard deviation is

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

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

$$T_j = \overline{Z_j} + N_o \sigma_j, \quad (62)$$

where N_o is the number of standard deviations specified at input. (Appropriate values of N_o 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

$$T_j = N_o \overline{Z_j} \quad (63)$$

for linear video and

$$T_j = N_o + \overline{Z_j} \quad (64)$$

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 i th 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

$$|J_1 - J_2| > 1 \quad (65)$$

or

$$LC_{J_2} > LC_{J_1} + \Delta A. \quad (66)$$

The J_3 detection is valid if J_2 is not valid and

$$|J_1 - J_3| > 1 \quad (67)$$

and

$$LC_{J_3} > LC_{J_2}. \quad (68)$$

If J_2 is valid, either Eq. 67 or

$$LC_{J_3} > LC_{J_1} + \Delta A \quad (69)$$

must be true and either

$$|J_2 - J_3| > 1 \quad (70)$$

or

$$LC_{J_3} > LC_{J_2} + \Delta A \quad (71)$$

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

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

the azimuth is

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

and the signal energy is

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

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

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

and

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

Table 5 - MWDET Variables

Fortran Variable	Description
A	Rayleigh random variable (α_i in Eq. 43)
AA	Azimuth of the k th 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.

DAVIS AND TRUNK

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 M
MER(I)	Indicator of the interfering-target problem (target within three range cells and 2.4 azimuth beamwidths of the i th target) for the i th target
MODEL(I)	Swerling fluctuation index for the i th 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 k th interfering target (NC in Eq. 35)
NCONZ	Pulse separation for declaring two detections
NDET(I)	Number of detections of the i th 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 k th interfering target (NNF in Eq. 37)
NNS	First signal pulse for the k th 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 j th detection of the i th target (R_{ij} in Eq. 72)
RES	Range-cell dimension (ΔR in Eq. 21)
RR	Range of the k th 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_T th 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 j th range cell
SNDDET(I,J)	Maximum signal amplitude of the j th detection of the i th target (\hat{S}_{ij} in Eq. 74)
SNINT	Maximum integrated signal-to-noise ratio
SNREF(K)	Signal energy of the k th interfering target (P_k in Eq. 40)
SS(I,J)	Signal energy of the i th pulse in the j th range cell (S_{ij} in Eqs. 42 and 45)
SUM	Integrated sum of the j th 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 i th target
TRGPOS(I,4)	Range of the i th target (R_k in Eq. 30)
TRGPOS(I,5)	Azimuth of the i th target (A_k in Eq. 35)
TWOPI	Two times 3.1415926536, or 2π
U	Mean value of the reference cells (\bar{Z}_j in Eq. 59a)
ULOW	Mean value of the lower half of the reference cells (\bar{Z}_j in Eq. 59c)
UUP	Mean value of upper half of the reference cells (\bar{Z}_j in Eq. 59b)
X(I,J)	Video return of the i th pulse in the j th cell (x_{ij} in Eqs. 41, 42, and 43)
XFIRST(J)	First threshold crossing in the j th cell (FC_j in text after Eq. 64)
XLAST(J)	Last threshold crossing in the j th 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 (\bar{Z}_j^2 in Eq. 60a)
XMSLOW	Mean square of lower half of the reference cells (\bar{Z}_j^2 in Eq. 60c)
XMSUP	Mean square of upper half of the reference cells (\bar{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.

DAVIS AND TRUNK

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

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

and

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

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]

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

where α and e are the true azimuth (re ship heading) and elevation angles of the target and ϵ 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 i th 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(1,5)	Azimuth of the target
TRGPOS(1,6)	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

$$F_i = (\theta_F - \theta_S)/N_i, \quad (79)$$

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

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

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

$$\theta = \theta_S + \sum_{j=1}^i \Delta_j \quad (81)$$

and

$$R = (K + 0.5)\Delta R, \quad (82)$$

where ΔR is the range-cell dimension and

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

DAVIS AND TRUNK

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

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

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

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

and

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

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

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

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 i th 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
ISSET	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 i th detection (pitch in Eq. 86)

Table continues.

Table 7 (Concluded) — VRCLT2 Variables

Fortran Variable	Description
RALIAN	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 i th 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 i th detection (R in Eq. 82)
RS	Initial range of the clutter region (R_S in Eq. 83)
SOUT(I)	Power of the i th 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 i th 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 INITIAL 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

DAVIS AND TRUNK

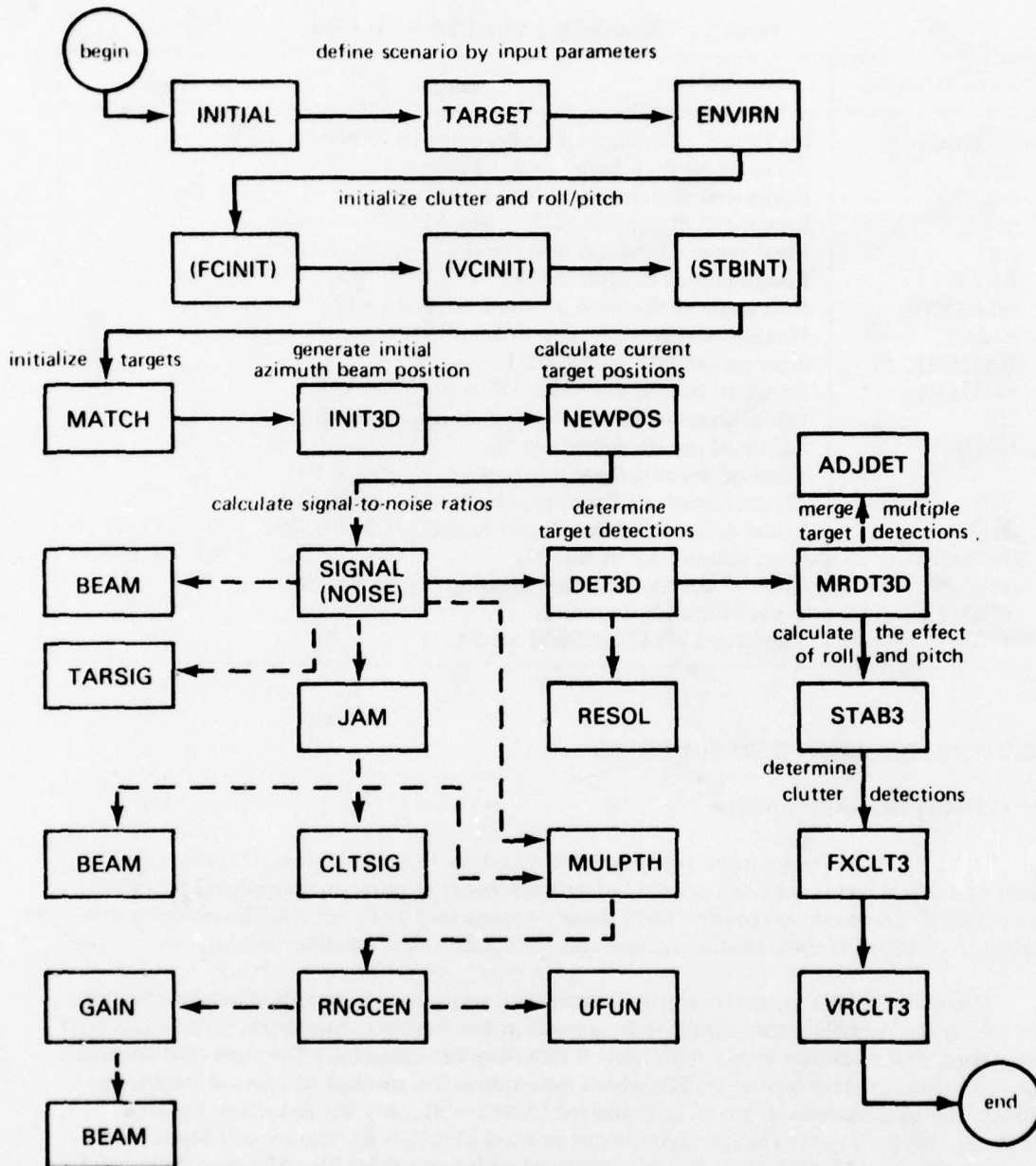


Fig. 3 - Subroutine linkage by the SURDET3D executive routine. The solid lines indicate program flow, and the dashed lines indicate subroutines called. The names in parentheses are entry points. The loops for multiple radar modes and multiple targets are not indicated.

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;

DAVIS AND TRUNK

- 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>I</i>)
BUFB(2,I)	Slant range to the true target- <i>I</i> position (n.mi.)
BUFB(3,I)	Azimuth of the true target- <i>I</i> position (rad)
BUFB(4,I)	Elevation of the true target- <i>I</i> position (rad)
BUFB(5,I)	Time when the radar scans by target <i>I</i> (s)
BVDEG	Elevation of target <i>I</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>I</i> with respect to mode <i>J</i> (dB re 1 <i>J</i>)
DBN	Total noise energy with respect to mode <i>J</i> (dB re 1 <i>J</i>)
DWL(<i>J</i>)	Frequency increment for mode <i>J</i> (Hz)
ELEV(1,K)	Elevation of the <i>k</i> th centroided detection of target <i>I</i>
ELOUT(<i>L</i>)	Elevation of the <i>l</i> 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(<i>J</i> ,1)	Number of pulses integrated for mode <i>J</i>
IOUT	Logical unit for the detection output file
ISC	Radar-scan counter
ISTAT(<i>I</i>)	Status indicator for target <i>I</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.

DAVIS AND TRUNK

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>I</i> : 0 = no merging problem -1 = merging problem with target <i>I</i> , target detected -2 = merging problem with target <i>I</i> , target not detected
MUL	Multipath indicator: 0 = no multipath 1 = multipath
NC(K)	Index of the <i>k</i> th detector fixed clutter point
NDET(I)	Number of centroided detections of target <i>I</i>
NDET3(I,J)	Number of detections of target <i>I</i> by mode <i>J</i>
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>I</i>
PTOUT(R)	Pitch at the time of the <i>k</i> th clutter detection
RADIAN	Conversion factor for radians to degrees ($180/\pi$)
RANGE(I,K)	Range of the <i>k</i> th centroided detection of target <i>I</i>
RANGE3(I,K,J)	Range of the <i>k</i> th detection of target <i>I</i> by mode <i>J</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>I</i> (<i>W</i>)
RC(12)	Signal energy for target <i>I</i> (<i>J</i>)
RC(13)	Clutter energy for target <i>I</i> (<i>J</i>)
RC(14)	Thermal noise plus jamming for target <i>I</i> (<i>J</i>)
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)

DAVIS AND TRUNK

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 (μ s),
- 5. Interlook period (s) (must be identical for all modes),
- 6. Scan offset (s),
- 7. Instrumented range (n.mi.),

NRL REPORT 8228

8. Mode-dependent loss (dB),
9. Number of pulses integrated,
10. Compressed-pulse length (μ s),
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 (μ s) (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 (12F6.2,13 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 (14,7F6.2 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,

DAVIS AND TRUNK

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);

NRL REPORT 8228

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),

DAVIS AND TRUNK

***** SCAN NUMBER # 11 *****												
TARGET	MODE	TIME	RANGE	AZIM	ELEV	SIGMA	ESIG	NAME	NCLT	NJAM	E/VI	HEPS
3	1	15.0	365.00	100.72	1.19	0.1	-183.	-202.	-740.	-740.	16.00	16.05
4	*DETECTI		364.87	100.50			22.					-1
5	*DETECTI		365.07	100.50			25.					-1
6	1	15.0	365.00	100.72	1.19	0.1	-184.	-202.	-740.	-740.	17.19	15.68
7	*DETECTI		364.87	100.50			21.					-1
8	*DETECTI		365.07	100.50			25.					-1
9	1	15.0	365.00	100.72	1.19	0.1	-188.	-202.	-740.	-740.	15.84	12.33
10	*DETECTI		365.07	100.50			20.					-1
11	1	15.0	365.00	100.72	1.19	0.1	-202.	-202.	-740.	-740.	0.00	-1.05
12	2	15.0	365.00	100.72	1.19	0.1	-183.	-202.	-740.	-740.	16.20	16.00
13	*DETECTI		365.06	100.50			27.					-1
14	2	15.0	365.00	100.72	1.19	0.1	-185.	-202.	-740.	-740.	17.01	16.81
15	*DETECTI		365.06	100.50			25.					-1
16	2	15.0	365.00	100.72	1.19	0.1	-188.	-202.	-740.	-740.	13.77	13.57
17	*DETECTI		365.06	100.50			23.					-1
18	2	15.0	365.00	100.72	1.19	0.1	-202.	-202.	-740.	-740.	-0.00	-99.00
19	SCAN NUMBERS	11.	TIME	14.50	NO. DETECTI	22.	RADAR ID	3059.	HEADINGS	1.57	NO. TARGETS	2.
20	DETECTI	1.	RANGE	1.7512	ELEV	TIME	ESIG	RLL	PITCH			
21	DETECTI	2.	60.0300	0.0316	15.0030	25.3616	0.3233	0.3233	-0.0534			
22	DETECTI	101.	60.1064	0.0316	15.0030	26.7080	0.3233	0.3233	-0.0534			
23	DETECTI	103.	5.0669	0.0035	15.7257	34.8937	0.3070	0.3070	-0.0610			
24	DETECTI	104.	8.5950	0.0054	17.5885	34.8937	0.2776	0.2776	0.0375			
25	DETECTI	105.	10.5061	0.0153	16.7553	34.8937	0.3457	0.3457	-0.0088			
26	DETECTI	106.	22.3230	0.0242	14.4326	34.8937	0.1357	0.1357	0.0733			
27	DETECTI	107.	16.5354	0.0035	17.0016	34.8937	0.3305	0.3305	0.0053			
28	DETECTI	108.	21.1603	0.0270	15.5146	34.8937	0.2829	0.2829	-0.0690			
29	DETECTI	110.	21.4003	0.0033	15.3007	34.8937	0.2564	0.2564	-0.0747			
30	DETECTI	200.	15.8806	0.0000	15.1761	30.4567	0.2344	0.2344	-0.0791			
31	DETECTI	200.	22.3230	0.0000	16.7074	30.4567	0.3440	0.3440	-0.0063			
32	DETECTI	200.	22.1930	0.0000	17.3017	30.4567	0.3105	0.3105	0.0222			
33	DETECTI	200.	17.2728	0.0000	17.4814	30.4567	0.2909	0.2909	0.0319			
34	DETECTI	200.	23.0357	0.0000	14.7500	30.4567	0.0707	0.0707	0.0815			
35	DETECTI	200.	24.5608	0.1227	15.3474	30.4567	0.2603	0.2603	-0.0745			
36	DETECTI	200.	21.0357	0.1715	15.3582	30.4567	0.2619	0.2619	-0.0741			
37	DETECTI	200.	22.9062	0.1708	15.4213	30.4567	0.2706	0.2706	-0.0722			
38	DETECTI	200.	20.0571	0.1114	15.4290	30.4567	0.2717	0.2717	-0.0719			
39	DETECTI	200.	23.0641	0.1162	15.4360	30.4567	0.2726	0.2726	-0.0717			
40	DETECTI	200.	22.3542	0.1844	15.4405	30.4567	0.2732	0.2732	-0.0715			
41	DETECTI	200.	21.2874	0.1493	15.4527	30.4567	0.2730	0.2730	-0.0711			
42	DETECTI	200.	22.7120	0.1570	15.4721	30.4567	0.2774	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

NRL REPORT 8228

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 i th detection of target KTAR in the j th 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 i th detection is added to the previous set of K adjacent detections if any of three conditions is satisfied for any k th detection in the set. The first condition is

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

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

$$|E - E_k| \leq 0.1 \gamma;$$

DAVIS AND TRUNK

the second condition is

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

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

$$|E - E_k| \leq 0.1 \gamma;$$

and the third condition is

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

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

$$|E - E_k| \leq 1.2 \gamma;$$

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 k th 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 i th 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 i th detection of target KTAR by the j th radar mode
AZ3(KTAR,I,J)	Same as variable A
DETPAR(K,1)	Range R_k of the k th adjacent detection
DETPAR(K,2)	Azimuth A_k of the k th adjacent detection
DETPAR(K,3)	Elevation E_k of the k th adjacent detection
DETPAR(K,4)	Signal power of the k th adjacent detection
E	Elevation angle E of the j th 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 j th mode
R	Range R of the i th detection of target KTAR by the j th radar mode
RANGE3(KTAR,I,J)	Same as variable R
RES	Range-cell dimension ΔR
RMODE(J,1)	Elevation angle E of the j th radar mode
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 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 j th 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

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

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

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

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

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

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

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

in which R is the target range.

DAVIS AND TRUNK

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

$$N_F = 11 - N_R, \quad (92)$$

and the index of the last range cell is

$$N_L = 15 + N_R. \quad (93)$$

Thus, if $N_R = 10$, signal must be placed in all 25 range cells. The signal return for the i th pulse and the j th range cell S_{ij} and an indicator of signal in the j th 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 k th target this is accomplished by first generating the appropriate fluctuating amplitudes F_{ik} for the i th 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 $U_i, i = 1, \dots, M$, are independent random numbers uniformly distributed between 0 and 1. For $NSW = 0$ (nonfluctuating target)

$$F_{ik} = 1, \quad i = 1, \dots, M. \quad (94)$$

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

$$F_{ik} = -\log U_1, \quad i = 1, \dots, M. \quad (95)$$

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

$$F_{ik} = -\log U_i, \quad i = 1, \dots, M. \quad (96)$$

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

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

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

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

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 k th target is centered in range cell K_R :

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

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

$$K_T = K_R + I, \quad I = -1, 0, 1, \quad (100)$$

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

$$F = [(\sin F_d)/F_d]^2, \quad (101)$$

where

$$F_d = 2.7832(R_k - R_R)/\Delta R \quad (102)$$

and

$$R_T = (K_T + 0.5)\Delta R + R_S. \quad (103)$$

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

$$G = [(\sin G_d)/G_d]^4, \quad (104)$$

where

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

in which A_k is the azimuth of the k th 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 k th target in the K_T -th range cell for the azimuth beam position specified by Eq. 88 is

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

where P_k is the signal energy of the k th 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 i th pulse and j th 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 j th cell is indicated by $I(j) = 1$. Thus, the i th return in the j th cell x_{ij} is given as follows. For clutter insignificant ($CM \leq N$) and no signal in the j th cell ($I(j) = 0$)

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

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

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

DAVIS AND TRUNK

where

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

and

$$\phi_i = 2\pi U_{i+M}. \quad (110)$$

For clutter significant ($CM > N$)

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

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

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

and

$$\phi_i = 2\pi U_{i+3M}, \quad (113)$$

with

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

the clutter is given by

$$CX_i = \rho CX_{i-1} + (1 - \rho^2)^{1/2} \alpha'_i \sin \phi'_i \quad (115)$$

and

$$CY_i = \rho CY_{i-1} + (1 - \rho^2)^{1/2} \alpha'_i \cos \phi'_i, \quad (116)$$

in which

$$\alpha'_i = C'(-2 \log U_i)^{1/2} \quad (117)$$

and

$$\phi'_i = 2\pi U_{i+2M}, \quad (118)$$

with

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

and the initial clutter values are

$$CX_0 = C' \alpha_0 \cos \phi'_0 \quad (120)$$

and

$$CY_0 = C' \alpha_0 \sin \phi'_0. \quad (121)$$

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

$$Z_j = \sum_{i=1}^M x_{ij}. \quad (122)$$

The detection threshold T_j for the j th range cell ($j = 12, 13, \text{ and } 14$) 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

$$\bar{Z}_j = \frac{1}{2N_R} \sum_{i=1}^{N_R} (Z_{j+1+i} + Z_{j-1-i}), \quad (123a)$$

$$\bar{Z}_j = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j+1+i}, \quad (123b)$$

or

$$\bar{Z}_j = \frac{1}{N_R} \sum_{i=1}^{N_R} Z_{j-1-i}, \quad (123c)$$

and the corresponding mean squares are

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

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

and

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

The standard deviation is

$$\sigma_j = [\overline{Z_j^2} - (\bar{Z}_j)^2]^{1/2}, \quad (125)$$

DAVIS AND TRUNK

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

$$T_j = \overline{Z_j} + F_o \sigma_j, \quad (126)$$

where the parameter F_o is used to set the false alarm rate. (Appropriate values of F_o 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

$$T_j = F_o \overline{Z_j} \quad (127)$$

for linear video and

$$T_j = F_o + \overline{Z_j} \quad (128)$$

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 j th range cell, the counter for the number of detections denoted by Π is increased by one, and the following detection parameters are saved:

- Π , 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 k th 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 <i>II</i> th detection of the <i>i</i> th target by the <i>j</i> 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 <i>j</i> 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>i</i> th pulse and the <i>j</i> 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>i</i> th interfering target
IS(J)	Indicator that the signal is in the <i>j</i> 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 <i>k</i> 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 <i>M</i>
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>i</i> th target) for the <i>i</i> th target
MODE	Active radar mode

Table continues.

Table 10 (Continues) — DET3D Variables

Fortran Variable	Description
MODEL(I)	Swerling fluctuation index for the i th 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 i th target by the j th 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 II th detection of the i th target by the j th mode
RES	Range-cell dimension (ΔR in Eq. 90)
RR	Range of the k th 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_T th range cell (R_T in Eq. 103)
S	Signal energy S
SM	Normalized signal energy including the effects of the pulse shape
SNDT3(I,II,J)	Signal amplitude of the II th detection of the i th target by the j th mode
SNINT	Maximum integrated signal-to-noise ratio
SNREF(K)	Signal energy of the k th interfering target (P_k in Eq. 106)
SS(I,J)	Signal energy of the i th pulse and the j th range cell (S_{ij} in Eqs. 108 and 111)
SUM(J)	Integrated sum of the j th 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 i th target (R in Eq. 91)
TRGPOS(I,5)	Azimuth of the i th target (A in Eq. 89)
TWOPI	Two times 3.1415926536, or 2π
U	Mean value of the reference cells (\bar{Z}_j in Eq. 123a)
ULOW	Mean value of lower half of the reference cells (\bar{Z}_j in Eq. 123c)
UUP	Mean value of upper half of the reference cells (\bar{Z}_j in Eq. 123b)
X(I,J)	Video return of the i th pulse in the j th 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 ($\overline{Z_f^2}$ in Eq. 124a)
XMSLOW	Mean square of the lower half of the reference cells ($\overline{Z_f^2}$ in Eq. 124c)
XMSUP	Mean square of the upper half of the reference cells ($\overline{Z_f^2}$ 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 beam-width).

The initialization section calculates the range-cell dimension ΔR by

$$\Delta R = c\tau_c/2, \quad (129)$$

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

$$R_i = R_S + (R_F - R_S)U_i \quad (130)$$

and

$$\theta_i = \theta_S + (\theta_F - \theta_S)V_i, \quad (131)$$

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.

DAVIS AND TRUNK

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 $U \leq P_r$, 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

$$R_m = (K + 0.5)\Delta R, \quad (132)$$

where

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

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

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

and

$$\epsilon_e = W_i \theta_e / 2, \quad (135)$$

where σ_θ is the standard deviation of the azimuth measurement, θ_e is the elevation beam-width, 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

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

and

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

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]

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

and the measured elevation position e_m is [3]

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

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]

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

and

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

where

$$D = \cos R \sin e_m + \sin R \sin a_m \cos e_m. \quad (142)$$

The detection time T_i is proportional to the azimuth:

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

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
ISSET	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.

DAVIS AND TRUNK

Table 11 (Concluded) — FXCLT3 Variables

Fortran Variable	Description
PTOUT	Pitch at the time of the i th 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 i th 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_θ in Eq. 134)
SIGR	Standard deviation of the range measurement (σ_R in Eq. 133)
SOUT	Energy of the i th 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 sub-routines (Table 12).

NRL REPORT 8228

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 (μ s),
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 (μ s),
SUBC(J) — sea-clutter improvement factor (dB),
RMODE(J,12) — intermediate-frequency bandwidth (MHz) (if 0 is entered, the bandwidth is set at $1.0/(\text{compressed-pulse length})$)
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),

DAVIS AND TRUNK

- SM — blanking time (μ s) (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.

NRL REPORT 8228

Table 12 (Concluded) — INITIAL 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>i</i> th target
MER3(I)	Indicator of an interfering-target problem (a target within three range cells and one azimuth beamwidth of the <i>i</i> th target) for the <i>i</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>i</i> th target by the <i>j</i> 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, SNET, 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 i th detection of target KTAR by the j th 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 j th mode, the nonadjacent detection counter NEWJJ is initialized to 0, and at the end of examining all detections for the j th mode, NDET(KTAR,J) is set equal to NEWJJ. Thus at the end of the j th mode the NEWJJ nonadjacent detections are stored in the first NEWJJ locations of the detection arrays associated with the J th 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

$$R = \frac{\sum_{k=1}^K S_k R_k}{\sum_{k=1}^K S_k}, \quad (144)$$

$$A = \frac{\sum_{k=1}^K S_k A_k}{\sum_{k=1}^K S_k}, \quad (145)$$

$$E = \frac{\sum_{k=1}^K S_k E_k}{\sum_{k=1}^K S_k}, \quad (146)$$

and

$$S = \max \{S_1, S_2, \dots, S_K\}, \quad (147)$$

where R_k , A_k , E_k , and S_k are the range, azimuth, elevation, and signal power respectively associated with the k th 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:

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

where

$$E_{\min} = \min \{E_1, E_2, \dots, E_K\} \quad (149)$$

and

$$E_{\max} = \max \{E_1, E_2, \dots, E_K\}. \quad (150)$$

DAVIS AND TRUNK

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

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

and

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

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]

DAVIS AND TRUNK

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

and the measured elevation position e_m is [3]

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

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 $R = 10^\circ$, $P = 5^\circ$, and $e = 15^\circ$, the azimuth error can be as large as 5° even though $\sigma_a = 0.5^\circ$. 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]

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

and

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

where

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

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),

DAVIS AND TRUNK

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

$$F_i = (\theta_F - \theta_S)/N_i, \quad (158)$$

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

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

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

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

$$R = (K + 0.5)\Delta R, \quad (161)$$

and

$$E = E_S + (E_F - E_S)W_i, \quad (162)$$

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

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

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

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

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

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

and

$$\text{pitch} = P_m \sin(2\pi t/T_p + \phi_p), \quad (166)$$

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

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

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 i th 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
ISSET	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 i th 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 i th detection
RMAX	Maximum roll angle (R_m in Eq. 165)
RMODE(1,5)	Scan period (ΔT in Eq. 164)

Table continues.

DAVIS AND TRUNK

Table 16 (Concluded) — VRCLT3 Variables

Fortran Variable	Description
ROUT(I)	Range of the <i>i</i> th detection (R in Eq. 161)
RS	Initial range of the clutter region (R_S in Eq. 163)
SOUT(I)	Power of the <i>i</i> th 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 <i>i</i> th 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 beam-width. 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.

