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Technical Memorandum

RADAR SIMULATION AND ANALYSIS BY DIGITAL COMPUTER

by D. M. WHITE

THE JOHNS HOPKINS UNIVERSITY ▪ APPLIED PHYSICS LABORATORY

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RADAR SIMULATION AND ANALYSIS BY DIGITAL COMPUTER

by D. M. WHITE

SPONSORED BY ARPA UNDER AO #479

THE JOHNS HOPKINS UNIVERSITY • APPLIED PHYSICS LABORATORY
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ABSTRACT

A digital computer program is described which simulates the radar-target engagement providing a representation of the detection, acquisition, and tracking processes. The program is arranged as a time simulation of the engagement between a radar and target, taking into account the detailed characteristics of the target cross section, radar and target motion throughout the engagement, surface clutter, atmospheric attenuation, and radar losses. In the output the program provides the user with target detection probabilities in the presence of surface clutter as well as receiver noise, radar search and track accuracies, signal-to-noise ratios, target characteristics versus time, angular and range rates, etc. The input requirements to the program are: (1) a deck of parameter cards describing the radar parameters, the clutter environment, and the initial radar-target geometry, (2) a deck of cards describing the target motion throughout the engagement, and (3) a deck of cards describing the target's cross section versus aspect angle. Many simplifications to the inputs are allowed for studying and isolating various parts of the radar problem.

PREFACE

This paper describes a digital computer program which is intended to serve as an aid in the design, analysis, and evaluation of radar systems. Techniques for analyzing the performance of a radar without the aid of a digital computer are well established and provide sufficiently accurate results if the problem is not too involved. However, the problems are often quite complicated which forces the radar analyst to reduce the complexity with simplifying assumptions, such as, specifying the target's average cross section as a constant, ignoring the effects of atmospheric attenuation and ground clutter, estimating the detection probability, etc. If numerous, accurate, and detailed analyses are required a digital computer program must be used.

The purpose of this program is to simulate the radar-target engagement in the real world in order to provide a representation of the detection, acquisition, and tracking processes. In the simulation process it takes into account the detailed characteristics of the target cross section, radar and target motion through the engagement, surface and rain clutter, atmospheric attenuation, and radar losses. In the output the program provides the user with target detection probabilities in the presence of surface and/or rain clutter as well as receiver noise, radar search and track accuracies, signal-to-noise ratios, target characteristics vs time, angular and range rates, etc.

The program is made as general purpose as possible by segmenting it into subprograms and subroutines, and by the liberal use of data inputs. In its complete form broad examples of its use are as follows: analyzing the performance of a radar against different kinds of targets for different sea states; optimizing the yield of data from a live test by simulating the test beforehand; optimizing the scanning pattern or any other parameter of a search radar in various situations; and providing assistance in determining optimum hardware parameters during the development of a radar system. If a complete simulation is not desired the target inputs can be simplified to allow the radar characteristics to be studied separately.

The program is written in FORTRAN II for the IBM 7094 computer. It compiles in approximately two-tenths of an hour and computes, for an average number of cases, in two-hundredths of an hour.

I am indebted to V. Schwab, G. T. Trotter, and E. Shotland whose contributions represent a significant part of the computer program.

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I. INTRODUCTION

The digital computer program described in this report was developed to calculate the performance of a radar against a single target in a dynamic situation. The program is hereinafter called the Radar Analysis Program for purpose of identification.

1.1 The Radar Analysis Problem

The radar problem that is to be analyzed is illustrated graphically in Figure 1-1. Certain complicating factors such as time variation of the target and radar positions, clutter echoes, antenna sidelobes, and changing situations prompts the radar analyst to use a digital computer.

Time Variation. The prime complicating characteristic of the radar analysis problem is the variation of the positions of radar and target with time. If the target and radar are allowed to move throughout an engagement then a detection probability calculation would have to be performed for every increment of time. This would be necessary to account for changes in the target's cross section, range to the target, size of the clutter echoes, and antenna position. The change of target cross section as a function of time is calculated with a fair amount of precision. The target cross section as a function of aspect angle is fed into the program as an input. The actual aspect angle as a function of time, as calculated during the engagement, is used to find the corresponding target cross section by table-look-up.

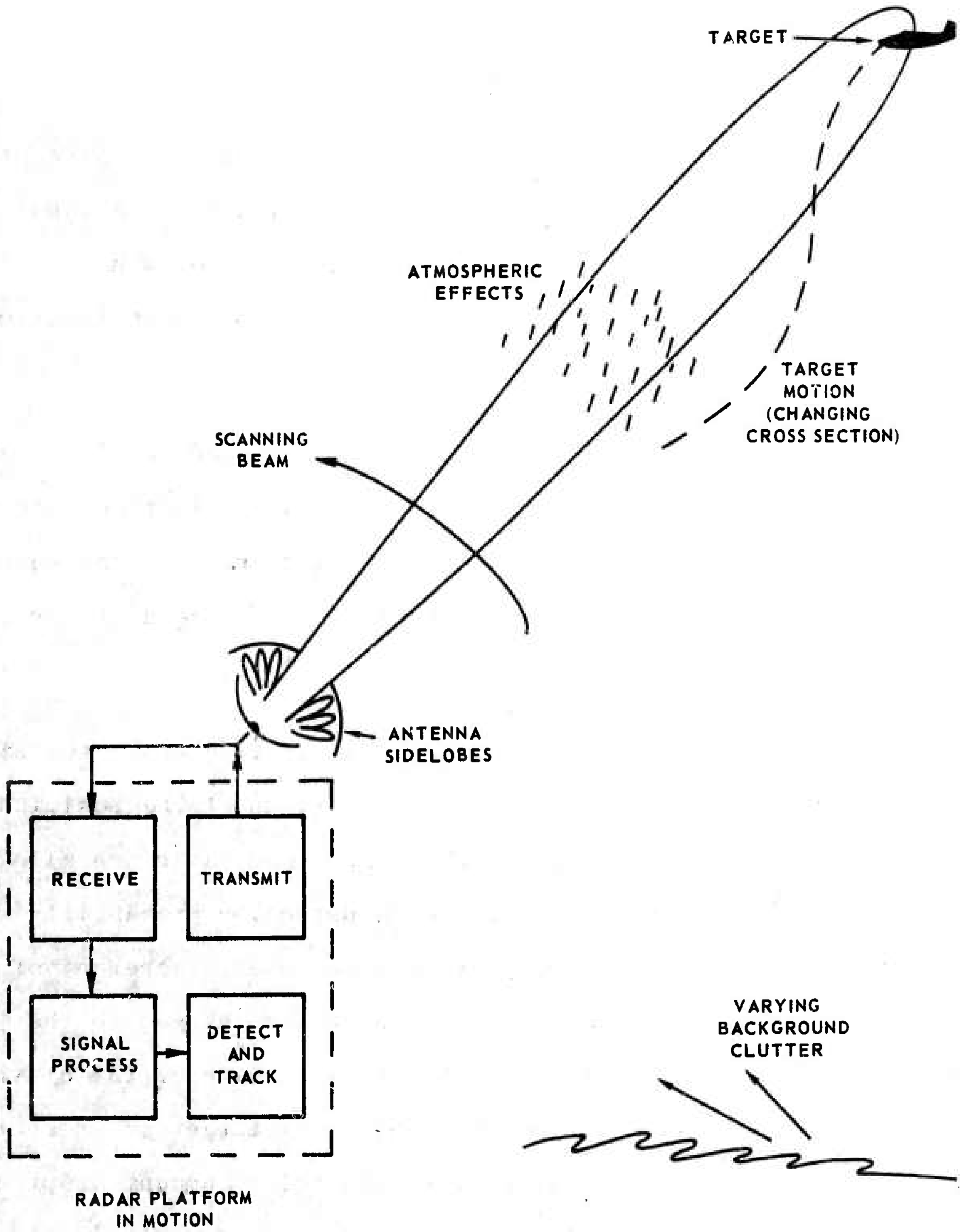

Fig. 1-1 RADAR ANALYSIS PROBLEM IN DYNAMIC SITUATION

Surface Clutter. The second most complicating factor in radar performance calculations is clutter, the reflections from the background land or sea. The magnitude of the received clutter power is calculated each increment of time and is added to the receiver noise power. This total noise power is used to form the signal-to-noise-plus-clutter-ratio which is the prime quantity for calculating the detection probability.

The most popular detection theory used for the detection probability calculation was developed by Marcum and Swerling.[1] However this theory assumes that the noise is random from pulse-to-pulse like receiver noise. If the total noise includes clutter echoes the Marcum-Swerling theory would yield an erroneous probability of detection since clutter echoes are in general not randomly distributed from pulse-to-pulse. To improve the calculation of the detection probability for a target in a clutter background a new theory is used which treats the clutter echoes realistically, i.e., some degree of correlation from pulse-to-pulse.[2] Both detection theories are incorporated as part of the Radar Analysis Program; their use will be described later.

Antenna Sidelobes. The clutter problem is complicated further when the antenna sidelobes are included in the simulation. For example under situations when the main beam of the antenna is

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[1] J.I. Marcum and P. Swerling, "Studies of Target Detection by Pulsed Radar," IRE Transactions on Information Theory, Vol. IT-6 (April, 1960).

[2] E. Shotland, "False Alarm Probabilities for Receiver Noise and Sea Clutter," JHU/APL Internal Memorandum BBD-1387, October, 1964.

pointing at a target at a high altitude the clutter echoes are not received via the main beam but with the sidelobes. In the present simulation the sidelobes are considered constant at a level specified in the program input.

Other facets of the radar-target engagement shown in Figure 1-1, or otherwise incorporated in the Radar Analysis Program, will be described in the remainder of the report.

Performance Calculations. Even though the detection process was emphasized in the above it is not the only performance characteristic that should be considered. Other performance characteristics that are included in the program are search and track accuracies (in range, doppler, and angle), range resolution, and target identification times.

All calculations are made as a function of time of the engagement at any desired time interval. Any number of runs can be performed in one program deck set-up to analyze radar performance, or target characteristics, as various parameters (total of 43) are varied one at a time or together. Examples of parameters that are often varied are clutter reflectivity (or sea state), radiated power, antenna gain, sidelobe level, time between false alarms, target range, and angle of the target's plane of motion.

1.2 Summary

The remaining chapters in this report are arranged according to the major divisions of the computer program, namely, inputs, processing, and outputs. The Radar Analysis Program is shown in block diagram form in Figure 1-2. The input parameters are arranged in five groups as shown and are discussed in Chapter II. These inputs are fed into the processing part of the program, which is discussed in Chapter III, resulting in the program outputs, which are described in Chapter IV.

In Chapter II the input parameters to the Radar Analysis Program are listed, described, and supported by examples. The prime problem that will be used as an example throughout Chapter II and the remaining chapters is the detection and track of a surface-launched ballistic missile by a radar mounted in an aircraft. This problem has all the elements of complexity such as rapid target motion, fluctuating target cross section, high clutter background, etc. and is the best example for illustrating what the program can and cannot do. The changes required on the input cards to analyze other problems will also be indicated. The inputs required for the target motion and the target cross section are the most involved and are arranged in decks (or tables); these are "looked-up" in the processing operation. The other parameters, which describe initial radar-to-target geometry, the clutter and noise parameters, and the radar characteristics, are fed in on one input card to a parameter for a total of 43.

In Chapter III a description of the processing and simulation techniques are given. An overall flow diagram of the program is given, followed by description of the more important subroutines such as the target and radar motion simulation, the radar simulation, and the detection routines.

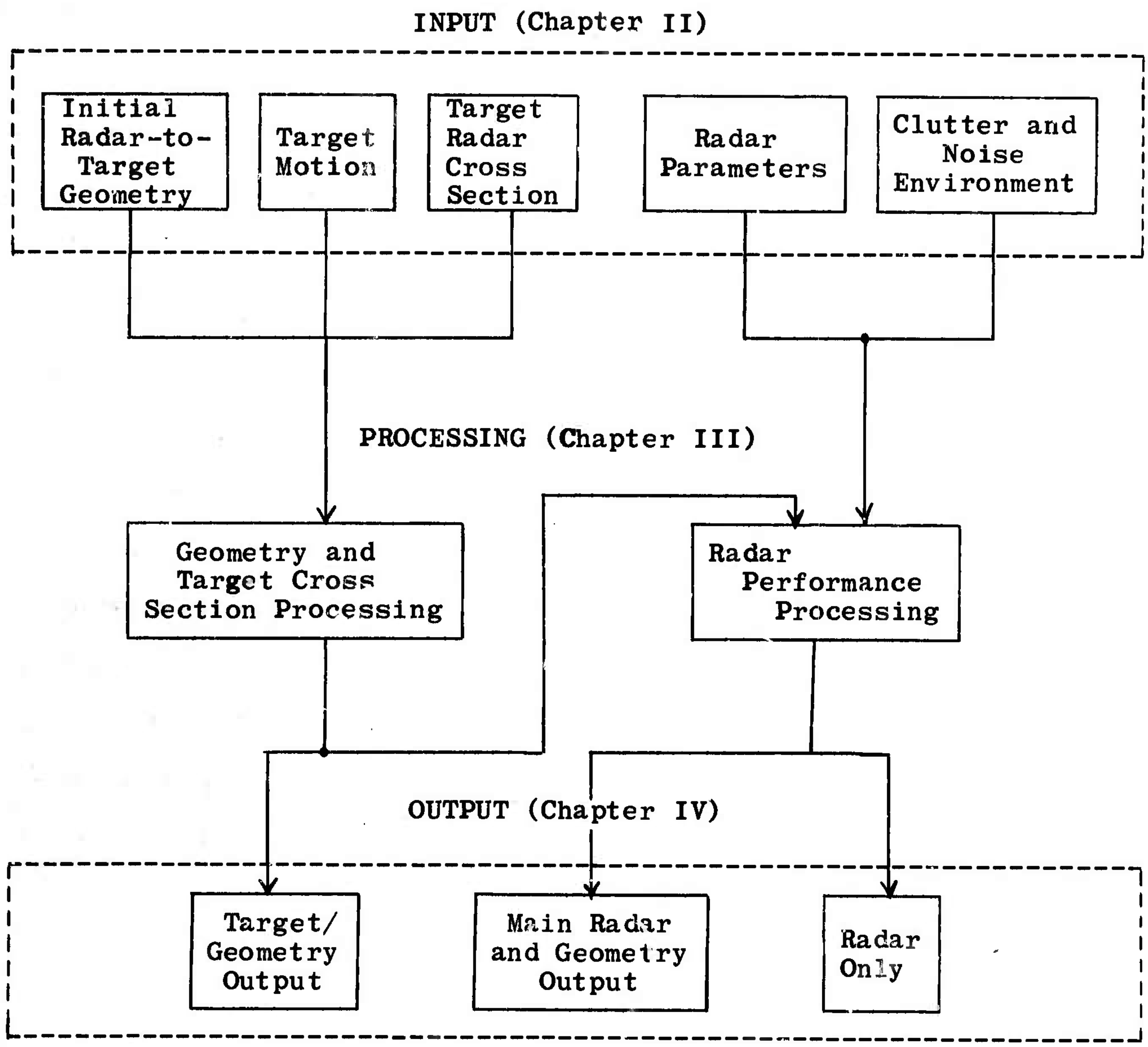

Figure 1-2

BLOCK DIAGRAM OF THE RADAR ANALYSIS PROGRAM

In Chapter IV the output parameters (66 are printed out) are described followed by the printed and plotted output for the examples given in Chapter II. Examples will be shown for the full-scale dynamic situation and the simplified simulation in which the target motion is static and the target [illegible] section is constant.

In Chapter V the significant developments of this study will be reviewed along with the limitations of the existing program and areas for future development.

The complete program, written in FORTRAN II, is given in Appendix B. A literature review of other digital computer programs for radar analysis or simulation is given in Appendix A.

II. PROGRAM INPUTS

The program data inputs consist of 43 input-parameter cards and two decks. The individual parameter cards describe the initial radar-to-target geometry, the radar characteristics, the clutter and noise parameters, and program control. The two decks of cards form two tables describing the target motion and the target radar-cross-section. These inputs will be defined and illustrated by examples. The prime example used will be for a radar mounted in an aircraft with a surface-launched missile as the target. The changes required in the inputs for other examples will be indicated.

The last section in this chapter will describe the input parameters and procedures used to control the type of output desired. Two types are available: the time simulation mode, in which the radar performance is analyzed against a moving target, and the detection-probability range-profile mode, in which the target motion and cross section are unchanging.

2.1 Target Motion

The target motion within a vertical plane is described with a deck of input cards. On each card in the deck there are eight numbers as listed and defined in Table 2-1. The time value referred to in Table 2-1 may have a zero or negative value on the first card and increase from card to card with any desired increment between 1 and 9999 seconds. The card preceding the target motion deck has the time increment, total number of cards, and the name

Table 2-1

TARGET MOTION TABLE

Card number	Maximum of 322
Time (T)	Time (from zero) in seconds
Down range position	Horizontal distance in feet of target in target plane at time (T) measured from initial target position.
Down range speed	Horizontal speed of target at time (T) in feet per second
Down range acceleration	Horizontal acceleration of target at time (T) in feet per second per second
Altitude position	Target altitude (or vertical position in target plane) at time (T) in feet
Altitude speed	Vertical velocity of target at time (T) in feet per second
Altitude acceleration	Vertical acceleration of target at time (T) in feet per second per second

of the target. The parameters that describe the initial radar-target geometry, discussed in a subsequent section, assume their given values on the time specified on the first card in the target motion table.

The target motion for the airborne-radar/missile-target problem is described by a deck of 41 cards using the format in Table 2-1. The actual table is printed in the first part of the program output discussed in Chapter IV and will therefore not be repeated here. It describes, however, 40 seconds of the flight of a ballistic missile that reaches an altitude, in this time, of 24,000 feet and a horizontal range, from the launch point, of 10,000 feet.

The values for targets other than a surface-launched ballistic missile are easily prepared. For a target that does not move during the engagement, the simplest case, only two cards are required: the first at time zero and the second at the maximum duration of the problem. Both cards would have the desired range and altitude values with the velocity and acceleration values equal to zero. On the other extreme a rapidly moving target could be simulated which could not possibly be achieved by a practical target.

The only restriction which this procedure has is that the target motion is restricted to a vertical plane. For missile targets whose trajectories are often in a plane this is not a problem but it may be for aircraft targets. For example, in the present version of the program an aircraft target cannot turn or bank. It may, however, dive or rise in a flight plan confined to a vertical plane.

2.2 Target Radar Cross Section

The radar cross section of a target is a term that relates the power density reflected from a target to the incident power density from the radar and is defined as follows.[1]

$$\sigma = 4\pi \frac{\text{Power delivered per unit solid angle in the direction of the radar}}{\text{Power per unit area incident on the target}}$$

The value of the radar cross section varies as a function of the orientation of the target with respect to the radar, the polarization of the radar, the radar wavelength, and the conductivity of the target's surface. In this program the radar cross section of the target at the desired radar wavelength is required and is fed into the computer on a deck of cards.

General Description. The deck of cards contains the radar cross section of the target as a function of the aspect angle, for both vertical and horizontal polarization. The aspect angle is defined as the angle between the imaginary line connecting the radar to the target and the center line through the target. For both missiles and aircraft the center line runs from nose to tail with the nose-on aspect angle taken as zero. The range of aspect angles covered are from 0 to 180 degrees. For symmetrical targets the cross section values for the aspect angles between 180 and 360 degrees are the same as the values for the corresponding angles between 0 to 180 degrees.

---

[1] R. S. Berkowitz, ed., Modern Radar (New York: John Wiley and Sons, 1966), pg. 549.

The radar cross section table is stored in the computer and is used by the processing part of the Radar Analysis Program every time a cross section value is desired for a particular aspect angle. This will be discussed further in the next chapter.

Airborne-radar/missile-target example. The radar cross section deck for the airborne-radar/missile-target example is partially shown in Table 2-2 indicating the format arrangement. The complete table is given in Chapter IV; it was prepared especially for this report and does not represent the cross section characteristics of a known missile. The values of the cross section table were plotted in Figure 2-1 to show the general characteristics of the target. The fine detail of the cross section is not shown in this figure because it was plotted in increments of three degrees. As shown in Table 2-2 the actual cross section data are fed into the program in .1-degree increments over aspect angles from 0 to 180° for vertical and horizontal polarizations.

This type of data is available from the Radar Target Scattering Range (RAT SCAT)[a], Holloman Air Force Base, New Mexico. At RAT SCAT the radar cross section of various targets and target models is measured for any frequency from 150 to 12,000 MHz at arbitrary polarizations. A program was developed to edit the RAT SCAT data (on punched paper tape or magnetic tape) and convert it to a deck of cards for direct input to the Radar Analysis Program.

[a] H. C. Marlow, et al.,"The RAT SCAT Cross-Section Facility," Proceedings of the IEEE, Vol. 53, No. 8, Special Issue on Radar Reflectivity, (August 1965), pp. 946-954.

Table 2-2

EXAMPLE OF RADAR CROSS SECTION INPUT CARDS

	Aspect angle α, in degrees	Cross section values in dB above one square meter											
		Polarization (Horizontal = H, Vertical = V)											
		H	V	H	V	H	V	H	V	H	V	H	V
*	0.	4.5	5.4	4.5	5.5	4.4	5.6	4.4	5.6	4.3	5.7	4.1	5.8
*	0.6	4.0	5.8	3.8	5.8	3.6	5.9	3.3	5.8	3.0	5.8	2.6	5.9
	Aspect angle	α		$\alpha + .1$		$\alpha + .2$		$\alpha + .3$		$\alpha + .4$		$\alpha + .5$	

*First two cards in radar cross section deck

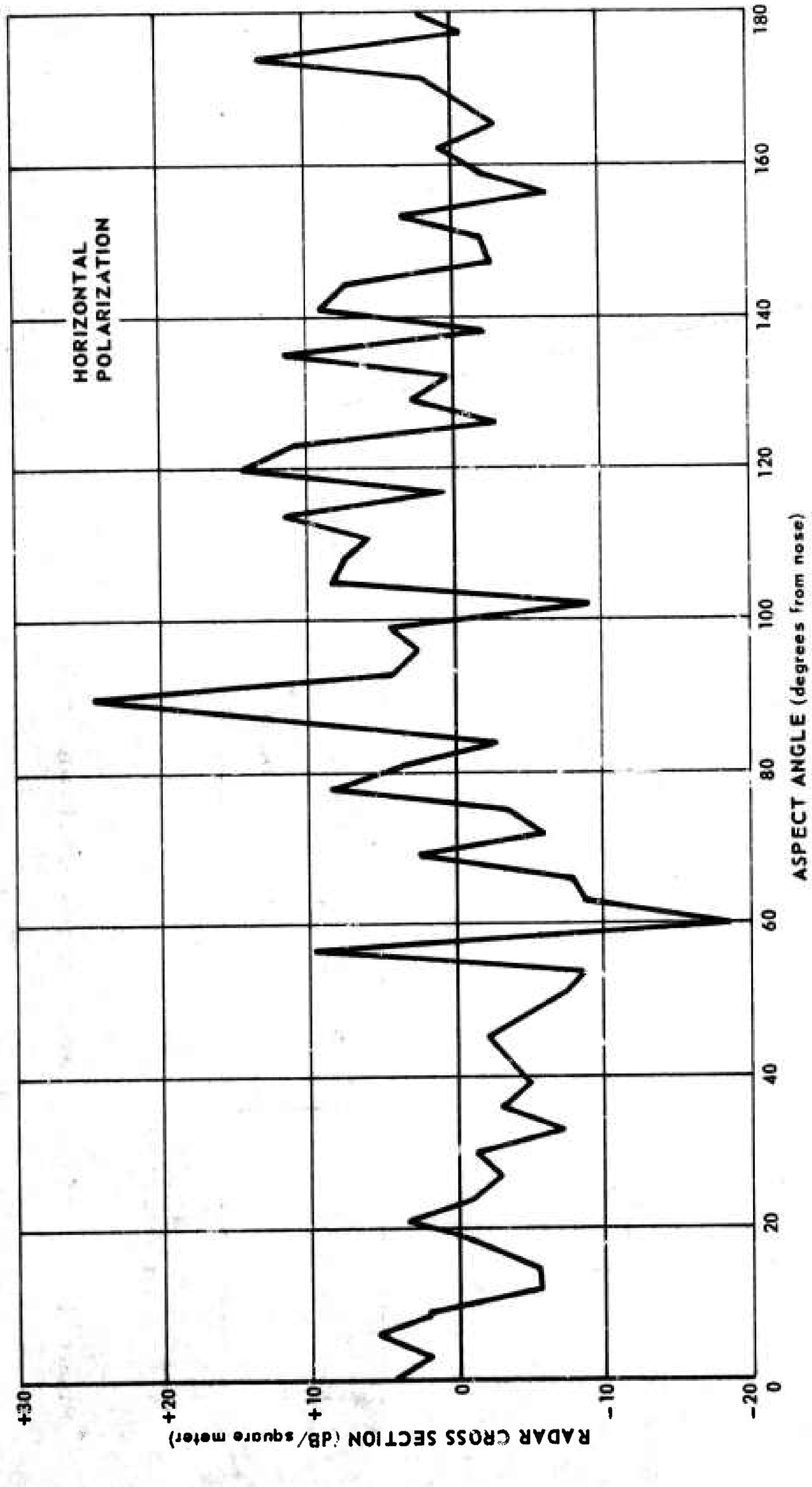

Fig. 2-1 RADAR CROSS SECTION OF THE TARGET MISSILE VERSUS ASPECT ANGLE

Other Targets. The cross section of targets other than missiles are described in the same way with certain limitations. For an aircraft, for example, the cross section as a function of azimuthal aspect angles for both horizontal and vertical polarization is not enough to completely describe the target. This is because the cross section is different for different angles off the plane of the wings. This is not the case for missiles (neglecting the effect of fins) and other targets that are basically symmetrical about their longitudinal axis.

The radar cross section input technique for simple targets like a sphere, whose cross section is constant as a function of aspect angle, is accomplished by entering the same cross section value for zero degrees aspect angle and for 180 degrees. The interpolating routine associated with the part of the program that "looks-up" this table will then choose this constant cross section value for all aspect angles. This same technique can be used to describe a target whose cross section is constant (or can be assumed constant) over a limited azimuth sector changing from sector to sector as desired.

2.3 Input Parameter Cards

Following the target motion and the target cross section decks is a set of 43 input parameter cards. These cards contain the values of the parameters that describe the initial radar-to-target geometry, the characteristics of the radar, the clutter and noise parameters, and the program options; these parameters are described in the following sections.

The parameters are arranged one to a card which includes the parameter number, the FORTRAN symbol, the value, the conversion factor, and the definition. All cards are printed in the first part of the output as shown in Chapter IV. Parameters that are given a value of zero can be omitted from the input parameter deck.

2.3.1 Initial Radar-to-Target Geometry

The initial geometry input parameters specify the distances and angles between the radar and target at the start of the engagement, and the velocity vector for the radar motion during the remainder of the engagement. The geometry is shown in Figure 2-2. The parameters shown are defined in Table 2-3 with values for the airborne-radar/missile-target example.

As indicated in Table 2-3 the parameters for the airborne-radar/missile-target example describe a radar in an aircraft that is flying at an altitude of 30,000 feet in level flight. The target motion throughout the engagement is confined to a plane which is positioned at an azimuthal angle of 30° with the reference.

The changes required in the geometric values of the input parameters for problems other than the airborne-radar/missile-target problem are apparent. If the radar were on a ship, for example, the altitude ZLOIT would be reduced to zero and the velocity VVA reduced to say 70 feet per second. The other angles and distances could be changed as desired. Note, however, that in all cases the target motion (described in Section 2.1) throughout the remainder of the problem is confined to a vertical plane, which is not a limitation for most problems.