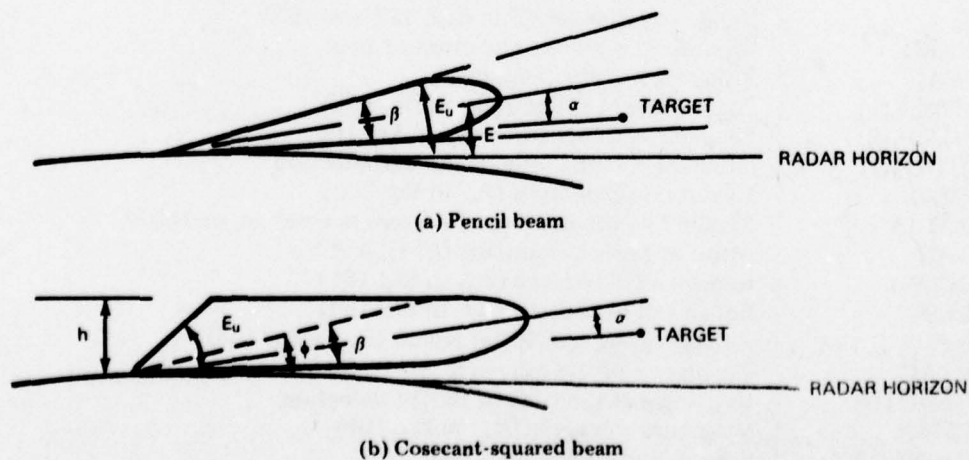


Fig. 5 — Beam patterns

NRL REPORT 8228

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

$$\theta = \frac{2.78}{\beta} \alpha, \quad (168)$$

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

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

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

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

and

$$f = f_{SL}, \quad |\theta| > \pi, \quad (170b)$$

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 :

$$E = \frac{k\beta}{2} \quad (171)$$

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

DAVIS AND TRUNK

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

where

$$p = \frac{2.78}{\beta} \quad (173)$$

and

$$\theta = \phi - E. \quad (174)$$

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

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

where

$$\theta = \tan^{-1} \frac{y}{x} \quad (176)$$

and

$$\begin{aligned} \theta' &= \frac{1}{1 + y^2/x^2} \left(\frac{y'}{x} - \frac{y}{x^2} \right), \\ &= \frac{xy' - y}{r^2}. \end{aligned} \quad (177)$$

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

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

NRL REPORT 8228

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

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

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

$$\cot p\theta_h - \frac{1}{p\theta_h} \approx \frac{-p\theta_h}{3} \quad (180)$$

and

$$\tan \phi_h \approx \phi_h. \quad (181)$$

This reduces Eq. 179 to

$$\frac{2p^2 \phi_h \theta_h}{3} = 1 \quad (182)$$

or, by substituting Eq. 174,

$$2p^2 \phi_h (\phi_h - E) = 3, \quad (183)$$

which can be rearranged into the quadratic form

$$\phi_h^2 - \phi_h E - \frac{3}{2p^2} = 0 \quad (184)$$

with the root

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

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

$$\begin{aligned} \phi_h &= \frac{1}{2} \left[\frac{k\beta}{2} + \left(\frac{k^2 \beta^2}{4} + \frac{6\beta^2}{(2.78)^2} \right)^{1/2} \right] \\ &= \frac{\beta}{4} [k + (k^2 + 3.1)^{1/2}]. \end{aligned} \quad (186)$$

DAVIS AND TRUNK

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:

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

where K is readily found to be

$$K = f(\phi_h) \csc^2 \phi_h, \quad (188)$$

so that

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

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 cosecant-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 ,

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

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

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

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

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

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 $\sigma_0 = -20$ 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

$$\sigma_0(\theta_p) = [(\sigma_{0H} \cos \theta_p)^2 + (\sigma_{0V} \sin \theta_p)^2]^{1/2}. \quad (192)$$

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

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

where $\bar{H}_{1/3}$ 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

$$\bar{H}_{1/3} = 0.02667 V^2, \quad (194)$$

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

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

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

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

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

$$\sin \alpha_v = \frac{2R_2 \sin \psi \cos \psi}{R} \quad (197)$$

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) (f_{PH} in Eq. 198)
FHV(K)	Pattern function (total) for target K
FV	Vertical beam-pattern factor (power) (f_{PV} 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)

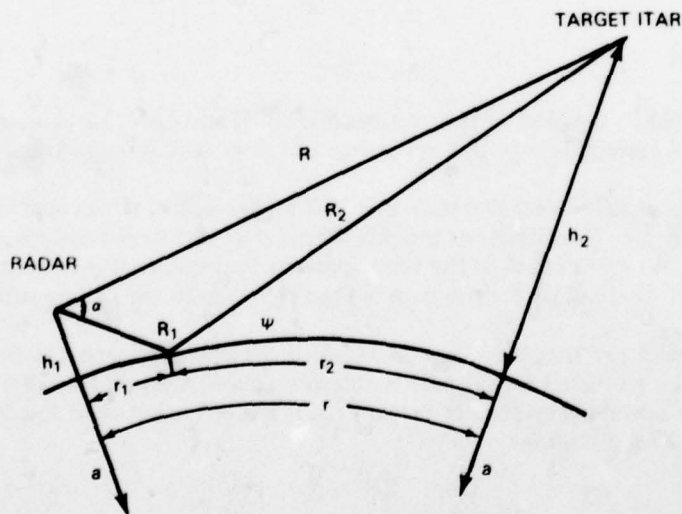


Fig. 6 — Geometrical parameters

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

$$f_P = f_{P_H} f_{P_V} \quad (198)$$

and the field strength ratio from

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

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 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

$$f_{HV} = f_H f_V. \quad (200)$$

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

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

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

DAVIS AND TRUNK

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

$$E_J = E_{0J} F^2. \quad (202)$$

The total jamming energy is

$$E_{TJ} = \sum_{J=1}^{N_J} E_J, \quad (203)$$

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

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

The Beaufort sea state is

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

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 $r d\phi dr$ is considered (Fig. 7). The energy received (dE) from this element is

$$dE = C \frac{G^2}{r^4} r d\phi dr, \quad (206)$$

where

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

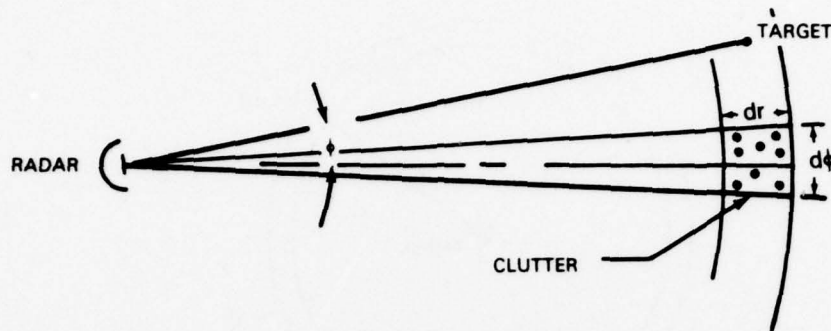


Fig. 7 - Differential clutter element

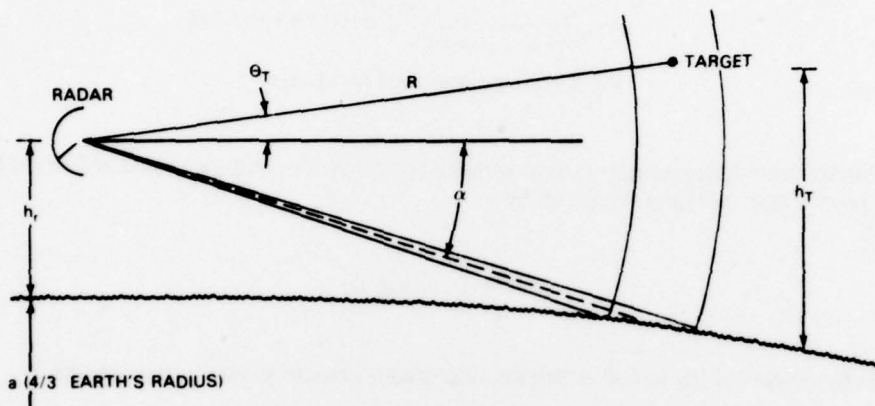


Fig. 8 - Geometry of a clutter element

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:

$$G = G(\theta_T + \alpha, \phi). \quad (208)$$

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

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

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

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

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

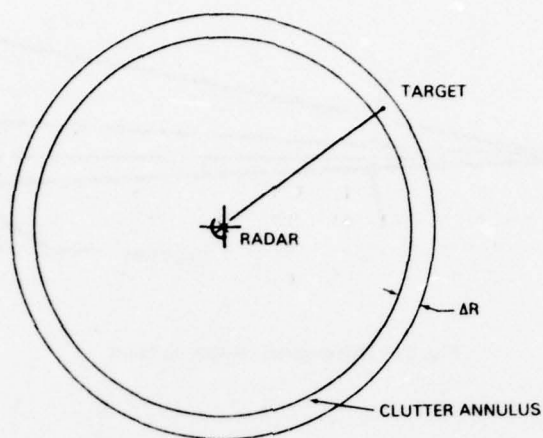


Fig. 9 - Annulus of total sea clutter

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

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

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

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

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

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

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 $U_r(R_1, R_2)$:

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

where

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

and

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

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

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

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 :

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

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

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

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

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

The notation can be simplified with the definitions

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

and

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

DAVIS AND TRUNK

so that Eq. 220 can be written as

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

Integration of Eq. 222 yields

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

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

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

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

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

The total sea-clutter energy can now be expressed as

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

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

$$E_c = EI_c. \quad (227)$$

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 j th 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

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

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

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

is given by

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

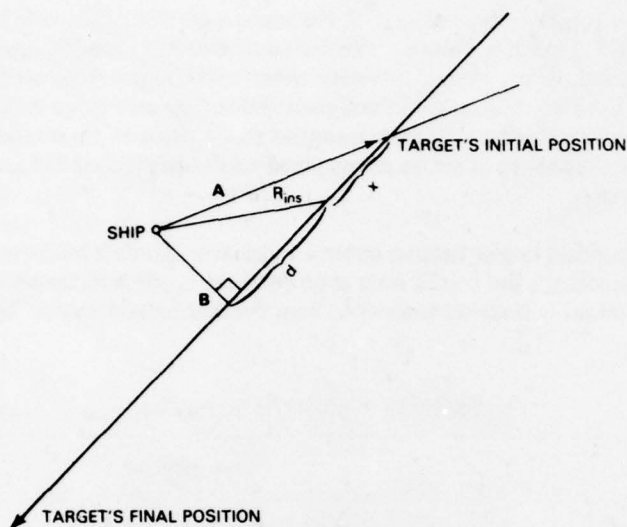


Fig. 10 — Target-and-ship geometry

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:

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

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

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

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

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

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.

DAVIS AND TRUNK

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 k th 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 ($ \mathbf{A} ^2$, or A^2 , in Eq. 228)
B(K)	The k th component of the vector B (n.mi.)
BMAG2	Magnitude of B squared, or $ \mathbf{B} ^2$
DISC	Quantity used in simplifying the calculations: $B^2 d^2$
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^2 d^2} = Bd $
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/ B $ 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 instrumented 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:

$$RMODE(J,9) = \min[TSCAN(I,J), I = 1, \dots, NTARG], \quad (234)$$

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.

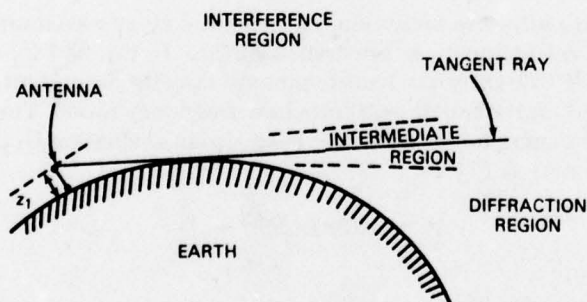


Fig. 11 — Interference, intermediate, and diffraction regions

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

$$\epsilon_c = \epsilon_1 - i60\lambda\sigma \quad (235)$$

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.

DAVIS AND TRUNK

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]

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

where X is the target ground range in natural units,

$$X = \frac{r}{L}, \quad (237)$$

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

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

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]

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

where H is the natural unit of height,

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

and

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

in which θ is the linear polarization.

NRL REPORT 8228

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

$$2r_1^3 - 3rr_1^2 + [r^2 - 2a(H_1 + H_2)]r_1 + 2aH_1r = 0, \quad (242)$$

where

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

Equation 242 has the solution

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

where

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

and

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

The grazing angle ψ is then found from the approximation

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

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

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

and

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

where

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

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

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

and

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

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:

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

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]

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

NRL REPORT 8228

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 ,

$$H_s = \frac{a}{2\sqrt{2}} \quad (254)$$

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

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

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
CUI	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

$$t_i \leq T \leq t_f, \quad (256)$$

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 from two to four altitude legs, the subroutine first determines the ratio of the elapsed time to the total target time according to

$$\Delta T = \frac{T - t_i}{t_f - t_i}. \quad (257)$$

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

$$x_T = x_i + \Delta T(x_f - x_i), \quad (258)$$

$$y_T = y_i + \Delta T(y_f - y_i), \quad (259)$$

and, for target type 0,

$$z_T = z_i + \Delta T(z_f - z_i), \quad (260)$$

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 k th altitude point, so that

$$t_a(k-1) < T \leq t_a(k), \quad (261)$$

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

$$t_a(1) = t_i \quad (262)$$

and

$$t_a(N) = t_f, \quad (263)$$

DAVIS AND TRUNK

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

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

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

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

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:

$$z_v = z_T - z_a(k-1) \quad (266)$$

and

$$d_v^2 = x_v^2 + y_v^2 + z_v^2. \quad (267)$$

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

$$T \leq t_m, \quad (268)$$

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

$$d = v(T - t_i), \quad (269)$$

so that

$$x_T = x_i + d \cos(\theta_i) \quad (270)$$

and

$$y_T = y_i + d \sin(\theta_i), \quad (271)$$

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

$$T > t_n, \quad (272)$$

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

$$d = v(T - t_n), \quad (273)$$

so that

$$x_T = x_n + d \cos \theta_f \quad (274)$$

and

$$y_T = y_n + d \sin \theta_f, \quad (275)$$

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

$$t_m < T \leq t_n, \quad (276)$$

then the target is performing its maneuver, so that if

$$\Delta = v(T - t_m)/r_m \quad (277)$$

and

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

then

$$x_T = x_c + r_m \cos \phi, \quad (279)$$

$$y_T = y_c + r_m \sin \phi, \quad (280)$$

and

$$z_T = z_i, \quad (281)$$

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

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

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

and

$$d_v^2 = x_v^2 + y_v^2, \quad (284)$$

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

$$dx_T = x_T - x_r, \quad (285)$$

DAVIS AND TRUNK

$$dy_T = y_T - y_r, \quad (286)$$

and

$$dz_T = z_T - z_r, \quad (287)$$

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

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

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

$$dT = s\theta_T/2\pi, \quad (289)$$

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

$$D = (dx_{T+dT}^2 + dy_{T+dT}^2)^{1/2}. \quad (290)$$

This can be approximated by

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

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

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

where h_1 is in nautical miles. If it is assumed that triangle ABT is a right triangle, then

$$\begin{aligned} \tan \alpha &= \frac{h_T - h_1}{D} \\ &= \frac{h_T}{D} - \left(\frac{D^{1/2}}{95.2} - \frac{h_a^{1/2}}{D^{1/2}} \right)^2. \end{aligned} \quad (293)$$

This completes the computational procedure in NEWPOS, and program control is returned to the executive routine.

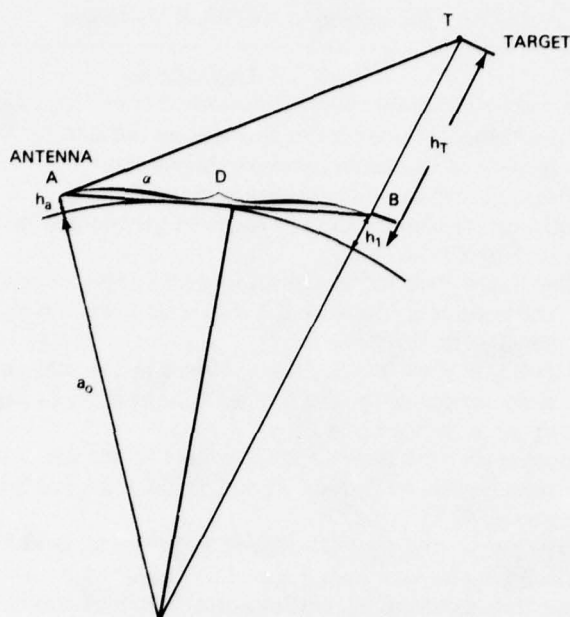


Fig. 12 — Geometry of target elevation

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 ($\tan \alpha$ 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})
DELTA	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.

DAVIS AND TRUNK

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 <i>J</i> (ΔT in Eq. 257)
DX	Coordinate <i>x</i> of target <i>J</i> with respect to the radar at time <i>T</i> and then corrected to time <i>T</i> + <i>dT</i> (n.mi.) (dx_T in Eq. 285 and dx_{T+dT} in Eq. 290)
DY	Coordinate <i>y</i> of target <i>J</i> with respect to the radar at time <i>T</i> and then corrected to time <i>T</i> + <i>dT</i> (n.mi.) (dy_T in Eq. 286 and dy_{T+dT} in Eq. 290)
DZ	Coordinate <i>z</i> of target <i>J</i> with respect to the radar at times <i>T</i> and then corrected to time <i>T</i> + <i>dT</i> (n.mi.) (dz_T in Eq. 287 and dz_{T+dT})
HEADF(J)	Final heading of target <i>J</i> with ITYPE(J) = 2 (θ_f in Eqs. 274 and 275)
HEADI(J)	Initial heading of target <i>J</i> with ITYPE(J) = 2 (θ_i in Eqs. 270 and 271)
IFLAG	Flag to indicate if calculations are being performed with respect to <i>T</i> (IFLAG = 1) or <i>T</i> + <i>dT</i> (IFLAG = 2)
ISTAT(J)	Status indicator for target <i>J</i> : 0 = inactive 1 = active
ITYPE(J)	Type of target profile for target <i>J</i> : 0 = straight-line trajectory 1 = altitude legs 2 = maneuver
NALT(J)	Number of altitude nodes for target <i>J</i> 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 <i>J</i> with ITYPE(J) = 2 (n.mi.) (r_m in Eqs. 276, 279, and 280)
SHIP(1)	Coordinate <i>x</i> of the radar position (n.mi.) (x_r in Eq. 285)
SHIP(2)	Coordinate <i>y</i> 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 <i>J</i> with ITYPE(J) = 2 (n.mi./h) (<i>v</i> in Eqs. 269 and 273)
T	Current game time (h) (<i>T</i> in Eq. 256)
TALT(J,1)	Time when target <i>J</i> arrives at altitude node <i>I</i> with ITYPE(J) = 1 (h) ($t_a(k)$ in Eq. 261)
TIME3(J)	Time when the radar scans target <i>J</i> (s) (<i>T</i> + <i>dT</i> in sentence containing Eq. 289)
TMANF(J)	Time when target <i>J</i> 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 IFLAC
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

$$|R_j - R_i| \leq \Delta D = (N_R + 2)\Delta R \quad (294)$$

and

$$|A_j - A_i| \leq 2.4 \theta, \quad (295)$$

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>i</i> th target (ΔD in Eq. 294)
INF(K)	Target number of the <i>k</i> 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 (<i>N_R</i> in Eq. 294)
NTAR	Target <i>I</i> of interest
RES	Dimension of the range-resolution cell (ΔR in Eq. 294)
SNREF(K)	Signal power of the <i>k</i> th interfering target
TH3DB	Antenna 3-dB azimuth beamwidth (θ in Eq. 295)
TRGPOS(I,4)	Range of the <i>i</i> th target (<i>R_i</i> in Eq. 294)
TRGPOS(I,5)	Azimuth of the <i>i</i> th target (<i>A_i</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.

NRL REPORT 8228

The subroutine is entered with a value of $\sin \psi$ that corresponds to the flat-earth solution to the problem

$$\sin \psi = 2 \left(\frac{\lambda}{4} \right) \frac{h_r + h_t}{(\lambda/4)^2 + 4 h_r h_t}, \quad (296)$$

where $\lambda/4$ represents the path-length difference and h_r , h_t , and ψ are defined in Fig. 13. This value of $\sin \psi$ 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:

$$\Delta = \frac{4 \sin \psi}{\frac{1 + [1 + (2h_r/a \sin^2 \psi)]^{1/2}}{h_r} + \frac{1 + [1 + (2h_t/a \sin^2 \psi)]^{1/2}}{h_t}}, \quad (297)$$

where a is $4/3$ of the earth's radius. The function f , defined as

$$f = \Delta - \frac{\lambda}{4}, \quad (298)$$

is evaluated, and its absolute value is compared to $\lambda/40$. If $|f| \geq \lambda/40$, the derivative of f with respect to $\sin \psi$ is determined and used to calculate a new value of $\sin \psi$:

$$\sin \psi_{\text{new}} = \sin \psi_{\text{old}} - f \left[\frac{1}{df/d(\sin \psi)} \right]. \quad (299)$$

A new value of Δ is then computed using $\sin \psi_{\text{new}}$, 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.

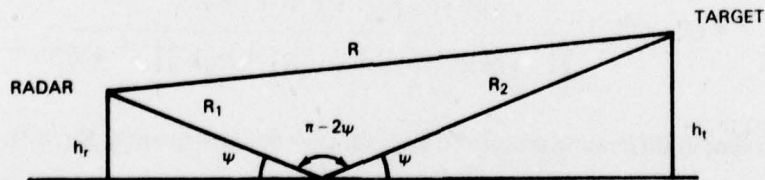


Fig. 13 - Flat-earth geometry

DAVIS AND TRUNK

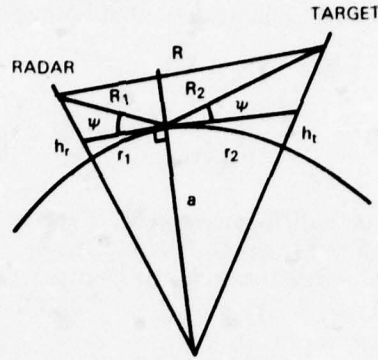


Fig. 14 — Spherical-earth geometry

Equation 297 is developed as follows: From Fig. 13 or Fig. 14

$$\begin{aligned}
 R &= (R_1^2 + R_2^2 + 2R_1R_2 \cos 2\psi)^{1/2} \\
 &= [(R_1 + R_2)^2 - 2R_1R_2(1 - \cos 2\psi)]^{1/2} \\
 &= [(R_1 + R_2)^2 - 4R_1R_2 \sin^2 \psi]^{1/2}.
 \end{aligned} \tag{300}$$

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 $\Delta = R - (R_1 + R_2)$,

$$\begin{aligned}
 \Delta &= (R_1 + R_2) \left\{ -1 + \left[1 - \frac{4R_1R_2 \sin^2 \psi}{(R_1 + R_2)^2} \right]^{1/2} \right\}, \\
 &= (R_1 + R_2) \frac{(4R_1R_2 \sin^2 \psi)/(R_1 + R_2)^2}{\left\{ 1 - [(4R_1R_2 \sin^2 \psi)/(R_1 + R_2)^2] \right\}^{1/2} + 1}.
 \end{aligned} \tag{302}$$

When the path-length difference is close to $\lambda/4$, $\sin \psi \approx 0$; consequently Eq. 302 can be simplified to

$$\Delta = \frac{2R_1R_2}{R_1 + R_2} \sin^2 \psi = \frac{2}{R_1^{-1} + R_2^{-1}} \sin^2 \psi. \tag{303}$$

NRL REPORT 8228

To reduce Eq. 303 to Eq. 297, R_1 and R_2 must be expressed in terms of h_r , h_t , and $\sin \psi$, which is accomplished as follows: From Fig. 14

$$\sin \psi = \frac{h_r^2 - R_1^2 + 2ah_r}{2R_1a} = \frac{h_r}{R_1} \left(\frac{h_r}{2a} + 1 \right) - \frac{R_1}{2a} \quad (304)$$

Neglecting $h_r/2a$ gives

$$\sin \psi = \frac{h_r}{R_1} - \frac{R_1}{2a} \quad (305)$$

Applying the quadratic formula to Eq. 305 yields

$$R_1 = \frac{2h_r}{\sin \psi + [\sin^2 \psi + (2h_r/a)]^{1/2}} \quad (306)$$

Similarly

$$R_2 = \frac{2h_t}{\sin \psi + [\sin^2 \psi + (2h_t/a)]^{1/2}} \quad (307)$$

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 , 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 ($\sin \psi$ 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

$$P_r = \frac{P_T G^2 \lambda^2 \sigma L_R L_T L_M}{R^4 (4\pi)^3}, \quad (308)$$

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

$$S_0 = P_r \tau. \quad (309)$$

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

$$S_1 = S_0 [f(\theta)]^2. \quad (310)$$

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

$$\sigma_R = V_m \sum \sigma_i, \quad (311)$$

where V_m is the volume of the radar resolution cell:

$$V_m = \left(\frac{\pi}{4}\right) R^2 \theta_B \phi_B \left(\frac{c\tau_c}{2}\right), \quad (312)$$

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.

NRL REPORT 8228

It can be shown that if the raindrop diameter D is small in comparison to λ , then σ_i can be represented by

$$\sigma_i = \frac{\pi^5}{\lambda^4} |K|^2 D^6, \quad (313)$$

where K depends on the dielectric constant of the scatterer and K^2 is approximately 0.93 for water at 10°C when $\lambda = 10$ 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):

$$\sum_i D^6 = 200r^{1.6}. \quad (314)$$

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

$$\sigma_R = 6.706 \times 10^{-6} \tau_c \theta_B \phi_B R^2 r^{1.6} \lambda^{-4}. \quad (315)$$

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

$$2\alpha = 1.753 \times 10^{-3} f^{1.87}, \quad (316)$$

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

$$\log_{10} A_r = -10^{-8} Rr\lambda^{-1.87}. \quad (317)$$

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

$$S = S_1 F^4 A_r [\min(B_{IF} \tau_c, 1)], \quad (318)$$

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

$$N_T = F_n k T_0, \quad (319)$$

where F_n is the receiver noise figure, k is Boltzmann's constant, and T_0 is the system temperature in degrees Kelvin.

DAVIS AND TRUNK

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

$$E_R = \frac{6\sigma_R S I_c \tau}{\sigma F^4 f^2(\theta)}, \quad (320)$$

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

$$E_N = (N_T + E_J + E_R) \max(B_{IF} \tau_c, 1), \quad (321)$$

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)	$\max(B_{IF} \tau_c, 1)$ 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.

DAVIS AND TRUNK

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:

$$\Delta = v(t_m - t_i), \quad (322)$$

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

$$x_m = x_i + \Delta \cos(h_i) \quad (323a)$$

and

$$y_m = y_i + \Delta \sin(h_i), \quad (323b)$$

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:

$$h_m = \cos^{-1} [(x_f - x_m) / [(x_f - x_m)^2 + (y_f - y_m)^2]^{1/2}], \quad (324)$$

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 $h_m \geq h_i + \pi$, or if $h_i \geq \pi$ and both $h_m < h_i$ and $h_m \geq h_i - \pi$ (the point (x_f, y_f) lies to the right of the initial heading vector), then the maneuver is clockwise and flagged by $\text{TURN} = -1$. Otherwise the maneuver is counterclockwise with $\text{TURN} = 1$.

The radius of the maneuver circle is

$$r_m = v^2/g, \quad (325)$$

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

$$x_c = x_m + r_m \cos(h_i + \text{TURN} \pi/2) \quad (326a)$$

and

$$y_c = y_m + r_m \sin(h_i + \text{TURN} \pi/2). \quad (326b)$$

If

$$d = [(x_f - x_c)^2 + (y_f - y_c)^2]^{1/2} < r_m, \quad (327)$$

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

$$\alpha = \cos^{-1} [(x_f - x_c)/d] \quad (328)$$

and

$$\beta = \sin^{-1} [r_m/d]. \quad (329)$$

The heading h_f of the target as it terminates its maneuver and begins its final leg is then

$$h_f = \alpha + \text{TURN} \beta, \quad \sin \alpha \geq 0, \quad (330a)$$

$$= 2\pi - \alpha + \text{TURN} \beta, \quad \sin \alpha < 0. \quad (330b)$$

DAVIS AND TRUNK

The point (x_n, y_n) where the target terminates its maneuver is

$$x_n = x_c + r_m \cos (h_f - \text{TURN } \pi/2) \quad (331a)$$

and

$$y_n = y_c + r_m \sin (h_f - \text{TURN } \pi/2), \quad (331b)$$

and the time t_n the target reaches (x_n, y_n) is

$$t_n = t_m + v(\Delta h)/g, \quad (332)$$

where

$$\Delta h = h_f - h_i, \quad (h_f - h_i) \geq 0, \quad (333a)$$

$$= h_f - h_i + 2\pi, \quad (h_f - h_i) < 0. \quad (333b)$$

The time t_f the target arrives at its final position is

$$t_f = t_n + [(x_f - x_n)^2 + (y_f - y_n)^2]^{1/2}/v. \quad (324)$$

(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

$$\alpha(\theta) = A_1 \cos 2\theta + A_2 \cos 4\theta + A_3 \cos 8\theta + A_4. \quad (335)$$

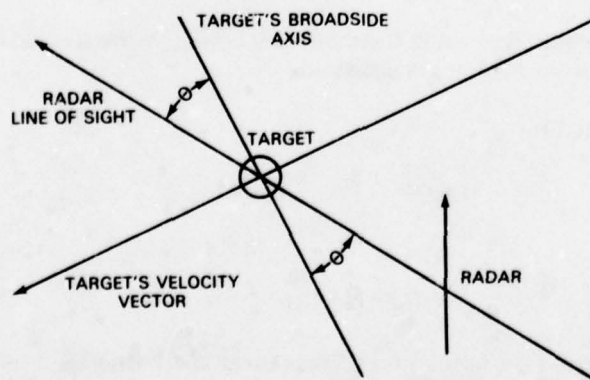


Fig. 15 — Geometry used in determining radar cross section of a target

NRL REPORT 8228

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 $\sin 2\theta$:

$$\begin{aligned} \alpha'(\theta) = & 2A_1 \sin 2\theta + 8A_2(2 \cos^2 \theta - 1) \sin 2\theta \\ & + 32A_3(16 \cos^6 \theta - 24 \cos^4 \theta + 10 \cos^2 \theta - 1) \sin 2\theta. \end{aligned} \quad (336)$$

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 $\alpha' = 0$ 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

$$\alpha(0) = 3A_2 - 3A_3 + 4A_4 = B. \quad (338)$$

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>I</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>I</i> of target <i>J</i> with $ITYPE(J) = 1$
CARD(I)	Temporary storage for the input parameters from the second data card for the target
CM(J,1)	Coordinate <i>x</i> of the center of the maneuver circle for target <i>J</i> with $ITYPE(J) = 2$ (x_c in Eq. 326a)
CM(J,2)	Coordinate <i>y</i> of the center of the maneuver circle for target <i>J</i> with $ITYPE(J) = 2$ (y_c in Eq. 326b)
DELR	Distance from the center of the maneuver circle to the final position for target <i>J</i> with $ITYPE(J) = 2$ (d in Eq. 327)
GTURN(J)	Radial acceleration for the maneuver by target <i>J</i> with $ITYPE = 2$ (g in Eq. 325)
HEADF(J)	Final heading of target <i>J</i> with $ITYPE(J) = 2$ (h_f in Eqs. 330)
HEADI(J)	Initial heading of target <i>J</i> with $ITYPE(J) = 2$ (h_i in Eqs. 323)
ITYPE(J)	Type of target profile for target <i>J</i> : 0 = straight-line trajectory 1 = altitude legs 2 = maneuver
MODEL(J)	Indicator of the Marcum-Swerling cross-section model for target <i>J</i>
NALT(J)	Number of altitude nodes for target <i>J</i> 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 <i>J</i> with $ITYPE = 2$
SIGJAM(J)	Jamming power for target <i>J</i> (W/MHz to W/Hz)
SIGTAR(J,1)	Head-on radar cross section for target <i>J</i> (m^2) (N in Eq. 339)
SIGTAR(J,2)	Broadside radar cross section for target <i>J</i> (m^2) (B in Eq. 338)
SIGTAR(J,3)	Minimum radar cross section for target <i>J</i> (m^2) (M in Eq. 340)
SPEED(J)	Speed of target <i>J</i> with $ITYPE(J) = 2$ (v in Eq. 325)
TALT(J,I)	Time when target <i>J</i> with $ITYPE(J) = 1$ arrives at altitude node <i>I</i>
TMANF(J)	Time when target <i>J</i> with $ITYPE(J) = 2$ terminates its maneuver (t_n in Eqs. 332 and 334)
TMANI(J)	Time when target <i>J</i> 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 <i>J</i> with $ITYPE(J) = 2$
XHEAD	Heading of the vector defined from the point the maneuver begins to the final position of target <i>J</i> with $ITYPE(J) = 2$ (h_m in Eq. 324)
XMANF(J,1)	Coordinate <i>x</i> for the point where target <i>J</i> with $ITYPE(J) = 2$ terminates its maneuver (x_n in Eqs. 331a and 334)
XMANF(J,2)	Coordinate <i>y</i> for the point where target <i>J</i> 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

$$\sigma(\theta) = A_1 \cos 2\theta + A_2 \cos 4\theta + A_3 \cos 8\theta + A_4, \quad (342)$$

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

$$F = 2(\pi X)^{1/2} e^{-C_1 X} |U_1(Z_1)U_1(Z_2)|, \quad (343)$$

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

$$U_1(Z_j) = i \frac{h_2(Z_j + A_1)}{h_2'(A_1)}. \quad (344)$$

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:

$$h_2(x) = i2^{4/3} 3^{1/6} Ai(xe^{i\pi/3}). \quad (345)$$

Expressions for evaluating the Airy functions are found in Ref. 10. The Airy function is

$$Ai(z) = c_1 f(z) - c_2 g(z), \quad (346)$$

where $f(z)$ and $g(z)$ are given by power series for small values of $|z|$:

$$f(z) = 1 + \frac{1}{3!} z^3 + \frac{1 \cdot 4}{6!} z^6 + \frac{1 \cdot 4 \cdot 7}{9!} z^9 + \dots \quad (347a)$$

and

$$g(z) = z + \frac{2}{4!} z^4 + \frac{2 \cdot 5}{7!} z^7 + \frac{2 \cdot 5 \cdot 8}{10!} z^{10} + \dots \quad (347b)$$

For values of $|z| > 3$, $Ai(z)$ is approximated by an asymptotic expansion:

$$Ai(z) \approx \frac{1}{2} \pi^{-1/2} z^{-1/4} e^{-\mu} \sum_{k=0}^{\infty} (-1)^k n_k \mu^{-k}, \quad (348)$$

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 k th term of the asymptotic expansion of the Airy function (Eq. 348) with argument $(Z_i + A_1)e^{i\pi/3}$
CAIRP	The k th 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	$-(1/2)\pi^{-1/2}(CA1)^{1/4}e^{-\mu}$ (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 k th term ($f(z)$ in Eq. 347a)
CFIP	$f'(A_1 e^{i\pi/3})$ summed to the k th term
CGI	$g[(Z_i + A_1)e^{i\pi/3}]$ summed to the k th term ($g(z)$ in Eq. 347b)
CGIP	$g'(A_1 e^{i\pi/3})$ summed to the k th term
CH2	h function used in determining U_1 ($h_2(Z_i + A_1)$ 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 = $ CZ $ and $ CA1 \leq 3$ 1 = $ CZ > 3$ 2 = $ CA1 > 3$ 3 = $ CZ $ and $ CA1 > 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 k th term of the power series for $f(z)$ (Eq. 347a)
XMUL2	Coefficient of the k th term of the power series for $g(z)$ (Eq. 347b)
Z	Height of the point in space under consideration (Z_j in Eq. 344)

DAVIS AND TRUNK

where

$$\mu = \frac{2z^{3/2}}{3}, \quad (349)$$

$$n_0 = 1, \quad (350)$$

and

$$n_k = \frac{\Gamma(3k + 1/2)}{54^k k! \Gamma(k + 1/2)} \quad (351)$$

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10. M. Abramowitz and I.A. Stegun, editors, "Handbook of Mathematical Functions," National Bureau of Standards Applied Mathematics Series 55, U.S. Government Printing Office, Washington, D.C., June 1964.