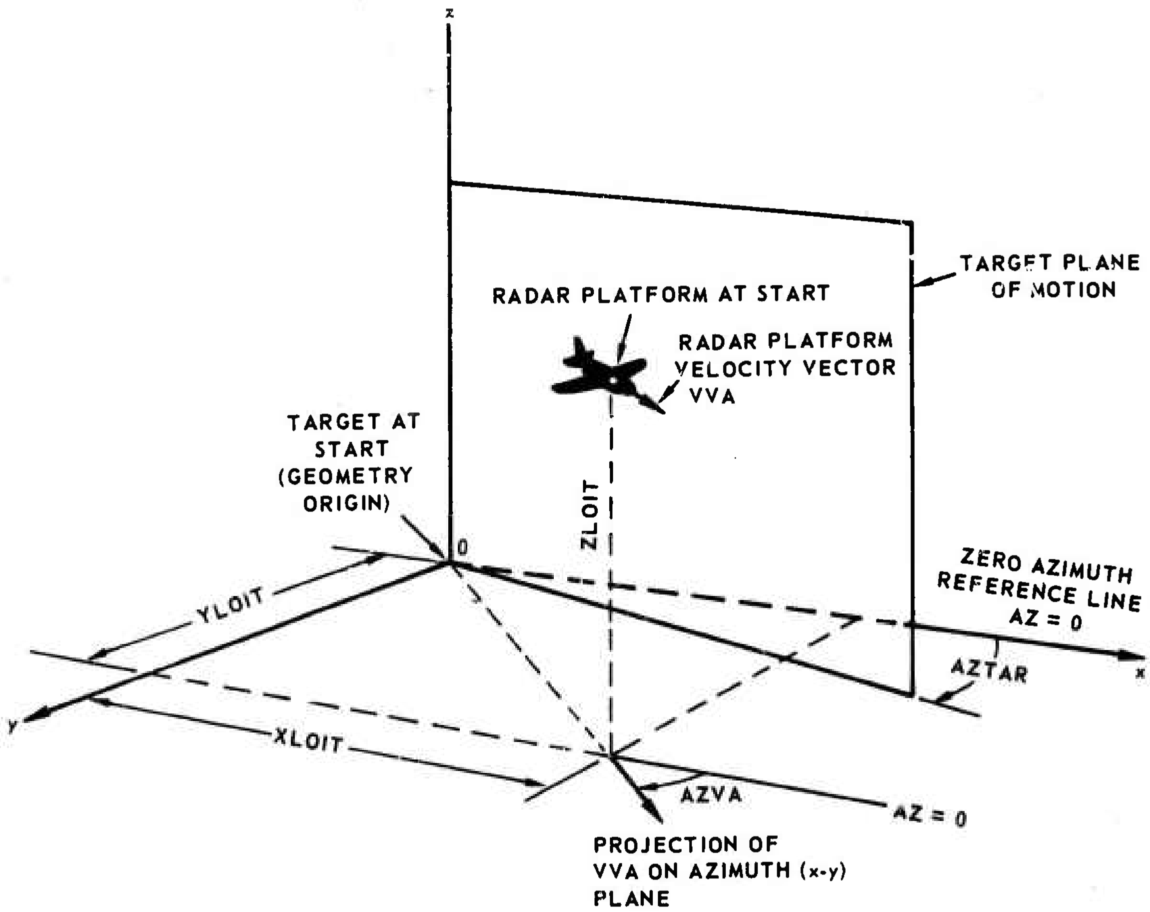

Fig. 2-2 INITIAL RADAR-TARGET GEOMETRY

Table 2-3

INITIAL RADAR-TO-TARGET GEOMETRY

INPUT PARAMETERS

PARAMETER	DEFINITION	EXAMPLE VALUE
XLOIT	Distance between radar and target along azimuth reference line, in nautical miles	30 nm
YLOIT	Distance between radar and target, perpendicular to azimuth reference line, in nautical miles	30 nm
ZLOIT	Altitude of radar, in feet	30,000 ft
AZTAR	Angle between target plane of motion and zero-azimuth reference line, in degrees	30°
VVA	Velocity vector of radar platform at start and throughout engagement, in feet per second	700 fps
ELVA	Elevation angle of VVA, in degrees	0°
AZVA	Azimuth angle of VVA, in degrees	60°
OLDK	Switch, 0 or 1, multiplying VVA	1

2.3.2 Radar Characteristics

The radar characteristics are fed into the program on input cards, one parameter to a card, and can be grouped into search radar and track radar parameters.

Search Radar. The search radar parameters are listed in Table 2-4 with descriptions and example values. These values will be used in the airborne-radar/missile-target example but are otherwise completely arbitrary. As listed these parameters describe a 5000 MHz (C-band) radar, radiating 500 kilowatts of power in pulses that are 10 microseconds wide and occur at a repetition rate of 1000 per second. Pulse compression is used with a time bandwidth product of 100. This indicates that the 10 microsecond transmit pulse will be compressed with a receiver that is matched to the code within the transmit pulse, to a pulse that is .1 microsecond wide. The system loss factor is listed as .1 (-10 dB) and includes atmospheric loss, radar-line loss, beam-shape loss, and scanning loss.[3]

The remaining search parameters describe the antenna and its scanning characteristics. A vertically polarized antenna was chosen which is 5.6-feet square (generating a 2° pencil beam) with an average sidelobe level of 30 dB below the mainlobe gain. The antenna beam will be scanning 26.6° sector in azimuth and a 30° sector in elevation, in one second. The time to scan the sector, HTSS, is the program clock and will specify the increment of time at which the radar calculations are performed by the program.

---

[3] D. K. Barton, Radar System Analysis (Englewood Cliffs: Prentice-Hall, Inc., 1964), p. 140.

Table 2-4

SEARCH-RADAR INPUT PARAMETERS

PARAMETER	DESCRIPTION	EXAMPLE
FMC	Radar frequency in megacycles	5000 MHz
PPEAK	Peak power in megawatts	.5 Mw
TDWELL	Width of transmit pulse in microseconds	10 μs
FR	Pulse repetition frequency in Hz	1000 Hz
FNOISE	Receiver noise figure	3 (5 dB)
SYSLF	System loss factor	.1
PCN	Pulse compression ratio	100
POL	Antenna polarization; one for horizontal and 0 for vertical*	1
HAPER	Horizontal aperture of antenna in feet	5.6 ft
VAPER	Vertical aperture of antenna in feet	5.6 ft
AAPEFF	Antenna aperture efficiency	.65
ETA	Sidelobe to mainlobe antenna gain ratio in decimal form	.001
XIHDEL	Azimuth search sector in degrees	26.6°
XIVDEL	Elevation search sector in degrees	30°
HTSS	Time to scan the sector; also the time increment between all calculations	1 sec

*POL = 0. actually indicates that the antenna polarization vector is parallel with the plane of target rotation, and POL = 1 when the polarization vector is perpendicular to the plane of rotation. Therefore for a ballistic missile and a vertically polarized radar POL = 0, while for an aircraft target and a vertically polarized radar POL = 1.

The search radar parameters will be used in the standard radar equation for calculation of the signal-to-noise ratio. The parameters may be modified to calculate the performance of radars with modulations different from the pulse radar depicted here.[4] For example, when analyzing a CW (continuous-wave) radar the peak power PPEAK is equal to the average power; the pulse width TDWELL is equal to the time the beam remains on the target; and the pulse repetition frequency FR is adjusted to make the number of pulses that hit the target equal to one.

Track Radar. The track radar input parameters for the Radar Analysis Program are listed in Table 2-5. These parameters are used to calculate the angle tracking accuracies according to equations by Barton.[5] The parameters are discussed completely in Barton[6] for monopulse and conical scan trackers. The values of the parameters indicated in Table 2-5 in the example column are for a monopulse tracking radar.

2.3.3 Clutter and Noise Parameters

The clutter and noise input parameters are required to determine the method for calculating the amplitude of the clutter and the detection theory to be used in calculating the probability of detection. The six input parameters, with a brief description and example values for the airborne-radar/missile-target example,

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[4] J. J. Bussgang, et al., "A Unified Analysis of Range Performance of CW, Pulse, and Pulse Doppler Radar," Proceedings of the IRE, Vol. 47, (October 1959), pp. 1753-1762.

[5] Barton, op. cit., p. 279.

[6] Ibid., pp. 263-315.

Table 2-5

TRACK-RADAR INPUT PARAMETERS

PARAMETER	DESCRIPTION	EXAMPLE
FNTRK	Track system factor; corrects for detector and type of tracker; Monopulse (coherent det) = 1 Monopulse (sq. law det) = 2 Conical scan (linear) = 2 Silent lobing (coherent) = 2 Silent lobing (sq. law) = 4	2.
CRL	Beam cross-over loss factor; equals 1 except for conical scan linear detector in which case it equals 2.	1.
BNSR	Nominal noise bandwidth of angular circuits; $\sqrt{b_n}$	1.
FKS	Normalized slope factor; 1.57 for monopulse	1.57
B1	Box car bandwidth, cps; PRF for pulse system; bandwidth of doppler filter for pulse doppler system	1000.
ATETS	Angular tracking error due to target motion, in milliradians	.5
ATEPS	Angular tracking error due to platform motion, in milliradians	.5
ATEOS	Angular tracking error due to other causes, in milliradians	.5

are given in Table 2-6.

The quantity σ_o listed in Table 2-6 is defined as the normalized clutter cross section and is equal to the radar cross section of the clutter medium per unit area intercepted by the antenna beam. A description of σ_o can be found in Skolnik[7] which includes representative values for different surfaces. A more detailed treatment of radar backscatter from land, sea, or atmosphere can be found in the classified literature.[8]

The selection or specification of the clutter and noise parameters for any given case is best described with the aid of Figure 2-3. A flow chart is shown with a box for each of the six parameters; the double lines between boxes indicate the path taken by the airborne-radar/missile-target example. The time between false alarms TAUFA is specified first. An option for determining the value of σ_o is then reached. Three options are available: σ_o is zero, that is, there is no clutter; σ_o is given, in which case a value is selected; or σ_o is to be calculated internally. In this latter case the sea state (if in fact the operation is taking place over the sea) is specified and the value of σ_o is calculated with an empirical equation based on the sea state, angle of incidence of the radar energy to the surface of the sea, and the radar polarization.

(Rain clutter, which is added to receiver noise, can be included by means of the last two parameters in Table 2-6.)

---

[7] M. I. Skolnik, Introduction to Radar Systems (New York: McGraw-Hill Book Company, Inc., 1962), p. 523.

[8] F. E. Nathanson, ed., "Report of Radar Clutter Signal Processing Committee: Part I, Radar Clutter Effects (U)," TG 842-1, The Johns Hopkins University Applied Physics Laboratory, September 1966, CONFIDENTIAL.

Table 2-6

CLUTTER AND NOISE INPUT PARAMETERS

PARAMETER	DESCRIPTION	EXAMPLE
TAUFA	False alarm time in seconds	10 sec
SIGOPT	σ_o calculation option: -1 = no clutter 0 = calculate σ_o 1 = given as SIGZ	0
SIGZ	Value of σ_o in dB when SIGOPT = 1	-
SEA	Sea state: 1 = rough sea (Beaufort state 5, 10 ft wave height) 0 = calm sea (Beaufort .5, 1 ft wave height)	1
FDMS	Frequency diversity: 1 = Use Marcum and Swerling 0 = Use Shotland theory	1
CASE	Swerling target case designation: 0 = nonfluctuating target 1 = scan-to-scan fluctuation with many nulls 2 = pulse-to-pulse fluctuation with many nulls 3 = scan-to-scan fluctuation with a few nulls 4 = pulse-to-pulse fluctuation with few nulls	4
RAIN	For rain clutter at the target RAIN = 1. Otherwise equals zero.	0
SUMSIG	Backscatter coefficient $\Sigma\sigma$ in meter^2/meter^3 in decibels. (See Skolnik, p. 539)	-

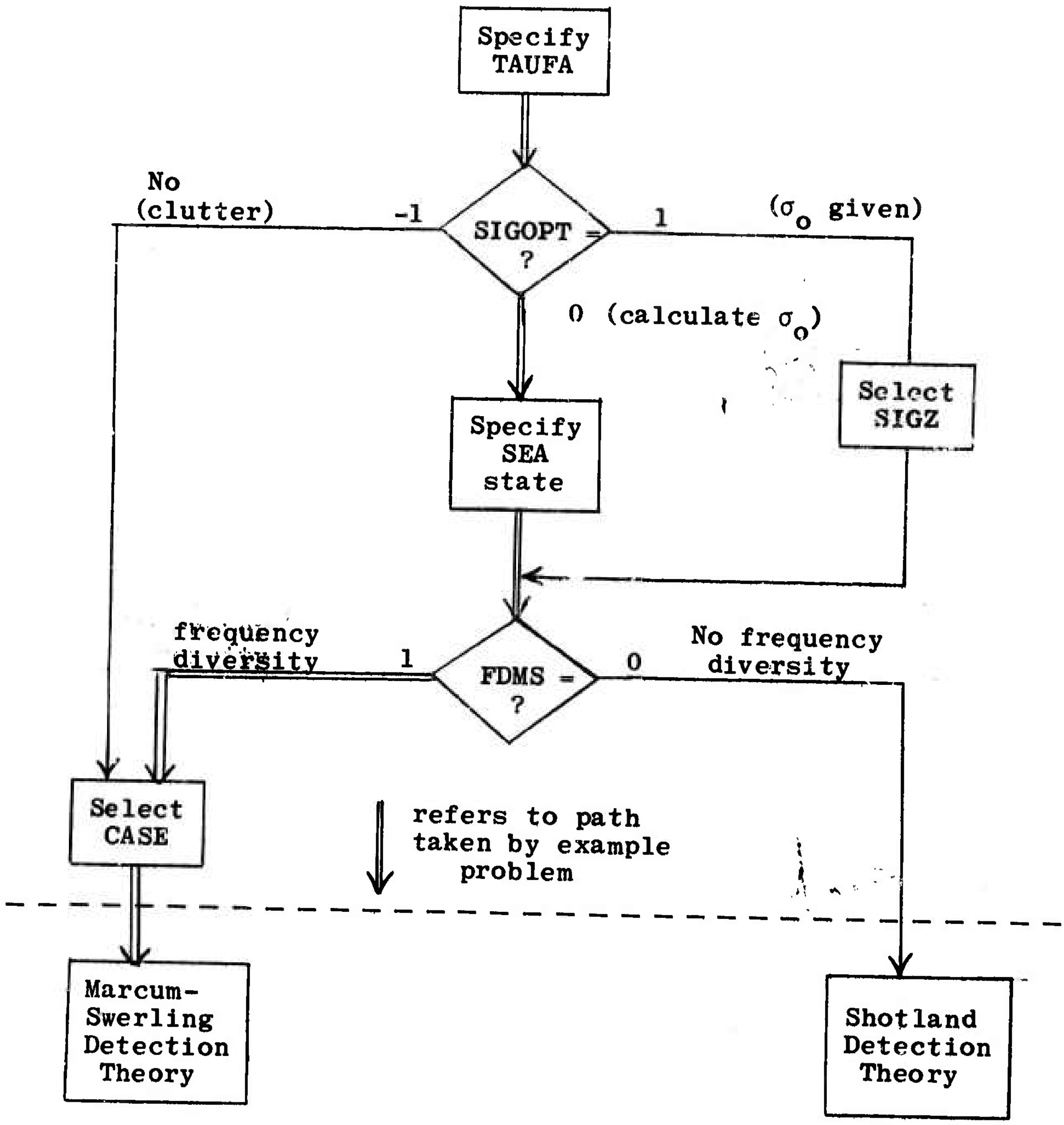

Figure 2-3

FLOW CHART FOR SELECTION OF CLUTTER AND NOISE INPUT PARAMETERS

The FDMS option is now reached which determines whether the Marcum-Swerling theory or the Shotland theory is to be used. In essence the parameter FDMS is not an option but a radar parameter that describes whether frequency diversity, i.e., frequency jumping from pulse-to-pulse, is used or not. If frequency diversity is used then the clutter is considered random from pulse-to-pulse[9] and Marcum-Swerling detection theory is used. If the radar does not use frequency diversity then the clutter is not random from pulse-to-pulse which means that the Shotland detection theory must be used. Note that if there is no clutter, SIGOPT = -1, then the FDMS option is bypassed and Marcum-Swerling theory is used in calculating the detection probability.

2.3.4 Program Options

There are two options for operating the Radar Analysis Program which are selected by means of the TARGOP parameter listed in Table 2-7.

Time Simulation (Primary Option). The primary option starts from TSTART and ends at TSTOP and runs as a time simulation of the radar-target engagement. Calculations of the radar detection probabilities and other performance characteristics, are made every time the antenna scans past the target. This mode is selected when the option TARGOP is equal to zero or some negative value.

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[9] V. W. Pidgeon, "Time, Frequency, and Spatial Correlation of Radar Sea Return," A Technical Note for Use of Space Systems for Planetary Geology and Geophysics, The American Astronautical Society, May 1967.

Table 2-7

INPUT PARAMETERS FOR PROGRAM OPTIONS

PARAMETER	DESCRIPTION	EXAMPLE
TSTART	Program starting time in seconds relative to zero time on the target motion input	0 secs
TSTOP	Program stopping time in seconds relative to zero time on the target motion input	39 secs
TARGOP	Program option: -x or 0 = Time simulation +R = Range profiles where R is the range increment	0 (2 n.m. in 2nd run)
BXLOIT	Maximum range value for performing calculations in the range profile option	78 n.m. (in 2nd run)
XLOIT	Minimum range value for calculations in the range profile option	30 n.m. (zero n.m. in 2nd run)

Range Profile (Secondary Option). The inputs described to this point are those required for the time simulation option. However, the program can also be used for plotting the radar performance versus range for a stationary, constant-cross-section target by simply specifying TARGOP as +R. For a stationary target with a constant cross section the two input decks are greatly simplified: the target-motion input deck is reduced to one card indicating the desired altitude, and the cross section input deck is reduced to one card indicating the desired cross section. The program then calculates the detection probability and other parameters as a function of range in increments of R. These calculations versus range are called range profiles and will be discussed further in Chapter IV.

Deck Arrangement. The input-deck arrangement for running the example problems discussed in this chapter is listed in Table 2-8. Two runs are made: (1) the airborne-radar/missile-target example in a full time simulation mode, and (2) the airborne radar versus a stationary target in a range profile run. The items listed in Table 2-8 were discussed in this chapter except for the control cards and cover cards. The control cards include the computer job cards and loading cards. The cover cards are associated with the data. There is a target-deck cover card which indicates the target name, number of cards, and the time increment. The cross section deck has both cover and trailer cards. The former indicating the name of the target and the increment of the aspect angle; the latter indicating the end of the cross section deck.

Table 2-8

ARRANGEMENT OF INPUT DECKS
FOR MULTIPLE RUNS

Description of Cards	Approximate Number of Cards
Control cards	3
Program	-
Data (Time simulation run)	
Target Motion Deck	42
Cross Section Deck	300
Input Parameters	43
Run 1 End	1
Run 2 Leader (Range Profile Run)	1
Stationary Target Card	2
Cross Section Card	3
Input Parameters Different from Run 1	3
End	

2.4 Summary

The input cards to the Radar Analysis Program have been described in some detail. The target motion in a vertical plane throughout the engagement and the target's radar cross section versus aspect angle are described on cards to practically any degree of detail. For the example problem studied here the target motion deck comprised of 41 cards describes a missile launched from the ground and reaching an altitude of 24,000 feet in 40 seconds. The target's radar cross section is described on 300 cards with values every .1 degree for aspect angles from 0 to 180° for vertical and horizontal polarization. The cross section values vary over 50 dB from -25 dB to +25 dB relative to one square meter.

The 43 input parameter cards describe the initial positions of the radar and target, the radar parameters, the clutter and noise parameters, and the program mode options. For the example problem these parameters describe an airplane flying at an altitude of 30,000 feet away from a missile launched, essentially straight up, at an initial range of 43 nautical miles. The radar in the airplane has an antenna 5.6 feet on a side operating at a frequency of 5000 MHz, radiating 500 kilowatts of power in a 10 μs pulse. The radar employs pulse compression and frequency jumping from pulse-to-pulse to reduce the effects of clutter contributed by a rough sea. The antenna is scanning a sector 26.6° in azimuth and 30° in elevation, centered on the target, in one second.

The calculations performed on these inputs will be described in the next chapter. The resulting outputs are discussed in Chapter IV.

III. PROCESSING

The processing part of the Radar Analysis Program includes those calculations and analytical models required to determine target cross section characteristics versus time, detection probabilities, time required for detection, tracking accuracies, and search accuracies. The calculations have been divided into three groups for purposes of discussion: geometry calculations, radar calculations, and detection calculations. These three blocks of calculations are shown in Figure 3-1, the Radar-Analysis-Program flow diagram, which is discussed next.

3.1 Flow Diagram

The simplified flow diagram, Figure 3-1, indicates the general calculating procedure for the time simulation or main mode of operation. The range-profile mode of operation is a special case and can also be described with the aid of Figure 3-1.

Time Simulation. The main mode of operation reads the input cards described in Chapter II, stores this information, and prints it out. The geometry calculations are performed next at time TSTART. In these calculations the target-motion input deck and the initial radar-to-target geometry parameters are used to calculate the ranges, angles, and range rates between the radar, target, and other points of interest. The aspect angle determined in this set of calculations allows the cross section of the target to be determined by looking up the value

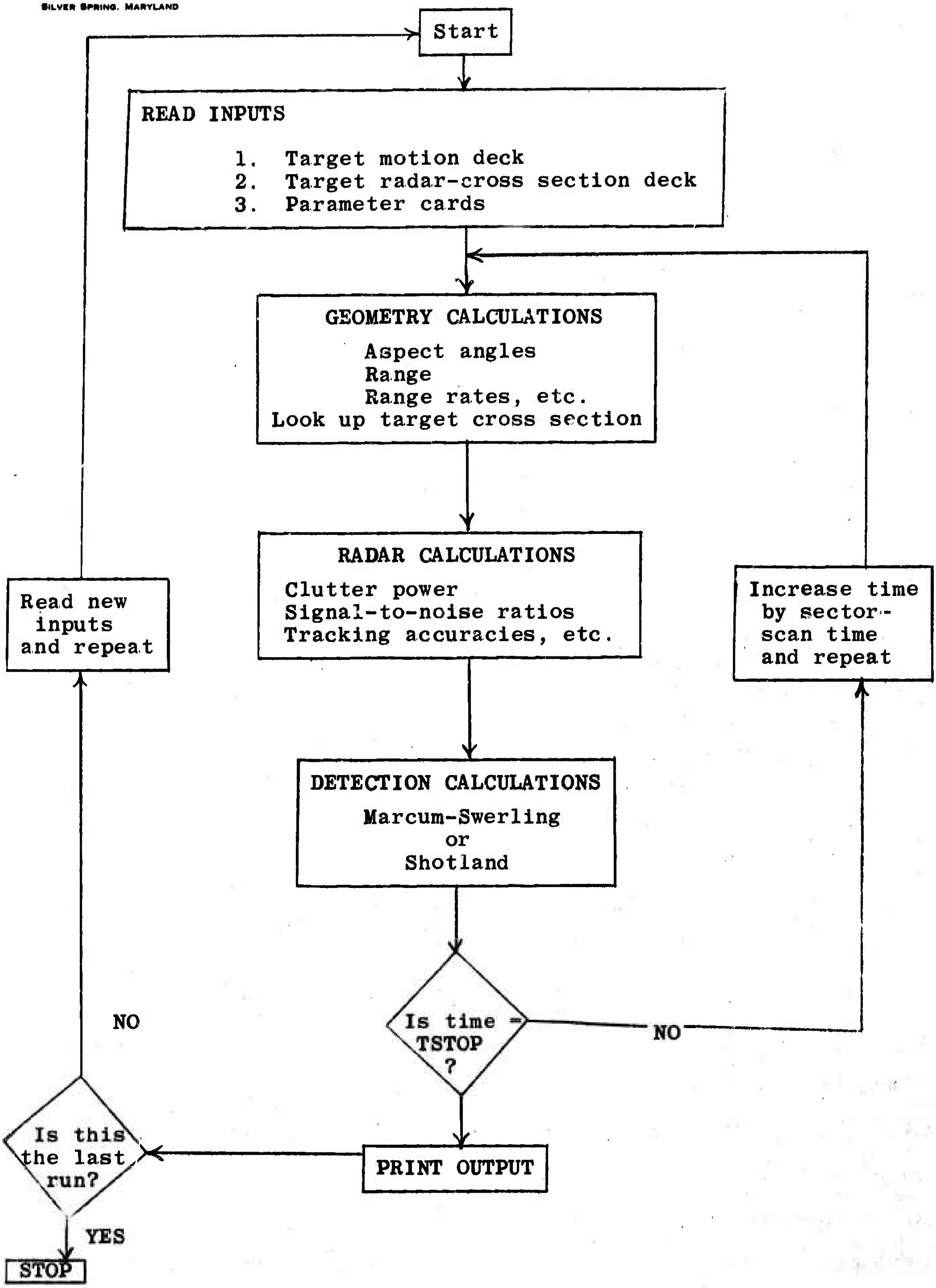

Figure 3-1
RADAR ANALYSIS PROGRAM FLOW DIAGRAM

in the radar-cross-section input table. These geometry and cross-section values are used in the next set of calculations, called radar in Figure 3-1, to determine the signal-to-noise ratios and the tracking accuracies (to name a few). The signal-to-noise ratio and the clutter and noise input parameters are then used in the detection calculations for finding the single-scan detection probabilities.

The time step of this set of calculations is then compared with the last time for calculations, TSTOP. If TSTOP has not been reached the time variable is increased by the increment of time required to scan a sector, HTSS, and the calculations are repeated. When TSTOP is finally reached the output is printed signifying the end of one run. Then if a new set of input parameters exists in the deck they are read and the entire processing operation is repeated.

Range Profiles. If the range profile option is selected, by specifying TARGOP as +R, the processing operation is somewhat simplified and the format of the output is different. Referring to Figure 3-1, the input is read as before except now the target-motion deck and the cross-section deck consist of only one card each. The parameter cards are essentially the same as for the time simulation except that the parameter TARGOP equals +R. (Those input parameters which do not apply to the range-profile case, such as TSTART and TSTOP, need not be changed or omitted since they are automatically avoided by the program.) This set of inputs, as described in Chapter II, specify a target whose altitude is constant, and whose cross section is constant and independent of aspect angle.

The processing for the range-profile option omits most of the geometry calculations and performs the radar and detection calculations as a function of range. Instead of the comparison of time with TSTOP as shown in Figure 3-1 the range-profile processing compares the range with the maximum specified range BXLOIT. If the range is smaller than BXLOIT it is incremented by +R and the calculations are repeated. If the range equals BXLOIT the run is printed out and the next run is processed.

Subroutines. The overall processing as described above is controlled by the main program. All the calculations are performed by subroutines. When the calculations are completed control is returned to the main program. The main program is then used for printing and plotting the output data.

There are two subroutines that are associated with the main program that do not perform calculations. These are TARGIN and CROSIN which are used in the first block shown in Figure 3-1 to read in the target-motion and cross-section input decks. They also are responsible for printing out this input data in the first part of the output. The main program and the subroutines are given in their FORTRAN II language in the Appendix B. The first page of Appendix B lists the parts of the program in the order called.

The actual calculations performed will be discussed in the next three sections. The final form of the output can be found in Chapter IV.

3.2 Geometry Calculations

The geometry calculations are performed by the subroutine GEOM and its associated subroutines: TARGET, AIRCFT, five vector subroutines, and RATSCT. (See Appendix B, Section 2.0, for a listing of these subroutines.)

The geometry subroutine is called by the main program each increment of time to solve the geometry illustrated in Figure 3-2. The geometry, as indicated, is solved in three dimensions over a spherical earth.[1]

Four points in space are involved in the calculations: the radar location, the target location, the point of reflection on the earth's surface, and the clutter spot. The procedure involved in calculating the pertinent ranges, range rates, and angles between these points is as follows. The target position and velocity at the time of interest are gotten from the target-motion input table, using interpolation if required; this is performed by subroutine TARGET. The radar position at the calculating time is determined by the subroutine AIRCFT, which determines the distance traveled due to the input velocity VVA specified for the radar platform. Then the ranges, range rates, and angles connecting the radar and target can be computed. They

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[1] A 4/3 earth radius is used to account for refraction.