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)

$$T = \hat{\mu} + F_2 \hat{\sigma} \quad (A1)$$

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)

$$T = F_1 \hat{\mu}, \quad (A2)$$

the appropriate value of F_1 can be found from

$$F_1 = 1 + F_2 \sqrt{\frac{4 - \pi}{M\pi}}, \quad (A3)$$

where M is the number of pulses integrated. For log video and a threshold of the form (Eqs. 64 and 128)

$$T = \hat{\mu} + F_3 \quad (A4)$$

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).

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Appendix B

PROGRAM LISTINGS OF ROUTINES EXCLUSIVE TO SURDET2D

```
0001      PROGRAM SURDET
C
C      THIS IS THE SURDET2D EXECUTIVE ROUTINE
C
C      CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C      DESCRIPTION OF DATA CARDS
C
C      DATA CARD NO. 1
C
C      DETAILED OUTPUT CONTROL INTEGER (IS 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      DATA CARD NO. 2
C
C      TITLE CARD - RUN IDENTIFICATION (I4,I9A4 FORMAT)
C      1 RADAR ID NUMBER FOR TARGET DETECTION OUTPUT FILES
C      2-20 ALPHANUMERIC DESCRIPTIVE TITLE
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      DATA CARD NO. 4
C
C      11 BASIC RADAR PARAMETERS (9F4.2,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
```

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0 = HORIZONTAL
90 = VERTICAL

DATA CARDS NO. 5 AND 6 (ONE SET FOR EACH RADAR SCAN MODE)

- 15 PARAMETERS FOR EACH SCAN MODE (10F8.2/5F8.2 FORMAT)
- 1 LOWER BOUNDARY ELEVATION ANGLE COVERAGE IN DEGREES
 - 2 UPPER BOUNDARY ELEVATION ANGLE COVERAGE IN DEGREES
 - 3 PEAK POWER IN MW
 - 4 PULSE LENGTH IN MICROSECONDS
 - 5 INTERLOOK PERIOD IN SECONDS
 - 6 SCAN OFFSET IN SECONDS
 - 7 INSTRUMENTED RANGE IN NMI
 - 8 MODE DEPENDENT LOSS IN DB
 - 9 NUMBER OF PULSES INTEGRATED
 - 10 COMPRESSED PULSE LENGTH IN MICROSECONDS
 - 11 SFA CLUTTER IMPROVEMENT FACTOR IN DB
 - 12 I.F. BANDWIDTH IN MHZ. IF 0, BANDWIDTH WILL BE SET AT 1.0/(COMPRESSED PULSE LENGTH)
 - 13 MODE DEPENDENT FREQUENCY INCREMENT IN MHZ
 - 14 BLANKING TIME IN MICROSECONDS. IF 0, SET AT PULSE LENGTH
 - 15 RAIN CLUTTER IMPROVEMENT FACTOR IN DB

DATA CARD NO. 7

- 7 PARAMETERS FOR MOVING WINDOW DETECTOR (7F8.2 FORMAT)
- 1 NO. OF REFERENCE CELLS ON EACH SIDE OF TARGET CELL
 - 2 CLUTTER CORRELATION COEFFICIENT
 - 3 NO. OF STANDARD DEVIATIONS USED IN THRESHOLD
 - 4 NO. OF DETECTIONS THAT CAN BE MISSED AND DETECTIONS STILL MERGED INTO A SINGLE DETECTION
 - 5 VIDEO TYPE INDICATOR
 - 0 = LINEAR VIDEO
 - 1 = LOG VIDEO
 - 6 NO. OF REFERENCE CELLS USED FOR THRESHOLD
 - 0 = ALL CELLS USED
 - <0 = SMALLER HALF USED
 - >0 = LARGER HALF USED
 - 7 PARAMETERS USED TO CALCULATE THRESHOLD
 - 1 = MEAN USED
 - 2 = MEAN AND VARIANCE USED

DATA CARD NO. 8

NUMBER OF TARGETS AND JAMPERS (2I5 FORMAT)

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```
0024      XKTOMS =.514444444
0025      XNXTOM =1852.
0026      FMPISQ =157.9136706
0027      FMPIQB =1984.401711
0028      5 JFR = 0
0029      READ 52,ANS1
0030      52 FFORMAT(1,615)
0031      READ 500,ITITLE
0032      500 FFORMAT(14,19A4)
0033      PRINT 501,ITITLE
0034      501 FFORMAT(1H1,14,5X,19A4)
0035      CALL INITAL
0036      10 CALL TARGET
0037      11 CALL ENVIRN
C
C      INITIALIZE CLUTTER FOR TRACKING
0038      CALL FCINIT
0039      CALL VCINIT
C
C      INITIALIZE ROLL AND PITCH
0040      CALL STBINT
C
C      READ IN TIME BY WHICH RADAR MUST BE INITIALIZED
0041      READ 59, RINIT
0042      59 FFORMAT(F8.2)
0043      PRINT 590, RINIT
0044      590 FFORMAT(1H0," GAME INITIALIZATION BY ",F8.2)
C
C      ADD SCAN OFFSET (FROM MODE 1) TO MAX RADAR INITIALIZATION TIME
0045      RINIT = RINIT/3600. + RMODE(1,6)
0046      ISC=0
0047      IKEYF=0
C      DETERMINE TIMES EACH TARGET COMES WITHIN INSTRUMENTED RANGE
C      OF EACH RADAR MODE
0048      CALL MATCH
C
C      DETERMINE INITIAL AND FINAL GAME TIMES
C
0049      T = RMODE(1,9)
0050      ENDTIM = XYZF(1,4)
C      SET TARGETS INITIALLY TO OVER-THE-HORIZON
0051      TRGPOS(1,4) = -1.
0052      IF(NSCAN .LT. 2) GO TO 17
C      DETERMINE INITIAL TIME FROM MATCH
0053      DO 15 J = 2,NSCAN
0054      IF(RMODE(J,9) .LT. T) T = RMODE(J,9)
0055      15 CONTINUE
0056      17 IF(NTARG .LT. 2) GO TO 19
C      DETERMINE END GAME TIME
0057      DO 18 I = 1,NTARG
```

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```
0058      TRGPS(I,4) = -1.
0059      IF(XYZF(I,4) .GT. ENDTIM) ENDTIM = XYZF(I,4)
0060      18 CONTINUE
0061      19 CONTINUE
C        SET INITIAL TIME FROM MATCH 30 SEC. EARLIER FOR CLUTTER SAMPLES
0062      T = T - 3./360.
C        SET INITIAL GAME TIME
0063      T = AMIN(T,RINIT)
C        WRITE ID ON DETECTION OUTPUT FILE
0064      TEMP = 2
0065      TEMPB = RMODE(1,5)*3600.
0066      WRITE (IOUT) ITITLE(1),TEMP,TEMPB
C
0067      IF (ANS1.EQ.0) GO TO 20
0068      MUL=ENVIR(3)
0069      IF ( MUL .NE. 0 ) PRINT 506
0070      IF ( MUL .EQ. 0 ) PRINT 505
0071      506 FORMAT(/, "          $$$$$ WITH MULTIPATH $$$$$",/)
0072      505 FORMAT(/,60X, "          $$$$$ NO MULTIPATH $$$$$",/)
C
C        NEW SCAN
0073      20 ISC = ISC + 1
0074      ICNT = 0
0075      BUF(3) = 0
C        SET SCAN PRINT FLAG
0076      IPFLAG = 0
C        DETERMINE TARGET AND JAMMER POSITIONS AT SCAN TIME T
0077      CALL NEWPOS
C
0078      DO 75 J = 1,NSCAN
0079      NEXT = J
C        ZERO ARRAYS
0080      DO 25 I = 1,NTARG
0081      MDET(I) = 0
0082      25 MER(I) = 0
0083      DO 70 I = 1,NTARG
C        CHECK IF TARGET ACTIVE
0084      IF(ISTAT(I) .NE. 1) GO TO 70
C        CHECK IF TARGET WITHIN DETECTION RANGE OF THIS MODE
0085      IF(TSCAN(I,J) .GT. T) GO TO 70
0086      TEMP = RMODE(J,1) - 0.63*RC(5)
0087      TEMP2 = RMODE(J,2) + 0.63*RC(5)
0088      IF(TRGPS(I,6) .GE. TEMP .AND. TRGPS(I,6) .LE.
1      TEMP2 .AND. TRGPS(I,4) .LE. RMODE(J,7)
2      .AND. TRGPS(I,4) .GT. SMODE(J,1)) GO TO 30
C        TARGET CANNOT BE DETECTED BY MODE J
0089      GO TO 70
0090      30 IF(RC(1) + DWL(NEXT) .NE. MFR) ISWIT = 0
0091      MFR=RC(1)+DWL(NEXT)
0092      RFR=RC(1)/MFR
```

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```
0093      RC(6)=GN/PFR**2
0094      RC(4)=THM*RF
0095      RC(5)=THV*RF
0096      PBB5 = RMDE(NEXT,1) + RC(5)/2.

C
0097      ALPHAD = 0
0098      SIGC = 0
0099      SIG = 0
0100      AR1 = 0
0101      AR2 = 0
0102      V = 0

C
0103      CHECK FOR PRINT
0104      IF( IPFLAG .NE. 0) GO TO 35
0105      IPFLAG = 1
0106      IF( ANSI.EQ.0 ) GO TO 35
0107      PRINT SCAN NUMBER
0108      PRINT 507,ISC
0109      507  FORMAT (////,30X,"++++++ SCAN NUMBER = ",I4," ++++++",/)
0110      IF( ANSI.NE.2 ) GO TO 35
0111      PRINT HEADING
0112      PRINT 40

C
0113      COMPUTE SIGNAL ENERGY AND NOISE AND CLUTTER ENERGIES FOR TARGET I
0114      35  CALL SIGNAL(I,RC(11),RC(12))
0115      CALL NOISE(I,RC(13),RC(14))
0116      TCRSS = TARC5

C
0117      DETERMINE TARGET DETECTIONS IN MODE J
0118      NREF = RC(15)
0119      NCONZ = RC(18)
0120      CALL MWDET(RC(12),RC(13),RC(14),IMODE(J,1),RC(16),RC(17),NREF,
0121      1      RC(19),I,NTARG,RC(4),NCONZ, ACONZ,RC(20),RC(21),RC(22),
0122      2      SNTRUE)
0123      IF (ANSI.NE.2) GO TO 65
0124      BHDEG=TRGPOS(I,5)*RADIAN
0125      BVDEG = TRGPOS(I,6)*RADIAN
0126      DBE=C0NV*ALOG(PC(12))
0127      DRN=C0NV*ALOG(RC(14))
0128      SN=DBE-DRN
0129      TRGP = TRGPOS(I,4)*6.0802
0130      AMBND8 = C0NV*ALOG(CMAX1(AMBN,1.0E-74))
0131      XJAMDB = C0NV*ALOG(CMAX1(XJAMN,1.0E-74))
0132      SCDB = C0NV*ALOG(CMAX1(SIGC,1.0E-74))
0133      SFAC4=C0NV*ALOG(CMAX1(FAC4,1.0E-74))
0134      SNTRUE = 10.*ALOG10(SNTRUE)
0135      PRINT 50, I, J, TIME(I), TRGP, BHDEG, BVDEG, TCRSS, SFAC4, DBE, AMBND8
0136      1      , SCDB, XJAMDB, SN, SNTRUE, MER(I)

0137      KNUM = NDET(I)
0138      IF (KNUM.EQ.0) GO TO 65
0139      DO 61 K=1,KNUM
0140      RPRR = RANGE(I,K)*6.0802
0141      AAAA = AZ(I,K)*RADIAN
```

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```
0134      IF( MER(I).NE.0 ) AAAA = .5*(AZ(I,2*K) + AZ(I,2*K-1))*RADIAN
0135      SSSS = SNDET(I,K)
0136      SSSS = 20.*ALOG10(SSSS)
0137      PRINT 55,RRRR,AAAA,SSSS
0138      55 FORMAT(5X,"*DETECTION*",4X,F12.2,F10.2,19X,F10.0)
0139      61 CONTINUE
0140      65 CONTINUE
0141      70 CONTINUE

      C
      C   MERGE DETECTIONS FOR THIS MODE
0142      CALL MFRDET(RC(19),NTARG,ACONZ)
      C   CALCULATE ROLL AND PITCH
0143      CALL STAB2

      C
      C   SET UP DETECTIONS FOR OUTPUT
0144      DO 74 I = 1,NTARG
0145      NCT = NDET(I)
0146      IF(NCT .EQ. 0) GO TO 74
0147      BUF(3) = BUF(3) + NCT
0148      DO 73 K = 1,NCT
0149      ICNT = ICNT+1
0150      BUFA(1,ICNT) = I
0151      BUFA(2,ICNT) = RANGE(I,K)
0152      BUFA(3,ICNT) = AZ(I,K)
0153      BUFA(4,ICNT) = ELEV(I,K)
0154      BUFA(5,ICNT) = TIME(I)
0155      BUFA(6,ICNT) = SNDET(I,K)
0156      BUFA(6,ICNT)=20.*ALOG10(BUFA(6,ICNT))
0157      BUFA(7,ICNT) = ROLL(I)
0158      BUFA(8,ICNT) = PITCH(I)
0159      73 CONTINUE
0160      74 CONTINUE
0161      75 CONTINUE

      C
      C   CLUTTER OUTPUT FOR TRACKING
0162      CALL FXCLT2
0163      CALL VRCLT2

      C
      C   SCAN OUTPUT
0164      BUF(1) = ISC
0165      BUF(2) = T*3600.
0166      BUF(3) = BUF(3) + IV
0167      BUF(4) = 2000+ITITLE(1)
0168      BUF(5) = SHIP(5)
0169      BUF(6) = NTARG
0170      WRITE (IOUT) (BUF(I),I=1,6)
0171      IF(ANS1.EQ.0) GO TO 220
0172      IF( BUF(3).EQ.0 ) GO TO 220
0173      PRINT 56, (BUF(I),I=1,6)
0174      56 FORMAT(1H"/" SCAN NUMBER=",F5.0," TIME=",F9.2," NO. DETECTI
```

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```
10NS=",F5.0,"   RADAR ID=",F6.0,"   HEADING=",F7.2,"   NO. TARGE
2TS=",F4.0/"
0175 PRINT 58
0176 58 FORMAT(18X,"ID",6X,"RANGE",5X,"AZIM",6X,"ELEV",6X,"TIME",6X,"ESIG"
1,6X,"ROLL",5X,"PITCH")
0177 220 CONTINUE
0178 DO 250 I = 1,NTARG
0179   BUFB(1,I) = I
0180   BUFB(2,I) = TRGPS(I,4)
0181   BUFB(3,I) = TRGPS(I,5)
0182   BUFB(4,I) = TRGPS(I,6)
0183   BUFB(5,I) = TIME(I)
0184 250 CONTINUE
0185 IF (IV.EQ.0) GO TO 270
0186 DO 260 I = 1,IV
0187   ICNT = ICNT+1
0188   BUFA(1,ICNT) = 200
0189   IF (1.LE.IC)
1BUFA(1,ICNT) = 100 + NC(I)
0190   BUFA(2,ICNT) = R0UT(I)
0191   BUFA(3,ICNT) = AZ0UT(I)
0192   BUFA(4,ICNT) = EL0UT(I)
0193   BUFA(5,ICNT) = TR0UT(I)
0194   BUFA(6,ICNT) = SR0UT(I)
0195   BUFA(6,ICNT)=20.*ALOG10(BUFA(6,ICNT))
0196   BUFA(7,ICNT) = RL0UT(I)
0197   BUFA(8,ICNT) = TR0UT(I)
0198 260 CONTINUE
0199 270 CONTINUE
0200 DO 275 J = 1,NTARG
0201   WRITE (IOUT) (BUFB(I,J),I=1,5)
0202 275 CONTINUE
0203   IF (ICNT.EQ.0) GO TO 290
0204   DO 277 J = 1,ICNT
0205     WRITE (IOUT) (BUFA(I,J),I = 1,8)
0206 277 CONTINUE
0207   IF (ANS1.EQ.0) GO TO 290
0208   DO 280 J = 1,ICNT
0209     PRINT 57, (BUFA(I,J),I = 1,8)
0210 57 FORMAT(" DETECTION NUM ",F5.0,7F10.4)
0211 280 CONTINUE
0212 290 CONTINUE
C
C NEW SCAN
0213   I = T + RM0DE(1,5)
0214   IF (T .GT. ENDTIM) GO TO 110
0215   GO TO 20
C
0216 80 CONTINUE
0217   IF (ISTEP.LE.4000) GO TO 20
```

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```
0218      110 ISTEP=ISTEP-1
0219      301 CONTINUE
0220      XJAMN=0.
C        READ IN RECYCLE CONTROL PARAMETER
C        IANS=1(SHIP),=2(TARGET),=3(ENVIRONMENT),=4(FINISHED)
0221      READ 52, IANS
0222      GO TO (5,10,11,140),IANS
0223      140 CONTINUE
0224      130 CONTINUE
0225      40 FORMAT (//,7X,"MODE",42X,"SIGMA",/, " TARGET",9X,"TIME      RANGE
           1,6X,"AZIM      ELEV      FACTOR  ESIG  NAMB  NCLT  NJAM
           2      E/M      MER  ")
0226      50 FORMAT(1X,2I4,F11.1,F12.2,F10.2,F10.2,F5.1,F5.0,F9.0,3F8.0,F9.2
           1,F7.2,15)
0227      60 FORMAT (1X,I4/(1X,5(F7.1,F7.5)))
0228      END
```

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```
0001      SUBROUTINE FXCLT2
0002      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
1          ,PI,TWOPI ,TWOPR,RADIAN,TAUC(30),DSTAR,DWLC(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 /FCIN/ N,PROB,RS,RF,THS,THF,SIGA,SIGR,ISET
0004      COMMON /FCPT/ R(100),AZ(100),RAN(400),N2,N3,N4
0005      COMMON /CLTOUT/ ROUT(201),AZOUT(201),ELOUT(201),TOUT(201),
1 RLOUT(201),PTOUT(201),SOUT(201),NC(100),IC,IV
0006      COMMON /STABIN/ RMAX,PMAX,RFAC,PFAC,PHASE(2)
C
0007      IC=0
0008      IF (N.EQ.0) GO TO 15
C      TIMZB IS THE TIME OF THE ZERO BEARING CROSSING
0009      TIMZB=T*3600.
C      TIMSCN IS THE SCAN TIME OF THE RADAR
0010      TIMSCN=RMODE(1,5)*3600.
C      RES IS THE RANGE GATE SIZE
0011      RES=RC(19)
0012      CALL SETVR(ISET)
0013      CALL VRANF(RAN,N4)
0014      ISET = 2147483647.*RAN(1)
0015      ISET = 2*(ISET/2) + 1
0016      DO 20 I=1,N
0017      IF (RAN(I).GT.PROB) GO TO 20
0018      IC=IC+1
0019      NC(IC)=I
0020      TH=RAN(I+N)*TWOPI
0021      RAY=SQRT(-2.*ALOG(RAN(I+N2)))
0022      K=(R(I)+SIGR*RAY*COS(TH))/RES
0023      ROUT(IC)=(K+0.5)*RES
0024      TOUT(IC)=TIMZB+TIMSCN+AZ(I)/TWOPI
C
C      GENERATION OF ROLL AND PITCH
C
0025      RLOUT(IC)=RMAX*SIN(TOUT(IC))*RFAC+PHASE(1)
0026      PTOUT(IC)=PMAX*SIN(TOUT(IC))*PFAC+PHASE(2)
0027      CR=COS(RLOUT(IC))
0028      SR=SIN(RLOUT(IC))
0029      CP=COS(PTOUT(IC))
0030      SP=SIN(PTOUT(IC))
0031      AA=AZ(I)-SHIP(5)
0032      TE=0.
0033      X=SIN(AA)*CR+(COS(AA)*SP+TE*CP)*SR
0034      Y=COS(AA)*CP-TE*SP
0035      A=ATAN2(X,Y)+TWOPI
C
C      GENERATION OF MEASURED ANGLES
C
```

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```
0036      AM  =A+SIGA*RAY+SIN(TH)+SHIP(5)
0037      FL0UT(IC)=0.0
0038      AZ0UT(IC)=AM0D(AM,TW0PI)
          C      ***** NEED TO GENERATE 0UTPUT POWER *****
0039      S0UT(IC)=55.55
0040      20  CONTINUE
0041      RETURN

          C
          C      INITIALIZATION OF THE CLUTTER ROUTINE
          C
0042      ENTRY FCINIT
0043      READ 50,ISET,N,PROB,RS,RF,SIGR,THS,THF,SIGA
0044      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
0045      PRINT 55,ISET,N,PROB,RS,RF,SIGR,THS,THF,SIGA
0046      55  FORMAT (1H0," FIXED CLUTTER ",2I8,7F8.3)
0047      CALL SETVR(ISET)

          C
          C      CALCULATION OF RANGE CELL DIMENSION
          C
0048      RES=TAU(1)*300000./2.
0049      RES=RES*3.2808/6.08
          C      RC(19) = RES      = RANGE RESOLUTION CELL SIZE
0050      RC(19)=RES
0051      IF (N.EQ.0) GO TO 15
0052      RS=RS/6.0802
0053      RF=RF/6.0802
0054      THS=THS/RADIAN
0055      THF=THF/RADIAN
0056      SIGA=SIGA*RC(4)
0057      SIGR=SIGR*RES
0058      IF (N.GT.100) N=100
0059      N2=2*N
0060      N3=3*N
0061      N4=4*N
0062      CALL VRANF(RAN,N2)
0063      ISET = 2147483647.*RAN(1)
0064      ISET = 2*(ISET/2) + 1
0065      DO 10 I=1,N
0066      R(I)=RS+(RF-RS)*RAN(1)
0067      10  AZ(I)=THS+(THF-THS)*RAN(1+N)
0068      15  RETURN
0069      END
```

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```
0001      SUBROUTINE INITAL
0002      DIMENSION AMODE(30,2)
0003      COMMON NSCAN, NEXT, NUMTGT, T, BLDT, ENDTIM, SMODE(30,20)
1          , PI, PI9VR2, T90PI, RADIAN, TAU(30), DSTAR, DNL(30)
2          , XYZI(20,4), XYZF(20,4), TRGPS(20,7), SIGJAM(20)
3          , SIGTAR(20,3), FMV(20), SIGMAH, ISWIT, TEMPWR
4          , SHIP(9), RC(30), RMODE(30,12), IMODE(30,2)
0004      COMMON/B/ ENVIR(10), SURC(30), RE, CNH, CCM, ACON, BETA,
          * DPTP(20), POLRZ, IKEYF, YKTOMS, XNMTOM, TARCS, WVL, FOPIGB, FOPISO
0005      COMMON/I/ PBR8, HOFK, TMTBK, DRDRWN, THH, THV, GN
0006      RC(10)=290.0+1.3A+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, AX, ' HEADING IS ',
1          , FR, 3)
0011      MILLI=1.0E+6
0012      DR 30 I=1,3
0013      30 SHIP(I)=SHIP(I)/6.0802
0014      PI=3.1415926536
0015      T90PI=PI*2.0
0016      PI9VR2=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      DRDRWN = RC(7)+RC(7)
0037      DR 60 J = 1, NSCAN
C          RMODE(I,5) IS USED AS RADAR SCAN RATE FOR ALL MODES
0038      READ 51, (RMODE(J,1), I=1,8), AMODE(J,1), RMODE(J,11), SURC(J)
          * RMODE(J,12), DNL(J), SM, SMODE(J,2)
0039      51  FORMAT(10F8.2)
0040      IMODE(J,1)=AMODE(J,1)
0041      PRINT 511, J, (RMODE(J,1), I=1,8), IMODE(J,1), RMODE(J,11), SURC(J)
```

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```
0042      ,RMODE(J,12),DNL(J),SM,SMODE(J,2)
0043 511 FORMAT(/, ' 16 MODE ',I2,' PARAMETERS ARE ',8F9.3,18,/,50X,6F9.3)
0044 IF (RMODE(J,5).GT.0.0) GO TO 55
0045 RMODE(J,5)=10.0
0046 55 RMODE(J,1)=RMODE(J,1)/RADIAN
0047 RMODE(J,2)=RMODE(J,2)/RADIAN
0048 IF (SM.FO.0) SM=RMODE(J,4)
0049 RMODE(J,1)=150.*SM/XNMTOM
0050 SMODE(J,2) = 10.**(-SMODE(J,2)/10.)
0051 RMODE(J,5)=RMODE(J,5)/3600.0
0052 RMODE(J,6)=RMODE(J,6)/3600.0
0053 RMODE(J,4)=RMODE(J,4)/MILION
0054 RMODE(J,8)=10.**(-RMODE(J,8)/10.)
0055 RMODE(J,3)=RMODE(J,3)*MILION
0056 TAU(J) = RMODE(J,11)/MILION
0057 IF (RMODE(J,12).LE.0) RMODE(J,12) = 1.0/RMODE(J,11)
0058 RMODE(J,12) = RMODE(J,12)*MILION
0059 IMODE(J,2)=MAX1(RMODE(J,12)*RMODE(J,11)/MILION +0.5,1.0)
0060 RMODE(J,11) = 10.**(-PMF)
0061 SUBC(J) = 10.**(-SUBC(J)/10.)
0062 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) = PSIG = 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) = THRSN = 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
0062 READ 70, (RC(I),I=15,18), (RC(I),I=20,22)
0063 70 FORMAT(10F8.2)
0064 PRINT 700, (RC(I),I=15,18), (RC(I),I=20,22)
0065 700 FORMAT(140,' ADDITIONAL RADAR PARAMETERS ARE ',7F9.3/)
0066 RETURN
0067 END
```