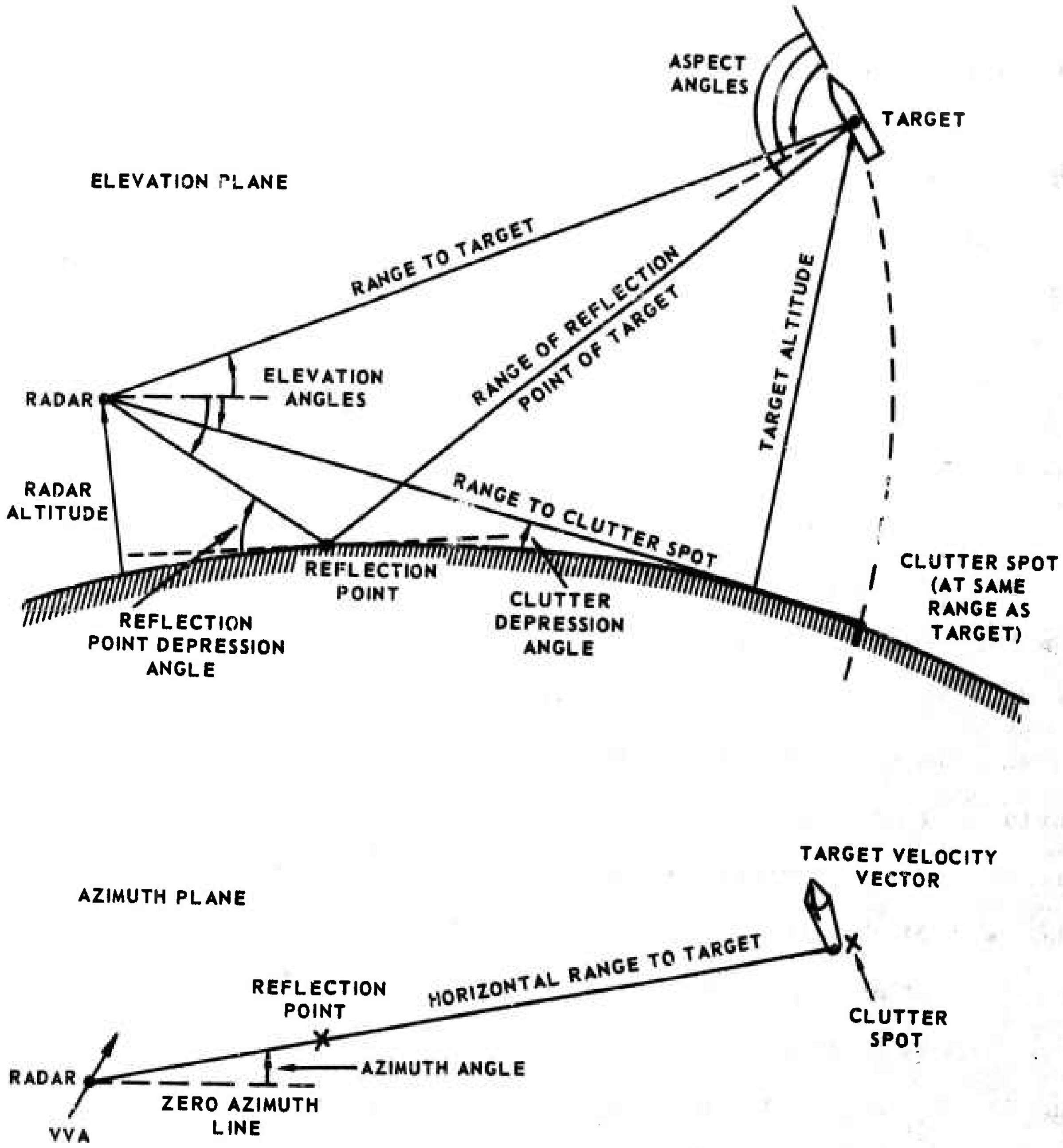

Fig. 3–2 RADAR-TO-TARGET GEOMETRY

are computed using subroutines for each of the vector operations involved; namely, finding the cross product between two vectors (CROSS), finding the dot product between two vectors (DOT), reducing a vector to its unit vector and magnitude (UNIT), multiplying a vector by a scalar (MULT), finding the angle of a vector given the sine and cosine (ANGLE), and finding the elevation and azimuth angle of a vector with reference to a given coordinate system (TRIAD).

The same procedure is used to find the ranges, range rates, and angles between the radar and the reflection point, and the radar and the clutter spot. The reflection point, located at the surface of the earth, comes into play when the radar's antenna is broad enough to permit energy to be reflected off the surface of the earth and up to the target. Two types of reflections are considered: single bounce, where the radar energy follows the reflected path to the target and the direct path back, and double bounce, where the energy travels the reflected path to and from the target. The clutter spot is simply the point on the surface at a range equal to the range to the target.

The aspect angles, also shown in Figure 3-2, are calculated by the geometry subroutine and are used directly in finding the target's cross section at this instant of time. Subroutine RATSCT is used to look up the cross section table. The cross section value selected is the value opposite the closest angle to the desired angle.

There are a total of 31 parameters (many with three components) which are calculated and stored by the geometry subroutine. However, at the present time only the most important ones are printed as described in Chapter IV on output.

3.3 Radar Calculations

The radar calculations are performed each time step by subroutine DAVE following the execution of the geometry subroutine. These calculations will be briefly described here with the details being available in Section 3.0 of Appendix B.

Antenna. The physical size of the antenna, the efficiency, and the radar frequency are used to calculate the antenna gain and the beamwidth. The value for the beamwidth is then used with the given values for the search sector and the time allowed to scan the sector to determine the scan rate. The scan rate is used with the given value for the pulse repetition period to calculate the number of pulses received from the target in one scan. The antenna gain and the number of received pulses per scan are prime parameters in the subsequent calculations of the signal power and the detection probability.

The antenna equations as they now exist can only be used for radars that use the same antenna for both transmit and receive. This, however, is the most common case.

Signal. The signal power is calculated with the standard range equation using the pertinent parameters supplied by the input cards. The signal power is determined for the direct signal from the radar to the target, the single bounce signal which takes one path to the target via a surface reflection, and the double bounce signal which reflects off the surface to and from the target. The appropriate antenna gain is used in each calculation. That is, in many cases the angle taken by the reflected-signal path is greater than the half-beamwidth of the antenna which puts it in the antenna's sidelobes. In this case the signal power for the single-bounce and double-bounce signals are reduced from the mainlobe signal by the given antenna sidelobe ratio (squared).

Clutter and Receiver-Noise Power. The signal power will be divided by the clutter and receiver-noise power to form the "signal-to-noise" ratio used in the detection-probability calculations. The receiver noise is calculated using the standard equation involving Boltzman's constant, the signal bandwidth, and the receiver noise figure; rain backscatter is added to receiver noise.

The clutter power, on the other hand, involves numerous parameters such as the antenna beamwidth and the geometrical quantities shown in Figure 3-3. The clutter power is calculated the same way as the target signal power, i.e., using the radar range equation, but using the clutter cross section instead of the target cross section. The clutter cross section is equal to the clutter area times the normalized clutter cross section σ_o, which was discussed in Chapter II.

As indicated in Figure 3-3 the clutter area to be used in the calculation depends on the range to the target. The reason for this is that the region on the earth's surface that must be

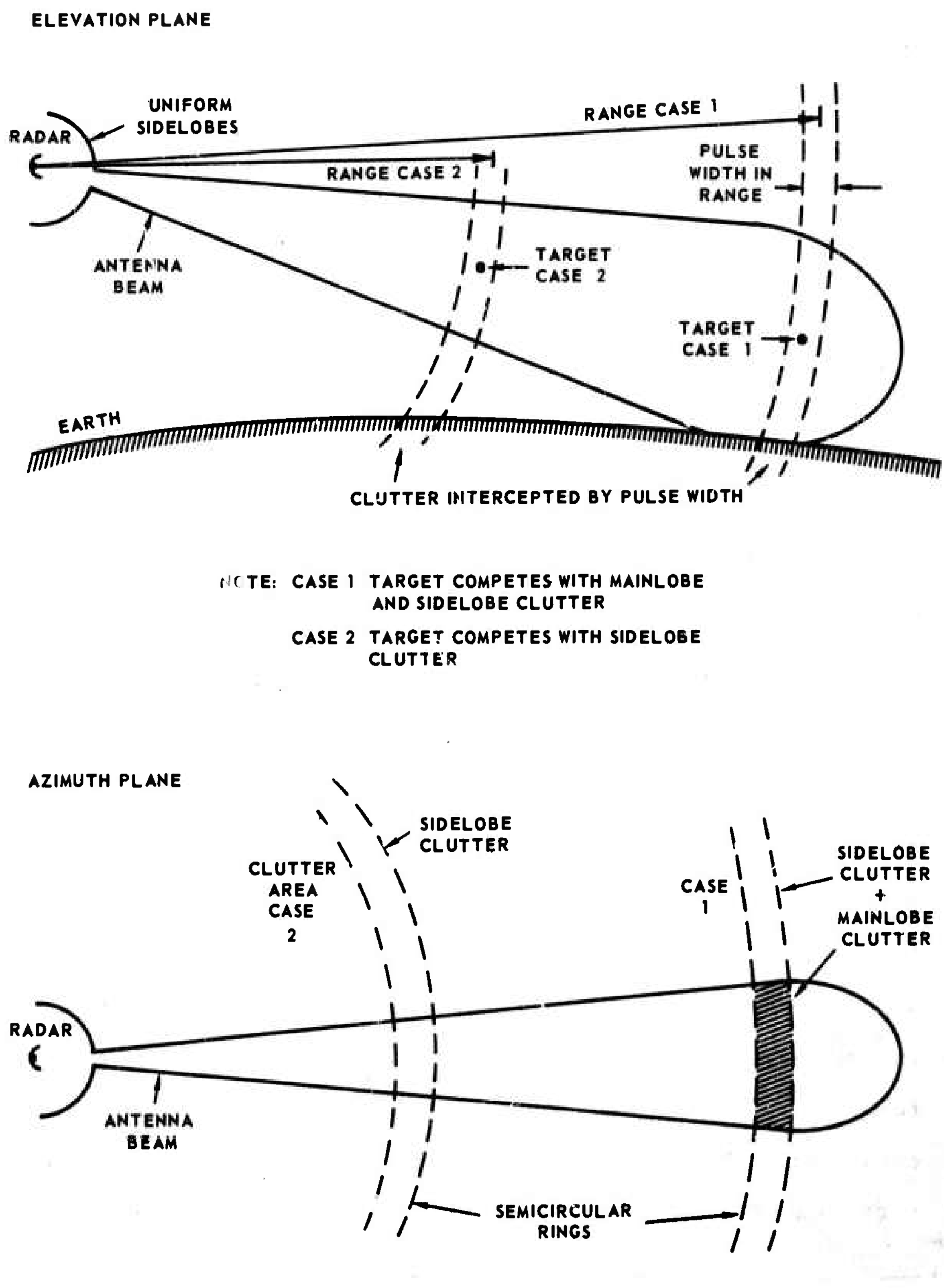

Fig. 3–3 CLUTTER AREA

used in calculating the clutter power is that region which is at the same range from the radar as the target. When the target is low in altitude and at a long range then the main beam intercepts both the target and the surface of the earth. In this instance, called Case 1 in Figure 3-3, the clutter area is made up of two pieces, one in the mainlobe of the antenna, the other in the sidelobe. In either case the clutter area is bounded by the pulse width in range.

When the target is close to the radar the clutter region may be at an elevation angle that is out of the main beam of the antenna, such as Case 2 in Figure 3-3. Even though the physical size of the clutter area for this case may be comparable to that of Case 1 the resultant clutter power received by the radar receiver is considerably reduced due to the low gain of the sidelobes.

<u>Accuracy Calculations</u>. The previous calculations can be combined to form the signal-to-noise ratio which is important in determining the radar's measurement accuracy as well as the detection probability. Once the target is detected the radar must determine the target's location, in range and angle, and its doppler velocity or range rate. Since the target echo exists in the presence of receiver noise or clutter the ability of the radar to extract the information is a problem in the statistical estimation of parameters. The general form of the error for measurements in range, range rate, or angle are of the form[a]

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[a] D. K. Barton, Radar System Analysis, (Englewood Cliffs: Prentice-Hall, Inc., 1964), pp. 38-63.

$$\text{error} = \frac{1}{\gamma\sqrt{\frac{2E}{N_o}}}$$

where E/N_o is equal to the signal-to-noise energy ratio which includes the observation time. The factor γ changes according to whether range, doppler velocity, or angle is being measured and according to other factors, such as the type of signal modulation. For the range measurement the γ factor is basically equal to the bandwidth of the signal; for doppler velocity it is equal to the length of the signal; for angle measurements it is equal to the inverse of the beamwidth.

Thus for accurate measurements of the three parameters it would be desirable to have a wide bandwidth signal, transmitted over a long time duration, and using an antenna with a very narrow beamwidth. In addition the signal-to-noise ratio must be high.

The mathematical form of the accuracy equation is the same for both the search accuracies and the tracking accuracies. The prime difference is that the tracking accuracies are usually better due to the longer time of the measurement. The search accuracies are naturally lower then the tracking accuracies since the time for measurement is short due to the finite time that the target remains in the scanning beam.

3.4 Detection Calculations

The detection problem was discussed briefly in Chapters I and II. It was indicated (See Figure 2-3) that two detection theories are used: Marcum-Swerling[3] and Shotland[4] theory. The Marcum-Swerling theory is a generalized theory for calculating the probability of detecting a target, with a fluctuating cross section, in the presence of receiver noise. It was put into a form, suitable for calculation by a digital computer, by Fehlner[5] and is incorporated in this program as subroutine MARCUM. The Shotland theory is an extension of the Marcum-Swerling theory to include the effect of clutter as an interfering noise source as well as receiver noise. The Shotland theory is programmed as subroutine EDDIE.

Generalized Detection Calculations. The basic parameters required to calculate the detection probability are the false-alarm time from the input cards, and the signal-to-noise ratio and number of received pulses per scan from the radar calculations. The detection of a target is a decision process and is based on establishing a threshold level at the output of the receiver. A target is assumed to be present if the signal out of the receiver is large enough to exceed the threshold. Occasionally noise alone will exceed the threshold generating a false alarm. The threshold level is calculated as a function of the noise power, the bandwidth,

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[3] J. I. Marcum and P. Swerling, "Studies of Target Detection by Pulsed Radar," IRE Transactions on Information Theory, vol. IT-6 (April, 1960).

[4] E. Shotland, "False Alarm Probabilities for Receiver Noise and Sea Clutter," JHU Applied Physics Laboratory, BBD-1387, October 27, 1964.

[5] L. F. Fehlner, "Marcum's and Swerling's Data on Target Detection by a Pulsed Radar," JHU Applied Physics Laboratory, TG-451, July 2, 1962.

and the number of pulses, to produce the false alarm time specified by the program input. The probability of detecting a target is then the probability that the target signal exceeds this predetermined threshold level which varies up or down according to the level of the noise power. The procedure for calculating the detection probabilities involves evaluating a series of incomplete Gamma functions, where each function is expressed as a series.[6]

Target and Clutter Statistics. The two detection theories provided in this program provide a fairly flexible arrangement for calculating the detection probability for targets and clutter with various statistical characteristics.

In the Marcum-Swerling theory incorporated in this program five target models may be specified.[7] The first, called Case 0, is a target with a constant cross section area. The targets in the other four cases have fluctuating cross sections. Case 1 and 2 targets have a Rayleigh amplitude distribution and apply to targets that can be represented as a number of independently fluctuating reflectors of about equal echoing area. Case 1 and 2 are often used for aircraft targets. Cases 3 and 4 apply to targets that can be represented as one large reflector with a number of small reflectors, such as a missile. Cases 1 and 3 apply for targets whose cross section fluctuates slowly, or with a period equal to the scan time. Cases 2 and 4 are for targets whose cross section fluctuates rapidly, i.e. from pulse-to-pulse.

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[6] Ibid., pp. 21-32.

[7] Marcum and Swerling, loc. cit.

Since the detection probability is higher for targets which fall in Cases 2 or 4 schemes are often devised to insure that the cross section fluctuates rapidly. One way of doing this is to employ frequency jumping which is accomplished by varying the transmitted frequency from pulse-to-pulse or within a pulse.

In the Shotland theory, as used in this program, both the target and the clutter are of the Case 1 variety, slowly fluctuating with Rayleigh amplitude distributions. The clutter does fluctuate somewhat faster than the target depending on the width of the clutter spectrum (calculated in the radar subroutine). Under these conditions, however, very large signal-to-noise ratios are required for detection. On the other hand, if frequency jumping is used with a sufficiently wide frequency range the target changes to a Case 2 or 4 target and in addition the clutter spectrum is widened causing the clutter to fluctuate randomly like receiver noise. Under these conditions the Marcum-Swerling theory can be used which will yield a much higher probability of detection.

3.5 Summary

The processing part of the program contains the calculations performed on the input data to ascertain the performance of the proposed radar in the given situation. The calculations are divided into three groups on geometry, radar, and detection.

As indicated in the program flow diagram the output for a particular run is stored in an array and is not printed until the calculations for that run are completed. This procedure has the advantage of assuring that all the results of calculations in one subroutine are available to other subroutines. In addition, it allows all of the output commands and formats to be placed in the main program.

The calculations and processing techniques discussed in this Chapter are used to produce the program output described in the next Chapter.

IV. PROGRAM OUTPUT

The results of the calculations discussed in Chapter III are provided as output in either a printed or digitally plotted format. The bulk of the output is printed by the main program, as previously mentioned, except for the target motion and cross section decks which are read and printed by separate subroutines. Two samples of the program output are included in this Chapter, one on the time simulation of the airborne-radar/missile-target example, proposed in Chapter II, and the other on the range profile for the same radar.

In review of the inputs proposed in Chapter II the airborne-radar/missile-target example to an airborne radar at an altitude of 30,000 feet and at a range of approximately 43 nautical miles (diagonal distance of 30 nautical miles on a square) from a ballistic missile launched from the surface. The radar operates at a nominal frequency of 5000 megacycles per second with a peak power of 500 kilowatts and employs frequency jumping from pulse-to-pulse. The ballistic missile flies in a vertical plane for 41 seconds reaching an altitude of 24,000 feet. The output of the program in the time simulation mode will cover 39 seconds of the engagement and will indicate the following: the success or failure of detecting the target, the length of time from missile launch required for detection, the accuracies of locating the target, etc.

For an example of the range profile option the target is assumed to be at a stationary altitude of 30,000 feet and have a constant cross section of .1 square meters. The range from the target is decreased in increments of 2 nautical miles from a range of 78 nautical miles with detection and radar calculations being made each increment. The single-scan detection probability and the signal-to-noise ratio are plotted versus range by the CALCOMP Plotter.

4.1 Time Simulation Example

The output for the time simulation of the airborne-radar/missile-target example is divided into four parts for discussion purposes. The first part is a listing of the input data. The remaining three parts give the output data arranged according to computed constants, geometry calculations, and radar and detection calculations.

4.1.1 Input Data

The data inputs are printed out in three parts: target motion deck, target cross section deck, and input parameter cards. The target motion for the ballistic missile is reproduced in Table 4-1. The cross section of the ballistic missile is given in Table 4-2. The cross section values are listed in decibels above a one square meter reference, for angles between 0 and 36.6 degrees.[1] The values are arranged in the format previously described in Table 2-2.

[1] Remainder of table to 180° aspect angle not shown.

Table 4-1

PROGRAM OUTPUT: TARGET-MOTION INPUT

EXAMPLE TARG BOOST TRAJECTORY COORDINATES

		DOWN RANGE			ALTITUDE		
CARD	TIME	POSITION	SPEED	ACCELERATION	POSITION	SPEED	ACCELERATION
1	0.	0.	0.	0.	0.	0.	25.66
2	1.	0.	0.	0.	13.0	25.9	26.14
3	2.	0.	-0.	0.01	5[illegible].0	52.3	26.59
4	3.	0.	-0.	0.02	11[illegible].0	79.1	27.01
5	4.	0.	0.1	0.03	210.0	106.3	27.40
6	5.	0.	0.1	0.03	330.0	133.8	27.74
7	6.	0.	0.1	0.04	478.0	161.8	28.14
8	7.	0.	1.4	3.49	654.0	190.1	28.45
9	8.	5.0	7.3	8.13	858.0	218.6	28.47
10	9.	17.0	16.5	9.55	1091.0	247.2	28.77
11	10.	38.0	26.6	10.73	1353.0	276.1	29.05
12	11.	70.0	37.9	11.84	1643.0	305.3	29.36
13	12.	114.0	50.2	12.85	1963.0	334.8	29.73
14	13.	171.0	63.5	13.74	2313.0	364.7	30.08
15	14.	242.0	77.7	14.53	2693.0	395.0	30.48
16	15.	327.0	92.6	15.23	3103.0	425.7	30.93
17	16.	427.0	108.1	15.83	3545.0	456.9	31.39
18	17.	543.0	124.2	16.33	4017.0	488.5	31.90
19	18.	675.0	141.1	17.51	4522.0	520.6	32.27
20	19.	825.0	159.2	18.70	5059.0	553.0	32.62
21	20.	994.0	178.5	19.89	5628.0	585.8	32.96
22	21.	1183.0	199.0	21.11	6230.0	618.9	33.34
23	22.	1392.0	220.7	22.31	6866.0	652.5	33.64
24	23.	1624.0	243.6	23.52	7535.0	686.3	33.93
25	24.	1880.0	267.7	24.72	8239.0	720.3	34.19
26	25.	2160.0	293.1	25.86	8976.0	754.6	34.27
27	26.	2466.0	319.5	26.99	9748.0	788.9	34.33
28	27.	2799.0	347.0	28.03	10554.0	823.2	34.18
29	28.	3160.0	375.6	29.01	11394.0	857.2	33.92
30	29.	3550.0	405.0	29.84	12268.0	890.9	33.33
31	30.	3970.0	435.1	30.26	13176.0	923.6	31.94
32	31.	4420.0	465.4	30.12	14115.0	954.4	29.49
33	32.	4900.0	495.8	30.89	15083.0	983.5	28.99
34	33.	5411.0	527.2	31.85	16081.0	1012.4	28.89
35	34.	5954.0	559.7	33.13	17108.0	1041.4	29.37
36	35.	6530.0	593.6	34.54	18165.0	1071.1	30.07
37	36.	7141.0	628.9	36.03	19251.0	1101.6	30.87
38	37.	7787.0	665.7	37.61	20368.0	1132.9	31.75
39	38.	8471.0	704.2	39.28	21517.0	1165.1	32.67
40	39.	9194.0	744.3	40.87	22698.0	1198.3	33.57
41	40.	9959.0	786.0	42.60	23914.0	1232.3	34.58

Table 4-2

PROGRAM OUTPUT: CROSS-SECTION INPUT

CROSS SECTION OF EXAMPLE MISSILE AT 5000 MC

0.	4.5	5.4	4.5	5.5	4.4	5.6	4.4	5.6	4.3	5.7	4.1	5.8
0.6	4.0	5.8	3.8	5.8	3.6	5.9	3.3	5.8	3.0	5.8	2.6	5.9
1.2	2.3	5.6	2.0	5.9	1.6	5.8	1.3	5.8	0.8	5.8	0.5	5.7
1.8	0.2	5.7	-0.1	5.6	-0.4	5.5	-0.6	5.5	-0.9	5.4	-1.0	5.3
2.4	-1.2	5.3	-1.4	5.2	-1.7	5.0	-1.8	4.9	-2.1	4.8	-2.3	4.7
3.0	2.0	-5.4	0.2	-7.5	0.2	9.8	0.6	9.8	2.1	9.8	3.7	9.8
3.6	4.8	9.8	4.7	-7.1	-1.0	-7.1	-6.7	-5.5	-0.3	-3.9	5.8	-3.9
4.2	9.2	-3.7	10.7	-4.0	10.5	-5.2	9.0	-7.9	7.8	9.8	10.4	9.8
4.8	12.8	-7.6	13.1	-7.6	11.6	-6.6	8.8	-6.6	7.7	-6.2	10.2	-4.4
5.4	11.5	-2.6	11.0	-1.6	5.2	-1.8	5.2	-3.4	8.4	-6.8	11.1	9.8
6.0	6.1	-2.6	5.9	-3.2	5.6	-4.0	5.1	-4.7	4.6	-5.6	4.1	-6.5
6.6	3.6	-7.6	2.9	-8.8	1.9	-10.5	1.2	-12.3	-0.	-15.1	-0.6	-17.4
7.2	-1.5	-21.3	-1.9	-20.5	-2.0	-17.8	-1.7	-16.0	-1.2	-13.2	-0.5	-11.8
7.8	0.2	-10.9	0.8	-9.9	1.4	-9.2	1.9	-8.5	2.4	-8.1	2.7	-7.9
8.4	2.9	-7.8	3.0	-7.8	3.0	-8.0	3.0	-8.3	2.9	-8.9	2.7	-9.3
9.0	2.3	-10.1	2.0	-11.1	1.6	-12.5	1.2	-13.6	0.4	-15.1	-0.	-15.5
9.6	-0.5	-15.2	-1.0	-13.9	-1.5	-12.3	-1.8	-11.0	-1.9	-9.6	-1.9	-8.4
10.2	-7.2	3.6	-1.0	2.5	0.9	1.3	-0.6	-4.1	3.2	-1.4	5.7	-2.2
10.8	-1.8	-3.9	-2.0	-3.7	-2.4	-3.5	-2.9	-3.4	-3.5	-3.4	-4.1	-3.4
11.4	2.4	1.6	3.5	2.4	4.6	2.0	4.4	0.5	3.2	-2.6	2.1	-7.5
12.0	-5.6	-4.5	-4.9	-5.2	-4.1	-5.7	-3.6	-6.1	-2.9	-6.8	-2.6	-7.3
12.6	-2.2	-8.0	-2.0	-8.7	-2.0	-9.4	-2.1	-10.3	-2.3	-11.0	-2.6	-11.2
13.2	-3.1	-11.5	-3.6	-11.4	-4.7	-11.2	-5.6	-10.9	-6.9	-10.3	-8.4	-9.8
13.8	-6.9	3.0	-3.2	0.2	-3.6	0.2	-3.9	-1.5	2.3	-1.3	7.0	-1.8
14.4	9.5	-5.0	9.3	-8.9	5.9	-5.4	-2.2	-2.5	-2.2	-2.7	-7.9	-8.6
15.0	-5.5	9.8	5.9	15.0	5.9	-3.3	6.8	-5.6	5.1	-5.6	-0.2	-3.6
15.6	-5.5	-3.6	-1.6	-2.2	-2.0	0.3	-5.1	2.4	0.7	3.8	4.3	4.1
16.2	-7.2	-9.2	-8.0	-9.5	-9.4	-10.4	-10.9	-10.8	-12.3	-10.9	-13.4	-10.8
16.8	3.6	0.6	3.6	1.7	2.6	0.1	-0.4	-2.2	-4.7	-3.4	-2.6	-4.1
17.4	2.3	-4.9	3.9	-5.0	1.3	-1.2	-0.3	2.2	1.5	3.7	-0.5	2.9
18.0	-1.6	-1.0	2.5	-3.9	3.6	-4.4	4.9	-5.0	7.5	-0.5	6.8	1.3
18.6	0.5	0.3	-6.0	-3.3	-1.0	-5.6	4.8	-1.0	8.0	-0.7	8.2	-3.2
19.2	0.1	2.2	2.4	2.4	3.7	-7.0	-5.2	-8.3	-6.5	-3.3	-4.4	-9.2
19.8	9.8	-4.7	1.3	19.5	1.3	1.1	2.9	1.8	3.3	2.0	3.3	1.3
20.4	3.3	1.3	1.3	2.4	0.4	3.2	3.3	-5.1	5.0	9.8	4.7	-5.1
21.0	3.4	-7.3	2.6	-7.7	1.1	0.3	-1.4	3.8	-2.3	2.8	-2.3	-1.6
21.6	3.1	-2.6	3.1	-2.4	3.0	-9.2	3.5	-10.0	0.6	-3.3	-3.0	0.3
22.2	-0.7	0.7	-4.1	-4.2	-1.4	9.9	-1.3	-3.2	-0.5	3.3	-3.6	-3.0
22.8	-4.4	-18.7	-6.2	-17.9	-8.6	-17.0	-10.8	-16.8	-11.6	-16.8	-9.8	-16.5
23.4	-8.8	-2.6	-3.5	0.9	2.7	1.2	1.7	-3.5	-4.6	0.1	-3.4	3.4
24.0	-0.9	-19.2	-0.9	-17.6	-1.0	-16.4	-1.3	-16.1	-2.2	-15.7	-3.0	-16.2
24.6	2.6	-7.2	-5.2	-2.7	-4.6	-6.3	-4.8	9.8	-7.0	-9.7	1.1	9.8
25.2	0.6	-8.0	-0.4	-3.0	-0.4	1.2	-8.1	-2.4	-5.0	-9.8	4.1	-2.8
25.8	3.6	1.8	-5.6	-4.9	-9.0	-3.1	-2.9	2.0	-3.3	-3.3	-0.6	1.5
26.4	-0.2	1.6	0.8	-4.9	1.4	-1.7	-3.8	-2.3	-6.5	-3.4	-6.0	1.1
27.0	-2.8	-4.8	-2.8	-6.9	-6.6	-4.0	-1.2	0.8	1.9	-5.3	-1.2	-6.4
27.6	-9.7	-5.1	-4.1	9.7	-1.7	-4.9	-9.3	-4.9	-5.2	-8.2	-0.7	-8.7
28.2	0.1	-1.3	0.9	-4.5	0.9	9.8	-6.1	-6.0	-2.1	-0.6	2.0	-2.2
28.8	2.9	-4.9	1.9	-3.9	3.2	-1.4	-2.8	-8.6	3.1	-6.8	9.1	-4.9
29.4	1.4	1.0	-5.8	0.1	-1.8	-1.9	-5.5	-5.2	-9.0	-2.2	-9.0	-1.6
30.0	-1.2	-6.8	-4.7	-2.5	-4.8	-1.5	-7.0	1.9	-5.5	-5.2	-0.9	-3.4
30.6	-5.2	-22.1	-7.7	-21.7	-10.3	-17.6	-12.3	-15.4	-10.4	-13.7	-8.4	-12.7
31.2	-6.5	-11.9	-5.3	-11.5	-4.6	-11.8	-4.6	-12.2	-4.8	-12.3	-5.3	-12.3
31.8	-6.0	-11.9	-6.6	-11.5	-7.1	-11.2	-7.8	-11.3	-8.8	-11.7	-10.0	-12.1
32.4	-12.6	-13.9	-15.7	-15.0	-18.1	-16.5	-15.3	-18.4	-11.3	-20.8	-9.0	-21.7
33.0	-7.3	-23.1	-6.6	-24.4	-6.5	-26.8	-7.0	-25.0	-8.6	-19.9	-11.1	-17.1
33.6	-8.2	-6.7	-2.7	-0.7	-0.6	-7.0	-5.3	9.7	-4.1	-4.7	-3.0	-8.8
34.2	-7.6	-16.7	-7.7	-13.6	-8.5	-21.1	-9.5	-18.2	-11.5	-15.6	-12.8	-14.0
34.8	-3.9	-3.7	-7.9	-2.0	9.8	-4.7	-9.8	-7.5	-4.0	-5.0	-9.5	-8.2
35.4	-16.7	-13.5	-13.8	-12.6	-10.6	-11.7	-8.9	-12.3	-7.7	-12.3	-7.4	-13.2
36.0	-2.9	-3.6	-1.1	-4.3	-4.2	0.7	-2.1	-6.7	-7.6	-7.1	-4.3	-6.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-4.4	[illegible]	[illegible]	[illegible]	[illegible]	-5.6	-8.9	[illegible]