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0001      SUBROUTINE MERDET (RES,N,ACONZ)
0002      COMMON /DET/ NDET(20),MER(20),RANGE(20,3),AZ(20,6),SNDT(20,3),
1          FLEV(20,3),TIME(20)
0003      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
0004      K=0
0005      DO 30 I=1,N
0006      IF (MER(I).NE.-1) GO TO 30
      C      HAVE A MERGE PROBLEM AND AM ORDERING DETECTIONS IN AZIMUTH
0007      II=NDET(I)
0008      IF (II.E.0) GO TO 30
0009      DO 25 J=1,II
0010      IF (K.GT.0) GO TO 10
0011      K=1
0012      KTAR(1)=I
0013      KDET(1)=J
0014      GO TO 20
0015      10 A=AZ(I,2+J-1)
0016      DO 15 KK=1,K
0017      IF (A.GT.AZ(KTAR(KK),2+KDET(KK)-1)) GO TO 15
0018      KC=0
0019      DO 12 JJ=KK,K
0020      KC=KC+1
0021      KTAR(K+2-KC)=KTAR(K+1-KC)
0022      KDET(K+2-KC)=KDET(K+1-KC)
0023      12 CONTINUE
0024      KTAR(KK)=I
0025      KDET(KK)=J
0026      GO TO 18
0027      15 CONTINUE
0028      KTAR(K+1)=I
0029      KDET(K+1)=J
0030      18 K=K+1
0031      20 CONTINUE
0032      25 CONTINUE
0033      30 CONTINUE
0034      IF (K.GT.1) GO TO 40
0035      IF (K.EQ.0) GO TO 35
0036      I=KTAR(1)
0037      AZ(I,1)=(AZ(I,2)+AZ(I,1))/2.
0038      35 RETURN
0039      40 CONTINUE
      C
      C      DECISION MADE ON THE PROPER DETECTIONS
      C
0040      KK=1
  
```

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```
0041      KC=0
0042      DØ 100 JJ=2,K
0043      I=KTAR(JJ)
0044      J=KDET(JJ)
0045      DØ 60 L=1,KK
0046      IF (ABS(RANGE(I,J)-RANGE(KTAR(L),KDET(L))).GT.1.5*RES) GO TO 60
0047      IF (AZ(KTAR(L),2*KDET(L))+ACONZ.LT.AZ(I,2*JJ)) GO TO 60
0048      GO TO 80
0049      60 CONTINUE
0050      IF (KC.EQ.0) GO TO 75
0051      DØ 70 L=1,KC
0052      IF (ABS(RANGE(I,J)-RANGE(KTRR(L),KDTT(L))).GT.1.5*RES) GO TO 70
0053      IF (AZ(KTRR(L),2*KDTT(L)) .LT.AZ(I,2*JJ)) GO TO 70
0054      GO TO 80
0055      70 CONTINUE
0056      75 KK=KK+1
0057      KTAR(KK)=KTAR(JJ)
0058      KDET(KK)=KDET(JJ)
0059      GO TO 100
0060      80 KC=KC+1
0061      KTRR(KC)=KTAR(JJ)
0062      KDTT(KC)=KDET(JJ)
0063      100 CONTINUE
C
C      CORRECTION OF OUTPUT ARRAYS
C
0064      DØ 110 I=1,N
0065      IF (MER(I).EQ.-1) NDET(I)=0
0066      110 CONTINUE
0067      DØ 150 K=1,KK
0068      I=KTAR(K)
0069      J=KDET(K)
0070      II=NDET(I)+1
0071      NDET(I)=II
0072      RANGE(I,II)=RANGE(I,J)
0073      SNDET(I,II)=SNDET(I,J)
0074      AZ(I,II)=(AZ(I,2*J)+AZ(I,2*J-1))/2.
0075      150 CONTINUE
0076      RETURN
0077      END
```

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```
0001 SUBROUTINE MWDET (S,C, FN, N3DB, COR, FSIG, NREF, RES, NTAR, N, TH3DB,  
1 NCONZ, ACONZ, XLOG, THRS, PARM, SNTRE)  
0002 COMMON /DET/ NDET(20), MER(20), RANGE(20,3), AZ(20,6), SNET(20,3),  
1 ELEV(20,3), TIME(20)  
0003 COMMON NSCAN, NEXT, NUMTGT, T, OLD, ENDTIM, SMODE(30,20)  
1 , PI, PIVRZ, TMOPI, 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/ MODE(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 DC(14), IC(14), XFIRST(14), XLAST(14), IDET(14), SNC(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 THRS DENOTES WHETHER ALL THE REFERENCE CELLS(THRS=0.0), THE  
C SMALLER HALF(THRS<0), OR THE LARGER HALF(THRS>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 SNTRE 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)
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0019      IF (SNINT.GT.2) GO TO 5
0020      NDET(NTAR)=0
0021      SNTRUE = 10.**(-9.9)
0022      RETURN
0023      5  SNREF(1)=S
0024      INF(1)=NTAR
0025      NRFF2=2*NREF
0026      CALL RESML(NREF,RES,NTAR,SNREF,INF,NI,TH3DB,N)
0027      CALL VRANF(R,1)
0028      DEL=TH3DB/(N3DB+1)
0029      AC0NZ=DEL*NC0NZ
0030      AZIM=TRGPOS(NTAR,5)+(R(1)-.5)*DEL
0031      AZIMS=AZIM-201.*DEL
0032      KRS=TRGPOS(NTAR,4)/RES
0033      RS=RES*KRS-13.*RES

C
C      *****
C
C      GENERATION OF SIGNAL VALUES
C
C      *****
C

0034      NS=201-2*N3DB-2
0035      NF=201+2*N3DB
0036      NRS=13-NREF-2
0037      NRF=13+NREF+2
0038      DO 7 I=NRS,NRF
0039      JS(I)=0
0040      DO 7 J=NS,NF
0041      7  SS(J,I)=0.
0042      IMERGE=0
0043      DO 40 K=1,NI
0044      KR=TRGPOS(INF(K),4)
0045      KR=(KR-RS)/RES
0046      IF (K.EQ.1.OR.KK.GT.16.OR.KR.LT.10) GO TO 8
0047      IMERGE=1

C
C      FLUCTUATING SIGNAL
C

0048      8  NSW=MODEL(INF(K))
0049      IF (NSW.GT.0) GO TO 11
0050      FL=1.0
0051      9  DO 10 J=NS,NF
0052      10  FLUCT(J)=FL
0053      GO TO 171
0054      11  GO TO (12,13,15,16),NSW
0055      12  CALL VRANF (R,1)
0056      FL =-ALOG(R(1))
0057      GO TO 9
0058      13  M=NF+1-NS

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0059      CALL VRANF (R,M)
0060      KK=0
0061      DO 14 J=NS,NF
0062      KK=KK+1
0063      14 FLUCT(J)=-ALOG(R(KK))
0064      GO TO 171
0065      15 CALL VRANF (R,2)
0066      FL=-.5*(ALOG(R(1))+ALOG(R(2)))
0067      GO TO 9
0068      16 M=NF+1-NS
0069      M2=2*M
0070      CALL VRANF (R,M2)
0071      KK=0
0072      DO 17 J=NS,NF
0073      KK=KK+1
0074      17 FLUCT(J)=-.5*(ALOG(R(KK))+ALOG(R(KK+M)))
0075      171 CONTINUE
0076      DO 35 I=1,3
0077      KT=KR+I-2
0078      IF (KT.LT.NRS.OR.KT.GT.NRF) GO TO 35
0079      IS(KT)=1
      C
      C      MODULATION OF SIN(X)/X PULSE SHAPE
      C
0080      RTEMP = KT*RES+RES/2.+RS
0081      FDIF=2.7832*(RR-RTEMP)/RES
0082      F=1.
0083      IF (FDIF.EQ.0) GO TO 18
0084      F=SIN(FDIF)/FDIF
0085      18 F=F*F
0086      SM=F*SNREF( K )/(C+FN)
      C
0087      AA=TRGPOS(INF(K),5)
0088      NC=(AA-AZIM)/DEL+201
0089      NRED=MAX0(1,N3DB/10)
0090      IF (I.EQ.2) NRED=0
0091      NNS=MAX0(NS,NC-N3DB+NRED)
0092      NNF=MIN0(NF,NC+N3DB-NRED)
      C
      C      MODULATION OF SIN(X)/X ANTENNA PATTERN
      C
0093      DO 20 J=NNS,NNF
0094      GDIF=2.7832*(J*DEL+AZIMS-AA)/TH3DB
0095      G=1.
0096      IF (GDIF.EQ.0) GO TO 19
0097      G=SIN(GDIF)/GDIF
0098      19 G=G**4
      C
      C      ***** NOTE , TARGETS ARE ADDED NONCOHERENTLY *****
      C
  
```

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```
0099      SS(J,KT)=SS(J,KT)+SM*G*FLUCT(J)
0100      20  CONTINUE
0101      35  CONTINUE
0102      40  CONTINUE
0103      SNTRUE = 0.
0104      NSS = 201 - (N3DB-1)/2
0105      NSF = 201 + N3DB/2
0106      DO 402 J = NSS,NSF
0107      402  SNTRUE = SNTRUE + SS(J,13)/N3DB
0108      DO 41 I=NRS,NRF
0109      IF (IS(I).EQ.0) GO TO 41
0110      41  CONTINUE
C
C      ++++++
C      GENERATION OF NOISE SAMPLES
C      ++++++
C
0111      M=NF+1-NS
0112      M2=2*M
0113      M3=3*M
0114      M4=4*M
0115      IF (N3DB+C .GT.FN) GO TO 100
C
C      CLUTTER IS NOT A FACTOR
C
0116      DO 90 I=NRS,NRF
0117      IF (IS(I).EQ.1) GO TO 75
C
C      NO SIGNAL PRESENT IN THIS CELL
C
0118      CALL VRANF (R,M)
0119      K=0
0120      DO 60 J=NS,NF
0121      K=K+1
0122      X(J,I)=SQRT(-2.*ALOG(R(K)))
0123      60  CONTINUE
0124      GO TO 99
C
C      SIGNAL PRESENT IN THIS CELL
C
0125      75  CALL VRANF (R,M2)
0126      K=0
0127      DO 80 J=NS,NF
0128      K=K+1
0129      A=SQRT(-2.*ALOG(R(K)))
0130      B=TAN(PI*R(K+M))
0131      X(J,I)=SQRT((A+COS(B)+SQRT(SS(J,I))*1.414)**2) (A+SIN(B)**2)
0132      80  CONTINUE
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0169      II=0
0170      DO 285 J=MS,NF
0171      DO 225 I=NRS,NRF
0172      225 SUM(I)=SUM(I)+X(J,I)-X(J-N3DB,I)
          C
          C      GENERATION OF THE DETECTION THRESHOLDS
          C
0173      DO 250 L=12,14
0174      ULOW=0.
0175      UUP=0.0
0176      XMSLOW=0.0
0177      XMSUP=0.0
0178      DO 230 I=1,NREF
0179      ULOW=ULOW+SUM(L-I-1)
0180      UUP=UUP+SUM(L+I+1)
0181      XMSLOW=XMSLOW+SUM(L-I-1)**2
0182      230 XMSUP=XMSUP+SUM(L+I+1)**2
0183      IF (THRSH.NE.0.0) GO TO 235
          C
          C      USE ALL REFERENCE CELLS
          C
0184      U=ULOW+UUP
0185      XMS=XMSLOW+XMSUP
0186      D(L)=U/NREF2+FSIG*SQRT(XMS/NREF2-(U/NREF2)**2)
0187      IF (PARM.GT.1.5) GO TO 250
0188      D(L)=FSIG*U/NREF2
0189      IF (XLOG.LT.0.0001) GO TO 250
0190      D(L)=FSIG+U/NREF2
0191      GO TO 250
          C
          C      USE EITHER MIN(THRSH<0) OR MAX(THRSH>0) REFERENCE CELLS
          C
0192      235 IF (THRSH.LT.0.0.AND.ULOW.LT.UUP) GO TO 240
0193      IF (THRSH.LT.0.0.AND.ULOW.GE.UUP) GO TO 245
0194      IF (THRSH.GT.0.0.AND.ULOW.LT.UUP) GO TO 245
0195      IF (THRSH.GT.0.0.AND.ULOW.GE.UUP) GO TO 240
0196      240 U=ULOW
0197      XMS=XMSLOW
0198      GO TO 248
0199      245 U=UUP
0200      XMS=XMSUP
0201      248 D(L)=U/NREF+FSIG*SQRT(XMS/NREF-(U/NREF)**2)
0202      IF (PARM.GT.1.5) GO TO 250
0203      D(L)=FSIG*U/NREF
0204      IF (XLOG.LT.0.0001) GO TO 250
0205      D(L)=FSIG+U/NREF
0206      250 CONTINUE
0207      IF (J.GT.MS) GO TO 249
0208      249 CONTINUE
          C

```

```

C      DO LOOP FOR DETECTION AND GENERATION OF CENTER PULSES
C
0209      DO 280 I=12,14
0210      IF (J.GT.MS) GO TO 255
0211      IDET(I)=1
0212      IC(I)=0
0213      IF (SUM(I).LT.D(I)) GO TO 280
0214      IDET(I)=3
0215      IC(I)=NCONZ
0216      GO TO 280
0217      255 K=IDET(I)
0218      GO TO (260,270,275,280),K

C
C      CHECK FOR INITIAL DETECTION
C
0219      260 IF (SUM(I).LT.D(I)) GO TO 280
0220      II=II+1
0221      ID(II)=I
0222      XFIRST(I)=J
0223      XLAST(I)=J
0224      SN(I)=SUM(I)
0225      IC(I)=NCONZ
0226      IDET(I)=2
0227      GO TO 280

C
C      CHECK FOR FINAL DETECTION
C
0228      270 IF (SUM(I).LT.D(I)) GO TO 273
0229      XLAST(I)=J
0230      IC(I)=NCONZ
0231      IF (SUM(I).LT.SN(I)) GO TO 280
0232      SN(I)=SUM(I)
0233      GO TO 280

C
C      CHECK TO SEE IF DETECTION ENDED
C
0234      273 IC(I)=IC(I)-1
0235      IF (IC(I).EQ.0) IDET(I)=4
0236      GO TO 280

C
C      CHECK TO SEE IF DETECTION FROM ANOTHER TARGET ENDED
C
0237      275 IF (SUM(I).GE.D(I)) IC(I)=NCONZ+1
0238      IC(I)=IC(I)-1
0239      IF (IC(I).GT.0) GO TO 280
0240      IDET(I)=1
0241      280 CONTINUE
0242      285 CONTINUE

C
C      *****

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```
C
C CHECK FOR DETECTIONS
C
C *****
C
0243 IF (II.GT.0) GO TO 300
0244 NDET(NTAR)=0
0245 MER(NTAR)=0
0246 IF (IMERGE.EQ.1) MER(NTAR)=-2
0247 RETURN

C
C MERGING OF MULTIPLE THRESHOLD CROSSINGS
C
0248 300 IF (IMERGE.EQ.1) GO TO 400
C
C NO MULTI TARGET RESOLUTION PROBLEMS
C
0249 GO TO (310,320,330), II
C ONLY 1 THRESHOLD CROSSING
0250 310 NDET(NTAR)=II
0251 MER(NTAR)=0
0252 312 DO 315 I=1,II
0253 RANGE(NTAR,I)=RS+(ID(I)+.5)*RES
0254 SDET(NTAR,I)=SN(ID(I))
0255 IF (XLOG.GT.0.0001) SDET(NTAR,I)=N3DB*EXP(SDET(NTAR,I)/N3DB)
0256 AZ(NTAR,I)=AZIMS+(XLAST(ID(I))+XFIRST(ID(I))-N3DB)*DEL/2.
0257 315 CONTINUE
0258 RETURN

C
C TWO CROSSINGS OF THE THRESHOLD
C
0259 320 IF (IDET(13).EQ.1.OR.IDET(13).EQ.3) GO TO 310
C
C THERE ARE TWO ADJACENT THRESHOLD CROSSINGS
C
0260 325 IF (XLAST(ID(1))+NCONZ.LT.XLAST(ID(2))) GO TO 310
0261 II=1
0262 GO TO 310

C
C THERE ARE THREE ADJACENT THRESHOLD CROSSINGS
C
0263 330 K=1
0264 IF (IABS(ID(1)-ID(2)).EQ.2.OR.
1 XLAST(ID(1))+NCONZ.LT.XLAST(ID(2))) K=2
0265 GO TO (340,350),K
0266 340 IF (IABS(ID(1)-ID(3)).EQ.2.AND.
1 XLAST(ID(2)) .LT.XLAST(ID(3))) GO TO 345
0267 II=1
0268 GO TO 310
0269 345 II=2
```

```

0270      ID(2)=ID(3)
0271      GO TO 310
0272      350  IF (IABS(ID(1)-ID(3)).EQ.2.0R.
           1      XLAST(ID(1))+NC0NZ.LT.XLAST(ID(3))) GO TO 355
0273          II=2
0274          GO TO 310
0275      355  IF (IABS(ID(2)-ID(3)).EQ.2.0R.
           1      XLAST(ID(2))+NC0NZ.LT.XLAST(ID(3))) GO TO 310
0276          II=2
0277          GO TO 310

C
C      ++++++
C      MERGING PROBLEM WITH ANOTHER TARGET ,PROBLEM SOLVED IN SUB. MERDET
C      ++++++
C

0278      400  NDET(NTAR)=II
0279          MER(NTAR)=-1
0280          DO 415 I=1,II
0281          RANGE(NTAR,I)=RS+(ID(I)+.5)*RES
0282          SNDET(NTAR,I)=SN(ID(I))
0283          IF (XLOG.GT.0.0001) SNDET(NTAR,I)=N3DB*EXP(SNDET(NTAR,I)/N3DB)
0284          AZ(NTAR,2*I-1)=AZIMS+XFIRST(ID(I))*DEL-N3DB*DEL/2.
0285          AZ(NTAR,2*I )=AZIMS+XLAST (ID(I))*DEL-N3DB*DEL/2.
0286      415  CONTINUE
0287          RETURN
0288          END
  
```

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```
0001      SUBROUTINE STAB2
0002      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)
0003      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
1          ,PI,TWOPI ,TWOPR ,RADIANS,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
0004      COMMON /DET/ NDET(20),MER(20),RANGE(20,3),AZ(20,6),SNDET(20,3),
1          ELEV(20,3),TIME(20)
0005      COMMON /STAB/ ROLL(20),PITCH(20)
0006      COMMON /STABIN/ RMAX,PMAX,RFAC,PFAC,PHASE(2)
0007      DO 30 I=1,NTARG
0008      IF (NDET(I).EQ.0) GO TO 30
0009      K=NDET(I)
0010      ROLL(I) =RMAX*SIN(TIME(I)*RFAC+PHASE(1))
0011      PITCH(I)=PMAX*SIN(TIME(I)*PFAC+PHASE(2))
0012      CR=COS(ROLL(I))
0013      SR=SIN(ROLL(I))
0014      CP=COS(PITCH(I))
0015      SP=SIN(PITCH(I))
0016      AA=TRGPOS(I,5)-SHIP(5)
0017      TE=TAN(TRGPOS(I,6))
0018      X=SIN(AA)*CR+(COS(AA)*SP+TE*CP)*SR
0019      Y=COS(AA)*CP-TE*SP
0020      A=ATAN2(X,Y)+TWOPI
0021      DO 25 J=1,K
0022      ATEMP=AZ(I,J)+A-AA
0023      AZ(I,J)=AMOD(ATEMP,TWOPI)
0024      30 CONTINUE
0025      RETURN

C
C      INITIALIZATION
C
0026      ENTRY STBINT
0027      READ 50,RMAX,PMAX,RPER,PPER
0028      50 FORMAT (4F8.2)
0029      PRINT 55,RMAX,PMAX,RPER,PPER
0030      55 FORMAT (1H0," ROLL AND PITCH ",4F8.2)
0031      RMAX=PMAX/RADIANS
0032      PMAX=PMAX/RADIANS
0033      RFAC=TWOPI/RPER
0034      PFAC=TWOPI/PPER
0035      CALL VRANF(PHASE,2)
0036      PHASE(1)=TWOPI*PHASE(1)
0037      PHASE(2)=TWOPI*PHASE(2)
0038      RETURN
0039      END
```

```

0001      SUBROUTINE VRCLT2
0002      COMMON NSCAN,NEXT,NUMTGT,T,OLDT,ENDTIM ,SMODE(30,20)
1          ,PI,PIQVR2 ,TWOPI,RADIAN,TAU(30),DSTAR,DWL(30)
2          ,XYZI(20,4),XYZF(20,4),TRGPS(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 /VCIN/ NREG,FN(5),RS(5),RF(5),THS(5),THF(5),ELS(5),ELF(5),
1          ISET
0004      COMMON /VCLT/ PI2,RAN(305),FLAM(5)
0005      COMMON /CLTOUT/ ROUT(201),AZOUT(201),ELOUT(201),TOUT(201),
1          RLOUT(201),PTOUT(201),SOUT(201),NC(100),IC,IV
0006      COMMON /STABIN/ RMAX,PMAX,RFAC,PFAC,PHASE(2)

C
0007      IV=IC
0008      IF (NREG.EQ.0) GO TO 95
0009      CALL SETVR(ISET)
0010      CALL VRANF(RAN,305)
0011      ISET = 2147483647.*RAN(305)
0012      ISET = 2*(ISET/2) + 1

C
0013      TIMZB IS THE TIME OF THE ZERO BEARING CROSSING
          TIMZB=T*3600.
C
0014      TIMSCN IS THE SCAN TIME OF THE RADAR
          TIMSCN=RMODE(1,5)*3600.
C
0015      RES IS THE RANGE GATE SIZE
          RES=RC(19)
0016      IRAN=0
0017      DO 20 I=1,NREG
0018      IRAN=IRAN+1
0019      IF (IRAN.GT.302) GO TO 30
0020      A = THS(I)-FLAM(I)*ALOG(RAN(IRAN))
0021      15 IF (A.GT.THF(I)) GO TO 20
0022      IV=IV+1
0023      AZOUT(IV)=A
0024      K=(RS(I) + (RF(I)-RS(I))*RAN(IRAN+1))/RES
0025      ROUT(IV)=(K+0.5)*RES
0026      ELOUT(IV)=0.0
0027      TOUT(IV)=TIMZB+TIMSCN*A/TWOPI
0028      RLOUT(IV)=RMAX+SIN(TOUT(IV))*RFAC+PHASE(1))
0029      PTOUT(IV)=PMAX+SIN(TOUT(IV))*PFAC+PHASE(2))
0030      SOUT(IV)=33.33
0031      IRAN=IRAN+3
0032      IF (IRAN.GT.302) GO TO 30
0033      A=A-FLAM(I)*ALOG(RAN(IRAN))
0034      GO TO 15
0035      20 CONTINUE
0036      30 RETURN

C
C      INITIALIZATION
C
0037      ENTRY VCINIT
    
```

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```

0038      READ 50,ISET,NREG
0039      50  FORMAT(2I8)
      C
      C   ISET IS THE INITIALIZATION NUMBER OF THE RANDOM NUMBER GENERATOR
      C   NREG IS THE NUMBER OF CLUTTER REGIONS
      C
0040      PRINT 55,ISET,NREG
0041      55  FORMAT (1H0," VARIABLE CLUTTER ",2I8)
0042      IF (NREG.EQ.0) GO TO 95
0043      IF (NREG.GT.5) NREG=5
0044      DO 5 I=1,NREG
0045      READ 51, FN(I),RS(I),RF(I),THS(I),THF(I)
0046      51  FORMAT (7F9.2)
      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
0047      PRINT 56, FN(I),RS(I),RF(I),THS(I),THF(I)
0048      56  FORMAT (25X,7F9.3)
0049      RS(I)=RS(I)/6.0802
0050      RF(I)=RF(I)/6.0802
0051      THS(I)=THS(I)/RADIAN
0052      THF(I)=THF(I)/RADIAN
0053      5   CONTINUE
0054      DO 10 I=1,NREG
0055      10  FLAN(I)=(THF(I)-THS(I))/FN(I)
0056      95  RETURN
0057      END