Table 4-3

PROGRAM OUTPUT: INPUT PARAMETER LIST

INPUT PARAMETERS

I1	I2	I3	SYMBOL	NOMINAL VALUE	CONVERSION FACTOR	DEFINITION
0	-0	12	FMC	0.50000000E 04*	0.09999999E 01	FREQUENCY,MC
0	-0	23	PPEAK	0.50000000E 00	0.09999999E 07	PEAK POWER,MEGAWATTS
0	-0	25	TOWELL	0.09999999E 02	0.09999999E-05	TRANSMIT PULSEWIDTH,MICROSEC
0	-0	24	FR	0.09999999E 04	0.09999999E 01	PULSE REPETION RATE,CPS
0	-0	44	POL	0.09999999E 01	0.09999999E 01	POLARIZATION,H=0,V=1
0	-0	28	FNOISE	0.30000000E 01	0.09999999E 01	RECEIVER NOISE FIGURE AT 290 DEG
0	-0	13	HAPER	0.56378289E 01	0.09999999E 01	HORIZONTAL ANTENNA APERTURE,FT.
0	-0	14	VAPER	0.56378289E 01	0.09999999E 01	VERTICAL ANTENNA APERTURE,FT.
0	-0	15	AAPEFF	0.65000000E 00	0.09999999E 01	ANTENNA APERTURE EFFICIENCY
0	-0	16	ETA	0.99999999E-03	0.09999999E 01	RELATIVE SIDELOBE LEVEL
0	-0	29	HTSS	0.09999999E 01	0.09999999E 01	TIME TO SCAN SECTOR, SEC.
0	-0	37	XIHDLL	0.26666000E 02	0.17453291E-01	AZIMUTH SEARCH SECTOR,DEG
0	-0	38	XIVDLL	0.30000000E 02	0.17453291E-01	ELEVATION SEARCH SECTOR,DEG
0	-0	26	SYSLF	0.09999999E-00	0.09999999E 01	SYSTEM LOSS FACTOR
0	-0	20	PCN	0.09999999E 03	0.09999999E 01	PULSE COMPRESSION TIME BANDWIDTH PRO
0	-0	36	TAUFA	0.09999999E 02	0.09999999E 01	FALSE ALARM TIME,SEC.
0	-0	2	VVA	0.70000000E 03	0.09999999E 01	AIRCRAFT VELOCITY,FT/SEC
0	-0	3	ELVA	0.	0.17453291E-01	ELEVATION ANGLE OF VVA,DEG
0	-0	4	AZVA	0.59999999E 02	0.17453291E-01	AZIMUTH ANGLE OF VVA,DEG
0	-0	5	XLOIT	0.30000000E 02	0.60800000E 04	X-VALUE OF A/C ORIGIN ON TARG COORD,
0	-0	6	YLOIT	0.30000000E 02	0.60800000E 04	Y-VALUE OF A/C ORIGIN ON TARG COORD,
0	-0	7	ZLOIT	0.30000000E 05	0.09999999E 01	Z-VALUE OF A/C ORIGIN ON TARG COORD,
0	-0	10	AZTAR	0.30000000E 02	0.17453291E-01	TARGET TRAJECTORY AZIMUTH ANGLE,DEG
0	-0	43	SEA	0.09999999E 01	0.09999999E 01	SEA STATE,ROUGH=1,CALM=0
0	-0	46	FNTRK	0.20000000E 01	0.09999999E 01	TRACK SYSTEM FACTOR
0	-0	47	CRL	0.09999999E 01	0.09999999E 01	BEAM CROSS-OVER LOSS FACTOR
0	-0	48	BNSK	0.09999999E 01	0.09999999E 01	NOMINAL NOISE BANDWIDTH OF ANG.CKT,C
0	-0	49	FKS	0.15700000E 01	0.09999999E 01	NORMALIZED SLOPE FACTOR
0	-0	50	BI	0.09999999E 04	0.09999999E 01	BOXCAR BANDWIDTH,CPS
0	-0	51	ATEIS	0.50000000E 00	0.99999999E-03	ANG TRACKING ERROR-TARGET MOTION,MIL
0	-0	52	ATEPS	0.50000000E 00	0.99999999E-03	ANG TRACKING ERROR-PLATFORM MOT.,MIL
0	-0	53	ATEOS	0.50000000E 00	0.99999999E-03	ANG TRACKING ERROR-OTHER EFFECTS,MIL
0	-0	58	FOMS	0.09999999E 01	0.09999999E 01	FREQUENCY JUMPING WHEN 1,OTHERWISE=0
0	-0	55	CASE	0.40000000E 01	0.09999999E 01	CASE FOR MARCUM-SWERLING
0	-0	56	SIGOPT	0.	0.09999999E 01	OPTION FOR SIGZ
0	-0	57	SIGZ	-0.30000000E 02	0.09999999E 01	SIGMA ZERO WHEN SIGOPT=1
0	-0	59	PUNOPT	0.	0.09999999E 01	PUNCH ALP1 + SIG12 VS TIME WHEN =1
0	-0	65	TSTART	0.	0.09999999E 01	START PROGRAM AT THIS TIME,SEC
0	-0	60	TSTOP	0.38999999E 02	0.09999999E 01	STOP AT THIS TIME
0	-0	61	TARGOP	0.	0.60800000E 04	- PROGRAM 1,+ PROG 2 RANGE INCRE NM
0	-0	62	BXLOIT	0.	0.60800000E 04	MAX VALUE OF XLOIT IN PROGRAM 2 , NM
0	-0	45	OLDK	0.09999999E 01	0.09999999E 01	OLD KCOM,MULTIPLIES STACFT
0	-0	64	RBLANK	0.	0.09999999E 01	BLANK MAIN-LOBE CLUTTER WHEN =1

*0.50000000E 04 corresponds to 0.500×10^4.

The input parameters that are used to describe the initial radar-target geometry, the clutter and noise conditions, the radar characteristics, and the output options, are reproduced in Table 4-3. These parameters, which were described in Chapter II, are given the values listed in the nominal-value column. The nominal values are multiplied by the number given in the conversion-factor column to agree with the units in the definition column.

4.1.2 Computed Constants

The first set of output parameters are constant with respect to time and are therefore calculated only once during each run. The results of these calculations are listed with definitions in Table 4-4. Note that the horizontal scan rate of the antenna was computed as 800 degrees per second. This implies that the airborne radar must employ an electronically scanned antenna since mechanical scanning cannot be performed at an 800 degree/second rate.

4.1.3 Geometry Output

The results of the geometry calculations occur on three pages of the printed output. The first page is for the ranges and range rates between the radar, target, reflection point, and clutter spot; the second page is for the angle calculations; and the third page is for the cross-section calculations.

The definitions of all the geometry output parameters are listed in Table 4-5 in two parts: part I for the range and angle calculations and part II for the cross-section calculations.

Table 4-4

PROGRAM OUTPUT: COMPUTED CONSTANTS FOR AIRBORNE-RADAR/MISSILE-TARGET EXAMPLE

Name	Definition	Computed Value
LAMBDA	Wavelength in feet	.1967
AR	Effective area of antenna in square feet	20.66
GAIN	Mainlobe gain in dB	38
BETAH	Horizontal beamdwidth in degrees	2.0
BETAV	Vertical beamwidth in degrees	2.0
FSCH	Horizontal scan rate in degrees/sec	800
TAU	Compressed pulse length in seconds	1.0×10^{-7}
N	Number of hits/scan	5
PO	Power received at initial range in watts/square feet	2.0×10^{-12}
PAVG	Average transmit power in watts	5×10^{3}
PNOISE	Noise power in dB above one milliwatt plus rain backscatter power when RAIN = 1.	-99
PFA	False alarm probability	1.4×10^{-8}

Table 4-5

DEFINITIONS OF GEOMETRY OUTPUT PARAMETERS, PART I

1. Page 1: Geometry Range Calculations

R	Radar-to-target range in feet
R1	Radar-to-reflection-point range in feet
R2	Target-to-reflection-point range in feet
RDOT R1DOT R2DOT	Respective range rates in feet/sec.
TDIR	Propagation time of direct signal in secs.
DELT	Time difference between one-way direct signal and one-way reflection signal in secs.

2. Page 2: Geometry Angle Calculations

ELAAT	Elevation angle of radar/target line in degrees
ELAAB	Elevation of radar/reflection-point line in degrees
ELAAC	Elevation of radar/clutter-point line in degrees
AZAAT	Azimuth angle of radar/target line in degrees
ALPHAB	Angle of incidence of radar/reflection-point line with respect to tangent at reflection point, in degrees
ALPHAC	Angle of incidence with respect to tangent at clutter point, in degrees
THETA(1)	Angle between target plane of rotation and radar polarization plane in degrees

Table 4-5

DEFINITIONS OF GEOMETRY OUTPUT PARAMETERS, PART II

3. Page 3: Geometry Cross-Sections Calculations

ALP(1)	Direct-path aspect angle in degrees
SIG(1,1)	Target cross section for direct path and horizontal polarization, in square feet (POL = 0)
SIG(1,2)	Target cross section for direct signal and vertical polarization, in square feet
ALP(2)	Single-bounce-path aspect angle in degrees
SIG(2,1)	Target cross section for single-bounce path and horizontal polarization, in square feet
SIG(2,2)	Target cross section for single-bounce path and vertical polarization, in square feet
ALP(3)	Double-bounce path aspect angle in degrees
SIG(3,1)	Target cross section for double-bounce path and horizontal polarization, in square feet
SIG(3,2)	Target cross section for double-bounce path and vertical polarization, in square feet

The geometrical quantitites that these definitions describe were previously illustrated in Figure 3-2.

The actual output for the geometry range calculations for the airborne-radar/missile-target example is reproduced in Table 4-6. This Table indicates that the range R changes only 16,000 feet (2.7 nautical miles) from the initial range, increasing from zero to 36 seconds and decreasing thereafter.

The geometry angle calculations are shown in Table 4-7. Note that all of the elevation angles are negative indicating that the antenna beam is pointing down throughout the engagement.

The last page of the geometry output showing the target cross-section values for the different signal paths is reproduced in Table 4-8.

4.1.4 Radar and Detection Output

The results of the radar and detection calculations are presented on two pages. The first page includes the output parameters associated with the detection probabilities and the accuracy calculations which are defined in Table 4-9. The second page presents the output parameters associated with the signal and clutter power level calculations which are defined in Table 4-10. The corresponding two pages of output for the airborne-radar/missile-target example are shown in Tables 4-11 and 4-12. Some of the most important conclusions revealed by these two tables are indicated below.

The first measurable single scan detection probability PD1, equal to .403, occurs 11 seconds after the missile launch.

Table 4-6

PROGRAM OUTPUT: GEOMETRY RANGE CALCULATIONS

TIME	R	R1	R2	RDOT	R1DOT	R2DOT	TDIR	DELT
SEC	FT	FT	FT	FT/SEC	FT/SEC	FT/SEC	SEC	SEC
0.	0.259832E 06	0.259832E 06	0.195318E-02	0.672009E 03	0.672009E 03	0.152602E-04	0.528344E-03	0.
1.0	0.260502E 06	0.260388E 06	0.117287E 03	0.669061E 03	0.440894E 03	0.233886E 03	0.529707E-03	0.291766E-08
2.0	0.261170E 06	0.260712E 06	0.469758E 03	0.666083E 03	0.204749E 03	0.472835E 03	0.531065E-03	0.116561E-07
3.0	0.261834E 06	0.260794E 06	0.106625E 04	0.663094E 03	-0.340628E 02	0.714481E 03	0.532416E-03	0.263826E-07
4.0	0.262496E 06	0.260646E 06	0.189616E 04	0.660006E 03	-0.274165E 03	0.957363E 03	0.533761E-03	0.468281E-07
5.0	0.263155E 06	0.260253E 06	0.297429E 04	0.657032E 03	-0.512900E 03	0.119901E 04	0.535101E-03	0.733926E-07
6.0	0.263810E 06	0.259619E 06	0.429594E 04	0.654063E 03	-0.750604E 03	0.143971E 04	0.536434E-03	0.106040E-06
7.0	0.264463E 06	0.258750E 06	0.585498E 04	0.649883E 03	-0.985284E 03	0.167619E 04	0.537761E-03	0.144719E-06
8.0	0.265108E 06	0.257650E 06	0.764383E 04	0.641349E 03	-0.121775E 04	0.190611E 04	0.539072E-03	0.189400E-06
9.0	0.265743E 06	0.256318E 06	0.966221E 04	0.629729E 03	-0.144450E 04	0.212722E 04	0.540365E-03	0.240259E-06
10.0	0.266367E 06	0.254760E 06	0.118998E 05	0.617312E 03	-0.166383E 04	0.234015E 04	0.541633E-03	0.297274E-06
11.0	0.266978E 06	0.252995E 06	0.143372E 05	0.603817E 03	-0.187511E 04	0.254399E 04	0.542876E-03	0.360196E-06
12.0	0.267575E 06	0.251019E 06	0.169786E 05	0.589449E 03	-0.207697E 04	0.273757E 04	0.544089E-03	0.429434E-06
13.0	0.268157E 06	0.248842E 06	0.198110E 05	0.574207E 03	-0.226939E 04	0.292092E 04	0.545272E-03	0.504966E-06
14.0	0.268722E 06	0.246479E 06	0.228205E 05	0.558197E 03	-0.245163E 04	0.309338E 04	0.546422E-03	0.586791E-06
15.0	0.269273E 06	0.243943E 06	0.259931E 05	0.541620E 03	-0.262302E 04	0.325449E 04	0.547541E-03	0.674867E-06
16.0	0.269806E 06	0.241234E 06	0.293289E 05	0.524578E 03	-0.278341E 04	0.340424E 04	0.548625E-03	0.769622E-06
17.0	0.270322E 06	0.238380E 06	0.327983E 05	0.507088E 03	-0.293222E 04	0.354203E 04	0.549674E-03	0.870627E-06
18.0	0.270820E 06	0.235375E 06	0.364078E 05	0.488966E 03	-0.306957E 04	0.366783E 04	0.550688E-03	0.978514E-06
19.0	0.271300E 06	0.232241E 06	0.401345E 05	0.469860E 03	-0.319458E 04	0.378038E 04	0.551663E-03	0.109305E-05
20.0	0.271760E 06	0.228990E 06	0.439636E 05	0.449770E 03	-0.330806E 04	0.388049E 04	0.552598E-03	0.121426E-05
21.0	0.272199E 06	0.225633E 06	0.478865E 05	0.428723E 03	-0.340934E 04	0.396752E 04	0.553491E-03	0.134236E-05
22.0	0.272617E 06	0.222176E 06	0.518949E 05	0.406714E 03	-0.349974E 04	0.404282E 04	0.554342E-03	0.147754E-05
23.0	0.273013E 06	0.218638E 06	0.559676E 05	0.383783E 03	-0.357800E 04	0.410511E 04	0.555146E-03	0.161964E-05
24.0	0.273384E 06	0.215022E 06	0.601025E 05	0.359948E 03	-0.364421E 04	0.415452E 04	0.555901E-03	0.176910E-05
25.0	0.273732E 06	0.211351E 06	0.642747E 05	0.335113E 03	-0.369999E 04	0.419257E 04	0.556608E-03	0.192547E-05
26.0	0.274055E 06	0.207627E 06	0.684823E 05	0.309608E 03	-0.374369E 04	0.421790E 04	0.557264E-03	0.208926E-05
27.0	0.274351E 06	0.203867E 06	0.727077E 05	0.283349E 03	-0.377634E 04	0.423146E 04	0.557868E-03	0.226025E-05
28.0	0.274621E 06	0.200080E 06	0.769396E 05	0.256369E 03	-0.379729E 04	0.423258E 04	0.558417E-03	0.243848E-05
29.0	0.274864E 06	0.196278E 06	0.811677E 05	0.228966E 03	-0.380727E 04	0.422226E 04	0.558911E-03	0.262398E-05
30.0	0.275079E 06	0.192468E 06	0.853820E 05	0.201292E 03	-0.380410E 04	0.419835E 04	0.559348E-03	0.281679E-05
31.0	0.275267E 06	0.188673E 06	0.895613E 05	0.173876E 03	-0.378557E 04	0.415898E 04	0.559730E-03	0.301631E-05
32.0	0.275428E 06	0.184907E 06	0.936909E 05	0.146785E 03	-0.375444E 04	0.410701E 04	0.560058E-03	0.322214E-05
33.0	0.275562E 06	0.181172E 06	0.977697E 05	0.119071E 03	-0.371820E 04	0.404931E 04	0.560329E-03	0.343454E-05
34.0	0.275667E 06	0.177471E 06	0.101789E 06	0.906292E 02	-0.367871E 04	0.398772E 04	0.560543E-03	0.365337E-05
35.0	0.275743E 06	0.173810E 06	0.105749E 06	0.611608E 02	-0.363845E 04	0.392455E 04	0.560698E-03	0.387887E-05
36.0	0.275789E 06	0.170193E 06	0.109640E 06	0.306792E 02	-0.359797E 04	0.386038E 04	0.560792E-03	0.411094E-05
37.0	0.275806E 06	0.166616E 06	0.113468E 06	-0.879744E 00	-0.355707E 04	0.379496E 04	0.560825E-03	0.435004E-05
38.0	0.275789E 06	0.163080E 06	0.117230E 06	-0.336805E 02	-0.351604E 04	0.372846E 04	0.560791E-03	0.459651E-05
39.0	0.275740E 06	0.159587E 06	0.120924E 06	-0.676018E 02	-0.347513E 04	0.366125E 04	0.560691E-03	0.485041E-05

Table 4-7

PROGRAM OUTPUT: GEOMETRY ANGLE CALCULATIONS

TIME	ELAAT	ELAAB	ELAAC	AZAAT	ALPHAB	ALPHAC	THETA(1)
SEC	DEG	DEG	DEG	DEG	DEG	DEG	DEG
0.	-6.63	-6.63	-6.63	165.00	6.40	6.37	0.
1.0	-6.61	-6.62	-6.62	165.04	6.38	6.35	0.
2.0	-6.59	-6.61	-6.60	165.08	6.37	6.33	0.
3.0	-6.56	-6.61	-6.58	165.12	6.37	6.32	0.
4.0	-6.52	-6.61	-6.57	165.16	6.38	6.30	0.01
5.0	-6.48	-6.62	-6.55	165.20	6.39	6.28	0.01
6.0	-6.43	-6.64	-6.53	165.24	6.40	6.26	0.01
7.0	-6.37	-6.66	-6.52	165.28	6.43	6.25	0.11
8.0	-6.31	-6.69	-6.50	165.32	6.46	6.23	0.51
9.0	-6.25	-6.73	-6.49	165.35	6.49	6.21	1.03
10.0	-6.18	-6.77	-6.47	165.39	6.54	6.20	1.49
11.0	-6.10	-6.81	-6.46	165.43	6.59	6.18	1.93
12.0	-6.02	-6.87	-6.44	165.47	6.64	6.17	2.34
13.0	-5.93	-6.93	-6.43	165.52	6.71	6.15	2.73
14.0	-5.84	-6.99	-6.41	165.56	6.78	6.14	3.10
15.0	-5.74	-7.07	-6.40	165.60	6.86	6.13	3.44
16.0	-5.63	-7.15	-6.39	165.64	6.94	6.11	3.75
17.0	-5.52	-7.23	-6.37	165.69	7.03	6.10	4.05
18.0	-5.40	-7.33	-6.36	165.73	7.13	6.09	4.33
19.0	-5.28	-7.43	-6.35	165.78	7.23	6.07	4.61
20.0	-5.15	-7.55	-6.34	165.82	7.34	6.06	4.90
21.0	-5.01	-7.64	-6.33	165.87	7.46	6.05	5.18
22.0	-4.87	-7.76	-6.32	165.92	7.59	6.04	5.47
23.0	-4.72	-7.89	-6.31	165.97	7.72	6.03	5.76
24.0	-4.57	-8.02	-6.30	166.02	7.86	6.02	6.04
25.0	-4.41	-8.16	-6.29	166.07	8.01	6.02	6.34
26.0	-4.24	-8.31	-6.29	166.12	8.16	6.01	6.62
27.0	-4.07	-8.47	-6.28	166.18	8.32	6.00	6.91
28.0	-3.89	-8.63	-6.27	166.23	8.49	5.99	7.20
29.0	-3.70	-8.80	-6.27	166.29	8.67	5.99	7.49
30.0	-3.51	-8.97	-6.26	166.35	8.85	5.98	7.78
31.0	-3.31	-9.15	-6.26	166.41	9.04	5.98	8.07
32.0	-3.11	-9.34	-6.25	166.47	9.24	5.97	8.36
33.0	-2.90	-9.54	-6.25	166.54	9.44	5.97	8.66
34.0	-2.68	-9.74	-6.25	166.60	9.65	5.97	8.95
35.0	-2.46	-9.94	-6.25	166.67	9.87	5.97	9.25
36.0	-2.23	-10.16	-6.25	166.74	10.09	5.96	9.55
37.0	-2.00	-10.38	-6.25	166.81	10.33	5.96	9.84
38.0	-1.76	-10.61	-6.25	166.89	10.56	5.96	10.14
39.0	-1.52	-10.84	-6.25	166.96	10.81	5.97	10.44

Table 4-8

PROGRAM OUTPUT: GEOMETRY CROSS-SECTION CALCULATIONS

TIME	ALP(1)	SIG(1,1)	SIG(1,2)	ALP(2)	SIG(2,1)	SIG(2,2)	ALP(3)	SIG(3,1)	SIG(3,2)
SEC	DEG	SQ FT	SQ FT	DEG	SQ FT	SQ FT	DEG	SQ FT	SQ FT
0.	83.37	31.77	138.67	83.37	31.77	138.67	83.37	31.77	138.67
1.0	83.39	31.77	138.67	89.87	9816.77	5520.37	96.36	7.80	52.72
2.0	83.41	31.77	138.67	89.88	9816.77	5520.37	96.35	1.91	37.32
3.0	83.44	31.77	138.67	89.90	9816.77	5520.37	96.35	1.91	37.32
4.0	83.43	31.77	138.67	89.86	9816.76	5520.37	96.30	1.91	37.32
5.0	83.48	36.47	159.21	89.90	9816.76	5520.37	96.32	1.91	37.32
6.0	83.54	36.47	159.21	89.94	9816.76	5520.37	96.35	1.91	37.32
7.0	83.22	56.15	105.19	89.61	8355.40	2465.88	96.00	19.59	10.76
8.0	81.84	9.16	38.19	88.22	240.96	85.51	94.59	71.13	191.40
9.0	80.07	23.02	31.76	86.43	118.02	115.34	92.79	60.54	95.92
10.0	78.52	17.88	39.07	84.87	200.48	264.18	91.21	289.88	539.30
11.0	77.08	2830.97	2642.43	83.42	31.89	138.54	89.75	22465.78	2074.14
12.0	75.77	39.07	31.78	82.09	20.07	36.45	88.41	408.91	215.09
13.0	74.56	11.01	8.75	80.87	21.06	51.45	87.18	296.72	408.98
14.0	73.46	448.74	459.13	79.75	29.01	40.89	86.04	24.69	35.61
15.0	72.46	1.67	1.63	78.74	85.49	81.67	85.02	264.22	264.22
16.0	71.57	57.82	60.52	77.84	28.29	23.04	84.11	18.71	18.71
17.0	70.77	17.05	15.93	77.03	2642.52	2703.46	83.29	69.91	151.63
18.0	70.03	4.58	2.26	76.28	42.88	46.96	82.52	37.34	40.90
19.0	69.30	10.51	9.38	75.54	37.33	39.07	81.77	9.35	38.00
20.0	68.58	6.68	1.45	74.81	6.23	10.49	81.04	24.84	49.02
21.0	67.88	101.96	1.93	74.10	3.21	7.41	80.32	13.97	26.93
22.0	67.21	2.82	8.69	73.41	448.71	448.71	79.62	14.91	20.93
23.0	66.54	1.96	9.09	72.74	364.18	310.98	78.93	74.54	81.58
24.0	65.89	1.87	6.01	72.05	1.92	2.70	78.27	56.58	64.77
25.0	65.26	6.14	13.46	71.44	35.65	36.46	77.61	16.03	25.12
26.0	64.65	101.54	10.00	70.82	17.04	15.94	76.99	2643.04	2702.94
27.0	64.06	3.91	3.91	70.22	2.21	3.16	76.38	132.38	129.45
28.0	63.48	98.99	8.74	69.63	18.18	12.17	75.78	38.97	31.88
29.0	62.93	103.84	27.17	69.07	19.00	10.91	75.21	3.24	22.67
30.0	62.39	2.35	23.35	68.52	1.74	1.42	74.66	10.13	14.77
31.0	61.86	1.68	14.26	67.99	2.36	5.10	74.11	3.26	7.36
32.0	61.35	2.60	6.12	67.47	3.01	8.24	73.59	429.17	458.52
33.0	60.86	1.88	4.13	66.97	2.06	4.43	73.08	381.53	365.12
34.0	60.37	8.50	14.37	66.48	2.01	8.98	72.58	316.37	265.52
35.0	59.90	6.31	3.73	66.00	1.80	3.85	72.10	1.93	2.68
36.0	59.45	1.39	0.42	65.54	3.75	20.98	71.63	57.88	60.45
37.0	59.02	1.17	2.54	65.10	1.00	0.86	71.18	34.79	33.31
38.0	58.60	2.74	2.03	64.67	2.81	14.81	70.75	102.06	7.32
39.0	58.20	3.56	3.56	64.27	99.81	14.79	70.34	1.64	2.08

Table 4-9

DEFINITIONS OF DETECTION PROBABILITIES AND RADAR ACCURACY CALCULATIONS

PD1	Single-scan detection probability for the direct path signal
PDCUM1	Cumulative detection probability
PDT	Detection probability for direct and reflected paths (when coincide)
PCUMT	Cumulative detection probability of combined signal
CASE	Marcum-Swerling fluctuating-target model (0-4)
VB	Threshold level above receiver noise
S/N	Signal-to-(receiver) noise ratio in dB
C/N	Clutter-to-(receiver) noise ratio in dB
MC	Number of correlated clutter pulses
FD1	Absolute target doppler frequency in cps
DOPDIF	Difference in doppler frequencies between direct and reflected paths, in cps
TDIF	Time difference between direct and reflected signals in microseconds
DELR	Search range accuracy in feet
DELD	Search doppler accuracy in cps
DELA	Search angular accuracy in milliradians
SIGNV	Angular tracking accuracy in vertical plane
SIGNH	Angular tracking accuracy in horizontal plane
SIGT	Total angular tracking accuracy in milliradians
ZT	Altitude of target in thousands of feet

Table 4-10

DEFINITIONS OF SIGNAL AND CLUTTER POWER LEVEL CALCULATIONS

SDD	Signal power for direct path in dBm (decibels above one milliwatt)
SDB	Signal power for single-bounce path in dBm
SBB	Signal power for double-bounce path in dBm
CLOM	Mainlobe clutter power in dBm (surface clutter)
CLOS	Sidelobe clutter power in dBm
CLO	Total resultant clutter power in dBm
SIGO	Normalized clutter cross section in dB
PHA	Phase difference between direct and bounce path in cycles
PHADEL	Phase change during one scan in cycles
REFL	Reflection coefficient
S/(C+N)	Signal-to-clutter plus noise ratio in dB

Table 4-11

PROGRAM OUTPUT: DETECTION PROBABILITIES AND RADAR ACCURACY CALCULATIONS

RANGE	PO1	PCUM1	POT	PCUMT	CASE	V8	S/N	C/N	MC	FD1	DOPOIF	TDIF	DELR	DELO	OELA	SIGNV	SIGNH	SIGT	ZT
N MI							DB	OB		CPS	CPS	US	FT	KCPS	MILS	MILS	MILS	MILS	KFT
0.	1.000	1.000	1.000	1.000	4.	27.	53.9	37.1	5.0	21.	3.	20.3	2.	350.6	4.	0.2	0.2	0.9	30.0
2.0	1.000	1.000	1.000	1.000	4.	27.	51.2	34.2	5.0	1861.	407.	18.7	2.	343.1	4.	0.2	0.2	0.9	30.0
4.0	1.000	1.000	1.000	1.000	4.	27.	46.0	28.8	5.0	2753.	449.	15.6	2.	335.1	4.	0.2	0.2	0.9	30.0
6.0	1.000	1.000	1.000	1.000	4.	27.	41.2	23.9	5.0	3121.	360.	12.7	2.	331.4	4.	0.2	0.2	0.9	30.0
8.0	1.000	1.000	1.000	1.000	4.	27.	37.1	19.8	5.0	3290.	270.	10.5	2.	330.3	4.	0.2	0.2	0.9	30.0
10.0	1.000	1.000	1.000	1.000	4.	27.	33.7	16.3	5.0	3377.	203.	8.9	2.	331.0	4.	0.2	0.2	0.9	30.0
12.0	1.000	1.000	1.000	1.000	4.	27.	30.8	13.4	5.0	3428.	155.	7.7	2.	333.5	4.	0.2	0.2	0.9	30.0
14.0	1.000	1.000	1.000	1.000	4.	27.	28.3	10.8	5.0	3459.	121.	6.7	2.	338.3	4.	0.2	0.2	0.9	30.0
16.0	1.000	1.000	1.000	1.000	4.	27.	26.1	8.6	5.0	3480.	97.	5.9	2.	345.9	4.	0.2	0.2	0.9	30.0
18.0	1.000	1.000	1.000	1.000	4.	27.	24.1	6.6	5.0	3494.	79.	5.3	2.	357.0	4.	0.2	0.2	0.9	30.0
20.0	1.000	1.000	1.000	1.000	4.	27.	22.3	4.8	5.0	3505.	65.	4.8	2.	372.0	4.	0.2	0.2	0.9	30.0
22.0	1.000	1.000	1.000	1.000	4.	27.	20.7	3.2	5.0	3512.	55.	4.4	2.	391.4	5.	0.2	0.2	0.9	30.0
24.0	1.000	1.000	1.000	1.000	4.	27.	19.2	1.6	5.0	3518.	47.	4.0	2.	415.7	5.	0.2	0.2	0.9	30.0
26.0	1.000	1.000	1.000	1.000	4.	27.	17.9	0.2	5.0	3523.	40.	3.7	2.	445.1	5.	0.3	0.3	0.9	30.0
28.0	1.000	1.000	1.000	1.000	4.	27.	16.6	-1.1	5.0	3527.	35.	3.5	2.	479.5	6.	0.3	0.3	1.0	30.0
30.0	1.000	1.000	1.000	1.000	4.	27.	15.4	-2.3	5.0	3530.	31.	3.2	3.	519.1	6.	0.3	0.3	1.0	30.0
32.0	0.999	1.000	0.999	1.000	4.	27.	14.3	-3.4	5.0	3532.	27.	3.0	3.	563.7	7.	0.3	0.3	1.0	30.0
34.0	0.996	1.000	0.996	1.000	4.	27.	13.3	-4.5	5.0	3534.	24.	2.9	3.	613.3	7.	0.4	0.4	1.0	30.0
36.0	0.989	1.000	0.989	1.000	4.	27.	12.3	-5.5	5.0	3536.	22.	2.7	3.	667.7	8.	0.4	0.4	1.0	30.0
38.0	0.972	1.000	0.972	1.000	4.	27.	11.3	-6.5	5.0	3537.	19.	2.6	4.	726.7	8.	0.4	0.4	1.1	30.0
40.0	0.939	1.000	0.939	1.000	4.	27.	10.5	-7.5	5.0	3538.	18.	2.4	4.	790.3	9.	0.5	0.5	1.1	30.0
42.0	0.882	1.000	0.882	1.000	4.	27.	9.6	-8.3	5.0	3539.	16.	2.3	4.	858.3	10.	0.5	0.5	1.1	30.0
44.0	0.795	1.000	0.795	1.000	4.	27.	8.8	-9.2	5.0	3540.	15.	2.2	5.	930.6	11.	0.5	0.5	1.2	30.0
46.0	0.680	1.000	0.680	1.000	4.	27.	8.0	-10.0	5.0	3541.	13.	2.1	5.	1007.2	12.	0.6	0.6	1.2	30.0
48.0	0.548	1.000	0.548	1.000	4.	27.	7.3	-10.8	5.0	3542.	12.	2.0	5.	1087.8	13.	0.6	0.6	1.2	30.0
50.0	0.415	1.000	0.415	1.000	4.	27.	6.6	-11.6	5.0	3542.	11.	1.9	6.	1172.6	14.	0.7	0.7	1.3	30.0
52.0	0.295	1.000	0.295	1.000	4.	27.	5.9	-12.4	5.0	3543.	11.	1.8	6.	1261.4	15.	0.7	0.7	1.3	30.0
54.0	0.198	1.000	0.198	1.000	4.	27.	5.3	-13.1	5.0	3543.	10.	1.8	7.	1354.1	16.	0.8	0.8	1.4	30.0
56.0	0.126	1.000	0.126	1.000	4.	27.	4.6	-13.8	5.0	3544.	9.	1.7	7.	1450.7	17.	0.8	0.8	1.5	30.0
58.0	0.077	1.000	0.077	1.000	4.	27.	4.0	-14.5	5.0	3544.	9.	1.6	8.	1551.3	18.	0.9	0.9	1.5	30.0
60.0	0.045	1.000	0.045	1.000	4.	27.	3.4	-15.2	5.0	3544.	8.	1.6	8.	1655.6	19.	1.0	1.0	1.6	30.0
62.0	0.026	1.000	0.026	1.000	4.	27.	2.9	-15.8	5.0	3545.	8.	1.5	9.	1763.8	20.	1.0	1.0	1.7	30.0
64.0	0.015	1.000	0.015	1.000	4.	27.	2.3	-16.5	5.0	3545.	7.	1.5	9.	1875.8	22.	1.1	1.1	1.8	30.0
66.0	0.008	1.000	0.008	1.000	4.	27.	1.8	-17.1	5.0	3545.	7.	1.4	10.	1991.6	23.	1.2	1.2	1.8	30.0
68.0	0.005	1.000	0.005	1.000	4.	27.	1.3	-17.7	5.0	3545.	6.	1.4	11.	2111.1	24.	1.2	1.2	1.9	30.0
70.0	0.003	1.000	0.003	1.000	4.	27.	0.8	-18.4	5.0	3546.	6.	1.3	11.	2234.3	26.	1.3	1.3	2.0	30.0
72.0	0.001	1.000	0.001	1.000	4.	27.	0.3	-19.0	5.0	3546.	6.	1.3	12.	2361.3	27.	1.4	1.4	2.1	30.0
74.0	0.001	1.000	0.001	1.000	4.	27.	-0.2	-19.6	5.0	3546.	5.	1.2	12.	2492.0	29.	1.4	1.4	2.2	30.0
76.0	0.000	1.000	0.000	1.000	4.	27.	-0.7	-20.2	5.0	3546.	5.	1.2	13.	2626.4	30.	1.5	1.5	2.3	30.0
78.0	0.000	1.000	0.000	1.000	4.	27.	-1.1	-20.8	5.0	3546.	5.	1.2	14.	2764.6	32.	1.6	1.6	2.4	30.0

Table 4-12

PROGRAM OUTPUT: SIGNAL AND CLUTTER POWER LEVEL CALCULATIONS

TIME	SDC	SDB	SBB	CLUM	CLOS	CLO	SIGO	PHA	PHADEL	REFL	DELFC	S/(C+N)
SEC	DBM	DBM	DBM	DBM	DBM	DBM	DB	CPS	CPS		CPS	DB
0.	-69.	0.	0.	-62.	-103.	-62.	-29.	0.	0.	0.	72.	-6.6
1.0	-69.	0.	0.	-62.	-103.	-62.	-29.	14.6	0.1	0.	71.	-6.6
2.0	-69.	0.	0.	-62.	-103.	-62.	-29.	58.3	0.3	0.	71.	-6.6
3.0	-69.	0.	0.	-62.	-103.	-62.	-29.	131.9	0.4	0.	71.	-6.6
4.0	-69.	0.	0.	-62.	-103.	-62.	-29.	234.1	0.6	0.	71.	-6.6
5.0	-68.	0.	0.	-62.	-103.	-62.	-29.	367.0	0.7	0.	71.	-6.0
6.0	-68.	0.	0.	-62.	-103.	-62.	-29.	530.2	0.9	0.	71.	-6.0
7.0	-70.	0.	0.	-62.	-103.	-62.	-29.	723.6	1.0	0.	71.	-7.8
8.0	-75.	0.	0.	-63.	-103.	-63.	-29.	947.0	1.2	0.	71.	-12.2
9.0	-76.	0.	0.	-63.	-103.	-63.	-29.	1201.3	1.3	0.	71.	-13.0
10.0	-75.	0.	0.	-63.	-103.	-63.	-29.	1486.4	1.5	0.	71.	-12.1
11.0	-56.	0.	0.	-63.	-103.	-63.	-29.	1801.0	1.7	0.	71.	6.3
12.0	-76.	0.	0.	-63.	-103.	-63.	-29.	2147.2	1.8	0.	71.	-12.9
13.0	-81.	0.	0.	-63.	-103.	-63.	-29.	2524.8	2.0	0.	71.	-18.5
14.0	-64.	0.	0.	-63.	-103.	-63.	-29.	2933.9	2.1	0.	70.	-1.3
15.0	-85.	0.	0.	-63.	-103.	-63.	-29.	3374.3	2.3	0.	70.	-25.8
16.0	-73.	0.	0.	-63.	-103.	-63.	-29.	3848.1	2.4	0.	70.	-10.1
17.0	-79.	0.	0.	-63.	-103.	-63.	-29.	4353.1	2.6	0.	70.	-15.9
18.0	-87.	0.	0.	-63.	-103.	-63.	-29.	4892.5	2.8	0.	70.	-24.4
19.0	-91.	0.	0.	-63.	-103.	-103.	-29.	5465.3	2.9	0.	70.	16.6
20.0	-89.	0.	0.	-63.	-103.	-103.	-29.	6071.3	3.1	0.	70.	8.5
21.0	-88.	0.	0.	-63.	-103.	-103.	-29.	6711.8	3.3	0.	70.	9.7
22.0	-82.	0.	0.	-63.	-103.	-103.	-29.	7387.7	3.5	0.	70.	16.2
23.0	-81.	0.	0.	-63.	-104.	-104.	-29.	8098.2	3.6	0.	70.	16.4
24.0	-83.	0.	0.	-63.	-104.	-104.	-29.	8845.5	3.8	0.	70.	14.6
25.0	-80.	0.	0.	-63.	-104.	-104.	-29.	9627.4	4.0	0.	69.	18.1
26.0	-81.	0.	0.	-63.	-104.	-104.	-29.	10446.3	4.2	0.	69.	16.8
27.0	-85.	0.	0.	-63.	-104.	-104.	-29.	11301.2	4.4	0.	69.	12.7
28.0	-82.	0.	0.	-63.	-104.	-104.	-29.	12192.4	4.5	0.	69.	16.2
29.0	-77.	0.	0.	-63.	-104.	-104.	-29.	13119.9	4.7	0.	69.	21.1
30.0	-78.	0.	0.	-63.	-104.	-104.	-29.	14084.0	4.9	0.	69.	20.4
31.0	-80.	0.	0.	-63.	-104.	-104.	-29.	15081.6	5.1	0.	69.	18.3
32.0	-83.	0.	0.	-63.	-104.	-104.	-29.	16110.7	5.2	0.	69.	14.6
33.0	-85.	0.	0.	-63.	-104.	-104.	-29.	17172.7	5.4	0.	68.	12.9
34.0	-80.	0.	0.	-63.	-104.	-104.	-29.	18266.8	5.5	0.	68.	18.3
35.0	-85.	0.	0.	-63.	-104.	-104.	-29.	19394.4	5.7	0.	68.	12.4
36.0	-95.	0.	0.	-63.	-104.	-104.	-29.	20554.7	5.9	0.	68.	2.9
37.0	-87.	0.	0.	-63.	-104.	-104.	-29.	21750.2	6.1	0.	68.	10.7
38.0	-88.	0.	0.	-63.	-104.	-104.	-29.	22962.5	6.3	0.	68.	9.8
39.0	-86.	0.	0.	-63.	-104.	-104.	-29.	24252.1	6.4	0.	68.	12.2

Reliable detection of the missile, however, does not occur until 19 seconds when the detection probability equals unity. From 19 seconds until the end of the engagement the detection probability fluctuates between unity and .03. The latter probability value occurs at 36 seconds where the missile cross section drops to its smallest value of .42 square feet.

The missile is not detected reliably until 19 seconds because of the high clutter conditions. As shown in Table 4-12 the clutter power level CLO is composed of clutter echoes entering the mainlobe of the antenna until 18 seconds. After 18 seconds the clutter level decreases abruptly because at this point the clutter echoes enter via the antenna sidelobes only. Thus the airborne radar in this particular engagement cannot detect the missile in a background of mainlobe clutter, but must wait until the missile is high enough for reliable detection in sidelobe clutter.

The effect of the high mainlobe clutter return is also reflected in the signal-to-noise-plus-clutter ratio, S/(C+N) in Table 4-12. As shown the ratio is less than unity below 19 seconds and greater than unity with fairly high values above 19 seconds.

After the radar detects the missile at 19 seconds its location is determined in the search mode to an accuracy of two feet in range, 358 KHz in doppler, and four milliradians in angle. The poor doppler accuracy would force this particular radar to determine velocity by measuring the range rate. The angle accuracy of the search radar in this case is high enough for the radar to begin tracking with an angular accuracy equal to one milliradian.

4.2 Range Profile Example

The time simulation mode analyzed the performance of the airborne radar in detail in detecting and locating the missile, launched approximately 43 nautical miles from the radar. The range profile output discussed here will indicate the detection performance of the same airborne radar but this time against a simplified, generalized target.

The target for the range profile run is described by the input parameters listed in Table 4-13. As shown the target analyzed will remain at an altitude of 30,000 feet and will have a constant cross section of .1 square meters (-10 dB/square meters). The three input parameters shown are the only ones that are changed from the previous time-simulation run. They specify calculations to be performed every two nautical miles from zero to a maximum of 78 nautical miles.

The results are shown in Tables 4-14 and 4-15 in the same format used in the time simulation output except that the target range is incremented instead of the time variable. The radar itself is operating in the same mode of operation as used in time simulation run, that is, searching for the target over a 26 by 30 degree sector in one second. This produces five return pulses which are integrated by the radar to produce the detection probabilities listed in Table 4-14. The corresponding signal-to-noise-plus-clutter ratio is listed versus range in Table 4-15.

Table 4-13

PROGRAM OUTPUT: INPUT DATA FOR RANGE PROFILE RUN

STILL TARGET BOOST TRAJECTORY COORDINATES

		OOWN RANGE			ALTITUDE		
CARD	TIME	POSITION	SPEED	ACCELERATION	POSITION	SPEED	ACCELERATION
1	0.	1.0	1.0	1.00	30000.0	1.0	1.00

CONSTANT CROSS SECTION TARGET FOR RANGE PROFILE OPTION

0.	-10.0	-10.0	-10.0	-10.0	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.

I1	I2	I3	SYMBOL	NOMINAL VALUE	CONVERSION FACTOR	DEFINITION
0	-0	61	TARGOP	0.20000000E 01	0.60800000E 04	- PROGRAM 1,+ PROG 2 RANGE INCRE NM
0	-0	5	XLOIT	0.	0.60800000E 04	X-VALUE OF A/C ORIGIN ON TARG COORD,
0	-0	62	BXLOIT	0.77999999E 02	0.60800000E 04	MAX VALUE OF XLOIT IN PROGRAM 2 , NM

Table 4-14

PROGRAM OUTPUT: PROBABILITIES AND ACCURACIES VERSUS RANGE

TIME	PD1	PCUM1	PDT	PCUMT	CASE	VB	S/N	C/N	MC	F01	OOPOIF	TDIF	DELR	OELD	DELA	SIGNV	SIGNH	SIGT	ZT
SEC							DB	DB		CPS	CPS	US	FT	KCPS	MILS	MILS	MILS	MILS	KFT
0.	0.000	0.000	0.000	0.000	4.	27.	30.5	37.0	5.0	6832.	0.	0.	26.	5161.6	60.	3.0	3.0	4.3	0.
1.0	0.000	0.000	0.000	0.000	4.	27.	30.4	37.0	5.0	6802.	-29.	0.0	26.	5160.9	60.	3.0	3.0	4.3	0.0
2.0	0.000	0.000	0.000	0.000	4.	27.	30.4	36.9	5.0	6772.	-58.	0.0	26.	5160.3	60.	3.0	3.0	4.3	0.1
3.0	0.000	0.000	0.000	0.000	4.	27.	30.3	36.9	5.0	6742.	-88.	0.0	26.	5159.6	60.	3.0	3.0	4.3	0.1
4.0	0.000	0.000	0.000	0.000	4.	27.	30.3	36.8	5.0	6710.	-118.	0.0	26.	5159.0	60.	3.0	3.0	4.3	0.2
5.0	0.000	0.000	0.000	0.000	4.	27.	30.8	36.8	5.0	6680.	-148.	0.1	24.	4814.1	56.	2.8	2.8	[illegible]	0.3
6.0	0.000	0.000	0.000	0.000	4.	27.	30.8	36.8	5.0	6650.	-178.	0.1	24.	4813.5	56.	2.8	2.8	4.0	0.5
7.0	0.000	0.000	0.000	0.000	4.	27.	29.0	36.7	5.0	6607.	-209.	0.1	30.	5921.1	69.	3.4	3.4	4.9	0.7
8.0	0.000	0.000	0.000	0.000	4.	27.	24.5	36.7	5.0	6521.	-239.	0.2	49.	9825.7	114.	5.7	5.7	8.1	0.9
9.0	0.000	0.000	0.000	0.000	4.	27.	23.7	36.6	5.0	6402.	-269.	0.2	54.	10772.5	125.	6.2	6.2	8.9	1.1
10.0	0.000	0.000	0.000	0.000	4.	27.	24.5	36.6	5.0	6276.	-300.	0.3	49.	9712.4	113.	5.6	5.6	8.0	1.4
11.0	0.403	0.403	0.403	0.403	4.	27.	42.8	36.5	5.0	6139.	-331.	0.4	6.	1180.8	14.	0.7	0.7	1.3	1.6
12.0	0.000	0.403	0.000	0.403	4.	27.	23.6	36.5	5.0	5993.	-362.	0.4	54.	10766.2	125.	6.2	6.2	8.9	2.0
13.0	0.000	0.403	0.000	0.403	4.	27.	17.9	36.5	5.0	5838.	-393.	0.5	103.	20510.1	238.	11.9	11.9	16.8	2.3
14.0	0.000	0.403	0.000	0.403	4.	27.	35.1	36.4	5.0	5675.	-425.	0.6	14.	2831.8	33.	1.6	1.6	2.5	2.7
15.0	0.000	0.403	0.000	0.403	4.	27.	10.5	36.4	5.0	5507.	-457.	0.7	238.	47531.5	551.	27.5	27.5	39.0	3.1
16.0	0.000	0.403	0.000	0.403	4.	27.	26.2	36.3	5.0	5333.	-489.	0.8	39.	7798.2	90.	4.5	4.5	6.5	3.5
17.0	0.000	0.403	0.000	0.403	4.	27.	20.4	36.3	5.0	5156.	-522.	0.9	76.	15199.6	176.	8.8	8.8	12.5	4.0
18.0	0.000	0.403	0.000	0.403	4.	27.	11.9	36.3	5.0	4971.	-556.	1.0	202.	40325.7	467.	23.4	23.4	33.1	4.5
19.0	1.000	1.000	1.000	1.000	4.	27.	18.0	-4.2	5.0	4777.	-589.	1.1	2.	358.1	4.	0.2	0.2	0.9	5.1
20.0	0.817	1.000	0.817	1.000	4.	27.	9.9	-4.2	5.0	4573.	-624.	1.2	5.	914.2	11.	0.5	0.5	1.1	5.6
21.0	0.937	1.000	0.937	1.000	4.	27.	11.1	-4.3	5.0	4359.	-658.	1.3	4.	792.9	9.	0.5	0.5	1.1	6.2
22.0	1.000	1.000	1.000	1.000	4.	27.	17.6	-4.3	5.0	4135.	-693.	1.5	2.	374.5	4.	0.2	0.2	0.9	6.9
23.0	1.000	1.000	1.000	1.000	4.	27.	17.8	-4.3	5.0	3902.	-729.	1.6	2.	367.1	4.	0.2	0.2	0.9	7.5
24.0	1.000	1.000	1.000	1.000	4.	27.	15.9	-4.3	5.0	3660.	-764.	1.8	2.	452.5	5.	0.3	0.3	0.9	8.2
25.0	1.000	1.000	1.000	1.000	4.	27.	19.4	-4.4	5.0	3407.	-801.	1.9	2.	302.8	4.	0.2	0.2	0.9	9.0
26.0	1.000	1.000	1.000	1.000	4.	27.	18.1	-4.4	5.0	3148.	-837.	2.1	2.	351.9	4.	0.2	0.2	0.9	9.7
27.0	0.999	1.000	0.999	1.000	4.	27.	14.0	-4.4	5.0	2881.	-873.	2.3	3.	563.8	7.	0.3	0.3	1.0	10.6
28.0	1.000	1.000	1.000	1.000	4.	27.	17.5	-4.4	5.0	2607.	-910.	2.4	2.	377.5	4.	0.2	0.2	0.9	11.4
29.0	1.000	1.000	1.000	1.000	4.	27.	22.4	-4.4	5.0	2328.	-946.	2.6	1.	214.4	2.	0.1	0.1	0.9	12.3
30.0	1.000	1.000	1.000	1.000	4.	27.	21.7	-4.5	5.0	2047.	-981.	2.8	1.	232.5	3.	0.1	0.1	0.9	13.2
31.0	1.000	1.000	1.000	1.000	4.	27.	19.6	-4.5	5.0	1768.	-1014.	3.0	1.	296.6	3.	0.2	0.2	0.9	14.1
32.0	1.000	1.000	1.000	1.000	4.	27.	15.9	-4.5	5.0	1492.	-1046.	3.2	2.	453.3	5.	0.3	0.3	0.9	15.1
33.0	0.999	1.000	0.999	1.000	4.	27.	14.2	-4.5	5.0	1211.	-1078.	3.4	3.	551.7	6.	0.3	0.3	1.0	16.1
34.0	1.000	1.000	1.000	1.000	4.	27.	19.6	-4.5	5.0	921.	-1110.	3.7	1.	296.1	3.	0.2	0.2	0.9	17.1
35.0	0.998	1.000	0.998	1.000	4.	27.	13.7	-4.5	5.0	622.	-1143.	3.9	3.	581.7	7.	0.3	0.3	1.0	18.2
36.0	0.030	1.000	0.030	1.000	4.	27.	4.2	-4.5	5.0	312.	-1178.	4.1	9.	1734.9	20.	1.0	1.0	1.7	19.3
37.0	0.980	1.000	0.980	1.000	4.	27.	12.1	-4.5	5.0	-9.	-1214.	4.4	4.	704.8	8.	0.4	0.4	1.0	20.4
38.0	0.940	1.000	0.940	1.000	4.	27.	11.1	-4.5	5.0	-342.	-1251.	4.6	4.	788.7	9.	0.5	0.5	1.1	21.5
39.0	0.997	1.000	0.997	1.000	4.	27.	13.5	-4.5	5.0	-687.	-1290.	4.9	3.	594.7	7.	0.3	0.3	1.0	22.7

Table 4-15

PROGRAM OUTPUT: SIGNAL AND CLUTTER POWER LEVELS VERSUS RANGE

RANGE	SDD	SD8	SBB	CLOM	CLOS	CLO	SIGO	PHA	PHADEL	REFL	DELFC	S/(C+N)
N MI	DBM	DBM	DBM	DBM	DBM	DBM	DB	CPS	CPS		CPS	DB
0.	-45.	0.	0.	-22.	-62.	-62.	-22.	101670.3	-0.0	0.	41.	16.8
2.0	-48.	0.	0.	-25.	-65.	-65.	-23.	93542.7	-2.0	0.	96.	17.0
4.0	-53.	0.	0.	-30.	-70.	-70.	-24.	77902.8	-2.2	0.	123.	17.2
6.0	-58.	0.	0.	-35.	-75.	-75.	-25.	63697.6	-1.8	0.	134.	17.3
8.0	-62.	0.	0.	-39.	-79.	-79.	-26.	52748.2	-1.4	0.	140.	17.3
10.0	-65.	0.	0.	-42.	-83.	-83.	-27.	44541.5	-1.0	0.	142.	17.3
12.0	-68.	0.	0.	-45.	-86.	-86.	-28.	38325.2	-0.8	0.	144.	17.2
14.0	-71.	0.	0.	-48.	-88.	-88.	-28.	33517.8	-0.6	0.	145.	17.1
16.0	-73.	0.	0.	-50.	-91.	-91.	-29.	29717.2	-0.5	0.	145.	16.9
18.0	-75.	0.	0.	-52.	-93.	-93.	-30.	26650.5	-0.4	0.	146.	16.6
20.0	-77.	0.	0.	-54.	-94.	-94.	-30.	24130.5	-0.3	0.	146.	16.3
22.0	-78.	0.	0.	-56.	-96.	-96.	-30.	22026.5	-0.3	0.	146.	15.8
24.0	-80.	0.	0.	-57.	-98.	-98.	-31.	20245.1	-0.2	0.	147.	15.3
26.0	-81.	0.	0.	-59.	-99.	-99.	-31.	18718.4	-0.2	0.	147.	14.7
28.0	-83.	0.	0.	-60.	-100.	-100.	-32.	17396.0	-0.2	0.	147.	14.1
30.0	-84.	0.	0.	-61.	-101.	-101.	-32.	16239.5	-0.2	0.	147.	13.4
32.0	-85.	0.	0.	-62.	-103.	-103.	-32.	15219.8	-0.1	0.	147.	12.7
34.0	-86.	0.	0.	-63.	-104.	-104.	-33.	14313.8	-0.1	0.	147.	11.9
36.0	-87.	0.	0.	-64.	-105.	-105.	-33.	13503.5	-0.1	0.	147.	11.2
38.0	-88.	0.	0.	-65.	-106.	-106.	-33.	12774.3	-0.1	0.	147.	10.5
40.0	-89.	0.	0.	-66.	-107.	-107.	-33.	12114.6	-0.1	0.	147.	9.7
42.0	-90.	0.	0.	-67.	-108.	-108.	-34.	11514.7	-0.1	0.	147.	9.0
44.0	-90.	0.	0.	-68.	-108.	-108.	-34.	10966.7	-0.1	0.	147.	8.3
46.0	-91.	0.	0.	-69.	-109.	-109.	-34.	10464.1	-0.1	0.	147.	7.5
48.0	-92.	0.	0.	-70.	-110.	-110.	-34.	10001.3	-0.1	0.	147.	7.0
50.0	-93.	0.	0.	-70.	-111.	-111.	-35.	9573.7	-0.1	0.	147.	6.3
52.0	-93.	0.	0.	-71.	-112.	-112.	-35.	9177.2	-0.1	0.	147.	5.7
54.0	-94.	0.	0.	-72.	-112.	-112.	-35.	8808.5	-0.0	0.	147.	5.1
56.0	-95.	0.	0.	-73.	-113.	-113.	-35.	8464.8	-0.0	0.	147.	4.5
58.0	-95.	0.	0.	-73.	-114.	-114.	-36.	8143.3	-0.0	0.	147.	3.9
60.0	-96.	0.	0.	-74.	-114.	-114.	-36.	7842.0	-0.0	0.	147.	3.3
62.0	-96.	0.	0.	-75.	-115.	-115.	-36.	7559.0	-0.0	0.	147.	2.8
64.0	-97.	0.	0.	-75.	-116.	-116.	-36.	7292.5	-0.0	0.	148.	2.2
66.0	-97.	0.	0.	-76.	-116.	-116.	-37.	7041.1	-0.0	0.	148.	1.7
68.0	-98.	0.	0.	-76.	-117.	-117.	-37.	6803.5	-0.0	0.	148.	1.2
70.0	-98.	0.	0.	-77.	-118.	-118.	-37.	6578.4	-0.0	0.	148.	0.7
72.0	-99.	0.	0.	-78.	-118.	-118.	-37.	6365.4	-0.0	0.	148.	0.2
74.0	-99.	0.	0.	-78.	-119.	-119.	-37.	6162.6	-0.0	0.	148.	-0.2
76.0	-100.	0.	0.	-79.	-119.	-119.	-38.	5969.6	-0.0	0.	148.	-0.7
78.0	-100.	0.	0.	-80.	-120.	-120.	-38.	5785.7	-0.0	0.	148.	-1.1

The detection probability PD1 and signal-to-noise-plus-clutter ratio are generally the most important quantities in the range profile option and are therefore plotted with the CALCOMP plotter as shown in Figure 4-1 and 4-2. These figures indicate that the airborne radar would reliably detect a .1 square meter target at an altitude of 30,000 feet out to a range of about 40 nautical miles. The target altitude of 30,000 feet is significant in that the clutter returns enter the receiver via the antenna sidelobes. If the target was much lower in altitude the clutter would be in the mainlobe of the antenna which would preclude target detection.