```

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Appendix C

PROGRAM LISTINGS OF ROUTINES EXCLUSIVE TO SURDET3D

```
0001      PROGRAM SURDET
C
C      THIS IS THE SURDET3D EXECUTIVE ROUTINE
C
C      CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
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      DATA CARD NO. 2
C
C          TITLE CARD = RUN IDENTIFICATION (I4,I9A4 FORMAT)
C          1 RADAR ID NUMBER FOR TARGET DETECTION OUTPUT FILES
C          2-20 ALPHANUMERIC DESCRIPTIVE TITLE
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      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
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0 = HORIZONTAL
90 = VERTICAL

DATA CARDS NO. 5 AND 6 (ONE SET FOR EACH RADAR SCAN MODE)

- 15 PARAMETERS FOR EACH SCAN MODE (10F8.2/5F8.2 FORMAT)
- 1 LOWER BOUNDARY ELEVATION ANGLE COVERAGE IN DEGREES
- 2 UPPER BOUNDARY ELEVATION ANGLE COVERAGE IN DEGREES
- 3 PEAK POWER IN MW
- 4 PULSE LENGTH IN MICROSECONDS
- 5 INTERLOAK PERIOD IN SECONDS
- 6 SCAN OFFSET IN SECONDS
- 7 INSTRUMENTED RANGE IN NMI
- 8 MODE DEPENDENT LOSS IN DB
- 9 NUMBER OF PULSES INTEGRATED
- 10 COMPRESSED PULSE LENGTH IN MICROSECONDS
- 11 SEA CLUTTER IMPROVEMENT FACTOR IN DB
- 12 I.F. BANDWIDTH IN MHZ, IF 0, BANDWIDTH WILL BE SET AT 1.0/(COMPRESSED PULSE LENGTH)
- 13 MODE DEPENDENT FREQUENCY INCREMENT IN MHZ
- 14 BLANKING TIME IN MICROSECONDS, IF 0, SET AT PULSE LENGTH
- 15 RAIN CLUTTER IMPROVEMENT FACTOR IN DB

DATA CARD NO. 7

- 7 PARAMETERS FOR MOVING WINDOW DETECTOR (7F8.2 FORMAT)
- 1 NO. OF REFERENCE CELLS ON EACH SIDE OF TARGET CELL
- 2 CLUTTER CORRELATION COEFFICIENT
- 3 NO. OF STANDARD DEVIATIONS USED IN THRESHOLD
- 4 AZIMUTH OFFSET BETWEEN BEAM POSITIONS IN DEGREES
- 5 VIDEO TYPE INDICATOR
 - 0 = LINEAR VIDEO
 - 1 = LOG VIDEO
- 6 NO. OF REFERENCE CELLS USED FOR THRESHOLD
 - 0 = ALL CELLS USED
 - 40 = SMALLER HALF USED
 - 80 = LARGER HALF USED
- 7 PARAMETERS USED TO CALCULATE THRESHOLD
 - 1 = MEAN USED
 - 2 = MEAN AND VARIANCE USED

DATA CARD NO. 8

- NUMBER OF TARGETS AND JAMMERS (2I5 FORMAT)
- 1 NO. OF TARGETS

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2 NR. OF JAMMERS

DATA CARDS NO. 9 AND 10 (ONE SET FOR EACH TARGET AND JAMMER)

CARD 9 13 TARGET PARAMETERS (12F6.2,13 FORMAT)
TARGET TRAJECTORY SHOULD NOT CROSS 0 DEGREES IN AZIMUTH
1-4 INITIAL COORDINATES (X,Y,Z,T) IN KFT AND SECONDS
5-8 TERMINAL COORDINATES (X,Y,Z,T) IN KFT AND SECONDS
9-11 RADAR REFLECTIVE AREAS FOR HEAD-ON,
BROAD-SIDE, AND MINIMUM IN SQ. METERS
12 JAMMING POWER DENSITY IN W/MHZ
13 HARCUM SPERRING CROSS SECTION MODEL

CARD 10 TARGET PROFILE PARAMETERS (14,7F6.2 FORMAT)

1 TARGET PROFILE TYPE
0 = STRAIGHT LINE TRAJECTORY
1 = 2-4 ALTITUDE LEGS
2 = G-MANEUVER AT CONSTANT ALTITUDE

REMAINING PROFILE PARAMETERS BY TARGET TYPE

IF TARGET TYPE = 0

2-8 IGNORED

IF TARGET TYPE = 1

2 = NR. OF ALTITUDE NODES
3 = FIRST ALTITUDE NODE IN KFT
4 = TIME OF ARRIVAL AT FIRST NODE IN SEC
5 = SECOND ALTITUDE NODE IN KFT
6 = TIME OF ARRIVAL AT SECOND NODE IN SEC
7 = THIRD ALTITUDE NODE IN KFT
8 = TIME OF ARRIVAL AT THIRD NODE IN SEC

IF TARGET TYPE = 2

2 = TARGET SPEED IN KFT/SEC
3 = INITIAL HEADING IN DEGREES
4 = TIME MANEUVER BEGINS IN SEC
5 = TARGET MANEUVER RADIAL ACCELERATION IN G'S

DATA CARD NO. 11

4 ENVIRONMENTAL PARAMETERS (4F8.2 FORMAT)

1 WIND SPEED IN KNOTS
2 HEIGHT OF WIND SPEED MEASUREMENT IN KFT
3 MULTIPATH INDICATOR
1 = MULTIPATH
0 = NO MULTIPATH
4 RAINFALL RATE IN MM/HR

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```

0022      CCM=30000000000.
0023      RFTA #.71A565021
0024      ACONE .607701593
0025      XRTOMS #.514400000
0026      XNTRM #1852.
0027      FRPISQ #157.9136706
0028      FRFIQH #19A4.401711
0029      5 RFR # 0
0030      READ 52,ANS1
0031      52 FORMAT(16I5)
0032      READ 500,ITITLE
0033      500 FORMAT(I4,19A4)
0034      PRINT 501,ITITLE
0035      501 FORMAT(1H1,I4,5X,19A4)
0036      CALL INITAL
0037      10 CALL TARGET
0038      11 CALL ENVIRN
C
C      INITIALIZE CLUTTER FOR TRACKING
0039      CALL FCINIT
0040      CALL VCINIT
C
C      INITIALIZE ROLL AND PITCH
0041      CALL STRINT
C
C      READ IN TIME BY WHICH RADAR MUST BE INITIALIZED
0042      READ 59, RINIT
0043      59 FORMAT(F8.2)
0044      PRINT 590, RINIT
0045      590 FORMAT(1H0,' GAME INITIALIZATION BY ',F8.2)
C
C      ADD SCAN OFFSET (FROM MODE 1) TO MAX RADAR INITIALIZATION TIME
0046      RINIT = RINIT/3600. + RMODE(1,6)
0047      ISC=0
0048      IKEYF=0
C      DETERMINE TIMES EACH TARGET COMES WITHIN INSTRUMENTED RANGE
C      OF EACH RADAR MODE
0049      CALL MATCH
C
C      DETERMINE INITIAL AND FINAL GAME TIMES
C
0050      T = RMODE(1,9)
0051      ENDTM = XYZF(1,4)
C      SET TARGETS INITIALLY TO OVER-THE-HORIZON
0052      TRGPS(1,4) = -1.
0053      IF(NSCAN .LT. 2) GO TO 17
C      DETERMINE INITIAL TIME FROM MATCH
0054      DO 15 J = 2,NSCAN
0055      IF(RMODE(J,9) .LT. T) T = RMODE(J,9)
0056      15 CONTINUE

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```

0057      17 IF(NTARG .LT. 2) GO TO 19
C         DETERMINE ENG GAME TIME
0058      DO 18 I = 1,NTARG
0059          TRGPS(I,4) = -1.
0060          IF(XYZF(I,4) .GT. ENDTIM) ENDTIM = XYZF(I,4)
0061      18 CONTINUE
0062      19 CONTINUE
C         SET INITIAL TIME FROM MATCH 30 SEC. EARLIER FOR CLUTTER SAMPLES
0063          T = T - 3./360.
C         SET INITIAL GAME TIME
0064          T = AMNI(T,RINIT)
0065          TEMP = 3
0066          TEMPR = RMODE(1,5)*300.
0067          WRITE (IOUT) ITITLE(1),TEMP,TEMPR
C
0068          IF (ANS1.EQ.0) GO TO 20
0069          MUL=ENVIR(3)
0070          IF (MUL .NE. 0 ) PRINT 506
0071          IF (MUL .EQ. 0 ) PRINT 505
0072      506 FORMAT(/,'          $$$$ WITH MULTIPATH $$$$',/)
0073      505 FORMAT(/,'          $$$$ NO MULTIPATH $$$$',/)
C
C         GENERATE INITIAL AZIMUTH BEAM POSITION
0074      20 CALL INIT3D(NTARG,AZINIT)
0075          ISC=ISC+1
C         INITIALIZE SCAN PRINT FLAG
0076          IPFLAG = 0
C         DETERMINE TARGET AND JAMMER POSITIONS AT SCAN TIME T
0077          CALL NEWPCS
C         PERFORM ELEVATION SCAN FOR EACH ACTIVE TARGET
0078          DO 75 I = 1,NTARG
C         CHECK IF TARGET ACTIVE
0079          IF(ISTAT(I) .NE. 1) GO TO 75
0080          DO 70 J = 1,NSCAN
0081          NEXT = J
C         CHECK IF TARGET WITHIN DETECTION RANGE OF THIS MADE
0082          IF(TSCAN(I,J) .GT. T) GO TO 70
0083          TEMP = RMODE(J,1) + 0.63*RC(5)
0084          TEMP2 = RMODE(J,2) + 0.63*RC(5)
0085          IF(TRGPS(I,6) .GE. TEMP .AND. TRGPS(I,6) .LE.
1          TEMP2 .AND. TRGPS(I,4) .LE. RMODE(J,7)
2          .AND. TRGPS(I,4) .GT. RMODE(J,1)) GO TO 30
C         TARGET CANNOT BE DETECTED BY MADE J
0086          GO TO 70
0087      30 IF(RC(1) + DNL(NEXT) .NE. OFF) ISWIT = 0
0088          RFR=RC(1)+DNL(NEXT)
0089          RFR=RC(1)/RFR
0090          RC(6)=GN/RFR**2
0091          RC(4)=THH*RFR
0092          RC(5)=THV*RFR

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0093      PRRS = RMODE(NEXT,1) + RC(5)/2.
          C
          C  COMPARE TARGET ELEVATION ANGLE TO ELEVATION BEAM CENTER
0094      IF(ABS(PRRS - TRGPS(I,6)) .GE. RC(5)) GO TO 70
0095      ALPHA = 0
0096      SIGC = 0
0097      SIG = 0
0098      AR1 = 0
0099      AR2 = 0
0100      V = 0
          C
          C  CHECK FOR PRINT
0101      IF(ANS1 .EQ. 0) GO TO 35
0102      IF( IPFLAG .NE. 0) GO TO 35
0103      IPFLAG = 1
          C
          C  PRINT SCAN NUMBER
0104      PRINT 507,ISC
0105      507  FORMAT (///,30X,'++++++ SCAN NUMBER = ',I4,' ++++++',/)
0106      IF( ANS1.NE.2 ) GO TO 35
          C
          C  PRINT HEADING
0107      PRINT 40
          C
          C  COMPUTE SIGNAL ENERGY AND NOISE AND CLUTTER ENERGIES FOR TARGET I
0108      35  CALL SIGNAL(I,RC(11),RC(12))
0109          CALL NOISE(I,RC(13),RC(14))
0110          TCRSS = TAPCS
          C
          C  DETERMINE TARGET DETECTIONS IN MODE J
0111      MREF = RC(15)
0112      CALL DET3D(RC(12),RC(13),RC(14),IMODE(J,1),RC(16),RC(17),MREF,
1          RC(19),I,NTARG,RC(4),J,AZINIT,RC(18),RC(20),RC(21),
2          RC(22),SNTRUE)
0113      IF (ANS1.NE.2) GO TO 65
0114      RHDEG=TRGPS(I,5)*RADIAN
0115      RVDEG = TRGPS(I,6)*RADIAN
0116      DRE=C0NV*ALOG(RC(12))
0117      DRN=C0NV*ALOG(RC(14))
0118      SN=DRE-DRN
0119      TRGP = TRGPS(I,4)*6.0A02
0120      AMHNB = C0NV*ALOG(AMAX1(AMBN,1.0E-74))
0121      XJAMDR = C0NV*ALOG(AMAX1(XJAMN,1.0E-74))
0122      SCDB = C0NV*ALOG(AMAX1(SIGC,1.0E-74))
0123      SFAC4=C0NV*ALOG(AMAX1(FAC4,1.0E-74))
0124      SNTRUE = 10.*ALOG10(SNTRUE)
0125      PRINT 50,I,J,TIME3(I),TRGP,RHDEG,RVDEG,TCRSS,SFAC4,DRE,AMHNB
1          ,SCDB,XJAMDR,SN,SNTRUE,MER3(I)
0126      KNUM=NDET3(I,J)
0127      IF (KNUM.EQ.0) GO TO 65
0128      LC 61 K=1,KNUM
0129      RRWR=RANGE3(I,K,J)*6.0A02
0130      AAAA=A73(I,K,J)*RADIAN
0131      SSSS=SHDET3(I,K,J)
0132      SSS = 20.*ALOG10(SSSS)

```

```

0133      PRINT 55,RRRF,AAAA,SSSS
0134      55 FORMAT(5X,'DETECTION',4X,F12.2,F10.2,19X,F10.0)
0135      61 CONTINUE
0136      65 CONTINUE
0137      70 CONTINUE
0138      75 CONTINUE

C
C      MERGE DETECTIONS
0139      CALL MRDT3D(RC(19),NTARG,RC(4),RC(5))

C
C      CALCULATE ROLL AND PITCH
0140      CALL STAB3
C      CLUTTER OUTPUT FOR TRACKING
0141      CALL FXCLT3
0142      CALL VCCLT3

C
C      NEW OUTPUT
0143      RUF(1) = ISC
0144      RUF(2) = T*3600.
0145      RUF(3) = IV
0146      DO 200 I = 1,NTARG
0147      RUF(3) = RUF(3)+NDET(I)
0148      200 CONTINUE
0149      RUF(4) = 3000+ITITLE(1)
0150      RUF(5) = SHIP(5)
0151      RUF(6) = NTARG
0152      WRITE (IOUT) (RUF(I),I=1,6)
0153      IF(ANSI.FG.0) GO TO 220
0154      IF(RUF(3).EQ.0) GO TO 220
0155      PRINT 56, (RUF(I),I=1,6)
0156      56 FORMAT(1H0,' SCAN NUMBER=',F5.0,' TIME=',F9.2,' NO. DETECTI
10NS=',F5.0,' RADAR ID=',F6.0,' HEADING=',F7.2,' NO. TARGE
2TSE=',F9.0/)

0157      57 FORMAT(' DETECTION NUM ',F5.0,7F10.4)
0158      PRINT 57
0159      58 FORMAT(19X,'ID',6X,'RANGE',5X,'AZIM',6X,'ELEV',6X,'TIME',6X,'ESIG'
1,6X,'ROLL',5X,'PITCH')

0160      220 CONTINUE
0161      ICNT = 0
0162      DO 250 I = 1,NTARG
0163      BUFR(1,I) = I
0164      BUFR(2,I) = TRGPS(I,4)
0165      BUFR(3,I) = TRGPS(I,5)
0166      BUFR(4,I) = TRGPS(I,6)
0167      BUFR(5,I) = TIME(I)
0168      NCT = NDET(I)
0169      IF(NCT.FG.0) GO TO 250
0170      DO 240 J = 1,NCT
0171      ICNT = ICNT+1
0172      BUFA(1,ICNT) = I
    
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```
0173 BUFA(2,ICNT) = RANGE(I,J)
0174 BUFA(3,ICNT) = AZ(I,J)
0175 BUFA(4,ICNT) = ELEV(I,J)
0176 BUFA(5,ICNT) = TIME(I)
0177 BUFA(6,ICNT) = SDEF(I,J)
0178 BUFA(6,ICNT)=20.*ALOG10(BUFA(6,ICNT))
0179 BUFA(7,ICNT) = RPLL(I)
0180 BUFA(8,ICNT) = PITCH(I)
0181 240 CONTINUE
0182 250 CONTINUE
0183 IF(IV.EQ.0) GO TO 270
0184 DO 260 I = 1,IV
0185 ICNT = ICNT+1
0186 BUFA(1,ICNT) = 200
0187 IF(I.LE.IC)
0188 1BUFA(1,ICNT) = 100 + NC(I)
0189 BUFA(2,ICNT) = RUT(I)
0190 BUFA(3,ICNT) = AZRUT(I)
0191 BUFA(4,ICNT) = ELRUT(I)
0192 BUFA(5,ICNT) = TRUT(I)
0193 BUFA(6,ICNT) = SRUT(I)
0194 BUFA(6,ICNT)=20.*ALOG10(BUFA(6,ICNT))
0195 BUFA(7,ICNT) = RLUT(I)
0196 BUFA(8,ICNT) = PTRUT(I)
0196 260 CONTINUE
0197 270 CONTINUE
0198 DO 275 J = 1,NTAG
0199 WRITE(1PUT) (BUFA(I,J),I=1,5)
0200 275 CONTINUE
0201 IF(ICNT.EQ.0) GO TO 290
0202 DO 277 J = 1,ICNT
0203 WRITE(1OUT) (BUFA(I,J),I = 1,8)
0204 277 CONTINUE
0205 IF(ANS1.EQ.0) GO TO 290
0206 DO 280 J = 1,ICNT
0207 PRINT 57,(BUFA(I,J),I = 1,8)
0208 280 CONTINUE
0209 290 CONTINUE
C
C NEW SCAN
0210 T = T + RMDE(1,5)
0211 IF(T.GT. ENDTIM) GO TO 110
0212 GO TO 20
C
C 80 CONTINUE
0213 IF (1STEP.LE.4000) GO TO 20
0214 110 1STEP=1STEP-1
0215 301 CONTINUE
0216 XJAM=0.
0217 C READ IN RECYCLE CONTROL PARAMETER
```

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```
C      IANS=#1(SHIP),#2(TARGET),#3(ENVIRONMENT),#4(FINISHED)
0218  READ 52, IANS
0219  GO TO (5,10,11,100),IANS
0220  140 CONTINUE
0221  130 CONTINUE
0222  40  FORMAT (//,7X,'MODE',42X,'SIGMA',/, ' TARGET',9X,'TIME RANGE'
      1,6X,'AZIM'      ELV      FACTOR  FSIG  NAMB  'CLT  NJAM
      2      F/N      MER3')
0223  50  FORMAT(1X,2I4,F11.1,F12.2,F10.2,F10.2,FS.1,FS.0,F9.0,3FA.0,F9.2
      1,F7.2,15)
0224  60  FORMAT (1X,I4/(1X,5(F7.1,F7.5)))
0225  END
```

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0001 SUBROUTINE ADJDET (RES,TH3DR,EL3DR,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
0002 COMMON NSCAN,NEXT,NUMTGT,T,PLDT,FNDTIM ,SMPDE(30,20)
1 ,PI,PIQVR2 ,TH3DI,RADIAN,TAI(30),NSTAR,DWL(30)
2 ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
3 ,SIGTAR(20,3),FMV(20),STGMAN,ISWIT,TEMPWR
4 ,SHIP(9),RC(30),RMPDE(30,12),IMODE(30,2)
0003 COMMON /MERSET/ DETPAR(100,4)
0004 COMMON /DET3/ NDET3(20,30),MER3(20),RANGE3(20,9,30),AZ3(20,9,30),
1 SDET3(20,9,30) TIME3(20),IKEY(20)
C
C RES IS THE RANGE RESOLUTION CELL SIZE
C TH3DR IS THE 3-DR AZIMUTH ANTENNA BEAMWIDTH
C EL3DR IS THE ELEVATION 3-DR 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
0005 R=RANGE3(KTAR,I,J)
0006 A = AZ3(KTAR,I,J)
0007 E = RMPDE(J,1) + RC(5)/2.
C
C TEST TO LOCATE ADJACENT DETECTIONS
C
0008 DO 10 IK=1,K
0009 IF (ABS(R-DETPAR(IK,1)).LT.1.2*RES.AND.
1 ABS(A-DETPAR(IK,2)).LT.0.1*TH3DR.AND.
2 ABS(E-DETPAR(IK,3)).LT.0.1*EL3DR) GO TO 20
0010 IF (ABS(R-DETPAR(IK,1)).LT.0.1*RES.AND.
1 ABS(A-DETPAR(IK,2)).LT.1.2*TH3DR.AND.
2 ABS(E-DETPAR(IK,3)).LT.0.1*EL3DR) GO TO 20
0011 IF (ABS(R-DETPAR(IK,1)).LT.0.1*RES.AND.
1 ABS(A-DETPAR(IK,2)).LT.0.1*TH3DR.AND.
2 ABS(E-DETPAR(IK,3)).LT.1.2*EL3DR) GO TO 20
0012 10 CONTINUE
0013 NEWJJ=NEWJJ+1
0014 RANGE3(KTAR,NEWJJ,J)=R
0015 AZ3(KTAR,NEWJJ,J)=A
0016 SDET3(KTAR,NEWJJ,J)=SDET3(KTAR,I,J)
0017 RETURN
0018 20 K=K+1
0019 DETPAR(K,1)=R
0020 DETPAR(K,2)=A
0021 DETPAR(K,3)=E
0022 DETPAR(K,4)=SDET3(KTAR,I,J)
0023 RETURN
0024 END

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0001  SUBROUTINE DET3D (S,C,PN,N3DR,COR,FSIG,NREF,RES,NTAR,N,TH3DR,
1  MODE,AZINIT,AZHRP,XLOG,THRSH,PARM,SN,TRUE)
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),MERR3(20),RANGE3(20,9,30),AZ3(20,9,30),
1  SNETX(20,9,30),TIME3(20),IKEY(20)
0003  COMMON /NSCAN/ NEXT,NUMTGT,T,PLDT,FAOTIM,SMODE(30,20)
1  ,PI,PINVR2,TABPI,RADIAN,TAU(30),DSTAR,DNL(30)
2  ,XYZT(20,4),XYZF(20,4),TRGPS(20,7),SIGJAM(20)
3  ,SIGTAR(20,3),FMV(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(12P),D(14)
C
C  S IS THE SIGNAL POWER
C  C IS THE CLUTTER POWER
C  PN IS THE NOISE POWER
C  N3DR 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  TH3DR 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  AZHRP 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(PARME2.) OR JUST THE
C  MEAN(PARME1.) SHOULD BE USED TO CALCULATE THE THRESHOLD
C
C  ***** NOTE, DETECTION TIME IS SET EQUAL TO T *****
0008  IF (N3DR.LE. 32.AND.NREF.LE.10) GO TO 3
0009  PRINT 50
0010  50  FORMAT (1H1,' EITHER N3DR 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')

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0015      STOP
0016      4 CONTINUE
      C
      C      TEST TO SEE IF THERE IS ANY CHANCE OF A TARGET DETECTION
      C
0017      90 FORMAT(1H0,2X,'DET',15,3E15,A)
0018      SNINT=3PR*8/(C+FN)
0019      IF (SNINT.GT.2) GO TO 5
0020      NDETS(NTAR,MODE)=0
0021      STRUE = 10.**(-9.9)
0022      RETURN
0023      5 SNREF(1)=S
0024      INF(1)=NTAR
0025      NREF2=2+NREF
0026      CALL RESOL(NREF,RES,NTAR,SNREF,INF,NI,TH3DR,N)
0027      502 FORMAT(1H0,' TARGETS ARE',10I5)
0028      KAZ=(TRGPRS(NTAR,5)-AZINIT)/AZBRP+.5
0029      II=0
      C
      C      DO LOOP FOR THE THREE AZIMUTH BEAM POSITIONS
      C
0030      IAZ=0
0031      205 IAZ=IAZ+1
0032      AZIM=AZBRP*(KAZ+IAZ-2)+AZINIT
0033      KPS=TRGPRS(NTAR,4)/RES
0034      RS=RES+KPS-13.*RES
      C
      C      *****
      C      GENERATION OF SIGNAL VALUES
      C      *****
0035      NS=1
0036      NF=NSOR
0037      NRS=13-NREF-2
0038      NRF=13+NREF+2
0039      DO 7 J=NRS,NRF
0040      IS(I)=0
0041      DO 7 J=NS,NF
0042      7 SS(J,I)=0.
0043      IMERGE=0
0044      DO 40 K=1,NI
0045      PR=TRGPRS(INF(K),4)
0046      KR=(PR-RS)/RES
0047      IF (K.EQ.1.OR.KR.GT.16.OR.KR.LT.10) GO TO A
0048      IMERGE=1
      C
      C      FLUCTUATING SIGNAL
      C
  
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```
0049      8  NSW=MODEL(INF(K))
0050      IF (NSW.GT.0) GO TO 11
0051      FL=1.0
0052      9  DO 11 J=NS,NF
0053      10  FLUCT(J,K)=FL
0054      GO TO 171
0055      11  GO TO (12,13,15,16),NSW
0056      12  IF (IKEY(NTAR).GT.0) GO TO 171
0057      CALL VRANF(R,1)
0058      FL=-ALOG(R(1))
0059      GO TO 9
0060      13  M=NF+1-NS
0061      CALL VRANF(R,M)
0062      KK=0
0063      DO 14 J=NS,NF
0064      KK=KK+1
0065      14  FLUCT(J,K)=-ALOG(R(KK))
0066      GO TO 171
0067      15  IF (IKEY(NTAR).GT.0) GO TO 171
0068      CALL VRANF(R,2)
0069      FL=-.5*(ALOG(R(1))+ALOG(R(2)))
0070      GO TO 9
0071      16  M=NF+1-NS
0072      M2=2*M
0073      CALL VRANF(R,M2)
0074      KK=0
0075      DO 17 J=NS,NF
0076      KK=KK+1
0077      17  FLUCT(J,K)=- (ALOG(R(KK))+ALOG(R(KK+M)))*(-.5)
0078      171 CONTINUE
0079      512  FORMAT (1H0,' Merging Problem (K,KP,IMERGE) = ',3I10)
0080      DO 35 I=1,3
0081      KT=KR+I-2
0082      IF (KT.LT.NRS.OR.KT.GT.NRF) GO TO 35
0083      IS(KT)=1
C
C  MODULATION OF SIN(X)/X PULSE SHAPE
C
0084      RTEMP = KT*RES+RES/2.+RS
0085      FDIFF=2.7432*(RR-RTEMP)/RES
0086      F=1.
0087      IF (FDIFF.EQ.0) GO TO 1A
0088      F=SIN(FDIFF)/FDIFF
0089      1A  F=FAF
0090      SM=FA*SMREF( K )/(C+FN)
0091      503  FORMAT (1H0,' KT,RS,RTEMP,RR,FDIFF,F,SM = ',5F12.4)
0092      A=TRGPOS(INF(K),5)
C
C  MODULATION OF SIN(X)/X ANTENNA PATTERN
C
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0093      GDIF=2.7832*(AZIM      = AA)/TH3DB
0094      519  FORMAT(1H0,' GDIF,AZIM,AA,AZINIT = ',4F12.6)
0095      G=1.
0096      IF (GDIF.EQ.0) GO TO 19
0097      G=SIN(GDIF)/GDIF
0098      19  G=G**4
0099      DO 20 J=NS,NF
C
C      ***** NOTE , TARGETS ARE ADDED NONCOHERENTLY *****
C
0100      SS(J,KT)=SS(J,KT)+SM*G*FLUCT(J,K)
0101      20  CONTINUE
0102      35  CONTINUE
0103      40  CONTINUE
0104      IF(IAZ .NE. 2) GO TO 405
0105      SNTRUE = 0.
0106      DO 402 J = NS,NF
0107      402  SNTRUE = SNTRUE + SS(J,13)/N3DB
0108      405  CONTINUE
0109      DO 41 I=NRS,NRF
0110      IF (IS(I).EQ.0) GO TO 41
0111      501  FORMAT(1H0,' I,NS,NF = ',3I5,25(/,10F12.4))
0112      41  CONTINUE
0113      IKFY(NTAR)=1
C
C      ++++++
C
C      GENERATION OF NOISE SAMPLES
C
C      ++++++
C
0114      M=NF+1-NS
0115      M2=2*M
0116      M3=3*M
0117      M4=4*M
0118      IF (N3DB+C .GT.FN) GO TO 100
C
C      CLUTTER IS NOT A FACTOR
C
0119      DO 90 I=NRS,NRF
0120      IF (IS(I).EQ.1) GO TO 75
C
C      NO SIGNAL PRESENT IN THIS CELL
C
0121      CALL VRANF(R,M)
0122      K=0
0123      DO 60 J=NS,NF
0124      K=K+1
0125      X(J,1)=SORT(-2.*ALOG(R(K)))
0126      60  CONTINUE

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```

0127      GO TO 90
      C
      C      SIGNAL PRESENT IN THIS CELL
      C
0128      75 CALL VRANF(R,M2)
0129      K=0
0130      DO 80 J=NS,NF
0131      K=K+1
0132      A=SQRT(-2.*ALOG(R(K)))
0133      R=TWAPPI*(K+1)
0134      X(J,I)=SQRT((A*CRS(H)+SQRT(SS(J,I))*1.414)**2 + (A*STN(P))**2)
0135      80 CONTINUE
0136      90 CONTINUE
0137      GO TO 200

      C
      C      CLUTTER IS A FACTOR
      C
0138      100 APLDX=SQRT(C/(C+FN))
0139      CC=APLDX
0140      FFN=SQRT(FN/(C+FN))
0141      P=SQRT(1.-CAR*CRP)
0142      DO 150 J=NRS,NRF
0143      CALL VRANF(R,2)
0144      APLDY= CC*STN(TWAPPI*R(1))+SQRT(-2.*ALOG(R(2)))
0145      APLDX= CC*CRS(TWAPPI*R(1))+SQRT(-2.*ALOG(R(2)))
0146      CALL VRANF(R,M4)
0147      K=0
0148      DO 120 J=NS,NF
0149      K=K+1
0150      A=SQRT(-2.*ALOG(R(K)))*CC
0151      A1=SQRT(-2.*ALOG(R(K+M)))*FFN
0152      R=TWAPPI*(K+M2)
0153      R1=TWAPPI*(K+M3)
0154      APLDX=CAR*APLDX+P**2*CRS(R)
0155      APLDY=CAR*APLDY+P**2*STN(R)
0156      X(J,I)=SQRT((APLDX+A1*CRS(R1))+SQRT(SS(J,I))*1.414)**2 +
      1      (APLDY+A1*STN(R1))**2)
0157      120 CONTINUE
0158      150 CONTINUE

      C
      C      GENERATION OF SUM
      C
0159      200 M=NS+JDN-1
0160      IF (ALOG(1.-P.0001)) GO TO 210

      C
      C      USE LOG VIDEO
      C
0161      DO 205 J=NS,MS
0162      DO 205 J=NRS,NRF
0163      205 X(J,I)=ALOG(1+(J,I))
  
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0164 210 CONTINUE
0165      DO 241 I=NRS,NRF
0166 241 CONTINUE
0167      DO 220 I=NRS,NRF
0168          SUM(I)=0.
0169      DO 220 J=NS,MS
0170 220 SUM(I)=SUM(I)+X(J,I)
      C
      C      GENERATION OF THE DETECTION THRESHOLDS
      C
0171      DO 250 J=12,14
0172          ULOW=0.
0173          UUP=0.0
0174          XMSLOW=0.0
0175          XMSUP=0.0
0176      DO 230 I=1,NREF
0177          ULOW=ULOW+SUM(J=I-1)
0178          UUP=UUP+SUM(J=I+1)
0179          XMSLOW=XMSLOW+SUM(J=I-1)**2
0180 230 XMSUP=XMSUP+SUM(J=I+1)**2
0181          IF (THRSH.NE.0.0) GO TO 235
      C
      C      USE ALL REFERENCE CELLS
      C
0182          UBLOW=UUP
0183          XMS=XMSLOW+XMSUP
0184          D(J)=U/NREF2+FSIG*SQRT(XMS/NREF2=(U/NREF2)**2)
0185          IF (PAPH.GT.1.5) GO TO 250
0186          D(J)=FSIG*U/NREF2
0187          IF (XLOG.LT.0.0001) GO TO 250
0188          D(J)=FSIG*U/NREF2
0189          GO TO 250
      C
      C      USE EITHER MIN(THRSH<0) OR MAX(THRSH>0) REFERENCE CELLS
      C
0190 235 IF (THRSH.LT.0.0.AND.ULOW.LT.UUP) GO TO 240
0191      IF (THRSH.LT.0.0.AND.ULOW.GE.UUP) GO TO 245
0192      IF (THRSH.GT.0.0.AND.ULOW.LT.UUP) GO TO 245
0193      IF (THRSH.GT.0.0.AND.ULOW.GE.UUP) GO TO 240
0194 240 UBLOW
0195      XMS=XMSLOW
0196      GO TO 248
0197 245 UBUP
0198      XMS=XMSUP
0199 248 D(J)=U/NREF+FSIG*SQRT(XMS/NREF=(U/NREF)**2)
0200      IF (PAPH.GT.1.5) GO TO 250
0201      D(J)=FSIG*U/NREF
0202      IF (XLOG.LT.0.0001) GO TO 250
0203      D(J)=FSIG*U/NREF
0204 250 CONTINUE
  