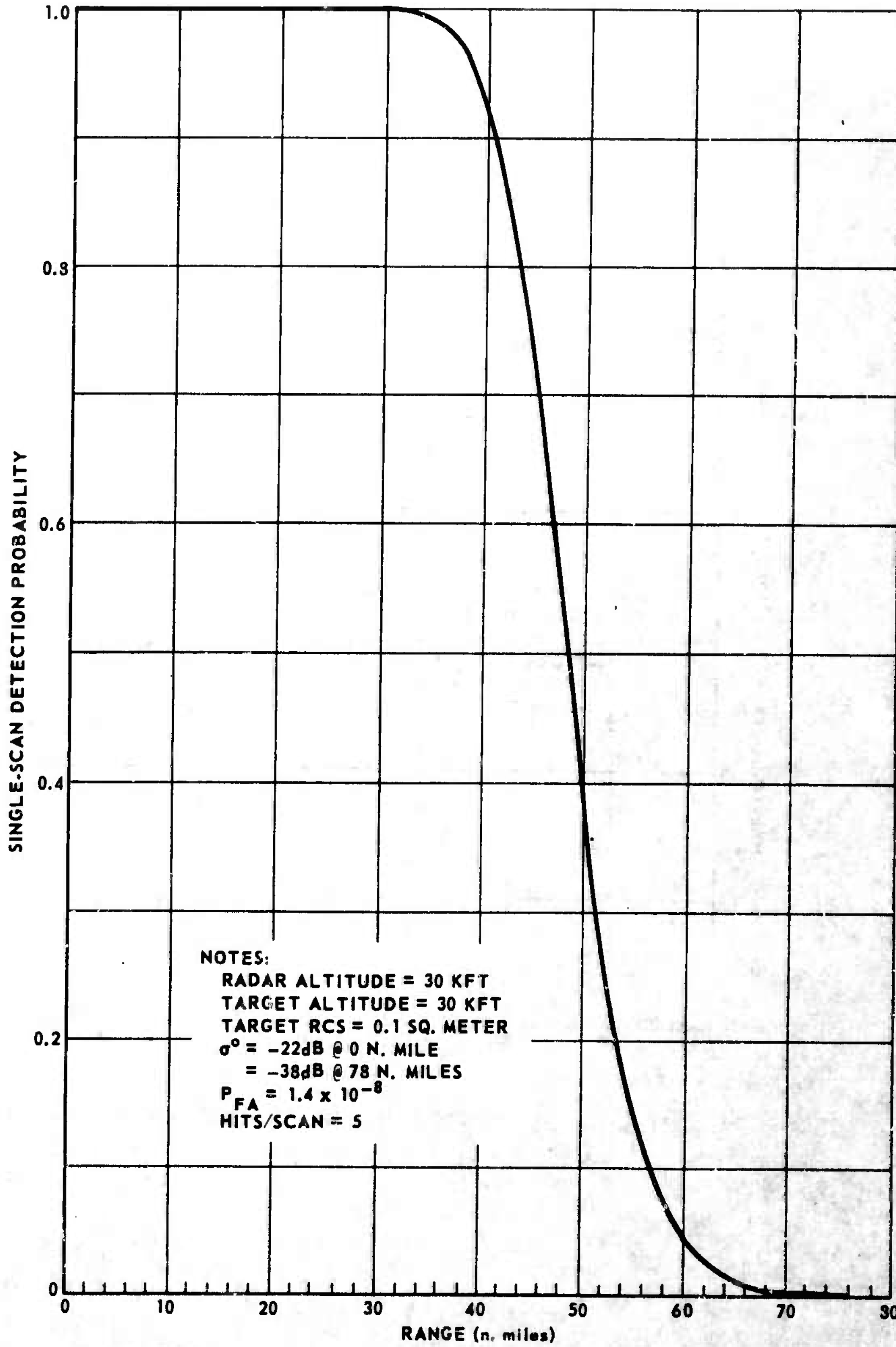

Fig. 4-1 DETECTION PROBABILITY VERSUS RANGE

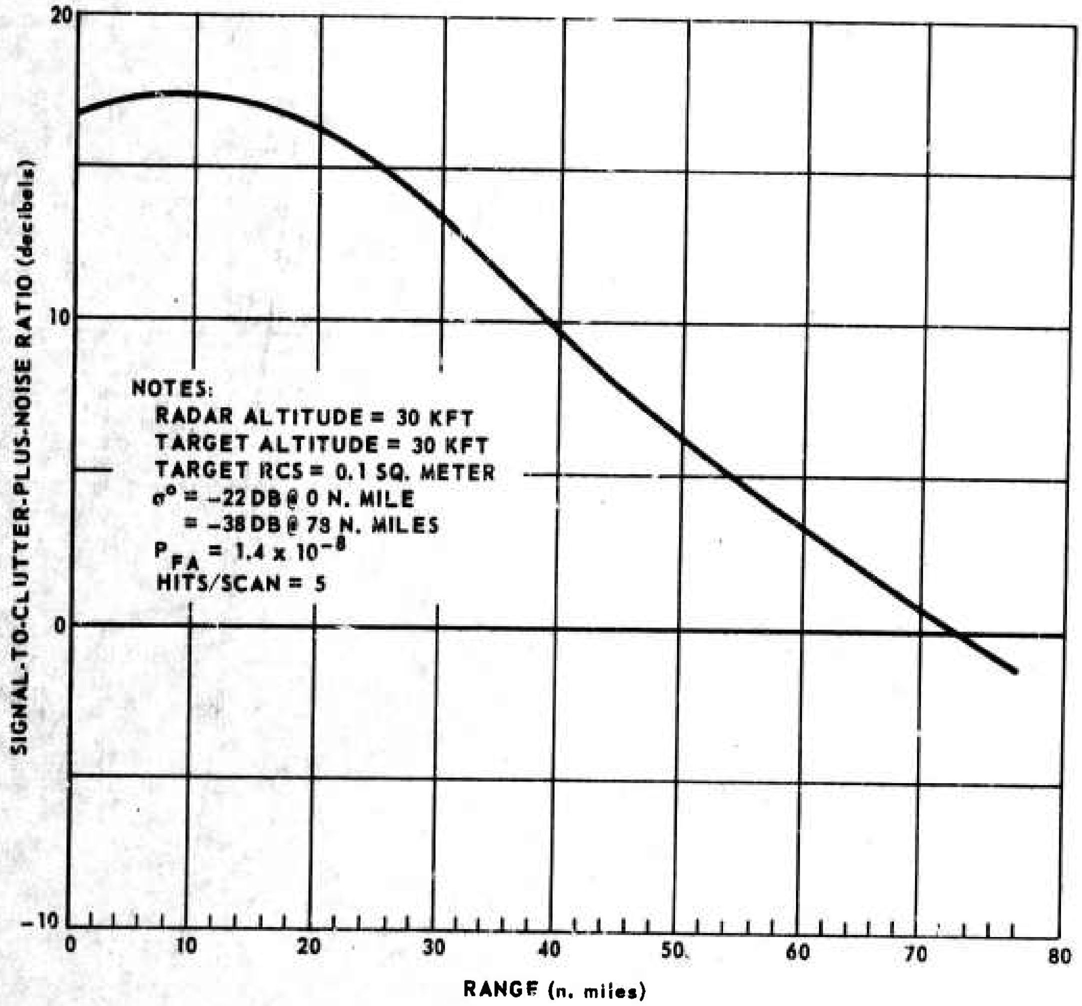

Fig. 4–2 SIGNAL-TO-CLUTTER-PLUS-NOISE RATIO VERSUS RANGE

V. SUMMARY AND CONCLUSIONS

The digital computer program for radar analysis and simulation has been described. In this chapter some of the highlights will be summarized and some areas for future development will be discussed.

5.1 Summary

The report started with a description of the basic radar problem to be analyzed in this study: the detection, acquisition and tracking performance of a generalized radar against a single moving target in a clutter environment. Chapters II through IV described the program inputs, the processing, and the program outputs, respectively. Chapter II on inputs described the manner in which the radar problem is defined by the user. A flexible but detailed arrangement was indicated for describing target motion, target cross section, initial radar-to-target geometry, radar characteristics, clutter and noise environment, and program options. Any of the input parameters may be changed for performing multiple runs on any one job.

The processing or calculations performed by the program, as described in Chapter III, were shown to be arranged as a time simulation of the radar-target engagement. The geometry calculations are performed with vector algebra permitting an accurate simulation of the radar and target motion, and calculation of the pertinent geometrical quantities between the radar, clutter, and reflection points. The radar calculations are performed each time step yielding signal-to-noise ratios, clutter characteristics, and search and tracking accuracies. The detection probabilities are calculated for many target and noise models, and include the cumulative detection probabilities. A program option permits the target model to be greatly simplified for performing radar comparisons with the target motion and cross section held constant.

A few samples of the program's output were presented in Chapter IV. In the time simulation mode the output is arranged as a function of time with calculations being made every time the radar antenna scans past the target. The output parameters are quite extensive and include: single-scan and cumulative detection probabilities for the direct and surface-reflected signals; search accuracies in range, doppler, and angle; angular tracking accuracies; clutter statistics and power levels; cross section variations; signal-to-noise ratios; and many geometrical parameters.

In the range profile mode the target's motion and cross section are held invariant to permit comparisons of radar performance. The target model is grossly oversimplified in this mode which is necessary to analyze the performance of a radar, or radars, for a broad range of target cross sections, target statistics, clutter conditions, and distances from the radar. That is, the boundaries of the radar's performance can be found by operating in the range profile mode with calculations being made for all probable cross section values, clutter conditions, etc., without regard to one particular radar-target engagement.

Thus, the range-profile mode is used for calculating general radar performance, while the time-simulation mode is for detailed radar performance.

The actual program was written in FORTRAN II in a manner to achieve considerable flexibility and growth capability. This was accomplished by dividing the program into 22 subroutines controlled by one main program. Thus, if any changes are required, or desired, they may be inserted into the subroutine in which they apply without affecting the status of the other subroutines.

5.2 Areas for Future Development

The program as it now exists is a fairly complete representation of the radar-target engagement. There are some areas, however, which deserve future attention; some of these were indicated in previous chapters.

Antenna. There are two antenna characteristics that are simplified in the present program that could be changed to achieve a more accurate representation of an actual antenna. They are the antenna beam pattern and the antenna beam motion.

Presently, the antenna beam pattern has a constant mainlobe gain over the solid angle defined by the half power points, and a constant sidelobe gain for all other angles. In the future, it may be desirable to modify the radar-calculation subroutine, or add an additional subroutine, to incorporate antenna gain variations with angle.

The motion of the antenna beam is presently arranged to scan the given angular sector in the allotted scan time with the target assumed to be in the center of the sector. A more accurate representation of the antenna beam motion can be incorporated by having the antenna beam follow a predetermined scan pattern starting from an initial position specified on the input or chosen randomly by Monte Carlo techniques. This method would change the time increment of the output. That is, the calculations of the radar detection probabilities would be performed only at those times in which the target is in the antenna beam. This may, or may not, occur once each sector-scan time as in the current program.

Acquisition Mode. Presently the transition from the search mode to the tracking mode is assumed to occur instantaneously. This somewhat unrealistic assumption can be corrected by calculating the time required to point the antenna at the target. The calculation can be programmed using techniques by Barton[1] and quantities available in the present program; namely, the time required to scan the search sector, the ratio between the size of the search sector and the tracking beam, and the signal-to-noise ratio.

Jamming. The present program does not consider jamming. However, radar performance in the presence of certain types of jamming, such as wide-band noise jammers, could be added in a straightforward manner by modifying the signal-to-clutter-plus-noise ratio to include the noise power received from a jammer.

[1] D. K. Barton, Radar System Analysis, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1964, Section 14.2.

Other Areas. There are evidently other areas of the program that could be improved or other simulations that could be added, to represent more accurately the real situation. Some of these areas are an improved simulation of the tracking mode, clutter model for land (sea clutter model and rain clutter already included), multiple target detection, sequential detection, and target motion not confined to a vertical plane.

APPENDIX A

LITERATURE REVIEW

The literature was searched for digital computer programs and radar simulation techniques applicable to this study. The pertinent literature can be conveniently grouped into the following categories: war game simulations, computer programs for radar analysis, and detection-probability algorithms.

War Game Simulations. Numerous programs exist which simulate the radar only to the extent of determining the outcome of a war game. Examples of war game simulations involving radars are programs written by Andrus[1], and Kennard[2]. The program by Andrus is designed to simulate the interactions between surface-to-air missile systems and aircraft. The different events of the game are assigned probability values and during the operation of the program the occurrence of an event is determined by comparing the given probability with an internally generated random number. The gross parameters of the system are fed into the program along with the number and positions of the aircraft. The program determines missile firing doctrines, optimum number and placement of the radars, and target kill probabilities.

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[1] A. F. Andrus, "A Computer Simulation for the Evaluation of Surface-to-Air Missile Systems in a Clear Environment," Naval Postgraduate School, TR/RP No. 67, June 1966.

[2] P. H. Kennard, "Effectiveness Studies of Manned Airborne Weapon Systems by Digital Simulation". Abstract: Instruments and Control System, vol. 32 (July, 1961), pp. 2171-1272.

These types of war game simulations are considerably different from the simulation in the Radar Analysis Program. The only radar parameters involved in the Andrus[3] program are the search radar maximum range, the probability of detecting a target, and the time required to acquire a target with the tracking radar. These are performance parameters of a radar and in the Radar Analysis Program they are calculated, as opposed to being provided as inputs in war game simulations.

Computer Programs for Radar Analysis. Three programs were found. They will be discussed in order of their increasing similarity to the Radar Analysis Program.

The first program by White and James[4] is an example of how a digital computer program can be used to simulate or model a radio communication system, which is in many ways similar to a radar system. Their specific problem was to model the transmitter, receiver, and atmospheric phenomena in order to study interference problems. This involved deriving mathematical equations to describe the operations of each significant parameter of the transmitter, receiver, and propagation phenomena. Some of the techniques which are used for modeling the antenna gain pattern and the propagation phenomena are the same as those used for the radar case and can be incorporated into the Radar Analysis Program if desired.

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[3] Andrus, op. cit., p. 4.

[4] D. R. J. White and W. G. James, "Digital Computer Simulation for Prediction and Analysis of Electromagnetic Interference," IRE Transactions on Communications Systems, vol. CS-9 no. 2, (June, 1961), pp. 148-159.

In the second example of a program for radar analysis, Wan briefly describes a completely analytical approach to a radar program that he says will be developed.[5] Wan's technique is to isolate parts of the problem, such as, the transmitter, receiver, antenna, noise power, weather, and target and to write a mathematical model of each in signal-space notation. The transmitter, for example, can be modeled strictly in the signal or frequency domain by representing it by the Fourier transform of the transmitted time waveform. The model for the target, on the other hand, is described in both signal and space notation; the cross section as a function of the transmitted frequency describes the target in the signal (or frequency) domain, while the range of the target from the radar describes the target in the space domain. These mathematical models, or transfer functions, of the different parts of the problem are combined to simulate a particular radar-target engagement. For example, if the radar is to operate in rain the transfer function which synthesizes the rain would be included.

The last program discussed in this section has the most similarity to the Radar Analysis Program. This program, by Boothe, is used to determine the performance of an acquisition radar through application of radar detection probability theory.[6] Both programs

[5] L.A. Wan, "Tactical System Radar Signal-Space Model," Ninth Conference on Military Electronics, September 22-24, 1965, sponsored by IEEE, pp. 13-17.

[6] R. R. Boothe, "A Digital Computer Program for Determining the Performance of an Acquisition Radar through Application of Radar Detection Probability Theory," Advanced Systems Laboratory, U. S. Army Missile Command, No. RD-TR-64-2, December 31, 1964.

are arranged as time simulations of a single radar, single target engagement. In addition both programs simulate the target motion and cross section by means of external input for maximum flexibility and use the standard radar equation for calculating signal-to-noise ratio. Some of the notable differences between the Boothe program and the Radar Analysis Program are in the calculation of the noise power from all sources and in the calculation of the detection probability. The Boothe program ignores clutter but does have an option for including jammer noise. The Boothe program incorporates a detection theory developed by Marcum[7] in 1947 which is a method for calculating the detection probability for a constant cross section target in a background of receiver noise. In 1960 Marcum in conjunction with Swerling extended the theory to include fluctuating targets.[8] This theory is used in the Radar Analysis Program in a computer program developed by Fehlner.[9]

Target Detection Programs. Two other sources were found which contain digital computer programs for calculating detection probability. Both of these programs use Marcum and Swerling detection theory.

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[7] J. I. Marcum, "A Statistical Theory of Target Detection by Pulsed Radar," The Rand Corporation, RM-754, December 1, 1947.

[8] J. I. Marcum and P. Swerling, "Studies of Target Detection by Pulsed Radar," Institute of Radio Engineers Transactions on Information Theory, Vol. IT-6, (April 1960).

[9] L. F. Fehlner, "Marcum's and Swerling's Data on Target Detection by Pulsed Radar," The Johns Hopkins University Applied Physics Laboratory, TG-451, July 2, 1962.

The first program, by Kirkwood, calculates the cumulative detection probability for targets approaching a scanning radar.[10] In Kirkwood's program only two out of the four Marcum-Swerling target models are used, and the single scan detection probabilities are not available. The program is available in the reference and is written in FORTRAN.

The other computer program for calculating detection probability, developed by Nolen, et al.,[11] is very similar to the work performed by Fehlner. Both of these programs were produced for the prime purpose of generating a set of general charts to be used by radar analysts for calculating the detection probability manually. The programs were run for a large number of cases to cover most conditions. The charts produced by the Nolen program, however, are only available for 20 integrated pulses while Fehlner's charts are available for up to 3000 integrated pulses. The program developed by Fehlner was arranged in a subroutine and is the main detection probability algorithm in the Radar Analysis Program.

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[10] P. K. Kirkwood, "Radar Cumulative Detection Probabilities for Radial and Nonradian Target Approaches," The Rand Corporation, RM 46[illegible]3-PR, September 1965.

[11] J. C. Nolen, et al.,"Statistics of Radar Detection," The Bendix Corporation, Baltimore, Maryland, February 1966.

APPENDIX B

RADAR ANALYSIS PROGRAM IN FORTRAN

Table B-1

SUBROUTINE NAMES IN PROGRAM LISTING

	Section No.
MAINP	1.0
TARGIN	1.1
CROSIN	1.2
GEOM	2.0
TARGET	2.1
AIRCFT	2.2
UNIT	2.3
CROSS	2.4
TRIAD	2.5
MULT	2.6
DOT	2.7
ANGLE	2.8
RATSCT	2.9
DAVE	3.0
EDDIE	4.0
PFA(f)	4.1
PFAC(f)	4.2
MARCUM	4.3
DGAM(f)	4.3.1
DEVAL(f)	4.3.2
GAM(f)	4.3.3
EVAL(f)	4.3.4
SUMLOG(f)	4.3.5

(f) Function Subroutine

```
1.0
CRADAR
C                    RADAR ANALYSIS PROGRAM
      DIMENSION D(6)
      DIMENSION GPR(10)
      DIMENSION XXAX(2), YXAX(2), XYAX(2), YYAX(2)
      DIMENSION XPH(2), YPH(2), XPV(2), YPV(2)
      DIMENSION EPH(322,6),CROSEC(1801,2),GT(80,32),H(80,40),COM(100)
      COMMON TIME,KSTEP,KHT,EPH,CROSEC,GT,H,COM
      NDIM = 80
      DO 5 I=1,100
    5 COM(I) = 0.
      KEND = 1
      ENDPLT = (+6HENDPLT)
      KHED = 0
      CALL TARGIN(TMAX)
      CALL CROSIN
    9 READ INPUT TAPE 5,12,NDUMA,NDUMB,KC,SYM,A,B,(D(I),I=1,6)
   12 FORMAT (I1,I2,I3,A6,2E15.8,6A6)
      IF(NDUMA) 101,102,101
  101 CALL TARGIN(TMAX)
  102 IF(NDUMB) 103,104,103
  103 CALL CROSIN
      GO TO 9
  104 IF(NDUMA) 9,105,9
  105 IF(KC) 15,15,106
  106 IF(KHED) 13,107,13
  107 WRITE OUTPUT TAPE 6,10
   10 FORMAT (1H1 54X 22HALBIS INPUT PARAMETERS //18H I1 I2  I3  SYMBOL
     1          7X 13HNOMINAL VALUE 3X 17HCONVERSION FACTOR 8X
     2          10HDEFINITION ///)
      KHED = 1
   13 WRITE OUTPUT TAPE 6,14,NDUMA,NDUMB,KC,SYM,A,B,(D(I),I=1,6)
   14 FORMAT (2X,I1,I3,I4,2X,A6,2E20.8,2X,6A6)
      COM(KC) = A*B
      GO TO 9
   15 CONTINUE
      IF(SYM-ENDPLT) 17,16,17
   16 KEND = 2
   17 KHED = 0
      KHT = 0
      COM(31) = COM(2)*COSF(COM(3))*COSF(COM(4))
      COM(32) = COM(2)*COSF(COM(3))*SINF(COM(4))
      COM(33) = COM(2)*SINF(COM(3))
      COM(34) = SINF(COM(10))
      COM(35) = COSF(COM(10))
      IF(COM(61)) 28,28,18
   18 TIME = TMAX
      SNAME = (+5HRANGE)
      TNAME = (+4HN MI)
      NHT = (COM(62)-COM(5))/COM(61) + 1.01
      NREM = NHT
   19 IF(NREM-NDIM) 21,21,22
   21 NSTEP = NREM
      NREM = 0
      GO TO 23
   22 NSTEP = NDIM
      NREM = NREM-NDIM
   23 DO 20 K=1,NSTEP
```

```
      COM(63) = COM(61)*FLOATF(KHT) + COM(5)
      KSTEP = K
      KHT = KHT+1
      CALL GEOM
      CALL DAVE
      CALL EDDIE
   20 H(K,1) = COM(63)/6080.
      NL = 4
      GO TO 301
   26 COM(63) = COM(5)
      SNAME = (+4HTIME)
      TNAME = (+3HSEC)
      HTSS = COM(29)
      NHT = MIN1F(TMAX,COM(60)-COM(65))/HTSS + 1.01
      NREM = NHT
   29 IF(NREM-NDIM) 31,31,32
   31 NSTEP = NREM
      NREM = 0
      GO TO 33
   32 NSTEP = NDIM
      NREM = NREM-NDIM
   33 DO 30 K=1,NSTEP
      TIME = HTSS*FLOATF(KHT) + COM(65)
      KSTEP = K
      KHT = KHT+1
      CALL GEOM
      CALL DAVE
   30 CALL EDDIE
C
C     ALBIS OUTPUT
C
      NL = 1
  301 LT = 1
  302 LP = 0
      GO TO (401,402,403,303,304),NL
  401 WRITE OUTPUT TAPE 6,801
      GO TO 305
  402 WRITE OUTPUT TAPE 6,802
      GO TO 305
  403 WRITE OUTPUT TAPE 6,803
      GO TO 305
  303 WRITE OUTPUT TAPE 6,390,SNAME,TNAME
      GO TO 305
  304 WRITE OUTPUT TAPE 6,391,SNAME,TNAME
  305 LL = 0
  355 KG = LT
      GO TO (501,502,503,306,307),NL
  501 WRITE OUTPUT TAPE 6,901,GT(KG,1),(GT(KG,I),I=6,11),GT(KG,23),
     1                          GT(KG,24)
      GO TO 306
  502 GPR(1) = GT(KG,2)
      GPR(2) = GT(KG,4)
      GPR(3) = GT(KG,5)
      GPR(4) = GT(KG,3)
      GPR(5) = GT(KG,12)
      GPR(6) = GT(KG,13)
      GPR(7) = GT(KG,28)
      DO 5502 I=1,7
 5502 GPR(I) = GPR(I)*57.2957795
```

```
      WRITE OUTPUT TAPE 6,902,GT(KG,1),(GPR(I),I=1,7)
      GO TO 308
  503 DO 5503 I=1,3
 5503 GPR(I) = GT(KG,I+13)*57.2957795
      WRITE OUTPUT TAPE 6,903,GT(KG,1),(GPR(I),GT(KG,I+16),GT(KG,I+19),
     1                                  I=1,3)
      GO TO 308
  306 WRITE OUTPUT TAPE 6,392,(H(LT,I),I=1,20)
      GO TO 308
  307 WRITE OUTPUT TAPE 6,393,H(LT,1),(H(LT,I),I=21,32)
  308 LT = LT+1
      IF(LT-NSTEP) 309,309,312
  309 LP = LP+1
      IF(LP-40) 310,302,302
  310 LL = LL+1
      IF(LL-5) 355,311,311
  311 WRITE OUTPUT TAPE 6,394
      GO TO 305
  312 NL = NL+1
      IF(NL-5) 301,301,314
  314 CONTINUE
  801 FORMAT (5H1TIME 7X 1HR 14X 2HR1 13X 2HR2 12X 4HRDOT 10X 5HR1DOT
     1          10X 5HR2DOT 11X 4HTDIR 11X 4HDELT /5H0 SEC 7X 2HFT 13X
     2          2HFT 13X 2HFT 11X 6HFT/SEC 9X 6HFT/SEC 9X 6HFT/SEC 10X
     3          3HSEC 12X 3HSEC //)
  802 FORMAT (55H1TIME    ELAAT     ELAAB      ELAAC      AZAAT     ALPHAB
     1          19H  ALPHAC   THETA(1) /5H0 SEC 4X 7(3HDEG 7X) //)
  803 FORMAT (55H1TIME  ALP(1)    SIG(1,1)  SIG(1,2)   ALP(2)    SIG(2,1)
     1          59H SIG(2,2)    ALP(3)    SIG(3,1)  SIG(3,2) /5H0 SEC
     2          3(4X 3HDEG 6X 5HSQ FT 5X 5HSQ FT 2X) //)
  390 FORMAT (1H1 A6,48HPDT   PCUMT   PDT   PCUMT   CASE   VB     S/N    C/N
     1          55H  MC         FDI    DOPDIF  TDIF   DELR     DELD  DELA  SIGNV
     2          19H  SIGNH  SIGT     ZT /1H0 A6,36X,2HDB 5X 2HDB 13X 3HCPS
     3          5X 3HCPS 4X 2HUS 4X 2HFT 5X
     4          37HKCPS  MILS  MILS    MILS    MILS     KFT //)
  391 FORMAT (1H1 A6,48H SDD      SCB      SBB    CLOM    CLUS     CLO    SIGO
     1          36H       PHA PHADEL   REFL    DELFC S/(C+N)   //
     2          1H0 A6,48H DBM      DBM      DBM     DBM     DBM      DBM     DB
     3          34H      CPS    CPS             CPS      DB      // )
  901 FORMAT (1H  F5.1,8E15.6)
  902 FORMAT (1H  F5.1,F9.2,6F10.2)
  903 FORMAT (1H  F5.1,F8.2,8F10.2)
  392 FORMAT (1H  F5.1,4F6.3,F4.0,F6.0,3F7.1,F9.0,F8.0,F5.1,F6.0,F8.1,
     1          F6.0,4F7.1)
  393 FORMAT (1H  F5.1,F6.0,6F7.0,F9.1,F7.1,F6.3,F8.0,F7.1)
  394 FORMAT (1H  )
      IF(CCM(59)) 888,891,888
  888 DO 889 K=1,NSTEP
      GT(K,20) = 10.*LOG10F(GT(K,20)/10.76387)
  889 GT(K,14) = GT(K,14)*57.2957795
      PUNCH 890,(GT(K,1),GT(K,14),GT(K,20),K=1,NSTEP)
  890 FORMAT (//(F6.1,F9.1,F10.1))
  891 CONTINUE
C
C     PLOTTING FOR VERSION II.
C
      IF(CCM(61)) 90,90,700
  700 DO 710 K=1,NSTEP
      H(K,2) = H(K,2)*10.
```

```
710 H(K,32) = (H(K,32)+20.)/5.
    XMAX = COM(62)/6080.
    DELTAX = XMAX/6.5
    ZEROX = -DELTAX
    XYAX(1) = 0.
    XYAX(2) = 0.
    YYAX(1) = 0.
    YYAX(2) = 10.
    XXAX(1) = XMAX
    XXAX(2) = 0.
    XPH(1) = -DELTAX/10.
    XPH(2) = DELTAX/10.
    DX1 = -.1*DELTAX
    DX2 = -.2*DELTAX
    DX3 = -.3*DELTAX
    DX4 = -.4*DELTAX
    DX5 = -.5*DELTAX
    NPV = COM(62)/COM(61) + .01
    CALL PLINI (-1,6HDWHITE,-6,3,DX4,1,ZEROX,DELTAX,XMAX,9.9,1,3H1.0)
    CALL PLALP (-6,2,DX3,7.9,2H.8)
    CALL PLALP (-6,2,DX3,5.9,2H.6)
    CALL PLALP (-6,2,DX3,3.9,2H.4)
    CALL PLALP (-6,2,DX3,1.9,2H.2)
    CALL PLALP (-6,1,DX1,-.1,1H0)
    CALL PLFUN (2,0,XYAX,2,YYAX,1,1)
    DO 720 I=1,10
    YPH(1) = 10.-FLOATF(I-1)
    YPH(2) = YPH(1)
720 CALL PLFUN (2,0,XPH,2,YPH,1,1)
    DO 725 I=1,NPV
    XPV(1) = COM(61)*FLOATF(I)/6080.
    XPV(2) = XPV(1)
    IF(XMODF(I,5)) 721,722,721
721 YPV(1) = -.05
    GO TO 723
722 TEMP = FPBCDF(XPV)
    YPV(1) = -.1
    CALL PLALP (-4,6,XPV+DX5,-.25,TEMP)
723 YPV(2) = -YPV(1)
    CALL PLFUN (2,0,XPV,2,YPV,1,1)
725 CONTINUE
    YXAX(1) = 0.
    YXAX(2) = 0.
    CALL PLFUN(2,0,XXAX,2,YXAX,1,1)
    CALL PLFUN (2,0,H(1,1),NSTEP,H(1,2),1,1)
    CALL PLEND (1)
    CALL PLINI (-1,6HDWHITE,-6,2,DX3,1,ZEROX,DELTAX,XMAX,9.9,1,2H30)
    CALL PLALP (-6,2,DX3,7.9,2H20)
    CALL PLALP (-6,2,DX3,5.9,2H10)
    CALL PLALP (-6,1,DX2,3.9,1H0)
    CALL PLALP (-6,3,DX4,1.9,3H-10)
    CALL PLALP (-6,3,DX4,-.1,3H-20)
    CALL PLFUN (2,0,XYAX,2,YYAX,1,1)
    DO 730 I=1,11
    YPH(1) = 10.-FLOATF(I-1)
    YPH(2) = YPH(1)
730 CALL PLFUN (2,0,XPH,2,YPH,1,1)
    DO 735 I=1,NPV
    XPV(1) = COM(61)*FLOATF(I)/6080.
```

```
      XPV(2) = XPV(1)
      IF(XMODF(I,5)) 731,732,731
  731 YPV(1) = 3.95
      GO TO 733
  732 TEMP = FPBCDF(XPV)
      YPV(1) = 3.9
      CALL PLALP (-4,0,XPV+DX5,3.75,TEMP)
  733 YPV(2) = 8.-YPV(1)
      CALL PLFUN (2,0,XPV,2,YPV,1,1)
  735 CONTINUE
      YXAX(1) = 4.
      YXAX(2) = 4.
      CALL PLFUN (2,0,XXAX,2,YXAX,1,1)
      CALL PLFUN (2,0,H(1,1),NSTEP,H(1,32),1,1)
      CALL PLEND (KEND)
C
C
   90 IF(NKEM) 9,9,91
   91 IF(COM(61)) 29,29,19
      END
```