```

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```
0205 505 FORMAT (1M0,10F12,4)
      C
      C DO LOOP FOR DETECTION OF CENTER PULSES
      C
0206      DO 280 I=12,14
0207 260 IF (SUM(I),LT,0(I)) GO TO 280
0208      IT=II+1
0209      NDET3(NTAR,MODE)=IT
0210      IF (IMERGE,EQ,1) MER3(NTAR)=-1
0211      WANGE3(NTAR,II,MODE)=RS+(I+.5)*RES
0212      A23 (NTAR,II,MODE)=A2IM
0213      SNDET3(NTAR,II,MODE)=SUM(I)
0214      IF (XLNG,GT,0.0001) SNDET3(NTAR,II,MODE)=N3DB*EXP(SUM(I)/N3DB)
0215 280 CONTINUE
0216 5280 FORMAT(1M0,' SUM AND THRESHOLD = ',5X,6F12,4)
0217      IF (IAZ,LT,3) GO TO 285
      C
      C CHECK FOR DETECTIONS
      C
0218      IF (II,GT,0.99,MER3(NTAR),EQ,-1) GO TO 300
0219      IF (IMERGE,EQ,1) MER3(NTAR)=-2
0220 300 RETURN
0221      END
```

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0001      SUBROUTINE FXCLT3
0002      COMMON NSCAN,NEXT,NUMTGT,T,RLDT,ENDTIM ,SMODE(30,20)
1         ,PI,PIVR2 ,T49PI,RADIAN,TAU(30),NSTAR,DW(30)
2         ,XYZI(20,4),XYZF(20,4),TRGPS(20,7),SIGJAM(20)
3         ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
4         ,SHIP(9),RC(30),RMODE(30,12),TMODE(30,2)
0003      COMMON /FCIN/ N,PROB,RG,RF,THS,THF,SIGA,SIGR,ISET
0004      COMMON /FCPT/ R(100),AZ(100),RAN(400),N2,N3,N4
0005      COMMON /CLTOUT/ RROUT(201),AZOUT(201),ELROUT(201),TROUT(201),
1 RROUT(201),PTROUT(201),SPROUT(201),NC(100),IC,IV
0006      COMMON /STABIN/ RMAX,PMAX,RFAC,PFAC,PHASE(2)
C
0007      IC=0
0008      IF (N.EQ.0) GO TO 15
C      TIMZR IS THE TIME OF THE ZERO BEARING CROSSING
0009      TIMZR=I*3600.
C      TIMSCN IS THE SCAN TIME OF THE RADAR
0010      TIMSCN=RMODE(1,5)*3600.
C      RES IS THE RANGE GATE SIZE
0011      RES=RC(19)
0012      CALL SFTVR(ISET)
0013      CALL VRANF(RAN,N4)
0014      ISET = 2147483647.*RAN(1)
0015      ISET = 2*(ISET/2) + 1
0016      DO 20 I=1,N
0017      IF (RAN(I).GT.PROB) GO TO 20
0018      IC=IC+1
0019      NC(IC)=I
0020      TH=PI*(I+N)*THRPI
0021      RAY=SQRT(-2.*ALOG(RAN(I+N2)))
0022      K=(R(I)+SIGR*RAY+COS(TH))/RES
0023      RROUT(IC)=(K+0.5)*RES
0024      TROUT(IC)=TIMZR+TIMSCN*AZ(I)/THRPI
C
C      GENERATION OF ROLL AND PITCH
C
0025      RLROUT(IC)=RMAX*SIN(TROUT(IC)*RFAC+PHASE(1))
0026      PTROUT(IC)=PMAX*SIN(TROUT(IC)*PFAC+PHASE(2))
0027      CR=COS(RLROUT(IC))
0028      SR=SIN(RLROUT(IC))
0029      CP=COS(PTROUT(IC))
0030      SP=SIN(PTROUT(IC))
0031      AA=AZ(I)-SHIP(5)
0032      EL=0.
0033      TE=0.
0034      Y=SIN(AA)*CR+(COS(AA)*SP+TE*CP)*SR
0035      Y=COS(AA)*CP-TE*SP
0036      AS=ATAN2(Y,Y)+THRPI
0037      FB=RSIN(CR*(COS(EL)*COS(AA)*SP+SIN(EL)*CP)-COS(EL)*SIN(AA)*SR)
C

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```

C      GENERATION OF MEASURED ANGLES
0038 C      ATEMP=A+SIGA*RAY*SIN(TM)
0039 C      AT=AMOD(ATEMP,TWOP)
0040 C      ET=E+0.5*RC(5)*RAN(I+N3)

C      CORRECTION OF ANGLE MEASUREMENTS WITH ROLL AND PITCH
0041 C      D=CP*SIN(ET)+SP*SIN(AT)*COS(ET)
0042 C      X=-SR*SIN(ET)+CR*SIN(AT)*COS(ET)
0043 C      Y=CP*COS(AT)*COS(ET)+SP*D
0044 C      AM=ATAN2(X,Y)+THOP1+SHIP(5)
0045 C      AZ=OUT(IC)=AMOD(AM,TWOP)
0046 C      EL=OUT(IC)=ARSIN(-SP*COS(AT)*COS(ET)+CP*D)
C      ***** NEED TO GENERATE OUTPUT POWER *****
0047 C      S=OUT(IC)=55.55
0048 C      20 CONTINUE
0049 C      RETURN

C      INITIALIZATION OF THE CLUTTER ROUTINE
0050 C      ENTRY FCINIT
0051 C      READ 50,ISET,N,PROR,RS,RF,SIGR,THS,THF,SIGA
0052 C      50 FORMAT (2I4,7F4,2)

C      ISET IS THE INITIALIZATION NUMBER FOR THE RANDOM NUMBER GENERATOR
C      N IS THE NUMBER OF FIXED CLUTTER PRINTS
C      PROR 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

0053 C      PRINT 55,ISET,N,PROR,RS,RF,SIGR,THS,THF,SIGA
0054 C      55 FORMAT (1H0,' FIXED CLUTTER ',2I4,7F4,3)
0055 C      CALL SETVR(ISET)

C      CALCULATION OF RANGE CELL DIMENSION
0056 C      RES=TAU(1)+300000./2.
0057 C      RFS=RES*3.2*DB/6.0A
C      RC(10) = RFS      = RANGE RESOLUTION CELL SIZE
0058 C      RC(19)=RES
0059 C      IF (N.EQ.0) GO TO 15
0060 C      RS=RS/6.0A02
0061 C      RF=RF/6.0A02
    
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```
0062      TMS=TMS/RADIAN
0063      THF=THF/RADIAN
0064      SIGA=SIGA*RC(4)
0065      SIGR=SIGR*RES
0066      IF (N.GT.100) N=100
0067      N2=2*N
0068      N3=3*N
0069      N4=4*N
0070      CALL VFANE(RAN,N2)
0071      ISET = 2147483647.*RAN(1)
0072      ISET = 2*(ISET/2) + 1
0073      DO 10 I=1,N
0074      R(I)=RS+(RF-RS)*RAN(I)
0075      10  AZ(I)=TMS+(THF-TMS)*RAN(I+N)
0076      15  RETURN
0077      END
```

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0001  SUBROUTINE INITAL
0002  DIMENSION AMRDE(30,2)
0003  COMMON NSCAN,NEXT,NUMTGT,T,PLDT,ENPTIM ,SMRDE(30,20)
1     ,PI,PIVR2 ,THRPI,RADIAN,TAU(30),DSTAR,DWL(30)
2     ,XYZI(20,4),XYZF(20,4),TRGPS(20,7),SIGJAM(20)
3     ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPWR
4     ,SHIP(9),RC(30),RMODE(30,12),IMRDE(30,2)
0004  COMMON/R/ ENVIR(10),SURC(30),RE,CNM,CCM,ACON,BETA,
*     DATP(20),PRLR2,IKEYF,XKTRN3,XNMTRN,TARCS,WVL,FOPTRH,FOPIS0
0005  COMMON/I/ PER8,HRFK,THETK,DRDOWN,THH,THV,GN
0006  RC(10)=290.0*1.3A*10.0**(-23)
C
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  D9 30 I=1,3
0013  30  SHIP(I)=SHIP(I)/6.0802
0014  PI=3.1415926536
0015  THRPI=PI*2.0
0016  PIVR2 =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,PRLR2
0021  IF(NSCAN.LE. 30) GO TO 10
0022  NSCAN = 30
0023  10  CONTINUE
0024  PRINT 501,(RC(I),I=1,9),NSCAN,PRLR2
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  DRDOWN = RC(7)+RC(7)
0037  D9 AC J = 1,NSCAN
C
0038  RMODE(J,5) IS USED AS RADAR SCAN RATE FOR ALL MODES
0039  READ 51,(RMODE(J,I),I=1,8),AMRDE(J,1),RMODE(J,11),SURC(J)
*     ,RMODE(J,12),DWL(J),SM,SMRDE(J,2)
0039  51  FORMAT(10F8.2)
0040  IMRDE(J,1)=AMRDE(J,1)

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0041      MPF=PMF
0042      PRINT 511,J,(RMODE(J,1),I=1,8),IMODE(J,1),PMODE(J,11),SURC(J)
      *      ,RMODE(J,12),DML(J),SM,SMODE(J,2)
0043      511 FORMAT(/,' 16 MODE ',I2,' PARAMETERS ARE ',BF9.3,IA,/,50X,6F9.3)
0044      IF (RMODE(J,5).GT.0.0) GO TO 55
0045      RMODE(J,5)=10.0
0046      55 RMODE(J,1)=RMODE(J,1)/RADIAN
0047      RMODE(J,2)=RMODE(J,2)/RADIAN
0048      IF (SM.EQ.0) SM=RMODE(J,4)
0049      SMODE(J,1)=150.*SM/XNMTM
0050      SMODE(J,2) = 10.*(SMODE(J,2)/10.)
0051      SMODE(J,3) = PMF
0052      RMODE(J,5)=RMODE(J,5)/3600.0
0053      RMODE(J,6)=RMODE(J,6)/3600.0
0054      RMODE(J,4)=RMODE(J,4)/MILIAN
0055      RMODE(J,8)=10.*(RMODE(J,8)/10.)
0056      RMODE(J,3)=RMODE(J,3)*MILIAN
0057      TAU(I) = RMODE(J,11)/MILIAN
0058      IF (RMODE(J,12).LF.0) RMODE(J,12) = 1.0/RMODE(J,11)
0059      RMODE(J,12) = RMODE(J,12)*MILIAN
0060      IMODE(J,2)=MAX1(RMODE(J,12)*PMODE(J,11)/MILIAN +0.5,1.0)
0061      RMODE(J,11) = 10.*(PMF)
0062      SURC(J) = 10.*(SUBC(J)/10.)
0063      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) = CRR = CLUTTER CORRELATION COEFFICIENT
C      RC(17) = FSIG = NO. STANDARD DEVIATIONS USED IN THRESHOLD
C      RC(18) = AZRHP = AZIMUTH OFFSET BETWEEN BEAM POSITIONS
C      RC(19) = RESOLUTION CELL SIZE (CALCULATED)
C      RC(20) = XLRG = VIDEO TYPE
C              0 LINEAR VIDEO
C              1 LRG VIDEO
C      RC(21) = THRSR = 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
0064      READ 70, (RC(I),I=15,18), (RC(I),I=20,22)
0065      70 FORMAT(10F8.2)
0066      PRINT 700, (RC(I),I=15,18), (RC(I),I=20,22)
0067      700 FORMAT(1H0,' ADDITIONAL RADAR PARAMETERS ARE ',7F9.3/)
C      AZIMUTH OFFSET FROM DEGREES TO RADIANS
0068      RC(18) = RC(18)/RADIAN
0069      RETURN
0070      END

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0001      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
0002      COMMON /NSCAN, NEXT, NUMTGT, T, PLDT, ENDTIM, SMODE(30,20)
          1      , PI, PINVR2, TAPPI, RADIAN, TAU(30), DSTAR, DNL(30)
          2      , XYZI(20,4), XYZF(20,4), THCPDS(20,7), SIGJAM(20)
          3      , SIGTAR(20,3), PHV(20), SIGHAM, ISAIT, TEMPWR
          4      , SHIP(9), RC(30), RMODE(30,12), IMODE(30,2)
0003      COMMON /NDET3/ NDET3(20,30), MER3(20), RANGE3(20,9,30), AZ3(20,9,30),
          1      SDET3(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      AZRRP IS THE AZIMUTH OFF SET BETWEEN AZIMUTH BEAM POSITIONS
          C
0004      AZRRP = RC(1A)
0005      CALL VPANF(AZINIT,1)
0006      AZINIT = AZINIT+AZRRP
0007      DO 10 I=1,N
0008      MER3(I)=0
0009      IKEY(I)=0
0010      DO 10 J=1,NSCAN
0011      NDET3(I,J)=0
0012      RETURN
0013      END

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```
0001 SUBROUTINE MROT3D (RES,N,TH3DR,EL3DR)
0002 COMMON NSCAN,NEXT,NUMTGT,T,RLDT,ENDTIM ,SHADE(30,20)
1 ,PI,PI*2,TH3PI,RADIAN,TAN(30),OSTAR,DAL(30)
2 ,XYZI(20,4),XYZF(20,4),TRGPS(20,7),SIGJAM(20)
3 ,SIGTAR(20,3),FHV(20),SIGMAH,TSWIT,TEMPWR
4 ,SHIP(9),RC(30),RHODE(30,12),IHODE(30,2)
0003 COMMON /MERSET/ DETPAR(100,4)
0004 COMMON /DET3/ NDET3(20,3),MER3(20),RANGE3(20,9,30),AZ3(20,9,30),
1 SDET3(20,9,30) ,TIME3(20),IKEY(20)
0005 COMMON /DET/ NDET(20),MER(20),RANGE(20,3),AZ(20,6),SDET(20,3),
1 ELEV(20,3),TIME(20)
C
C RES IS THE RANGE RESOLUTION
C N IS THE NUMBER OF TARGETS
C TH3DR IS THE AZIMUTH 3-DB ANTENNA BEAMWIDTH
C EL3DR IS THE ELEVATION 3-DB ANTENNA BEAMWIDTH
C
C THIS ROUTINE RESOLVES ALL MERGING PROBLEMS AND MAKES THE POSITION
C ESTIMATES 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
0006 DO 1000 KTAR=1,N
C
C FIND FIRST UNUSED DETECTION FOR TARGET = KTAR
C
0007 DO 10 JJ=1,NSCAN
0008 IF (NDET3(KTAR,J).GT.0) GO TO 15
0009 10 CONTINUE
0010 NDET(KTAR)=0
0011 MER(KTAR)=MER3(KTAR)
0012 TIME(KTAR)=TIME3(KTAR)
0013 GO TO 1000
0014 15 II=0
0015 20 K=1
0016 JJ=NDET3(KTAR,J)
0017 DETPAR(K,1)=RANGE3(KTAR,JJ,J)
0018 DETPAR(K,2)= AZ3(KTAR,JJ,J)
0019 DETPAR(K,3) = RHODE(J,1) + RC(5)/2.
0020 DETPAR(K,4)=SDET3(KTAR,JJ,J)
0021 NDET3(KTAR,J)=JJ-1
0022 25 KSTART=K
C
C FIND ALL ADJACENT DETECTIONS
C
0023 DO 100 LTAR=KTAR,N
0024 IF (LTAR.EQ.KTAR) GO TO 30
0025 IF (MER3(KTAR).NE.-1) GO TO 100
0026 IF (MER3(LTAR).NE.-1) GO TO 100
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0027      30  DO 45 J=1,NSCAN
0028          JJ=NDETS(LTAR,J)
0029          IF (JJ,EQ,0) GO TO 45
0030          NE=JJ#0
0031          DO 40 I=1,JJ
0032          CALL ADJDET(KFS,TH3DR,EL3DR,K,NE=JJ,LTAR,I,J)
0033      40  CONTINUE
0034          NDETS(LTAR,J)=NE+JJ
0035      45  CONTINUE
0036      100 CONTINUE
0037          IF (K,GT,KSTART) GO TO 25

C
C      ESTIMATE OF POSITION
C

0038          II=II+1
0039          IF (II,GT,3) GO TO 400
0040          NDET(KTAR)=II
0041          TIME(KTAR)=TIME3(KTAR)
0042          MER(KTAR)=MER3(KTAR)
0043          SN#0
0044          SP#0
0045          SA#0
0046          SF#0
0047          SMAX#0
0048          EMIN=100000.
0049          EMAX=100000.
0050          DO 200 I=1,K
0051          SR=SR+DETPAR(I,1)*DETPAR(I,4)
0052          SA=SA+DETPAR(I,2)*DETPAR(I,4)
0053          SF=SF+DETPAR(I,3)*DETPAR(I,4)
0054          SN=SN+DETPAR(I,4)
0055          EMIN=AMIN1(EMIN,DETPAR(I,3))
0056          EMAX=AMAX1(EMAX,DETPAR(I,3))
0057          SMAX=AMAX1(SMAX,DETPAR(I,2))
0058      200 CONTINUE
0059          RANGE(KTAR,II)=SR/SN
0060          AZ(KTAR,II)=SA/SN
0061          SJDET(KTAR,II)=SMAX
0062          ELEV(KTAR,II)=SF/SN
0063          IF (SF/SN,GT,EL3DR) GO TO 210
0064          ELEV(KTAR,II)=(EMAX+EMIN)/2.
0065      210 DO 220 J=1,NSCAN
0066          IF (NDETS(KTAR,J),GT,0) GO TO 20
0067      220 CONTINUE
0068          GO TO 1000
0069      400 PRINT 50,II,KTAR
0070          50  FORMAT (1H, ' THERE ARE TOO MANY DETECTIONS!',I5, 'DETECTIONS FOR
TARGET # ',I3)
0071      1000 CONTINUE
0072          RETURN
0073          END

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0001      SUBROUTINE STARS
0002      COMMON/INTARG,NJAM,SPEED(20),HEAD1(20),HEADF(20),TMAN1(20),
1          TMANF(20),XMAN1(20,3),XMANF(20,3),GTURN(20),TUMF(20),
2          CM(20,2),PADM(20),ITYPE(20),ALT(20,5),TALT(20,5),NALT(20)
0003      COMMON/NSCAN,NEXT,NU-TGT,I,PLDT,ENDT14,SHADE(30,20)
1          ,PI,P1VR2,TAPPI,RADIAN,TAN(30),DSTAR,DAL(30)
2          ,XYZI(20,4),XYZF(20,4),TRGPS(20,7),SIGJAM(20)
3          ,SIGTAR(20,3),FHV(20),SIGMAH,ISAIT,TEMPR
4          ,SHIP(9),WC(30),RHODE(30,12),IMADE(30,2)
0004      COMMON/DETA,NDET(20),MER(20),RANGE(20,3),AZ(20,6),SFOFT(20,3),
1          FLEV(20,3),TIME(20)
0005      COMMON/STAR/ROLL(20),PITCH(20)
0006      COMMON/STARIN/RMAX,PMAX,RFAC,PFAC,PHASE(2)
0007      DO 30 I=1,NTARG
0008      IF (NDET(I).EQ.0) GO TO 30
0009      K=NDET(I)
0010      ROLL(I) =RMAX*SIN(TIME(I)*RFAC+PHASE(1))
0011      PITCH(I) =PMAX*SIN(TIME(I)*PFAC+PHASE(2))
0012      CR=COS(ROLL(I))
0013      SR=SIN(ROLL(I))
0014      CP=COS(PITCH(I))
0015      SP=SIN(PITCH(I))
0016      AA=TRGPS(I,5)-SHIP(5)
0017      EL=TRGPS(I,6)
0018      TE=TAN(TRGPS(I,6))
0019      X= SIN(AA)*CR+(COS(AA)*SP+TE*CP)*SR
0020      Y= COS(AA)*CP-TE*SP
0021      A=ATAN2(X,Y)+TAPPI
0022      E=ARSIN(CR*(COS(EL)*COS(AA)*SP+SIN(EL)*CP)-COS(EL)*SIN(AA)*SR)
0023      20  D9 25 J=1,K
C
C      GENERATION OF MEASURED ANGLES
C
0024      ATEMP=AZ(I,J)+A-TRGPS(I,5)
0025      AT=AMOD(ATEMP,TAPPI)
0026      FT =FLEV(I,J)+F-EL
C
C      CORRECTION OF ANGLE MEASUREMENTS WITH ROLL AND PITCH
C
0027      B=CR*SIN(ET)+SR*SIN(AT)*COS(FT)
0028      Y=SP*SIN(ET)+CR*SIN(AT)*COS(ET)
0029      Y=CP*COS(AT)*COS(FT)+SP*D
0030      A=ATAN2(X,Y)+TAPPI+SHIP(5)
0031      AZ(I,J)=AMOD(A,TAPPI)
0032      ELEV(I,J)=ARSIN(-SP*COS(AT)*COS(FT)+CP*D)
0033      25  CONTINUE
0034      30  CONTINUE
0035      RETURN
C

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C
C   INITIALIZATION
C
0036   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
0037   READ 50,RMAX,PMAX,RPER,PPER
0038   50   FORMAT (4F8,2)
0039   PRINT 55,RMAX,PMAX,RPER,PPER
0040   55   FORMAT (1HD,' ROLL AND PITCH ',4F8,2)
0041   RMAX=RMAX/RADIAN
0042   PMAX=PMAX/RADIAN
0043   RPER=2*PI/RPER
0044   PPER=2*PI/PPER
0045   CALL VPANF(PHASE,2)
0046   PHASE(1)=RPT*PHASE(1)
0047   PHASE(2)=RPT*PHASE(2)
0048   RETURN
0049   END

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0001      SUBROUTINE VCFLT3
0002      COMMON /NSCAN, NEXI, NUNMGT, T, RLDT, ENDTIM, SMAD(30,20)
          ,PI,PIVR2, T=0PI, RADTAN, TAN(30), OSTAP, CWL(30)
          ,XYZI(20,4), XYZF(20,4), TRGPS(20,7), SIGJAN(20)
          , SIGTAR(20,3), FHV(20), SIGMAH, ISWIT, TEMPWF
          , SHIP(9), RC(30), RMADE(30,12), IMADE(30,2)
0003      COMMON /VCIN/ NREG, FN(5), RS(5), RF(5), THS(5), TWF(5), ELS(5), FLF(5),
          , ISET
0004      COMMON /VCLT/ PI2, PAN(305), FLA(5)
0005      COMMON /CLTOUT/ ROUT(201), AZPUT(201), ELOUT(201), TOUT(201),
          , RLPUT(201), PTOUT(201), SOUT(201), NC(100), IC, IV
0006      COMMON /STARIN/ RMAX, PMAX, RFAC, PFAC, PHASE(2)
C
0007      IV=IC
0008      IF (NREG.EQ.0) GO TO 95
0009      CALL SETVP(ISET)
0010      CALL VRANF(PAN,305)
0011      ISET = 2147483647.*RAN(305)
0012      ISET = 2*(ISET/2) + 1
C
0013      TIMZR IS THE TIME OF THE ZERO BEARING CROSSING
          TIMZR=3600.
C
0014      TIMSCN IS THE SCAN TIME OF THE RADAR
          TIMSCN=PMODE(1,5)*3600.
C
0015      RES IS THE RANGE GATE SIZE
          RES=PC(19)
0016      IRAN=0
0017      DO 20 I=1, NREG
0018      IRAN=IRAN+1
0019      IF (IRAN.GT.302) GO TO 30
0020      A = THS(I)*FLA(I)*ALRG(RAN(IRAN))
0021      15 IF (A.GT.TWF(I)) GO TO 20
0022      IV=IV+1
0023      AZPUT(IV)=A
0024      K=(RS(I) + (RF(I)-RS(I))*RAN(IRAN+1))/RES
0025      ROUT(IV)=(K+0.5)*RES
0026      ELPUT(IV)=ELS(I)+(FLF(I)-ELS(I))*RAN(IRAN+2)
0027      TOUT(IV)=TIMZR+TIMSCN*A/TWPI
0028      RLPUT(IV)=RMAX*SIN(TOUT(IV)*PFAC+PHASE(1))
0029      PTOUT(IV)=PMAX*SIN(TOUT(IV)*PFAC+PHASE(2))
0030      SOUT(IV)=33.33
0031      IRAN=IRAN+3
0032      IF (IRAN.GT.302) GO TO 30
0033      A=A*FLA(I)*ALRG(RAN(IRAN))
0034      GO TO 15
0035      20 CONTINUE
0036      30 RETURN
C
C      INITIALIZATION
C
0037      ENTRY VCINIT
  
```

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```

0038      READ 50,ISET,NREG
0039      50  FORMAT(21F)
      C
      C      ISET IS THE INITIALIZATION NUMBER OF THE RANDOM NUMBER GENERATOR
      C      NREG IS THE NUMBER OF CLUTTER REGIONS
      C
0040      PRINT 55,ISET,NREG
0041      55  FORMAT (1H0,' VARIABLE CLUTTER ',21A)
0042      IF (NREG.EQ.0) GO TO 95
0043      IF (NREG.GT.5) NREG=5
0044      DO 5 I=1,NREG
0045      READ 51,FN(I),RS(I),RF(I),THS(I),THF(I),ELS(I),ELF(I)
0046      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
0047      PRINT 56,FN(I),RS(I),RF(I),THS(I),THF(I),ELS(I),ELF(I)
0048      56  FORMAT (25X,7F9.3)
0049      RS(I)=RS(I)/6.0002
0050      RF(I)=RF(I)/6.0002
0051      THS(I)=THS(I)/RADIAN
0052      THF(I)=THF(I)/RADIAN
0053      ELS(I)=ELS(I)/RADIAN
0054      ELF(I)=ELF(I)/RADIAN
0055      5  CONTINUE
0056      DO 10 I=1,NREG
0057      10  FLAM(I)=(THF(I)-THS(I))/FN(I)
0058      95  RETURN
0059      END

```

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Appendix D

PROGRAM LISTINGS OF ROUTINES COMMON TO BOTH VERSIONS OF SURDET

```
0001      FUNCTION BEAM(ALPHA,BETA,GAMMA,KEY1)
0002      COMMON /NSCAN,NEXT,NUMTGT,T,PLDT,ENCTIM ,SMODE(30,20)
1          ,PI,PICVR2 ,THOPI,RADIAN,TAU(30),DSTAR,DAL(30)
2          ,XYZI(20,4),XYZF(20,4),TRGPS(20,7),SIGJAN(20)
3          ,SIGTAN(20,3),FMV(20),SIGMAH,IS=IT,TEMPHH
4          ,SHIP(9),PC(30),RMODE(30,12),IMODE(30,2)
0003      COMMON /I/ PRRS,HREF,THETRK,DRDOWN,THH,THV,GM
0004      THETA=2.7A*ALPHA/BETA
0005      IF(GAMMA.EQ.1..AND.KEY1.EQ.1) GO TO 40
0006      IF (THETA.GT.1.E-6) GO TO 20
0007      SINC=1.0
0008      GO TO 30
0009      20 SINC = (SIN(THETA)/THETA)**2
0010      SINC=AMAX1(DRDOWN,SINC)
0011      IF(ABS(THETA).GT.3.14159)SINC=DRDOWN
0012      GO TO 30
0013      40 CONTINUE
0014      THETRK = 2.*PRRS
0015      HREF = .25*(THETRK+SQR(THETRK*THETRK+3.1*PC(5)*PC(5)))
0016      IF(PRRS=ALPHA.GT.HREF) GO TO 50
0017      IF(ABS(THETA).GT.1.E-6) GO TO 55
0018      SINC = 1.
0019      GO TO 30
0020      55 SINC = (SIN(THETA)/THETA)**2
0021      GO TO 30
0022      50 CONTINUE
0023      IF(PRRS=ALPHA .LT. RMODE(NEXT,2)) GO TO 60
0024      SINC = DRDOWN
0025      GO TO 30
0026      60 CONTINUE
0027      THETA = 2.7A3*(HREF-PRRS)/BETA
0028      SINC = (SIN(THETA)/THETA*SIN(HREF)/SIN(PRRS-ALPHA))**2
0029      30 BEAM = SINC
0030      65 CONTINUE
0031      RETURN
0032      END
```

```

0001 SURROUTINE CLTSIG (XFRE,XHEAN,XANG,SIGZ,PALRZ)
0002 COMMON/4/ SIGOH(7,6,5),SIGOV(7,6,5),XPAR(3,7)
0003 DIMENSION ILM(2,6,5),INDEX(3,2),NOX(3)
0004 DIMENSION HMGIS(7,6,2),VAGIS(7,6,2)
0005 DIMENSION PAR(3)
0006 EQUIVALENCE (VAGIS,SIGOV(1,1,4))
0007 EQUIVALENCE (HMGIS,SIGOH(1,1,4))
0008 DATA PALRANG,PALPRL,PALDRR,PALDFE / 400.0 /
0009 DATA NOX / 7,6,5/
0010 DATA XPAR / 500.,1.,1.,1250.,2.,3.,3000.,3.,10.,5600.,4.,30.,
    * 9000.,5.,190.,17000.,6.,0.,0.,35000.,0.,0./
0011 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.,-38.,-34.,-32.,
    * -65.,-53.,-40.,-35.,-33.,-31.,-30./
0012 DATA HMGIS/
    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 -58.,-50.,-41.,-38.,-35.,-35.,-35.,
    1 -53.,-46.,-38.,-34.,-32.,-31.,-31.,
    1 -60.,-60.,-66.,-57.,-50.,-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./
0013 DATA SIGOV/
    * -98.,-98.,-86.,-83.,-80.,-80.,-80.,
    * -91.,-91.,-85.,-74.,-65.,-65.,-65.,
    * -90.,-87.,-72.,-64.,-58.,-56.,-56.,
    * -85.,-79.,-65.,-56.,-51.,-51.,-51.,
    * -72.,-72.,-55.,-53.,-48.,-48.,-48.,
    
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*      -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 VNGTS/
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.OLDBAU.AND.PBLRZ.EQ.OLDBLZ)
*AND.(XANG=OLDANG).LE.0.01) GO TO 65
ANG = PBLRZ*3.14159265/180.
0017  PAR(1) = AMAX1(500.,AMIN1(XFRE,35000.))
0018  PAR(2) = AMAX1(1.,AMIN1(XBEAU,6.))
0019  PAR(3) = AMAX1(1.,AMIN1(10.*XANG,100.))
0020  DO 10 I = 1,3
0021  DO 30 K = 1,ND
0022  DO 30 K = 1,ND
0023  IF(PAR(I).GT.XPAR(I,K)) GO TO 30
0024  INDEX(I,1) = MAX0(K-1,1)
0025  INDEX(I,2) = K
0026  GO TO 0
0027  30 CONTINUE
0028  0 IF(INDEX(I,2).NE.1) GO TO 10
0029  INDEX(I,2) = 2
0030  10 CONTINUE
0031  C
C      CHECK FOR NONEXISTENT DATA

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NAVAL RESEARCH LAB WASHINGTON D C
SURVEILLANCE RADAR DETECTION (SURDET) PROGRAM.(U)
AUG 78 L C DAVIS, G V TRUNK

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0001      SUBROUTINE ENVIRN
0002      COMMON NSCAN, NEXT, NUMTGT, T, PLDT, ENDTM , SMPDE(30,20)
1          , PI, PIOPR2 , TAPPI, RADIAN, TAU(30), DSTAR, DWL(30)
2          , XYZJ(20,4), XYZF(20,4), TRGPS(20,7), SIGJAI(20)
3          , SIGTAR(20,3), FMV(20), SIGMAH, ISKIT, TEMPWR
4          , SHIP(9), RC(30), PMPDE(30,12), IMPDE(30,2)
0003      COMMON/R/ ENVIR(10), SURC(30), RF, CNM, CCM, ACCN, BETA,
*          DPTP(20), POLRZ, IKEYF, XKTPMS, XNMTM, TARCS, WVL, FOPICR, FOPISO
0004      COMMON/H/FAC4, AMRN, XJANN, IKEYJG, XXXXX
0005      READ 50, (ENVIR(I), I=1,4)
0006      50  FORMAT (4F8.2)
0007      PRINT 500, (ENVIR(I), I=1,4)
0008      500  FORMAT(/, ' 4 ENVIRONMENTAL PARAMETERS ARE ', 4F8.2)
0009      FAC4=1.
0010      ENVIR(2) = ENVIR(2)/6.0802
0011      SIGMAH = .0066667*(XKTPMS*ENVIR(1))**2*(XNMTM*ENVIR(2)/10.)
*          **(-.19364)
0012      RETURN
0013      END
```