1.1

```
      SUBROUTINE TARGIN(TMAX)
      DIMENSION TNAME(2)
      DIMENSION EPH(322,6),CROSEC(1801,2),GT(80,32),H(80,40),COM(100)
      COMMON TIME,KSTEP,KHT,EPH,CROSEC,GT,H,COM
C     TARGET INPUT
 1001 FORMAT (6X,2A6,2X,I3,2X,1F3.0)
 1002 FORMAT (I3,3X,1F4.0,2(3X,1F7.0,4X,1F7.1,2X,1F6.2))
 2001 FORMAT (1H1 ,2A6,29H BOOST TRAJECTORY COORDINATES,//)
 2002 FORMAT (1H ,24X,10HDOWN RANGE,26X,8HALTITUDE,//)
 2003 FORMAT (1H ,10HCARD  TIME,2(4X,31HPOSITION   SPEED   ACCELERATION,
     1),//)
 2004 FORMAT (1H ,I4,2X,F4.0,2(4X,F8.1,2X,F7.1,3X,F6.2,4X))
C
      TMAX = 0.
   10 READ INPUT TAPE 5,1001,(TNAME(J),J=1,2),NMAX,TAU
      WRITE OUTPUT TAPE 6,2001,(TNAME(J),J=1,2)
      WRITE OUTPUT TAPE 6,2002
      WRITE OUTPUT TAPE 6,2003
      DO 11 K=1,NMAX
      READ INPUT TAPE 5,1002,L,T,(EPH(L,J),J=1,6)
      TMAX = MAX1F(T,TMAX)
   11 WRITE OUTPUT TAPE 6,2004,L,T,(EPH(L,J),J=1,6)
      COM(9) = TAU
      RETURN
      END
```

1.2

```
      SUBROUTINE CROSIN
      DIMENSION EPH(322,6),CROSEC(1801,2),GT(80,32),H(80,40),COM(100)
      COMMON TIME,KSTEP,KHT,EPH,CROSEC,GT,H,COM
C     CROSS-SECTIO INPUT
 1005 FORMAT (13F6.1)
 1006 FORMAT (1F6.3,12A6)
 4000 FORMAT (1H ,13(F6.1,3X),2X)
 4002 FORMAT (1H1,12A6)
      DIMENSION EX(13),RNAME(12)
C
   30 READ INPUT TAPE 5,1006,DELALP,(RNAME(K),K=1,12)
      WRITE OUTPUT TAPE 6,4002,(RNAME(L),L=1,12)
      K=0
   31 READ INPUT TAPE 5,1005,(EX(J),J=1,13)
      IF(EX(1)-180.) 32,34,34
   32 WRITE OUTPUT TAPE 6,4000,(EX(L),L=1,13)
      DO 33 J=1,6
      LH=2*J
      LV=LH+1
      LE=K+J
      CROSEC(LE,1) = EXPF((EX(LH)/10.)*2.3025851)*10.76387
   33 CROSEC(LE,2) = EXPF((EX(LV)/10.)*2.3025851)*10.76387
      K=K+6
      GO TO 31
   34 CONTINUE
      CROSEC(K,1) = CROSEC(K-1,1)
      CROSEC(K,2) = CROSEC(K-1,2)
      COM(11) = DELALP
      RETURN
      END
```

2.0

```
      SUBROUTINE GEOM
      DIMENSION ROOT(3),VOOT(3),ROOA(3),VOOA(3),UROOT(3),UVOOT(3)
      DIMENSION ROAT(3),ROTA(3),URQAT(3),UVOAT(3),UROTA(3),UVOOA(3)
      DIMENSION VECTOR(3),UVERT(3),TRIADA(3,3),HAT(3),HAB(3),ROOB(3)
      DIMENSION ROOC(3),ROAB(3),ROAC(3),ROTB(3),UROAB(3),UROAC(3)
      DIMENSION UROTB(3),ALP(3),THETA(3),SIGCRO(3,2)
      DIMENSION VOAT(3),ROTC(3),UROTC(3)
      DIMENSION VECT1(3),VECT2(3)
      DIMENSION HAC(3)
      DIMENSION EPH(322,6),CROSEC(1601,2),GT(80,32),HCOM(80,40),COM(100)
      COMMON TIME,KSTEP,KHT,EPH,CROSEC,GT,HCOM,COM
C
C     CONSTANTS
C
      K = KSTEP
      UVERT(1)=0.
      UVERT(2)=0.
      UVERT(3)=1.
      RE=2787840C.
      PI=4.*ATANF(1.)
      RATODE=180./PI
      CLIGHT=0.98357100E+09
      VVA = COM(2)
      DELALP = COM(11)
C
C     GEOMETRY
C
C     TARGET AND AIRCRAFT
C
      CALL TARGET (TIME,ROOT,VOOT)
      CALL AIRCFT (TIME,ROOA,VOOA)
      CALL UNIT (ROOT,UROOT,ROT)
      CALL UNIT (VOOT,UVOOT,VVT)
      IF(TIME) 224,223,224
  223 DO 225 J=1,3
      UVOOT(J) = UVERT(J)
  225 UROOT(J) = UVERT(J)
  224 CONTINUE
      DO 220 J=1,3
      ROAT(J)=ROOT(J)-ROOA(J)
      ROTA(J)=-ROAT(J)
  220 VOAT(J)=VOOT(J)-VOOA(J)
      CALL UNIT (ROAT,UROAT,RAT)
      CALL UNIT (VOAT,UVOAT,VAT)
      CALL UNIT (ROTA,UROTA,SCALAR)
      CALL UNIT (VOOA,UVOOA,VVA)
      CALL CROSS (UVERT,UVOOA,VECTOR)
      CALL UNIT (VECTOR,VECTOR,SCALAR)
      DO 221 J=1,3
      TRIADA(1,J)=UVOOA(J)
  221 TRIADA(2,J)=VECTOR(J)
      CALL CROSS (UVOOA,VECTOR,VECTOR)
      CALL UNIT (VECTOR,VECTOR,SCALAR)
      DO 222 J=1,3
  222 TRIADA(3,J)=VECTOR(J)
      CALL TRIAD (TRIADA,UROAT,ELAAT,AZAAT)
C
```

```
C      BOUNCE POINT - ROUND EARTH WITH REFRACTION
C
      RS=SQRTF(ROAT(1)**2+ROAT(2)**2)
      A=1.
      B=-1.5*RS
      C=-RE*(ROOT(3)+ROOA(3))+0.5*RS*RS
      D=RE*RS*ROOA(3)
      RS1=(ROOA(3)*RS)/(ROOT(3)+ROOA(3))
  231 F=RS1*(RS1*(RS1*A+B)+C)+D
      FP=RS1*(RS1*3.*A+2.*B)+C
      DELRS1=-F/FP
      IF(ABSF(DELRS1)-1.) 233,232,232
  232 RS1=RS1+DELRS1
      GO TO 231
  233 ALPHAB=ROOA(3)/RS1-RS1/(2.*RE)
      H=RS*RS/(2.*RE)
      H1=RS1*RS1/(2.*RE)
      RS2=RS-RS1
      R=SQRTF((ROOA(3)-ROOT(3)+H)**2+RS**2)
      R1=SQRTF((ROOA(3)+H1)**2+RS1**2)
      R2=SQRTF((ROOT(3)-H+H1)**2+RS2**2)
      ALPHAC = ARCSIN(ROOA(3)/RAT - (RAT**2-ROOA(3)**2)/(2.*RAT*RE))
C
C      TIME DERIVATIVES OF RS,R,R1 AND R2
C
      RSRSDT=ROAT(1)*VOAT(1)+ROAT(2)*VOAT(2)
      RSDOT=RSRSDT/RS
      BDOT=-1.5*RSDOT
      CDOT=-RE*(VOOT(3)+VOOA(3))+RSRSDT
      DDOT=RE*(RSDOT*ROOA(3)+RS*VOOA(3))
      RS1DOT=-(RS1*(RS1*BDOT+CDOT)+DDOT)/(RS1*(RS1*3.*A+2.*B)+C)
      RS2DOT=RSDOT-RS1DOT
      RRDOT=(ROOA(3)-ROOT(3)+H)*(VOOA(3)-VOOT(3)+(RSRSDT/RE))+RSRSDT
      RDOT=RRDOT/R
      R1R1DT=(ROOA(3)+H1)*(VOOA(3)+(RS1*RS1DOT/RE))+RS1*RS1DOT
      R1DOT=R1R1DT/R1
      R2R2DT=(ROOT(3)-H+H1)*(VOOT(3)-RSRSDT/RE+(RS1*RS1DOT/RE))+
     1          RS2*RS2DOT
      R2DOT=R2R2DT/R2
      TDIR=(2.*R)/CLIGHT
      TDOUB=(2.*(R1+R2))/CLIGHT
      TSING=0.5*(TDIR+TDOUB)
      DELT=TDOUB-TSING
      DOPDIR=2.*RDOT
      DOP1=RDOT+R1DOT+R2DOT
      DOP2=2.*(R1DOT+R2DOT)
C
C      BOUNCE AND CLUTTER POINTS IN FLAT EARTH COORDINATES
C
      HAT(1)=ROOT(1)-ROOA(1)
      HAT(2)=ROOT(2)-ROOA(2)
      HAT(3)=0.
      CALL UNIT (HAT,HAT,SCALAR)
      CALL MULT(RS1,HAT,HAB)
      ROOB(1)=ROOA(1)+HAB(1)
      ROOB(2)=ROOA(2)+HAB(2)
      ROOB(3)=0.
      XE = SQRTF(RAT**2 - ROOA(3)**2)
      CALL MULT(XE,HAT,HAC)
```

```
      ROCC(1) = ROCA(1) + HAC(1)
      ROCC(2) = ROCA(2) + HAC(2)
      ROCC(3)=0.
      DO 240 J=1,3
      ROAB(J)=ROOB(J)-ROOA(J)
      ROAC(J)=ROOC(J)-ROOA(J)
      ROTC(J)=ROOC(J)-ROOT(J)
  240 ROTB(J)=ROOB(J)-ROOT(J)
      CALL UNIT (ROAB,UROAB,RAB)
      CALL UNIT (ROAC,UROAC,RAC)
      CALL UNIT (ROTB,UROTB,RTB)
      CALL UNIT (ROTC,UROTC,RTC)
      CALL TRIAD (TRIADA,UROAB,ELAAB,AZAAB)
      CALL TRIAD (TRIADA,UROAC,ELAAC,AZAAC)
C
C     DIRECT, SINGLE AND DOUBLE BOUNCE SIGNALS
C
      CALL DOT (UVDOT,UROTA,COSALP)
      CALL CROSS (UVDOT,UROTA,VECTOR)
      CALL UNIT (VECTOR,VECTOR,SINALP)
      CALL ANGLE (SINALP,COSALP,ALP(1))
      CALL DOT (UVDOT,UROTB,COSALP)
      CALL CROSS (UVDOT,UROTB,VECTOR)
      CALL UNIT (VECTOR,VECTOR,SINALP)
      CALL ANGLE (SINALP,COSALP,ALP(3))
      IF(TIME) 242,241,242
  241 ALP(3) = ALP(1)
  242 CONTINUE
      CALL CROSS (UVDOT,ROTA,VECT1)
      CALL CROSS (UVERT,ROTA,VECT2)
      CALL UNIT (VECT1,VECT1,SCALAR)
      CALL UNIT (VECT2,VECT2,SCALAR)
      CALL DOT (VECT1,VECT2,COSTH)
      CALL CROSS (VECT1,VECT2,VECTOR)
      CALL UNIT (VECTOR,VECTOR,SINTH)
      CALL ANGLE (SINTH,COSTH,THET)
      DO 249 J=1,3
  249 THETA(J)=THET
      ALP(2)=ALP(1)+0.5*(ALP(3)-ALP(1))
      DO 250 J=1,3
      ALPP=ALP(J)*RATODE
      CALL RATSCT (ALPP,SIGMAH,SIGMAV,DELALP)
      SINTH=SINF(THETA(J))
      COSTH=COSF(THETA(J))
      SIGCRO(J,1)=SIGMAH*COSTH**2+SIGMAV*SINTH**2
  250 SIGCRO(J,2)=SIGMAH*SINTH**2+SIGMAV*COSTH**2
C
C     STORED GEOMETRIC VARIABLES
C
      GT(K,1) = TIME
      GT(K,2) = ELAAT
      GT(K,3) = AZAAT
      GT(K,4) = ELAAB
      GT(K,5) = ELAAC
      GT(K,6) = R
      GT(K,7) = R1
      GT(K,8) = R2
      GT(K,9) = RDOT
      GT(K,10) = R1DOT
```

```
      GT(K,11) = R2DOT
      GT(K,12) = ALPHAB
      GT(K,13) = ALPHAC
      GT(K,14) = ALP(1)
      GT(K,15) = ALP(2)
      GT(K,16) = ALP(3)
      GT(K,17) = SIGCRC(1,1)
      GT(K,18) = SIGCRC(2,1)
      GT(K,19) = SIGCRC(3,1)
      GT(K,20) = SIGCRC(1,2)
      GT(K,21) = SIGCRC(2,2)
      GT(K,22) = SIGCRC(3,2)
      GT(K,23) = TDIR
      GT(K,24) = DELT
      GT(K,25) = DLPDIR
      GT(K,26) = DCP1
      GT(K,27) = DCP2
      GT(K,28) = THETA(1)
      GT(K,29) = RCCT(3)
      RETURN
      END
```

2.1

```
      SUBROUTINE TARGET (TIME,R,V)
      DIMENSION R(3),V(3)
      DIMENSION EPH(322,6),CROSEC(1601,2),GT(80,32),H(80,40),COM(100)
      COMMON DUMT,KSTEP,KHT,EPH,CROSEC,GT,H,COM
      TAU = COM(9)
      K = TIME/TAU + 1.01
      TI=TAU*FLOATF(K-1)
      TD=TIME-TI
      R(1) = EPH(K,1)*COM(35)
      R(2) = EPH(K,1)*COM(34)
      R(3) = EPH(K,4)
      V(1) = EPH(K,2)*COM(35)
      V(2) = EPH(K,2)*COM(34)
      V(3) = EPH(K,5)
      IF(COM(61)) 3,3,2
    3 IF(TD) 2,2,1
    1 THETA=TD/TAU
      THETA2=THETA**2
      THETA3=THETA2*THETA
      A=2.*THETA3-3.*THETA2+1.
      B=-2.*THETA3+3.*THETA2
      C=TAU*(THETA3-2.*THETA2+THETA)
      D=TAU*(THETA3-THETA2)
      K1=K+1
      R(3) = A*EPH(K,4)+B*EPH(K1,4)+C*EPH(K,5)+D*EPH(K1,5)
      V(3) = A*EPH(K,5)+B*EPH(K1,5)+C*EPH(K,6)+D*EPH(K1,6)
      XR = A*EPH(K,1)+B*EPH(K1,1)+C*EPH(K,2)+D*EPH(K1,2)
      XV = A*EPH(K,2)+B*EPH(K1,2)+C*EPH(K,3)+D*EPH(K1,3)
      R(1) = XR*COM(35)
      R(2) = XR*COM(34)
      V(1) = XV*COM(35)
      V(2) = XV*COM(34)
    2 RETURN
      END
```

2.2

```
      SUBROUTINE AIRCFT (TIME,R,V)
      DIMENSION R(3),V(3)
      DIMENSION EPH(322,6),CRUSEC(1601,2),GT(80,32),H(80,40),COM(100)
      COMMON DUMT,KSTEP,KHT,EPH,CRUSEC,GT,H,COM
      V(1) = COM(31)
      V(2) = COM(32)
      V(3) = COM(33)
      THETA = COM(45)*(TIME-COM(8))
      R(1) = COM(63) + THETA*V(1)
      R(2) = COM(6)+THETA*V(2)
      R(3) = COM(7)+THETA*V(3)
      RETURN
      END
```

2.3

```
      SUBROUTINE UNIT (XX,YY,ZZZ)
      DIMENSION XX(3),YY(3)
      ZZZ=SQRTF(XX(1)**2+XX(2)**2+XX(3)**2)
      IF(ZZZ) 1,1,2
    1 YY(1) = 0.
      YY(2) = 0.
      YY(3) = 0.
      GO TO 3
    2 YY(1) = XX(1)/ZZZ
      YY(2)=XX(2)/ZZZ
      YY(3)=XX(3)/ZZZ
    3 RETURN
      END
```

2.4

```
      SUBROUTINE CROSS (XX,YY,ZZ)
      DIMENSION XX(3),YY(3),ZZ(3)
      A = XX(2)*YY(3) - YY(2)*XX(3)
      B = XX(3)*YY(1) - YY(3)*XX(1)
      ZZ(3) = XX(1)*YY(2) - YY(1)*XX(2)
      ZZ(1) = A
      ZZ(2) = B
      RETURN
      END
```

2.5

```
      SUBROUTINE TRIAD (TRI,VEC,EL,AZ)
      DIMENSION TRI(3,3),VEC(3),UVEC(3)
      CALL UNIT (VEC,UVEC,SCALAR)
      SUM1=0.
      SUM2=0.
      SUM3=0.
      DO 1 J=1,3
      SUM1=SUM1+TRI(1,J)*UVEC(J)
      SUM2=SUM2+TRI(2,J)*UVEC(J)
    1 SUM3=SUM3+TRI(3,J)*UVEC(J)
      COSEL=SQRTF(SUM1**2+SUM2**2)
      SINAZ=SUM2/COSEL
      COSAZ=SUM1/COSEL
      EL = ATANF(SUM3/COSEL)
      CALL ANGLE (SINAZ,COSAZ,AZ)
      RETURN
      END
```

2.6

```
      SUBROUTINE MULT (XXX,YY,ZZ)
      DIMENSION YY(3),ZZ(3)
      ZZ(1)=XXX*YY(1)
      ZZ(2)=XXX*YY(2)
      ZZ(3)=XXX*YY(3)
      RETURN
      END
```

2.7

```
      SUBROUTINE DOT (XX,YY,ZZZ)
      DIMENSION XX(3),YY(3)
      ZZZ=XX(1)*YY(1)+XX(2)*YY(2)+XX(3)*YY(3)
      RETURN
      END
```

2.8

```
      SUBROUTINE ANGLE (SINCHI,COSCHI,CHI)
      PI = 3.1415927
      R=SQRTF(SINCHI**2+COSCHI**2)
      SINCHI=SINCHI/R
      COSCHI=COSCHI/R
      IF(COSCHI) 4,1,4
    1 IF(SINCHI) 2,2,3
    2 CHI = (3.*PI)/2.
      GO TO 10
    3 CHI = PI/2.
      GO TO 10
    4 CHIP=ATANF(SINCHI/COSCHI)
      IF(SINCHI) 8,5,5
    5 IF(COSCHI) 7,6,6
    6 CHI=CHIP
      GO TO 10
    7 CHI=CHIP+PI
      GO TO 10
    8 IF(COSCHI) 7,9,9
    9 CHI = CHIP+2.*PI
   10 CONTINUE
      RETURN
      END
```

2.9

```
      SUBROUTINE RATSCT (ANGLE,SIGMAH,SIGMAV,DELALP)
      DIMENSION EPH(322,6),CROSEC(1801,2),GT(80,32),H(80,40),COM(100)
      COMMON TIME,KSTEP,KHT,EPH,CROSEC,GT,H,COM
      K1 = ANGLE/DELALP + 1.5
      SIGMAH = CROSEC(K1,1)
      SIGMAV = CROSEC(K1,2)
      RETURN
      END
```

3.0

```
      SUBROUTINE DAVE
      DIMENSION TPR(12)
      DIMENSION EPH(322,6),CRUSEC(1801,2),GT(80,32),H(80,40),COM(100)
      COMMON TIME,KSTEP,KHT,EPH,CRUSEC,GT,H,COM
      K = KSTEP
C
C     GET INPUTS FROM COMMON
C
      VVA = COM(2)
      FMC = COM(12)
      HAPER = COM(13)
      VAPER = COM(14)
      AAPEFF = COM(15)
      ETA = COM(16)
      PCN = COM(20)
      PPEAK = COM(23)
      FR = COM(24)
      TOWELL = COM(25)
      SYSLF = COM(26)
      TZBEAM = COM(27)
      FNOISE = COM(28)
      HTSS = COM(29)
      VSC = COM(30)
      XIHDEL = COM(37)
      XIVDEL = COM(38)
      XIHZ = COM(39)
      XIVZ = COM(40)
      XIH2 = COM(41)
      XIV2 = COM(42)
      SEA = COM(43)
      POL = COM(44)
      FNTRK = COM(46)
      CRL = COM(47)
      BNSR = SQRTF(COM(48))
      FKS = COM(49)
      BI = COM(50)
      ATETS = COM(51)**2
      ATEPS = COM(52)**2
      ATECS = COM(53)**2
      SIGUP1 = COM(56)
      SIGZ = 10.**(COM(57)/10.)
      RBLANK = COM(64)
      RAIN = COM(21)
      SUMSIG = 10.**(COM(22)/10.)
C
C     GET STUFF FROM GEOM
C
      L = K
      RANGE = GT(L,6)
      R1 = GT(L,7)
      R2 = GT(L,8)
      IF(POL) 14,12,14
   12 SIGCC = GT(L,17)
      SIGCB = GT(L,18)
      SIGBB = GT(L,19)
      GO TO 16
   14 SIGCC = GT(L,20)
```

```
      SIGDB = GT(L,21)
      SIGBB = GT(L,22)
   16 ALPHAC = GT(L,13)
      ALPHAB = ABSF(GT(L,12))
      XIVC = GT(L,5)
      DDPDIR = GT(L,25)
      DDP1 = GT(L,26)
      DDP2 = GT(L,27)
      ELAAT = GT(L,2)
      ELAAB = GT(L,4)
      DELT = GT(L,24)
C
      C = 9.83571 E8
      PI = 3.1415927
      BOLTZ = 1.3804 E-23
      STEMP = 290.
C
C     ANTENNA
C
      FLAMB = C/(FMC*1.E6)
      ANAREA = AAPEFF*HAPER*VAPER
      AGAINA = 4.*PI*ANAREA/(FLAMB**2)
      BETAH = FLAMB/HAPER
      BETAV = FLAMB/VAPER
      HBEAMP = 1.
      VBEAMP = 1.
      IF(ABSF(ELAAT-ELAAB)-BETAV/2.) 501,501,502
  501 BBEAMP = 1.
      GO TO 503
  502 BBEAMP = ETA
  503 CONTINUE
      FSCH = XIHDEL*XIVDEL/(HTSS*BETAV)
      TEMP = FSCH*(TIME-TZBEAM) + XIHZ
      XIFG = TEMP - XIHDEL*INTF(TEMP/XIH2)
      IF(VSC) 520,510,520
  510 XIVG = XIVZ
      GO TO 530
  520 TEMP = XIVZ + BETAV*INTF((FSCH*(TIME-TZBEAM)+XIHZ)/XIH2)
      XIVG = TEMP - XIVDEL*INTF(TEMP/XIV2)
  530 CONTINUE
C     FOR NOW, USE XIHT, XIVT
      XIFG = GT(L,3)
      XIVG = GT(L,2)
C
      PHIVC = XIVC-XIVG
C
C     REFLECTION COEFFICIENT
C
      IF(PCL) 720,710,720
  710 IF(ALPHAB-1.0472) 711,711,712
  711 REFL = 1.-ALPHAB*.6/PI
      GO TO 730
  712 REFL = .8
      GO TO 730
  720 IF(ALPHAB-.08727) 721,721,722
  721 REFL = 1.-ALPHAB*32.4/PI
      GO TO 730
  722 REFL = .8-.92836*EXPF(-10.08*ALPHAB/PI)
  730 IF(SEA) 732,731,732
```

```
  731 TEMP = 1.
      GO TO 733
  732 TEMP = 10.
  733 REFL = REFL*EXPF(-8.*(PI*TEMP*ALPHAB/FLAMB)**2)
C
C     SIGNAL PROCESSING
C
      PCS = PCN
C
C     ATMOSPHERIC ATTENUATION
C
      ATMLDD = 1.
      ATMLDB = 1.
      ATMLBB = 1.
C
C     TRANSMITTER
C
      PZ = (PPEAK*ANAREA**2)/(4.*PI*FLAMB**2*RANGE**4)
      PAVG = PPEAK*TDWELL*FR
      PULSE = TDWELL/PCN
C
C     SIGNAL
C
      FLOSS = SYSLF*PCS
      TEMP = PZ*FLOSS
      SDD = TEMP*SIGDD*ATMLDD*HBEAMP**2*VBEAMP**2
      SDB = TEMP*SIGDB*(RANGE/(R1+R2))**2*REFL**2*ATMLDB*HBEAMP**2
     1          *VBEAMP*BBEAMP
      SBB = TEMP*SIGBB*(RANGE/(R1+R2))**4*REFL**4*ATMLBB*BBEAMP**2
      IF(DELT-PULSE) 210,210,220
  210 IF(SEA) 220,211,220
  211 STT = SDD+SBB+4.*SDB
      GO TO 230
  220 STT = SDD
  230 CONTINUE
C
C     DOPPLER
C
      FDD = DOPDIR/FLAMB
      FDB = DOP1/FLAMB
      FBB = DOP2/FLAMB
C
C     PHASE DIFFERENCE
C
      PHA = (R1+R2-RANGE)/FLAMB
      IF(PCL) 251,252,251
  251 IF(ALPHAB-.08727) 252,252,253
  252 PHA = PHA+.5
  253 PHADEL = (DOP2-DOP1)*BETAH/(FLAMB*FSCH)
C
C     CLUTTER
C
      IF(ALPHAC) 294,294,295
  294 SIGZ = 0.
      GO TO 332
  295 IF(ALPHAC-PI/2.) 297,297,296
  296 ALPHAC = PI-ALPHAC
  297 IF(ABSF(ALPHAC-PI/2.)-1.E-5) 298,299,299
  298 ALPHAC = PI/2.-1.E-5
```

```
  299 CONTINUE
      IF(SIGOPT) 301,302,332
  301 CLUTTR = 0.
      GO TO 350
  302 IF(FMC-3000.) 308,303,303
  303 IF(SEA) 305,304,305
  304 BSEA = .5
      GO TO 306
  305 BSEA = 5.
  306 SIGZ = 2.*SINF(ALPHAC)*10.**(-5.2+.6*BSEA)
      GO TO 332
  308 IF(SEA) 320,310,320
  310 C1 = .005012
      C2 = 2.98
      C3 = .66
      GO TO 330
  320 C1 = .1566
      C2 = 2.66
      C3 = 4.27
  330 SIGZ = C1*(ALPHAC**C2)/(FLAMB**C3)
  332 TEMP = RANGE*C*TDWELL/(2.*COSF(ALPHAC))
      ACM = TEMP*BETAH
      ACS = TEMP*PI
      SIGCM = SIGZ*ACM
      SIGCS = SIGZ*ACS
      CLM = PZ* SIGCM*SYSLF
      CLS = PZ*SIGCS*ETA**2*SYSLF
      CLUTTR = CLS
      IF(RBLANK) 350,338,350
  338 IF(ABSF(PHIVC)-BETAV/2.) 340,350,350
  340 CLUTTR = CLUTTR + CLM - ETA**2*CLM
  350 TEMP = XIHG + BETAH*SIGNF(1.,XIHG)/4.
      CLBW = (4.*VVA*ABSF(COSF(XIVG)*SINF(TEMP)*SINF(BETAH/4.))+8.)
     1      /FLAMB
C
C     NOISE PLUS RAIN CLUTTER
C
      PNOISE = BOLTZ*STEMP*FNOISE*PCN/TDWELL
      CLRAIN = PPEAK*SYSLF*ANAREA*C*TDWELL*SUMSIG*RAIN/(64.0
     2        *3.281*LOGF(2.)*RANGE**2)
      PNOISE = PNOISE + CLRAIN
C
C     TRACKING ACCURACY
C
      TEMP = FNTRK*CRL*BNSR/(FKS*SQRTF(SDD*B1/(PNOISE+CLUTTR)))
      SIGNH = TEMP*BETAH
      SIGNV = TEMP*BETAV
      TRKERR = SQRTF(SIGNH**2 + SIGNV**2 + ATETS + ATEPS + ATEOS)
C
C     SEARCH ACCURACY
C
      EN = INTF(BETAH*FR/FSCH + .5)
      TEMP = SQRTF(EN*SDD/(PNOISE+CLUTTR))
      DELD = 1.732051*FLAMB/(2.*PI*TDWELL*TEMP)
      DELR = 1.732051*PULSE*C/(2.*PI*TEMP)
      DELA = FNTRK*CRL*SQRTF(BETAH**2+BETAV**2)/(FKS*TEMP)
C
C     STORE DETECTION PARAMETERS
C
```

```
      COM(100) = PNOISE
      COM(99) = CLBW
      COM(98) = BETAH
      COM(97) = PULSE
      COM(96) = FSCH
      COM(95) = STT
      COM(94) = SDD
      COM(93) = CLUTTR
C
C     STORE OUTPUTS
C
      H(K,1) = TIME
      H(K,11) = FDD
      H(K,12) = FDD-FDB
      H(K,13) = GT(L,24)*1.E6
      H(K,14) = DELR
      H(K,15) = DELD
      H(K,16) = DELA
      H(K,17) = SIGNV
      H(K,18) = SIGNH
      H(K,19) = TRKERR
      DO 80 I=16,19
   80 H(K,I) = H(K,I)*1.E3
      H(K,20) = GT(L,29)*1.E-3
      H(K,21) = SDD
      H(K,22) = SDB
      H(K,23) = SBB
      H(K,24) = CLM
      H(K,25) = CLS
      H(K,26) = CLUTTR
      DO 82 I=21,26
   82 H(K,I) = 10.*LOG10F(H(K,I)*1.E3)
      H(K,27) = 10.*LOG10F(SIGZ)
      H(K,28) = PHA
      H(K,29) = PHADEL
      H(K,30) = REFL
      H(K,31) = CLBW
      H(K,32) = 10.*LOG10F(STT/(PNOISE+CLUTTR))
      IF(KHT-1) 90,90,99
   90 TPR(1) = FLAMB
      TPR(2) = ANAREA
      TPR(3) = 10.*LOG10F(AGAINA)
      TPR(4) = BETAH*57.2957795
      TPR(5) = BETAV*57.2957795
      TPR(6) = FSCH*57.2957795
      TPR(9) = PZ
      TPR(10) = PAVG
      TPR(7) = PULSE
      TPR(11) = 10.*LOG10F(PNOISE*1.E3)
      TPR(8) = EN
      WRITE OUTPUT TAPE 6,91,(TPR(I),I=1,11)
   91 FORMAT (1H1 54X 18HCOMPUTED CONSTANTS ///9H LAMBDA = E13.4,4H FT./
     1 9H0     AR = E13.4,6H SQFT. 5X 8HGAIN    = E13.4,3H DB 8X
     2 8HBETAH   = E13.4,5H DEG. 6X 8HBETAV   = E13.4,5H DEG. /
     3 9H0FSCH    = E13.4,4H D/S 7X 8HTAU     = E13.4,5H SEC. 6X
     4 8HN       = E13.4/9H0P0     = E13.4,7H W/SQFT 4X 8HPAVG    = E13.4,
     5 6H WATTS 5X 8HPNOISE = E13.4,4H DBM )
   99 CONTINUE
C
      RETURN
      END
```

```
4.0
      SUBROUTINE EDDIE
      DIMENSION XBAR(2),SGNL(2),PD(2)
      DIMENSION EPH(322,6),CROSEC(1801,2),GT(80,32),H(80,40),COM(100)
      COMMON TIME,KSTEP,KHT,EPH,CROSEC,GT,H,COM
C
C     GET STUFF FROM DAVE
C
      K = KSTEP
      IF(KHT-1) 80,80,82
   80 PCOM1 = 0.
      PCOMT = 0.
   82 DO 5 I=1,2
    5 SGNL(I) = COM(I+93)
      CLUTTR = COM(93)
      PNOISE = COM(100)
      DELFC = COM(99)
      BETAH = COM(98)
      PULSE = COM(97)
      FSCH = COM(96)
C
C     GET STUFF FROM COMMON
C
      FR = COM(24)
      TAUFA = COM(36)
      KASE = COM(55)+.5
      IF(KASE) 3,3,4
    3 KASE = 1
    4 CONTINUE
      FOMS = COM(58)
      L = K
      ALPHAB = GT(L,12)
C
C     SET DETECTION PARAMETERS
C
      N = BETAH*FR/FSCH + .5
      NC = BETAH*DELFC/FSCH + .5
      IF(NC) 7,7,8
    7 NC = 1
    8 EN = N
      ENC = NC
      EMC = EN/ENC
      FAP = EN*PULSE*.69314718/TAUFA
      FAPL = LOG10F(FAP)
      ZBAR = CLUTTR/PNOISE
      IF(FOMS) 50,6,50
    6 IF(ZBAR-.1) 50,9,9
    9 IF(ZBAR-10.) 10,10,30
C
C     NEITHER CLUTTER NOR NOISE DOMINANT--EQS. 16-17A.
C
   10 CONTINUE
      EMCZ = EMC*ZBAR
      VZ = 7.*EN*ZBAR
      PLZ = LOG10F(PFA(N,NC,ZBAR,VZ))
   11 V1 = VZ + .01*VZ*SIGNF(1.,PLZ-FAPL)
      PL1 = LOG10F(PFA(N,NC,ZBAR,V1))
      IF(SIGNF(1.,PLZ-FAPL)-SIGNF(1.,FAPL-PL1)) 12,14,12
```

```
   12 V2 = V1
      PL2 = PL1
      GO TO 11
   14 VB = V2 + (V1-V2)*(PL2-FAPL)/(PL2-PL1)
      DO 20 I=1,2
      XBAR(I) = SGNL(I)/PNOISE
      A1 = EN*XBAR(I)
      A2 = EMC2 + A1
      A3 = 1. + A2
      B = ENC*LOGF(A3) - LOGF(A2) - (ENC-1.)*LOGF(A1) - VB/A3
      PD(I) = EXPF(B)
   20 CONTINUE
      H(K,6) = 0.
      GO TO 99
C
C     CLUTTER DOMINANT--EQS. 18-19
C
   30 V2 = (ENC+10.)*EMC
      PL2 = LOG10F(PFAC(N,NC,V2))
   31 V1 = V2 + .01*V2*SIGNF(1.,PL2-FAPL)
      PL1 = LOG10F(PFAC(N,NC,V1))
      IF(SIGNF(1.,PL2-FAPL)-SIGNF(1.,FAPL-PL1)) 32,34,32
   32 V2 = V1
      PL2 = PL1
      GO TO 31
   34 VB = V2 + (V1-V2)*(PL2-FAPL)/(PL2-PL1)
      DO 40 I=1,2
      XBAR(I) = SGNL(I)/CLUTTR
      IF(XBAR(I)-1.E-2) 41,42,42
   41 PD(I) = 0.
      GO TO 40
   42 A1 = ENC*XBAR(I)
      A2 = (1.+A1)/A1
      A3 = VB/EMC
      IF(NC-1) 35,35,37
   35 PD(I) = EXPF(-A3/(1.+A1))
      GO TO 40
   37 SUM = 0.
      JMAX = NC-1
      DO 38 J=1,JMAX
      R = 0.
      DO 36 M=1,J
   36 R = R + EVAL(A3,M-1)
   38 SUM = SUM + EXPF(FLOATF(NC-1-J)*LOGF(A2)+LOGF(R)-LOGF(A1))
      PD(I) = SUM + EXPF(-A3/(1.+A1)+(ENC-1.)*LOGF(A2))
   40 CONTINUE
      H(K,6) = -1.
      GO TO 99
C
C     NOISE DOMINANT--MARCUM-SWERLING
C
   50 CONTINUE
      FAN = LOG10F(TAUFA/(EN*PULSE))
      DO 60 I=1,2
      XBAR(I) = SGNL(I)/(CLUTTR+PNOISE)
      CALL MARCUM (N,FAN,XBAR(I),KASE,PD(I),VB)
   60 CONTINUE
      H(K,6) = KASE
   99 CONTINUE
```

```
      IF(ALPHAB) 199,299,299
  199 PD(1) = 0.
      PD(2) = 0.
  299 CONTINUE
      PCUM1 = PCUM1 + (1.-PCUM1)*PD(1)
      PCUMT = PCUMT + (1.-PCUMT)*PD(2)
      H(K,2) = PD(1)
      H(K,3) = PCUM1
      H(K,4) = PD(2)
      H(K,5) = PCUMT
      H(K,7) = VB
      H(K,8) = 10.*LOG10F(SGNL(2)/FNOISE)
      H(K,9) = 10.*LOG10F(ZBAR)
      H(K,10) = EMC
      IF(KHT-1) 100,100,102
  100 WRITE OUTPUT TAPE 6,101,FAP
  101 FORMAT (9HOPFA     = E13.4)
  102 CONTINUE
      RETURN
      END
```

4.1

```
      FUNCTION PFA(N,NC,ZBAR,VB)
C           COMPUTES FALSE-ALARM PROBABILITY OF RECEIVER NOISE
C           AND CLUTTER ONLY.  N IS NO. OF PULSES, NC IS NO. OF
C           INDEPENDENT CLUTTER GROUPS, ZBAR IS AVERAGE CLUTTER TO
C           NOISE RATIO, VB IS THE THRESHOLD.  SEE BBD-1387.
C
      FMC = FLOATF(N)/FLOATF(NC)
      FMCZ = FMC*ZBAR
      FMCZO = 1.+FMCZ
      NNC = N-NC
      FNNC = FLOATF(NNC)
      SUM = 0.
      Q = FNNC*LOGF(FMCZO/FMCZ) - SUMLOG(NNC-1)
      DO 99 I=1,NC
      NU = I-1
      FNU = FLOATF(NU)
      R = 0.
      KK = NC-NU
      DO 4 K=1,KK
    4 R = R + EVAL(VB/FMCZO,K-1)
      IF(R) 99,99,5
    5 TERM = Q+SUMLOG(NNC-1+NU)-SUMLOG(NU)-FNU*LOGF(FMCZ)+LOGF(R)
      TERM = EXPF(TERM)
      IF(XMODF(NU,2)) 10,20,10
   10 TERM = -TERM
   20 SUM = SUM+TERM
   99 CONTINUE
      PFA = SUM
      RETURN
      END
```

4.2

```
      FUNCTION PFAC(N,NC,YC)
C
C     FALSE ALARM PROBABILITY, SIMPLIFIED FOR THE CASE WHERE
C     CLUTTER IS DOMINANT. (CLO-4-117, EQ. 18)
C
```

```
      SUM = 0.
      Y = YC*FLOATF(NC)/FLOATF(N)
      DO 10 I=1,NC
   10 SUM = SUM + EVAL(Y,I-I)
      PFAC = SUM
      RETURN
      END
```

4.3

```
      SUBROUTINE MARCUM (N,FAN,SNR,KASE,PN,BIAS)
C
C     COMPUTE MARCUM-SWERLING DETECTION PROBABILITIES
C
C     TEST INPUTS
C
      IF(N) 99,99,2
    2 IF(FAN) 99,99,3
    3 IF(KASE) 99,4,4
    4 IF(KASE-4) 5,5,99
    5 IF(SNR) 99,99,6
C
C     ESTIMATE BIAS LEVEL
C
D   6 ENPR = 0.
      ENPR = FAN
      EN = N
D     YBPR = 0.
      IF(N-12) 7,7,8
    7 YBPR = EN*(1.+2.2*ENPR/EN**(2./3.+.015*ENPR))
      GO TO 11
    8 YBPR = EN*(1.+1.3*ENPR/EN**(.5+.011*ENPR))
C
C     COMPUTE BIAS LEVEL
C
D  11 ENPR = 10.**ENPR
D     GAMPR = DGAM(YBPR,N-1)
D     PYB = .5**(1./ENPR)
D     IF(GAMPR-PYB) 10,12,12
D  10 H = .01
      GO TO 14
D  12 H = -.01
D  14 YO = YBPR
D     EO = DEVAL(YO,N-1)
D  16 Y1 = YO+H
D     E1 = DEVAL(Y1,N-1)
D     STEP = GAMPR + H*(EO+E1)/2.
D     IF(SIGNF(1.,STEP-PYB)-SIGNF(1.,H)) 18,20,18
D  18 YO = Y1
D     EO = E1
D     GAMPR = STEP
      GO TO 16
D  20 IF(H) 22,24,24
D  22 YB = Y1 - H*(PYB-STEP)/(GAMPR-STEP)
      GO TO 30
D  24 YB = YO + H*(PYB-GAMPR)/(STEP-GAMPR)
   30 BIAS = YB
C
C     SELECT M-S CASE
C
      X = SNR
      K = KASE+1
      GO TO (100,200,300,400,500), K
C
C     CASE 0
C
  100 SUM = 0.
```

```
      P = EN*X
      IF(YB-P-EN) 150,102,102
  102 KS = -(EN+1.)/2. + SQRTF(((EN-1.)/2.)**2+P*YB)
      KS = XMAXOF(KS,0)
      GS = 1.-GAM(YB,KS+N-1,TN)
      TS = EVAL(P,KS)*GS
      G = GS
      K = KS
      TERM = TS
      TL = TN
  110 TEMP = SUM+TERM
      IF(SUM-TEMP) 112,116,116
  112 SUM = TEMP
      IF(K) 116,116,114
  114 TERM = TERM*FLOATF(K)*(G-TL)/(P*G)
      G = G-TL
      K = K-1
      TL = TL*FLOATF(K+N)/YB
      GO TO 110
  116 TL = TN*YB/FLOATF(KS+N)
      K = KS+1
      G = GS+TL
      TERM = TS*P*G/(GS*FLOATF(K))
  120 TEMP = SUM+TERM
      IF(SUM-TEMP) 122,190,190
  122 SUM = TEMP
      TL = TL*YB/FLOATF(K+N)
      K = K+1
      TERM = TERM*P*(G+TL)/(G*FLOATF(K))
      G = G+TL
      GO TO 120
  150 KS = -1. - EN/2. + SQRTF(EN**2/4.+P*YB)
      KS =XMAXOF(KS,0)
      GS = GAM(YB,KS+N-1,TN)
      IF(GS) 174,174,155
  155 TS = EVAL(P,KS)*GS
      G = GS
      TERM = TS
      K = KS
      TL = TN
  160 TEMP = SUM+TERM
      IF(SUM-TEMP) 162,166,166
  162 SUM = TEMP
      IF(K) 166,166,164
  164 TERM = TERM*FLOATF(K)*(G+TL)/(P*G)
      G = G+TL
      TL = TL*FLOATF(K+N-1)/YB
      K = K-1
      GO TO 160
  166 TL = TN*YB/FLOATF(KS+N)
      K = KS+1
      G = GS-TL
      TERM = TS*P*G/(GS*FLOATF(K))
  170 TEMP = SUM + TERM
      IF(SUM-TEMP) 172,174,174
  172 SUM = TEMP
      TL = TL*YB/FLOATF(K+N)
      TERM = TERM*P*(G-TL)/(G*FLOATF(K+1))
      G = G-TL
```

```
      K = K+1
      GO TO 170
  174 SUM = 1.-SUM
  190 PN = SUM
      GO TO 90
C
C     CASE 1
C
  200 IF(N-1) 210,210,220
  210 PN = EXPF(-YB/(1.+X))
      GO TO 90
  220 TEMP = 1. + 1./(EN*X)
      PN = 1. - GAM(YB,N-2,DUM) + EXPF((EN-1.)*LOGF(TEMP)-YB/(1.+EN*X))
     1                              *GAM(YB/TEMP,N-2,DUM)
      GO TO 90
C
C     CASE 2
C
  300 IF(N-1) 310,310,320
  310 PN = EXPF(-YB/(1.+X))
      GO TO 90
  320 PN = 1. - GAM(YB/(1.+X),N-1,DUM)
      GO TO 90
C
C     CASE 3
C
  400 IF(N-2) 410,420,430
  410 PN = (1.+2.*X*YB/(X+2.)**2)*EXPF(-2.*YB/(2.+X))
      GO TO 90
  420 PN = (1.+YB/(1.+X))*EXPF(-YB/(1.+X))
      GO TO 90
  430 C = 2./(2.+EN*X)
      D = 1.-C
      IF(YB*D-EN) 440,450,450
  440 SUM = 0.
      TERM = 1.
      J = N
  442 TEMP = SUM+TERM
      IF(SUM-TEMP) 444,446,446
  444 SUM = TEMP
      TERM = TERM*YB*D/FLOATF(J)
      J = J+1
      GO TO 442
  446 PN = 1. - GAM(YB,N-2,DUM) + C*YB*EVAL(YB,N-2)
     1          + D*EVAL(YB,N-1)*(1.+C*YB-(EN-2.)*C/D)*SUM
      GO TO 90
  450 PN = 1. - GAM(YB,N-3,DUM) + YB*EVAL(YB,N-3)*C/D
     1          + EXPF(-C*YB-(EN-2.)*LOGF(D))*(1.+C*YB-(EN-2.)*C/D)
     2            *GAM(YB*D,N-3,DUM)
      GO TO 90
C
C     CASE 4
C
  500 SUM = 0.
      C = 2./(2.+X)
      D = 1.-C
      Q = C/D
      P = C*YB
      KS = (3.*EN+(YB*D))/2.-SQRTF((EN-1.+(YB*D))**2/4.+(YB*D)*(EN+1.))
```

```
      KS = XMINOF(KS,N)
      KS = XMAXOF(KS,0)
      K = KS
      J = N-KS
      FKS = KS
      K = XMINOF(KS,N)
      IF(YB-EN*(1.+D)) 550,501,501
  501 GS = 1. - GAM(P,2*N-1-KS,TN)
      IF(GS) 526,526,502
  502 TS = EXPF(FKS*LOGF(C)+(EN-FKS)*LOGF(D)+SUMLOG(N)-SUMLOG(KS)
     1          -SUMLOG(J)+LOGF(GS))
      G = GS
      TERM = TS
      TL = TN
  510 TEMP = SUM+TERM
      IF(SUM-TEMP) 512,516,516
  512 SUM = TEMP
      IF(K) 516,516,514
  514 TL = TL*P/FLOATF(2*N-K)
      TERM = TERM*FLOATF(K)*(G+TL)/(Q*FLOATF(N-K+1)*G)
      G = G+TL
      K = K-1
      GO TO 510
  516 IF(KS-N) 518,526,526
  518 TERM = TS*Q*FLOATF(N-KS)*(GS-TN)/(FLOATF(KS+1)*GS)
      G = GS-TN
      TL = TN*FLOATF(2*N-1-KS)/P
      K = KS+1
  520 TEMP = SUM+TERM
      IF(SUM-TEMP) 522,526,526
  522 SUM = TEMP
      IF(K-N) 524,526,526
  524 TERM = TERM*Q*FLOATF(N-K)*(G-TL)/(FLOATF(K+1)*G)
      G = G-TL
      TL = TL*FLOATF(2*N-1-K)/P
      K = K+1
      GO TO 520
  526 PN = SUM
      GO TO 90
  550 GS = GAM(P,2*N-1-KS,TN)
      IF(GS) 576,576,552
  552 TS = EXPF(FKS*LOGF(C)+(EN-FKS)*LOGF(D)+SUMLOG(N)-SUMLOG(KS)
     1          -SUMLOG(J)+LOGF(GS))
      G = GS
      TERM = TS
      TL = TN
  560 TEMP = SUM+TERM
      IF(SUM-TEMP) 562,566,566
  562 SUM = TEMP
      IF(K) 566,566,564
  564 TL = TL*P/FLOATF(2*N-K)
      TERM = TERM*FLOATF(K)*(G-TL)/(Q*FLOATF(N-K+1)*G)
      G = G-TL
      K = K-1
      GO TO 560
  566 IF(KS-N) 568,576,576
  568 TERM = TS*Q*FLOATF(N-KS)*(GS+TN)/(FLOATF(KS+1)*GS)
      G = GS+TN
      TL = TN*FLOATF(2*N-1-KS)/P
```

```
      )
      K = KS+1
  570 TEMP = SUM+TERM
      IF(SUM-TEMP) 572,576,576
  572 SUM = TEMP
      IF(K-N) 574,576,576
  574 TERM = TERM*G*FLOATF(N-K)*(G+TL)/(FLOATF(K+1)*G)
      G = G+TL
      TL = TL*FLOATF(2*N-1-K)/P
      K = K+1
      GO TO 570
  576 PN = 1.-SUM
      GO TO 90
C
C     SET PROBABILITY
C
   90 IF(PN) 91,94,92
   91 PN = 0.
      GO TO 94
   92 IF(PN-1.) 94,94,93
   93 PN = 1.
   94 RETURN
C
C     ERROR MESSAGE FOR BAD INPUTS
C
   99 WRITE OUTPUT TAPE 6,9,N,FAN,SNR,KASE
    9 FORMAT (1H0 /50H UNREASONABLE CALL SEQUENCE TO MARCUM, ZERO RESULT
     1                    7HS GIVEN //4H N = I8,5X,5HFAN = E16.8,5X,5HSNR =
     2                   E16.8,5X,6HKASE = I8)
      PN = 0.
      BIAS = 0.
      RETURN
      END
```

4.3.1

```
      FUNCTION DGAM(B,N)
C              INTEGRAL = 1-(SUM, J=0 TO N, OF EXPF(J*LOGF(B)-B-LOGF(NFAC)))
D     SUM = 0.
D     K = B
      IF(K-N) 100,200,200
  100 J = N+1
D     TERM =DEVAL(B,J)
D  10 TEMP = SUM+TERM
D     IF(SUM-TEMP) 15,20,20
D  15 SUM = TEMP
      J = J+1
D     FJ = J
D     TERM = TERM*B/FJ
      GO TO 10
D  20 DGAM = SUM
      RETURN
  200 J = N
D     TERM =DEVAL(B,J)
D  30 TEMP = SUM+TERM
D     IF(SUM-TEMP) 35,40,40
D  35 SUM = TEMP
      IF(J-1) 40,36,36
D  36 FJ = J
D     TERM = TERM*FJ/B
      J = J-1
```

```
      GO TO 30
D  40 DGAM = 1.-SUM
      RETURN
      END
```

4.3.2

```
      FUNCTION DEVAL(Y,N)
D     XPON = -Y
      IF(N) 20,20,10
D  10 EN = N
D     XPON = XPON+EN*LOGF(Y)-SUMLOG(N)
D  20 DEVAL = EXPF(XPON)
      RETURN
      END
```

4.3.3

```
      FUNCTION GAM(B,N,TN)
C                       SINGLE PRECISION VERSION OF DGAM
      SUM = 0.
      K = B
      IF(K-N) 100,200,200
  100 J = N+1
      TERM = EVAL(B,J)
      TN = TERM*FLOATF(J)/B
   10 TEMP  = SUM+TERM
      IF(SUM-TEMP) 15,20,20
   15 SUM = TEMP
      J = J+1
      FJ = J
      TERM = TERM*B/FJ
      GO TO 10
   20 GAM = SUM
      RETURN
  200 J = N
      TERM = EVAL(B,J)
      TN = TERM
   30 TEMP = SUM+TERM
      IF(SUM-TEMP) 35,40,40
   35 SUM = TEMP
      IF(J-1) 40,36,36
   36 FJ = J
      TERM = TERM*FJ/B
      J = J-1
      GO TO 30
   40 GAM = 1.-SUM
      RETURN
      END
```

4.3.4

```
      FUNCTION EVAL(Y,N)
      XPON = -Y
      IF(N) 20,20,10
   10 EN = N
      XPON = XPON+EN*LOGF(Y)-SUMLOG(N)
   20 EVAL = EXPF(XPON)
      RETURN
      END
```

4.3.5

```
D      FUNCTION SUMLOG(N)
D      DIMENSION A(200)
       NMAX = 200
       IF(DUMA-DUMB) 20,10,20
    10 DUMA = 1.
       DUMB = 0.
       NLAST = 1
D      A(1) = 0.
    20 NN = XABSF(N)
       IF(NN-1) 30,30,40
D   30 SUMLOG = 0.
       RETURN
    40 IF(NN-NLAST) 50,50,60
D   50 SUMLOG = A(NN)
       RETURN
    60 K = NLAST+1
       IF(NN-NMAX) 70,70,80
    70 DO 72 I=K,NN
D   72 A(I) = A(I-1) + LOGF(FLOATF(I))
       NLAST = NN
       GO TO 50
    80 IF(NLAST-NMAX) 82,90,90
    82 DO 84 I=K,NMAX
D   84 A(I) = A(I-1) + LOGF(FLOATF(I))
       NLAST = NMAX
D   90 B = A(NMAX)
       K = NMAX+1
       DO 92 I=K,NN
D   92 B = B + LOGF(FLOATF(I))
D      SUMLOG = B
       RETURN
       END
```

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13. ABSTRACT

→ A digital computer program is described which simulates the radar-target engagement providing a representation of the detection, acquisition, and tracking processes. The program is arranged as a time simulation of the engagement between a radar and target, taking into account the detailed characteristics of the target cross section, radar and target motion throughout the engagement, surface clutter, atmospheric attenuation, and radar losses. In the output the program provides the user with target detection probabilities in the presence of surface clutter as well as receiver noise, radar search and track accuracies, signal-to-noise ratios, target characteristics vs time, angular and range rates, etc. The input requirements to the program are: (1) a deck of parameter cards describing the radar parameters, the clutter environment, and the initial radar-target geometry, (2) a deck of cards describing the target motion throughout the engagement, and (3) a deck of cards describing the target's cross section vs aspect angle. Many simplifications to the inputs are allowed for studying and isolating various parts of the radar problem. (U) ←

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