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0001      SURROUTINE GAIN(IKEY,JTAR,ITAR,GAINR)
      C
      C      JTAR = TARGET UNDER DETECTION
      C      ITAR = TARGET FOR WHICH FIELD STRENGTH RATIO IS TO BE DETERMINED
      C
0002      COMMON NSCAN,NEXT,NUMTGT,T,PLDT,ENDTIM ,SMODE(30,20)
      1      ,PI,PIVR2 ,TWDDI,RADIAN,TAU(30),OSTAR,OWL(30)
      2      ,XYZI(20,4),XYZF(20,4),TRGPS(20,7),SIGJAM(20)
      3      ,SIGTAR(20,3),FHV(20),SIGMAH,ISWIT,TEMPAR
      4      ,SHIP(9),RC(30),RMODE(30,12),JMODE(30,2)
0003      COMMON/R/ ENVIF(10),SURC(30),RE,CNM,CCM,ACAN,RETA,
      *      DATR(20),PRLRZ,IKEYF,XKTRNS,XNMTM,TARCS,WVL,FOP10H,FOP150
0004      COMMON/G/ SRTAR,SINPSI,COSPSI
0005      COMMON/I/ PBRS,MAFK,IMETAK,DPDWH,TMH,TMV,GN
0006      IF(IKEY.EQ.1) GO TO 10
0007      GAINR = SORT(FHV(ITAR))
0008      RETURN
0009      10 CONTINUE
0010      PAH = SMLANG(TRGPS(JTAR,5)-TRGPS(ITAR,5))
0011      ALFV = (2.*SRTAR*SINPSI+COSPSI)/(TRGPS(ITAR,4)*XNMTM)
0012      IF(ALFV.LE.1.)GO TO 30
0013      IF(ALFV.LE.1.01)GO TO 40
0014      40 ALFV=1.
0015      30 CONTINUE
0016      ALFV = ARSIN(ALFV)
0017      ALFV = TRGPS(ITAR,6)-ALFV
0018      PAV = SMLANG(TRGPS(JTAR,6)-ALFV)
0019      IF(RC(2).EQ.1.) PAV = (PBRS-ALFV)
0020      IF(RC(2).EQ.1.) GO TO 20
0021      IF(PAH.LE.(1.13*RC(4)).AND.PAV.LE.(1.13*RC(5))) GO TO 20
0022      GAINR = RC(7)
0023      RETURN
0024      20 FH = REAM(PAH,RC(4),RC(2),1)
0025      FV = REAM(PAV,RC(5),RC(2),1)
0026      GAINR = FH+FV
0027      GAINF = AMAX1(RC(7),SORT(GAINR))
0028      RETURN
0029      END
    
```

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```
0001      SUBROUTINE JAM(JTAR,EJ,EC)
0002      COMMON NSCAN,NEXT,NUMTGT,T,OLDY,ENDTIM ,SMODE(30,20)
1          ,PI,PIGVR2 ,THDP1,RADIAN,TAU(30),DSTAR,DWL(30)
2          ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAM(20)
3          ,SIGTAR(20,3),FMV(20),SIGMAM,ISHIT,TEMPNR
4          ,SHIP(9),RC(30),RMODE(30,12),IMODE(30,2)
0003      COMMON/8/ ENVIR(10),SUBC(30),RE,CNM,CCM,ACGN,BETA,
*          DOTP(20),POLRZ,IKEYF,XKTOMS,XNMTM,TARCS,WVL,FOPISQ,FOPISQ
0004      COMMON/D/ ALPHAD,SIGZ,V,ARI,AR2,SIGC,SIG
0005      COMMON/H/FAC4,AMBK,XJAMN,IKEYJG,XXXXX
0006      COMMON/I/ PBBB,HRFK,IMETBK,DBDOWN,TMM,THV,GN
0007      COMMON/TS/ISTAT(20),TSCAN(20,30)
0008      FJ=0,U
0009      FACTOR= WVL*WVL/FOPISQ*RC(6)*RC(8)*RMODE(NEXT,8)
0010      HR = SHIP(3)*XNMTM
0011      HT = TRGPOS(JTAR,3)*XNMTM
0012      SL = DBDOWN*DBDOWN
0013      AGAIN = 1
0014      THETA = RC(5)
0015      PHIB = RC(4)
0016      DO 20 J=1,NUMTGT
C          CHECK IF TARGET ACTIVE
0017          IF(ISTAT(J) .NE. 1) GO TO 20
0018          PJ=SIGJAM(J)
0019          SR = TRGPOS(J,4)*XNMTM
0020          IF((PJ.LE.(0.)) .AND. J.EQ.JTAR).OR.SR.LE.(0.)) GO TO 20
0021          OAH=SMLANG(TRGPOS(JTAR,5)-TRGPOS(J,5))
0022          OAV=SMLANG(TRGPOS(JTAR,6)-TRGPOS(J,6))
0023          IF(RC(2).EQ.1.) OAV = (PBBB-TRGPOS(J,6))
0024          IF(RC(2).EQ.1.) GO TO 10
0025          IF (OAH.LE.(1.13*RC(4)).AND.OAV.LE.(1.13*RC(5))) GO TO 10
0026          FMV(J)=DBDOWN
0027          GO TO 15
0028          10 FM = BEAM(OAH,RC(4),RC(2),0)
0029          FV = BEAM(OAV,RC(5),RC(2),1)
0030          FMV(J)=FM*FV
0031          IF(RC(2).EQ.1.0 .AND. TRGPOS(J,6) .LT. RMODE(NEXT,2) .AND. FM
*          .GT. DBDOWN) GO TO 15
0032          FMV(J)=AMAX1(DBDOWN,FMV(J))
0033          15 XJAMFA = FACTOR*PJ*FMV(J)/(SR*SR)
0034          CALL MULPTH(JTAR,J,FAC)
0035          XJAMFA = XJAMFA*FAC*FAC
0036          EJ = EJ + XJAMFA
0037          XJAMN = EJ
0038          20 CONTINUE
C          CALCULATE THE EFFECT OF CLUTTER
0039          EC = 0.
0040          25 SR = TRGPOS(JTAR,4)*XNMTM
0041          IF(ENVIR(1).LT.0) GO TO 30
0042          DC = (1.-HR/(2.*PE))*SQRT(SR*SR - HR*HR)
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0043 IF(DC,GE,DSTAR*XNMTM) GO TO 30
0044 SINLF = MP/SR - SR/(2.*RE)
0045 IF(SINLF.LT.0) GO TO 30
0046 ALPHA = ARSIN(SINLF)
0047 ALPHAD = ALPHA*RADIAN
0048 TEMP = ENVIR(1)*XNMTM*(7.5/(ENVIR(2)*XNMTM))*.09682
0049 BEAUS = ACOS(TEMP/XNMTM)*RETA
0050 XFRE=RC(1)+DNL(NEXT)
0051 CALL CLTSIG (XFRE,REAU,ALPHAD,SIGZ,POLRZ)
0052 V = TAU(NEXT)*CNH/(2.*CRS(ALPHA))*XNMTM
0053 THET = ARSIN((HT-MR)/SR - SR/(2.*RE))
0054 IF(RC(2).EQ.1.) THET1 = PARS-DSTAR*XNMTM/RE
0055 SMTB = -SIN(THETB/2.+THETT)
0056 SPTB = SIN(THETB/2.-THETT)
0057 RADM2 = SMTB*SMTB-2.*HR/RE
0058 RADP2 = SPTB*SPTB-2.*HR/RE
0059 IF(RADM2.LT.0) GO TO 26
0060 RMTB = 2.*HR/(SMTB+SQRT(RADM2))
0061 GO TO 27
0062 26 RMTB = 1.E+35
0063 27 IF(RADP2.LT.0) GO TO 2A
0064 RPTB = 2.*HR/(SPTB+SQRT(RADP2))
0065 IF(RPTB.LT.0) RPTB = 1.E+35
0066 GO TO 29
0067 28 RPTB = 1.E+35
0068 29 CONTINUE
0069 R1 = AMIN1(SR,DSTAR*XNMTM)
0070 R2 = AMIN1(SR+V,DSTAR*XNMTM)
0071 IF(RMTB.LT.0) RMTB = 1.E+35
0072 S1 = AMAX1(R1,RPTB)
0073 S2 = AMIN1(R2,RMTB)
0074 WS = .5*PHIB *(1./(S1*S1)-1./(S2*S2))
0075 WR = PI*(1./(R1*R1)-1./(R2*R2))
0076 WS = AMAX1(0.0,WS)
0077 AR1 = WR
0078 AR2 = WS
0079 C = TEMP*HR*SR**4*SIGZ/TARCS
0080 SIG = C
0081 SIGC = C*((AGAIN=8L)*WS+8L*HR)*SURC(NEXT)
0082 EC = SIGC
0083 30 CONTINUE
0084 RETURN
0085 END

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0001 SUBROUTINE MATCH
0002 COMMON NSCAN, NEXT, NUMTGT, T, OLOT, ENDTIM, SMODE(30,20)
1 PI, PIRVR2, TRAPT, RADIAN, TAU(30), DSTAR, DWL(30)
2 , XYZI(20,4), XYZF(20,4), TRGPS(20,7), SIGJAM(20)
3 , SIGTAR(20,3), FHV(20), SIGMAH, ISWIT, TEMPHR
4 , SHIP(9), RC(30), RMODE(30,12), IMODE(30,2)
0003 COMMON/R/ ENVIR(10), SURC(30), RE, CNM, CCM, ACRN, BETA,
* DSTR(20), POLRZ, IKEYF, XKTOMS, XNMTM, TARCS, NVL, FOPIOR, FOPISO
0004 COMMON/C/A(3), R(20,3), RMAG2(20)
0005 COMMON/TH/NTARG, IJAM, 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)
0006 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
0007 TMAX = 1.E30
0008 DT OG J = 1, NTARG
C INITIALIZE ISTAT VECTOR
C ISTAT = 0 TARGET NOT ACTIVATED
C ISTAT = 1 TARGET ACTIVE
0009 ISTAT(J) = 0
0010 DO 10 K=1,3
0011 A(K)=XYZI(J,K)=SHIP(K)
0012 10 CONTINUE
0013 RMAG2=A(1)*A(1)+A(2)*A(2)+A(3)*A(3)
0014 IF (ITYPE(J) .EQ. 2) GO TO 25
C
C NO MANEUVER
0015 B(J,1) = XYZF(J,1) - XYZI(J,1)
0016 B(J,2) = XYZF(J,2) - XYZI(J,2)
0017 TEMP = XYZF(J,3)
0018 IF (ITYPE(J) .EQ. 0) GO TO 18
0019 TEMP = ALT(J,2)
0020 18 B(J,3) = TEMP - XYZI(J,3)
0021 20 RMAG2(J) = B(J,1)*B(J,1) + B(J,2)*B(J,2) + B(J,3)*B(J,3)
0022 GO TO 22
C
C MANEUVER
0023 25 B(J,1) = COS(HEADI(J))
0024 B(J,2) = SIN(HEADI(J))
0025 RMAG2(J) = B(J,1)*B(J,1) + B(J,2)*B(J,2)
0026 B(J,3) = 0.
0027 22 ADSTR = A(1)*B(J,1) + A(2)*B(J,2) + A(3)*B(J,3)
0028 ADSTR2=ADSTR*ADSTR
0029 K = ITYPE(J)+1

```

```

0030      IF (K .NE. 2) GO TO 27
C        STORE CRITICAL VALUES FOR TARGET TYPE 1 TO REINITIATE NEW MODE
0031      XAR = ADOTR
0032      YAR2 = ADOTR2
0033      XMAG2 = MMAG2(J)
0034      XAMAG2 = AMAG2
0035      LFG = 1
C
0036      27 DO 80 I = 1, NSCAN
0037      29 TSCAN(J,I) = RMDE(I,6) + XYZI(J,4)
0038      R2 = RMDE(I,7) + RMDE(I,7)
0039      DISC = ADOTR2 - BMAG2(J) * (AMAG2 - R2)
0040      GO TO (30,40,55), K
0041      30 IF (DISC .GE. 0.0) GO TO 60
C
C        TARGET NEVER WITHIN RANGE
0042      35 TSCAN(J,I) = TMAX
0043      GO TO 80
C
C        ALTITUDE LEGS
0044      40 IF (LFG .EQ. 1) GO TO 42
C        RESET VALUES FOR INITIAL LEG
0045      ADOTR = XAR
0046      ADOTR2 = XAR2
0047      BMAG2(J) = XMMAG2
0048      AMAG2 = XAMAG2
0049      LFG = 1
0050      42 IF (DISC .LT. 0.0) GO TO 45
0051      TEM1 = TALT(J,LEG)
0052      TEM2 = TALT(J,LEG+1)
0053      TERM = SQRT(DISC)
0054      UMINUS = -1.0 * (ADOTR + TERM) / BMAG2(J)
0055      UPLUS = (TERM - ADOTR) / BMAG2(J)
0056      WMINUS = MAX1(UMINUS, 0.0)
0057      WPLUS = MIN1(UPLUS, 1.0)
0058      IF (WMINUS .GT. WPLUS) GO TO 45
0059      XSCAN = TEM1 + WMINUS * (TEM2 - TEM1)
0060      IF ((XSCAN .GE. TEM1) .AND. (XSCAN .LE. TEM2)) GO TO 75
C
C        TARGET NEVER WITHIN RANGE ON THIS LEG - LOOK AT NEXT LEG
0061      45 LFG = LFG+1
0062      IF (LFG .GE. NALT(J)) GO TO 35
0063      R(J,3) = ALT(J,LFG+1) - ALT(J,LFG)
0064      DT = (TALT(J,LEG) - XYZI(J,4)) / (XYZF(J,4) - XYZI(J,4))
0065      A(1) = XYZI(J,1) + DT * (XYZF(J,1) - XYZI(J,1)) - SHIP(1)
0066      A(2) = XYZI(J,2) + DT * (XYZF(J,2) - XYZI(J,2)) - SHIP(2)
0067      A(3) = ALT(J,LFG) - SHIP(3)
0068      MMAG2(J) = R(J,1) * A(1) + A(2) * A(2) + A(3) * A(3)
0069      BMAG2(J) = R(J,1) * R(J,1) + R(J,2) * R(J,2) + A(J,3) * R(J,3)
0070      ADOTR = A(1) * R(J,1) + A(2) * R(J,2) + A(3) * R(J,3)

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0071      ADOTR2=ADOTB*ADOTB
0072      DISC = ADOTR2 - RMAG2(J)*(AMAG2 - R2)
0073      GO TO 42
          C
          C      MANEUVER
0074      55 TEM1 = TMANI(J)
0075      IF(DISC .GE. 0.0) GO TO 65
          C
          C      TARGET NOT WITHIN RANGE PRIOR TO MANEUVER
          C      DEFAULT TO BEGINNING OF MANEUVER
0076      5R XSCAN = TMANI(J)
0077      GO TO 75
          C
0078      60 TEM1 = XYZF(J,4)
0079      65 TERM=SQRT(DISC)
0080      UMINUS=-1.0*(ADOTR+TERM)/RMAG2(J)
0081      UPLUS=(TERM-ADOTR)/RMAG2(J)
0082      WMINUS=AMAX1(UMINUS,0.0)
0083      WPLUS=AMIN1(UPLUS,1.0)
0084      IF(WMINUS .GT. WPLUS) GO TO (35,35,58), *
0085      XSCAN = XYZI(J,4) + WMINUS*(TEM1 - XYZI(J,4))
0086      75 IF (TSCAN(J,I) .GE. XSCAN) GO TO 80
0087      XN = AINT((XSCAN - TSCAN(J,I))/RMPDE(I,5))
0088      TSCAN(J,I) = TSCAN(J,I) + XN*RMPDE(I,5)
0089      IF(XSCAN .EQ. TSCAN(J,I)) GO TO 80
0090      TSCAN(J,I) = TSCAN(J,I) + RMPDE(I,4)
0091      80 CONTINUE
0092      90 CONTINUE
          C
0093      DETERMINE EARLIEST TIME EACH MODE SEES A TARGET
0094      05 95 I = 1, NSCAN
0095      TMIN = TMAX
0096      05 92 J = 1, NTARG
0097      TSCAN(J,I) = TSCAN(J,I) - RMPDE(I,5)*1.1
0098      IF(TSCAN(J,I) .GE. TMIN) GO TO 92
0099      TMIN = TSCAN(J,I)
0100      92 CONTINUE
0101      RMPDE(I,9) = TMIN
0102      95 CONTINUE
0103      RETURN
          END
  
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NRL REPORT 8228

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0001      SUBROUTINE MULPTH(JTAR,ITAP,FAC) FROM COPY FURNISHED TO DDC
C
C      JTAR = TARGET UNDER DETECTION (DIRECTION OF RADAR)
C      ITAR = TARGET FOR WHICH PATTERN PROPAGATION FACTOR IS BEING CALC
C
0002      COMMON NSCAN,NEXT,NUMTGT,7,PLDZ,ENDTIM ,SMODE(30,20)
1          ,PI,PIQVR2 ,THRPP1,RADIAN,TAU(30),DSTAR,DWL(30)
2          ,XYZI(20,4),XYZF(20,4),TRGPS(20,7),SIGJAM(20)
3          ,SIGTAR(20,3),FMV(20),SIGMAH,IS*IT,TEMP*H
4          ,SMIP(9),RC(30),RMODE(30,12),IMODE(30,2)
0003      COMMON/R/ ENVIR(10),SUHC(30),RE,CNM,CCM,ACRN,RETA,
*          DSTR(20),PDLRZ,[KEYF,XKTOMS,XNMTM,TARCS,MVL,FOPIDH,FOPISC
0004      COMMON/F/ HR,HT
0005      COMMON/G/SRTAP,SINPS1,COSPS1
0006      COMPLEX CI,CTEMY,CP,CA,CU1,CU2,CTEMW,CGAMV,CGAMH
*          ,CGAM
0007      FAC = 1.
0008      IF(ENVIR(3) .EQ. 0.) RETURN
C      CHECK FOR NEW SCAN MODE
0009      IF(IS*IT.EQ.1) GO TO 5
C      RADAR MODE DEPENDENT CALCULATIONS
0010      XNZERN = 1.000313
0011      HR = SIN[PI(3)*XNMTM]
0012      PAR = HR/RE
0013      CHR = HR*(1.-PAR)
0014      XHPAR = 2.*PI/MVL
0015      XFRF=RC(1)+DWL(NEXT)
0016      IF(XFRF.GT.1500.) GO TO 6
0017      EPS1 = 80.
0018      SIG1 = 4.3
0019      GO TO A
0020      6 IF(XFRF.GT.3000.) GO TO 7
0021      EPS1 = 80.-0.00733*(XFRF-1500.)
0022      SIG1 = 4.3+0.00148*(XFRF-1500.)
0023      GO TO A
0024      7 EPS1 = 69-0.005714*(XFRF-3000.)
0025      SIG1 = 6.52+0.001314*(XFRF-3000.)
0026      A CONTINUE
0027      CI = (0.0,1.)
0028      CTEMY = CMPLX(EPS1,-60.*MVL*SIG1)
0029      XKZERN = XHPAR*XNZERN
0030      H = (2.*XKZERN*XKZERN/RE)**(-1./3.)
0031      XL = 2.*(4.*XKZERN/(RE*RE))**(-1./3.)
0032      Z1 = MM/H
0033      CP = CI*XKZERN+CSQRT(CTEMY-1.)*(COS(PDLRZ/RADIAN)
*          + SIN(PDLRZ/RADIAN)/CTEMY)
0034      CA = 2.3381*CFXP(CI*2.*PI/3.) + 1./(H*CP)
0035      XI*CA = ATNAG(CA)
0036      CALL UFUN(Z1,CA,CU1)

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0037      IS*IT = 1
0038      5 CONTINUE
0039      IKEY = -1
0040      GRRT = TRGPOS(ITAR,7)*XNMTOM
0041      20 CONTINUE
0042      HT = TRGPOS(ITAR,3)*XNMTOM
0043      HSUM = HR*HT
0044      RAT = HT/RE
0045      CHT = HT*(1,-RAT)
0046      TEMP = SQRT(4./3.*(RE*(CHR+CHT)+GRRT*GRRT/4.))
0047      TEMPHI = ARCS(2.*RE*GRRT*ABS(CHH-CHT)/(TEMP*TEMP+TEMP))
0048      GRRAD = GRRT/2.*SIGN(1.,CHR-CHT)*TEMP*ACS((TEMPHI+PI)/3.)
0049      GRTAR = GRRT-GRRAD
0050      SRRAD = SQRT(HR*HR*(1.+RAR)*GRRAD*GRRAD)
0051      SRTAR = SQRT(HT*HT*(1.+RAT)*GRTAR*GRTAR)
0052      TANPSI = CHR/GRRAD - GRRAD/(2.*RE)
0053      IF(TANPSI.LE.0) GO TO 40
0054      COSPSI = GRRAD/SRRAD*(1.+RAR)
0055      SINPSI = GRRAD/SRRAD*(TANPSI+HR/GRRAD*RAR)
0056      50 CONTINUE
0057      RREF = SRRAD+SRTAR
0058      PRREF = SRRAD-SRTAR
0059      TEMW = 2.*PRREF/RREF
0060      DISP = SQRT((1.-HSUM/RE)*RREF/GRRT
0061      *COSPSI/(1.+TEMW/(RE*SINPSI)))
0062      TEMG = (2.*SINPSI/RREF)**2*PRREF
0063      PTHDIF = RREF*TEMG/(1.+SQRT(1.-TEMG))
0064      IF(IKEY.EQ.1) GO TO 30
0065      IF(PTHDIF.GE.*VL/4.) GO TO 30
0066      IKEY = 1
0067      CRITR = GRRT
0068      XNAT = CRITR/XL
0069      SINPSI = 2.**VL/4.*HSUM/(*VL/4.**VL/4.+4.*HR*HT)
0070      CALL RRGCE(*VL/4.,GRRAD,GRTAR,SRRAD,SRTAR,SINPSI)
0071      CRITR = GRRAD+GRTAR
0072      GRRT = GRRAD+GRTAR
0073      COSPSI = SQRT(1.-SINPSI*SINPSI)
0074      XNAT1 = CRITR/XL
0075      GO TO 50
0076      30 CONTINUE
0077      CTEMW = CSQRT(CTEMW-COSPSI*COSPSI)
0078      CGAMV = (CTEMW*SINPSI-CTEMW)/(CTEMW*SINPSI+CTEMW)
0079      CGAMH = (SINPSI-CTEMW)/(SINPSI+CTEMW)
0080      CGAM = .5*CLRG((CGAMH+COS(PALRZ/RADIAN))**2
0081      * (CGAMV+SIN(PALRZ/RADIAN))**2)
0082      CGAMI=AIMAG(CGAM)
0083      IF ( CGAMI .GT. 0.0 ) GOTO 51
0084      CGAM=CMPLX( REAL(CGAM),3.1416+CGAMI)
0085      51 CGAM=CEXP( CGAM )
0086      RMRREF = (ABS(CGAM))

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0085 PHIRF = AIMAG(CLAG(CGAM))
0086 TEMG1 = (2.*XKPAR*SIGMAH*SINPSI)**2
0087 XMUR = EXP(-TEMG1/2.)
0088 CALL GAIN(1,JTAR,ITAR,GV)
0089 CALL GAIN(0,JTAR,ITAR,GD)
0090 FAC1 = CABS(1.+GV/GD*PHIRF*DISP*XMUR*CEXP(CI*(-XKZFP*
      *PTHDIF=PHIRF)))
0091 IF(IKEY,EN,-1) GO TO 10
0092 Z2 = HT/H
0093 XNAT2 = 2.*(SQRT(2.*RE*CHT) + SQRT(2.*RE*CHR))/XL
0094 CALL UFUN(Z2,CA,C112)
0095 FAC2 = 2.*SQRT(PT*XNAT2)*EXP(-XINCA*XNAT2)*CABS(CU1*CU2)
0096 CALL INTER(0,FAC1,XNAT1,FAC2,XNAT2,FAC,XNAT)
0097 RETURN
0098 10 FAC = FAC1
0099 RETURN
0100 40 CONTINUE
0101 FAC = 1.E-20
0102 RETURN
0103 END

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0001      SUBROUTINE NEWPBS
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.
0002      COMMON /NSCAN, NEXT, NUMTGT, T, ODOT, ENDTM, SMODE(30,20)
1          ,PI,PI*VR2, TWRPI, RADIAN, TAU(30), DSTAR, DWL(30)
2          ,XYZI(20,4), XYZF(20,4), TRGPS(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 /R/ ENVIR(10), SUAC(30), RF, CNM, CCM, ACCN, BETA,
*          DPTP(20), PRLRZ, IKEYF, XKTONS, XNNTOM, TARCS, AVL, FOPHQ, FOPISG
0004      COMMON /C/ DEL(3), VEL(20,3), VELMG2(20)
0005      COMMON /T/ NTARG, N, JAM, 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)
0006      COMMON /DET3/ NDET3(20,30), MER3(20), RANGE3(20,9,30), AZ3(20,9,30),
1          , SMDT3(20,9,30), TIME3(20), IKEY(20)
0007      DIMENSION TAZ(20)
0008      COMMON /TS/ ISTAT(20), TSCAN(20,30)
C
C
C      SET FLAG FOR POSITION CALCULATION AT TIME T
0009      IFLAG = 1
0010      DO 90 J = 1, NUMTGT
C          J = TARGET NUMBER
0011      TT = T
C          DETERMINE TARGET STATUS
C          ISTAT = 0 TARGET INACTIVE
C          ISTAT = 1 TARGET ACTIVE
0012      ISTAT(J) = 0
0013      IF((TT .LT. XYZI(J,4)) .OR. (TT .GT. XYZF(J,4))) GO TO 90
0014      ISTAT(J) = 1
C          CHECK FOR AZIMUTH CORRECTIONS
C          SCAN RATE TAKEN FROM RMODE(1,5) FOR ALL MODES
0015      IF(IFLAG .EQ. 2) TT = TT + (TAZ(J)/TWRPI)*RMODE(1,5)
C
C          DETERMINE TARGET TYPE
0016      IS = (ITYPE(J) .EQ. 2) GO TO 11
C          NO MANEUVER
0017      DT = (TT - XYZI(J,4))/(XYZF(J,4) - XYZI(J,4))
0018      DO 7 I = 1,2
0019      TRGPS(J,I) = XYZI(J,I) + DT*(XYZF(J,I) - XYZI(J,I))

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0020       7 CONTINUE
C
0021       IF (ITYPE(J) .EQ. 1) GO TO 8
0022       TRGPS(J,3) = XYZI(J,3) + DT*(XYZF(J,3) - XYZI(J,3))
0023       GO TO 20
C
0024       DETERMINE ALTITUDE LEG
0025       A N = NALT(J)
0026       DO 9 I = 1,N
0027       IF (TT .LE. TALT(J,I)) GO TO 10
C
0028       9 CONTINUE
C
0029       TARGET ON LEG I=1
C
0030       TIME EXCEEDS TARGET FINAL TIME
0031       TS = TT+3600.
0032       TSS = TALT(J,N)+3600.
0033       PRINT 400, TS, TSS, J
0034       J00 FORMAT(1H0/5X,'CURRENT TIME',F10.2,' EXCEEDS FINAL TARGET TIME',
0035       1 F10.2,' IN NEWPOS FOR TARGET',I5/)
0036       I = N
0037       10 DT = (TT - TALT(J,I-1))/(TALT(J,I) - TALT(J,I-1))
0038       TRGPS(J,3) = ALT(J,I-1) + DT*(ALT(J,I) - ALT(J,I-1))
C
0039       CORRECT ALTITUDE COMPONENT OF TARGET DIRECTION VECTOR
0040       VEL(J,3) = TRGPS(J,3) - ALT(J,I-1)
0041       VELMC2(J) = VEL(J,1)*VEL(J,1)+VEL(J,2)*VEL(J,2)+VEL(J,3)*VEL(J,3)
0042       GO TO 20
C
0043       MANEUVERING TARGET
C
0044       TARGET AT CONSTANT ALTITUDE (TRGPS(J,3) SET IN TARGET)
0045       11 IF (TT .LE. TMANF(J)) GO TO 12
C
0046       TARGET BEYOND MANEUVER
0047       DELT = (TT - TMANF(J))*SPEED(J)
0048       VEL(J,1) = COS(HEADF(J))
0049       VEL(J,2) = SIN(HEADF(J))
0050       TRGPS(J,1) = XMANF(J,1) + DELT*VEL(J,1)
0051       TRGPS(J,2) = XMANF(J,2) + DELT*VEL(J,2)
0052       GO TO 18
C
0053       12 IF (TT .GT. TMANI(J)) GO TO 15
C
0054       TARGET PRIOR TO MANEUVER
0055       DELT = (TT - XYZI(J,4))*SPEED(J)
0056       VEL(J,1) = COS(HEADI(J))
0057       VEL(J,2) = SIN(HEADI(J))
0058       TRGPS(J,1) = XYZI(J,1) + DELT*VEL(J,1)
0059       TRGPS(J,2) = XYZI(J,2) + DELT*VEL(J,2)
0060       GO TO 18
C
0061       TARGET WITHIN MANEUVER
0062       15 DELT = (TT - TMANI(J))*SPEED(J)/RADN(J)
0063       ANG = HEADI(J) + TURN(J)*(DELT - PI/VR2)
0064       TRGPS(J,1) = CM(J,1) + RADN(J)*COS(ANG)

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0055 TRGPS(J,2) = CM(J,2) + RADN(J)*SI(ANG)
0056 ANG = ANG + TURN(J)*PI*VR2
0057 VFL(1,1) = COS(ANG)
0058 VFL(J,2) = SIN(ANG)
0059 18 VFLMG2(J) = VFL(J,1)*VFL(1,1)+VFL(J,2)*VFL(J,2)
0060 20 DO 22 I = 1,5
0061 DEL(I)=TRGPS(J,1)-SHIP(I)
0062 22 CONTINUE
0063 DSTAR=95.2*SHIP(4)
0064 DX=DEL(1)
0065 DY=DEL(2)
0066 DZ=DEL(3)
C NO. COMPUTE THE TARGET HORIZONTAL ANGLE (CCW FROM EAST)
0067 28 IF (ABS(DX).GT.0.000001) GO TO 30
C THE TARGET IS AT PLUS OR MINUS PI/2
0068 RTEMP = PI*VR2
0069 IF (DY.GE.0.0) GO TO 40
0070 RTEMP = -PI*VR2
0071 GO TO 40
0072 30 RTEMP = ATAN(DY/DX)
0073 IF (DX.GE.0.0) GO TO 40
0074 RTEMP = RTEMP+PI
0075 40 IF (RTEMP.GE.0.0) GO TO 50
0076 RTEMP = RTEMP+TWOPI
0077 50 TRGPS(J,5)=RTEMP
0078 IF(IFLAG.EQ.2) GO TO 52
C STORE AZIMUTH
0079 AZ(J) = TRGPS(J,5)
0080 GO TO 90
0081 52 D = SQRT(DX*DX + DY*DY)
0082 DHALF=SQRT(D)
0083 TRGPS(J,4)=SQRT(DX*DX+DY*DY+DZ*DZ)
C TIMES AND TIME ARRAYS IN SECONDS
0084 TIME(J) = TT*3600.
0085 TRGPS(J,7) = 0
0086 IF(J.GT.NTARG) GO TO 24
C D*TP USED FOR TARGET CROSSSECTION CALCULATION IN TARGIS
0087 D*TP(J) = (DEL(1)*VEL(J,1)+DEL(2)*VEL(J,2)+DEL(3)*VEL(J,3))/
1 (SQRT(VFLMG2(J))*TRGPS(J,4))
0088 24 IF (D.GT.0.000001) GO TO 55
C THE TARGET IS NOW DIRECTLY OVERHEAD
0089 TRGPS(J,6)=PI*VR2
0090 GO TO 90
0091 55 R=DHALF/95.2*SHIP(4)/DHALF
0092 RPRIME=TRGPS(J,3)/D-R
0093 TRGPS(J,8) = ATAN(RPRIME)
0094 IF (RPRIME.LT.0.0.AND.0.GT.DSTAR) GO TO 80
C THE TARGET HAS NOW BEEN FOUND TO BE IN SIGHT
0095 GO TO 90
C THE FOLLOWING APPLIES TO AN OUT OF SIGHT TARGET
0096 80 TRGPS(J,4)=TRGPS(J,4)
0097 ISTAT(J) = 0
0098 90 CONTINUE
C
C CHECK FOR AZIMUTH CORRECTION
0099 IF(IFLAG.EQ.2) RETURN
0100 IFLAG = 2
0101 GO TO 5
0102 END
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0001      SUBROUTINE RESOL (PREF,RES,NTAR,SNREF,INF,NI,TH3DB,N)
0002      COMMON NSCAN,NEXT,NUMTGT,T,PLUT,ENDT14,SHADE(30,20)
1         ,PI,PIA/R2,T*PI,RADIAN,TAU(30),DSTAR,DWL(30)
2         ,XYZI(20,4),XYZF(20,4),TRGPS(20,7),SIGJAM(20)
3         ,SIGTAR(20,5),FHV(20),SIGMAH,ISWIT,TEMPWR
4         ,SHIP(9),HC(30),HMODE(30,12),I4MODE(30,2)
0003      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
0004      NT=1
0005      DELR=(NREF+2)*RES
0006      DO 20 I=1,N
0007      IF (T.EQ.NTAR) GO TO 20
0008      IF (ABS(TRGPS(I,4)-TRGPS(NTAR,4)).GT.DELR) GO TO 20
0009      IF (ABS(TRGPS(I,5)-TRGPS(NTAR,5)).GT.2.4*TH3DB) GO TO 20
0010      INF(NI)=1
0011      INF(NI)=I
C      CALCULATE SIGNAL ENERGY FOR INTERFERING TARGET
C
0012      CALL SIGNAL(I,PAR,SNREF(NI))
C
0013      20 CONTINUE
0014      RETURN
0015      END

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SURPTITINE WNGCEN(DELTA,SR1,SR2,41,42,5)
CAMMHN NSCAN,NEXT,NUMTGT,Y,ALDT,ENNTI4,SMODE(30,20)
1 PI,PIAVR2,THAPI,RADIAN,TAN(30),DSTAR,DWL(30)
2 XYZI(20,4),XYZP(20,4),TRGPS(20,7),SIGJAN(20)
3 SIGTAR(20,3),FMV(20),SIGMAN,ISWIT,TEMPAR
4 SHIP(9),HC(30),SMODE(30,12),IMODE(30,2)
CAMMHN/H/ FNVIN(10),SUAC(30),RE,CNH,CCM,ACAN,RETA,
D9TP(20),ALRZ,IKEYF,XYTSMR,XNNTOM,TARCS,WVL,FOPION,FAPISG
* CAMMHN/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 + 6./ASS * (1./V1+1./V2)
R = S-F/FP
IF(ARS(F).LT,DELTA/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

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0001 SUBROUTINE SIGNAL(JTAR,PWR,SIGEN)
      C JTAR = TARGET UNDER CONSIDERATION
      C PWR = POWER RECEIVED
      C SIGEN = SIGNAL ENERGY
0002 COMMON NSCAN,NEXT,HUMTGT,T,CLDT,ENDTIM,SMODE(30,20)
      1 ,PI,PIVR2,THDDI,RADIAN,TAU(30),NSTAR,DWL(30)
      2 ,XYZI(20,4),XYZF(20,4),TRGPS(20,7),SIGJAM(20)
      3 ,SJTAR(20,3),FHV(20),SIGMAH,TSWIT,TEMPAH
      4 ,SHIP(9),RC(30),RMDE(30,12),IMDE(30,2)
0003 COMMON/B/ ENVIR(10),SURC(30),RE,CNM,CCM,ACCN,BETA,
      * DQTP(20),POLRZ,IKEYF,XKTRMS,XNTRM,TARCS,WVL,FOPTR,FOPISD
0004 COMMON/H/FAC4,AMRN,XJAMN,IKEYJC,XXXXX
0005 COMMON/I/ PRBS,HQFK,THEYBK,DRDCH,THH,THV,GN
0006 COMMON/MO/MODEL(20)
0007 COMMON/SIG/RM,HA,ES
      C COMPUTE SIGNAL ENERGY FOR TARGET JTAR
0008 CALL TARSIG(JTAR)
0009 WVL=300./(RC(1)+DWL(NEXT))
0010 S = RMDE(NEXT,3)*RC(6)*RC(6)*WVL*WVL*TARCS
0011 M = TRGPS(JTAR,4)
0012 RM = XNTRM
0013 DRDCH
0014 HQRD
0015 HMT = P*XNTRM*XNTRM*XNTRM*XNTRM*XNTRM
0016 PWR = S*RC(A)*RC(9)*RMDE(NEXT,A)/(RMT*FOPTR)
0017 FHV(JTAR) = 1.
0018 IF(RC(2),NE.1.) GO TO 50
0019 FM = 1.
0020 RAV = (PRBS = TRGPS(JTAR,6))
0021 FV = REAM(RAV,RC(5),RC(2),1)
0022 FHV(JTAR) = FM*FV
0023 IF(TRGPS(JTAR,6) .LT. RMDE(NEXT,2)) GO TO 50
0024 FHV(JTAR) = AMAX1(FHV(JTAR),DBDOWN)
0025 50 CONTINUE
0026 ES = PWR*RMDE(NEXT,4)
0027 TEMPAR = ES
0028 ES = ES*FHV(JTAR)*FHV(JTAR)
0029 CALL MULTPH(JTAR,JTAR,FAC)
0030 FAC4 = FAC*FAC*FAC*FAC
      C COMPUTE TWO WAY RAIN ATTENUATION
0031 EA = 10.**(-1.E-HORN*ENVIR(4)*WVL**(-1.87))
      C COMPUTE SIGNAL ENERGY
0032 ES = ES*FAC4*AMTNI(RMDE(NEXT,12)*TAU(NEXT),1.)*4
0033 SIGEN = ES
0034 RETURN
0035 ENTRY PRISF(JTAR,EC,EN)
      C JTAR = TARGET UNDER CONSIDERATION
      C EC = CLUTTER ENERGY

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C      EN = NOISE ENERGY (INCLUDING JAMMING)
C
0035      EN = RC(3)*RC(10)
0037      AMRN = EN
C      CALCULATE JAMMING (EJ) AND CLUTTER (EC) ENERGIES
0038      CALL JAM(JTAR,FJ,EC)
C      COMPUTE RAIN CROSS SECTION
0039      RNCS = 6.706E-6*TAU(NEXT)*RC(4)*RC(5)*RM *RM **VL**(-4)
      **FLVTR(4)**1.6
C      CALCULATE RAIN BACKSCATTER
0040      ER = (S*RNCS/(TANCS*FAC4*FMV(JTAR)*FMV(JTAR)))*SINDE(NEXT,2)
0041      TEMP = PRRS = RC(5)/4.
0042      IF(TEMP.GE.1) GO TO 60
C      INCLUDE MULTIPATH AVERAGING FACTOR
0043      EP = 6.*ER
C      COMPUTE NOISE ENERGY TO INCLUDE RAIN BACKSCATTER AND RAIN-
C      ATTENUATED JAMMING ENERGY
0044      60 EN = (EN + ER + EJ*RA/2.)*FLCAT(IMODE(NEXT,2))
C      COMPUTE RAIN ATTENUATED CLUTTER
0045      EC = EC*RA*FLCAT(IMODE(NEXT,2))
0046      RETURN
0047      END

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0001      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 MODES AND CORRESPONDING ARRIVAL
C                    TIMES. PROFILE CONSISTS OF STRAIGHT LINE
C                    TRAJECTORIES BETWEEN MODES, 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
0002      COMMON /NSCAN, NEXI, NUNTGT, T, PLUT, ENDTIM, SHODE(30,20)
1          , XI, PI, RW, T, TH, DI, RADIAN, TAU(30), DSTAR, DWL(30)
2          , XYZI(20,4), XYZF(20,4), TRGPS(20,7), SIGJAM(20)
3          , SIGTAR(20,3), FHV(20), SIGMAH, ISWIT, TEMPWR
4          , SHIP(9), WC(30), RANGE(30,12), INPDE(30,2)
0003      COMMON /Z ENVIR(10), SURC(30), ME, CNM, CCM, ACAN, META,
*          , DETP(20), PRLRZ, YKEYF, XTRMS, XNNTAV, TAPCR, AVL, FAPJCR, FAPTSO
0004      COMMON /E /A(20,4)
0005      COMMON /HRC /HRCDEL(20)
0006      COMMON /T /NTARG, NJAM, SPEED(20), HEADI(20), HEADF(20), THA1(20),
1          , THANF(20), AMANI(20,3), XMANF(20,3), GTURN(20), TURN(20),
2          , CM(20,2), RADH(20), ITYPE(20), ALT(20,5), TALT(20,5), NALT(20)
0007      DIMENSION CAPD(10), DEL(3)
0008      READ 2, NTARG, NJAM
0009      2 FORMAT(215)
0010      PRINT 500, NTARG, NJAM
0011      500 FORMAT(' NUMBER OF TARGETS = ', I2, 'X', ' NUMBER OF JAMMERS = ', I2)
0012      NUNTGT = NTARG + NJAM
0013      J = 0
0014      5 DO 90 J = 1, NUNTGT
0015      J = J + 1
0016      READ 6, (XYZI(J, I), I=1, 4),
1          (XYZF(J, I), I=1, 4), (SIGTAR(J, I), I=1, 3), SIGJAM(J), HRCDEL(J)

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0017      6 FORMAT(2F6.2,13)
0018      PRINT 100, J, (XYZI(J,I), I=1,4), (XYZF(J,I), I=1,4),
          1      (SIGTAR(J,I), I=1,3), SIGJAM(J), MDEL(J)
0019      600 FORMAT(/, ' INPUT PARAMETERS FOR TARGET ', I2, ' ARE', 4F10.2, /, 40X,
          1      4F10.2, 4F6.2, 15)
          C      SCALE INPUT TO NAUTICAL MILES, HOURS, AND RADIAN FOR INTERNAL
          C      CALCULATIONS
0020      DO 7 I = 1, 3
0021      XYZI(J,I) = XYZI(J,I)/6.0802
0022      XYZF(J,I) = XYZF(J,I)/6.0802
0023      7 CONTINUE
0024      XYZI(J,4) = XYZI(J,4)/3600.
0025      XYZF(J,4) = XYZF(J,4)/3600.
0026      SIGJAM(J) = SIGJAM(J)/1.0F+6
0027      READ R, ITYPE(J), (CARD(I), I=1,7)
0028      8 FORMAT(14,7F6.2)
          C      CHECK FOR TYPE OF TARGET PROFILE
          C      IF (ITYPE(J) .EQ. 0) GO TO 90
0029      PRINT 100, ITYPE(J), (CARD(I), I=1,7)
0030      800 FORMAT(/1X,10,5X,7F10.2)
0031      IF (ITYPE(J) .NE. 1) GO TO 10
0032      C      ALTITUDE LEGS
          C      NALT(J) = CARD(1)
0033      NALT(J) = CARD(1)
0034      N = NALT(J)
0035      IF (N .GT. 3) N = 3
          C      NALT UPDATED TO CONTAIN NO. OF ALTITUDE NODES PLUS TWO (FOR
          C      INITIAL AND FINAL ALTITUDES)
0036      NALT(J) = N + 2
0037      ALT(J,1) = XYZI(J,3)
0038      TALT(J,1) = XYZI(J,4)
0039      ALT(J,NALT(J)) = XYZF(J,3)
0040      TALT(J,NALT(J)) = XYZF(J,4)
          C      STORE INTERMEDIATE ALTITUDE NODES
0041      DO 9 I=1,N
0042      ALT(J,I+1) = CARD(2+I)/6.0802
0043      TALT(J,I+1) = CARD(2+I)/3600.
0044      9 CONTINUE
0045      GO TO 90
          C      HANDLE OVER
0046      10 IF (ITYPE(J) .EQ. 2) GO TO 15
0047      PRINT 100, J, ITYPE(J)
0048      100 FORMAT(100,5X, 'TARGET', I3, ' HAS UNDEFINED TARGET TYPE', I3,
          1      ' TARGET DELETED')
0049      J = J - 1
0050      IF (K .LE. NTARG) NTARG = NTARG - 1
0051      IF (K .GT. NTARG) NJAM = NJAM - 1
0052      GO TO 90
0053      15 SPEED(J) = CARD(1)*3600./6.0802
0054      HEADI(J) = CARD(2)/RADIAN
0055      THANT(J) = CARD(3)/3600.
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NRL REPORT 8228

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0056      CTURN(J) = CAR0(4)*32.17*3600.+3600./6000.2
0057      TRPPS(J,3) = XYZI(J,3)
      C
      C   SCALE INPUT TO NAUTICAL MILES, HOURS, AND RADIAN FOR INTERNAL
      C   CALCULATIONS
      C   TARGET MANEUVER PARAMETERS
      C   CALCULATE TARGET BEGIN AND END MANEUVER POSITIONS IN X-Y PLANE
      C   TARGET END MANEUVER ON HEADING TOWARDS FINAL POSITION
      C   TARGET POSITION AT BEGINNING OF MANEUVER
0058      DELT = (TMANI(J) - XYZI(J,4))*SPEED(J)
0059      XMANI(J,1) = XYZI(J,1) + DELT*COS(HEADI(J))
0060      XMANI(J,2) = XYZI(J,2) + DELT*SIN(HEADI(J))
      C   DETERMINE DIRECTION OF MANEUVER
      C   TURN = 1 CW MANEUVER
      C   TURN = -1 CCW MANEUVER
      C   COMPUTE HEADING OF VECTOR FROM TARGET POSITION XMANI TO XYZF
0061      DEL(1) = XYZF(J,1) - XMANI(J,1)
0062      DEL(2) = XYZF(J,2) - XMANI(J,2)
0063      XHEAD = ARCOS(DEL(1)/SQRT(DEL(1)*DEL(1)+DEL(2)*DEL(2)))
0064      IF(DEL(2) .LT. 0.0) XHEAD = TWPI - XHEAD
0065      TURN(J) = 1.
      C   RIGHT HAND TURN ASSUMED FOR 180 DEGREE TURN
0066      HTEST = HEADI(J) + PI
0067      IF(HTEST .GE. TWPI) GO TO 25
0068      IF((XHEAD .LT. HEADI(J)) .OR. (XHEAD .GE. HTEST))
1         TURN(J) = -1.*TURN(J)
0069      GO TO 30
0070      25 HTEST = HTEST - TWPI
0071      IF((XHEAD .LT. HEADI(J)) .AND. (XHEAD .GE. HTEST))
1         TURN(J) = -1.*TURN(J)
0072      30 CONTINUE
      C
      C   CALCULATE CENTER AND RADIUS OF MANEUVER CIRCLE
0073      RADM(J) = SPEED(J)*SPEED(J)/GTURN(J)
0074      CM(J,1) = XMANI(J,1) + RADM(J)*COS(HEADI(J)+TURN(J)*PI/VP2)
0075      CM(J,2) = XMANI(J,2) + RADM(J)*SIN(HEADI(J)+TURN(J)*PI/VP2)
      C   DETERMINE IF MANEUVER POSSIBLE
      C   COMPUTE DISTANCE FROM CM TO XYZF
0076      DEL(1) = XYZF(J,1) - CM(J,1)
0077      DEL(2) = XYZF(J,2) - CM(J,2)
0078      DELR = SQRT(DEL(1)*DEL(1) + DEL(2)*DEL(2))
0079      IF (DELR .GE. RADM(J)) GO TO 75
      C   IMPOSSIBLE MANEUVER
0080      PRINT 400, J
0081      400 FORMAT(1H0,5X,'MANEUVER IMPOSSIBLE FOR TARGET',I3,
1         '      TARGET DELETED')
0082      J = J - 1
0083      IF(N .LT. NTARG) NTARG = NTARG - 1
0084      IF(N .GT. NTARG) NJAM = NJAM - 1
0085      GO TO 00

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C
C   DETERMINE TARGET POSITION AT END OF MANEUVER
C
0086   75 STNR = RADN(J)/DELR
0087   CDSA = DEL(1)/DELR
0088   SINA = DEL(2)/DELR
0089   ANA = ACOS(CDSA)
0090   ANR = ASIN(STNR)
C
C   DETERMINE QUADRANT OF XYZF RELATIVE TO CM
0091   R1 IF(SINA .GE. 0.) GO TO R5
C
0092   HEADF(J) = T*PI - ANA + TURN(J)*ANR
0093   GO TO R4
C
0094   QUADRANTS 3 AND 4
0095   R5 HEADF(J) = ANA + TURN(J)*ANR
0096   R4 DHEAD = TURN(J)*(HEADF(J) - HEADI(J))
0097   R3 IF(DHEAD .LT. 0.) DHEAD = DHEAD + T*PI
0098   XMANF(J,1) = CM(J,1) + RADN(J)*COS(HEADF(J) - TURN(J)*PI*VR2)
0099   YMANF(J,2) = CM(J,2) + RADN(J)*SIN(HEADF(J) - TURN(J)*PI*VR2)
0100   ZMANF(J) = ZMANI(J) + DHEAD*SPEED(J)/GTURN(J)
C
C   CALCULATE TIME TARGET ARRIVES AT FINAL POSITION
0100   DEL(1) = XYZF(J,1) - XMANF(J,1)
0101   DEL(2) = XYZF(J,2) - XMANF(J,2)
0102   DELR = SQRT(DEL(1)*DEL(1) + DEL(2)*DEL(2))
0103   XYZF(J,4) = DELR/SPEED(J) + ZMANF(J)
0104   90 CONTINUE
0105   NUMTGT = NTARG + NJAM
C
C   SET UP ARRAY FOR TARGET CROSS SECTION CALCULATIONS
0106   D1 95 J = 1,NTARG
0107   A(J,4) = (2.*SIGTAR(J,3) + SIGTAR(J,2))/3.
0108   A(J,3) = (3.*SIGTAR(J,1) + SIGTAR(J,2) - 4.*A(J,4))/12.
0109   A(J,2) = 5.*A(J,3) - SIGTAR(J,1) + A(J,4)
0110   A(J,1) = 2.*A(J,2) - 4.*A(J,3)
0111   95 CONTINUE
0112   RETURN
0113   END

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NRL REPORT 8228

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0001      SUPERINTIVE TARSIG(JTAR)
          C
          C      JTAR = TARGET NUMBER
          C
0002      COMMON /SCAN, NEXT, MUMTGT, T, PLDT, ENDTIM, SMODE(30,20)
          1      , F1, P1, VPP, TMRPT, RAUTAN, TAN(30), NSTAR, DAL(30)
          2      , XYZI(20,4), XYZF(20,4), TRGPS(20,7), SIGJAN(20)
          3      , SIGTAR(20,3), ENV(20), SIGMAH, ISHIT, TEMPAR
          4      , SHIP(9), RC(30), RMODE(30,12), IMODE(30,2)
0003      COMMON /H/ ENVIR(10), SURC(30), FE, CNH, CCM, ACCN, BET4,
          *      (ATP(20), PHLRZ, IKEYF, XXTONS, XNXTON, TARCS, LVL, EOPICH, FAFISC
0004      COMMON /F/A(20,4)
0005      DIMENSION TEMP(4)
0006      TEMP(1) = DATP(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
    
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0001 SUBROUTINE URUN(Z,CA,CANS)
0002 COMMON NSCAN,NEXT,NUMTGT,T,PLDT,ENDTIM,IRMODE(30,20)
1      ,PI,PIVR2,TMRPI,RADIAN,TAU(30),RSTAR,CWL(30)
2      ,XYZI(20,4),XYZF(20,4),TRGPOS(20,7),SIGJAN(20)
3      ,SIGTAR(20,3),FMV(20),SIGMAN,IS=IT,TEMPWR
4      ,SMIP(9),RC(30),RMODE(30,12),IMODE(30,2)
0003 COMMON/R/ FNVIR(10),SURC(30),RE,CN,CCK,ACCN,BETA,
*      DPTP(20),FOLRZ,IKEYF,XKTONS,XNMTM,TARCS,XVL,FPPIGH,FPPISQ
0004 COMPLEX CA,CANS,C1,CXP3,CZ,CA1,C23,CA13,CFI,CFIP,CGI,CGIP
*      ,CF,CFP,CG,CGF,CH2,CH2P,CZ2,C2A,CZ4,CA14,CCE,CCEA
*      ,CC,CCP,CAIR,CAIRP,CFM,CFPM,CGM,CGPM,COLTA
0005 IF(IS=IT,EQ.1) GO TO 5
0006 CI = (0.0,1.0)
0007 XC1 = .35502P0539
0008 XC2 = .2588194034
0009 KPI = SQRT(PI)
0010 CXP3 = CEXP(CI*PI/3.)
0011 CA1 = CA*CXP3
0012 PLFZ = 0
0013 5 CONTINUE
0014 IF(Z,EQ.,PLDZ) GO TO 90
0015 PLDZ = Z
0016 CZ = (Z+CA)*CXP3
0017 IKEY = 0
0018 IF(CARS(CZ),GT,3.) IKEY = IKEY+1
0019 IF(CARS(CA1),GT,3.) IKEY = IKEY+2
0020 IF(IKEY,EQ,3) GO TO 10
0021 IF(IS=IT,EQ.1,AND,IKEY,EQ.1) GO TO 10
0022 CZ3 = CZ+CZ+CZ
0023 CA13 = CA1+CA1+CA1
0024 CFI = 1
0025 CFIP = 0
0026 CGI = CA1
0027 CGIP = 1.
0028 CFM = 1.
0029 CFPM = 1./CA1
0030 CGM = CZ
0031 CGPM = 1
0032 XMUL1 = 1
0033 XMUL2 = 1
0034 I = 0
0035 20 I = I+1
0036 XMUL1 = XMUL1/(3*I)*(3*I-1)
0037 XMUL2 = XMUL2/((3*I+1)*3+1)
0038 CFM = CFM+CZ3
0039 CFPM = CFPM+CA13*(3+1)/(MAX0(1,3*I-3))
0040 CGM = CGM+CZ3
0041 CGPM = CGPM+CA13*(3+I+1)/(3*I-2)
0042 CF = XMUL1+CFM

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0043      CFP = XMUL1*CFPM
0044      CG = XMUL2*CGM
0045      CGP = XMUL2*CGFM
0046      CFI = CFI+CF
0047      CFIP = CFIP+CFP
0048      CGI = CGI+CG
0049      CGIP = CGIP+CGP
0050      IKEY1 = IKEY+1
0051      GO TO (22,23,24), IKEY1
0052      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
0053      GO TO 20
0054      23 IF(CABS(XC1+CFP-XC2*CGP),LT.,.005*CABS(XC1+CFIP-XC2*CGIP))
*      GO TO 21
0055      GO TO 20
0056      24 IF(CABS(XC1+CF-XC2*CG),LT.,.005*CABS(XC1+CFI-XC2*CGI))
*      GO TO 21
0057      GO TO 20
0058      21 CONTINUE
0059      IF(IKEY,EQ,1) GO TO 25
0060      CH2 = C1*3.02617*(XC1+CFI-XC2*CGI)
0061      25 IF(IKEY,LT,2) CH2P = C1*3.02617*(XC1+CFIP-XC2*CGIP)*CXP3
0062      IF(IKEY,EQ,0) GO TO 70
0063      IF(ISHT,EQ,1,AND,IKEY,EQ,2) GO TO 70
0064      10 CONTINUE
0065      CDZ = 2./3.*CEXP(1.5*CLRG(CZ))
0066      CDA = 2./3.*CEXP(1.5*CLRG(CA1))
0067      CZ4 = 1./CSQRT(CSQRT(CZ))
0068      CA14 = CSQRT(CSQRT(CA1))
0069      CCE = CEXP(-CDZ)
0070      CCFA = CEXP(-CDA)
0071      CC = .5*(CZ4+CCE/CFI)
0072      CCP = -.5*(CA14+CCFA/HTPI)
0073      XMUL1 = 1.
0074      CAIP = 1.
0075      CFP = 1.
0076      CAIPP = 1.
0077      CFPM = 1.
0078      I = 0
0079      40 I = I+1
0080      K = 6*I-1
0081      DO 50 J = 1,3
0082      XMUL1 = XMUL1*K
0083      K = K+2
0084      50 CONTINUE
0085      XMUL1 = XMUL1/(216*(1+(2*I-1)))
0086      CFM = CFM/CDZ
0087      CF = XMUL1*CFM
0088      CFPM = CFP*(6*I+1)/(1-6*I)/CDA

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0009      CFF = AMUL1*CFPM
0010      CAIR = CAIR+(-1)**I*CF
0011      CAIRP = CAIRP+(-1)**I*CFP
0012      GO TO (51,52,53), IKEY
0013      51 IF(CARS(CF).LT..002) GO TO 60
0014      GO TO 40
0015      52 IF(CARS(CFP).LT..002) GO TO 60
0016      GO TO 40
0017      53 IF(CARS(CF).LT..002.AND.CARS(CFP).LT..002) GO TO 60
0018      GO TO 40
0019      60 CONTINUE
0100      IF(IKEY.NE.2) CH2 = CI+3.02617*CC+CAIR
0101      IF(IKEY.EE.2) CH2P = CI+3.02617*CCP+CAIRP+CKP3
0102      70 CONTINUE
0103      CANS = CI*CH2/CH2P
0104      CALDA = CANS
0105      RETURN
0106      80 CANS = CALDA
0107      RETURN
0108      END
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