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RANGE PERFORMANCE CALCULATIONS USING THE NVEOL–GEORGIA TECH RESEARCH INSTITUTE 0.1- TO 100-GHz RADAR PERFORMANCE MODEL

by

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and

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May 1983

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U.S. ARMY ELECTRONICS R&D COMMAND

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

A computer model that can be used to calculate radar range performance at any frequency in the 0.1- to 100-GHz electromagnetic spectrum is described. Three different numerical examples are used to demonstrate how to use the radar range performance model. Input/output documentation are included for each case that was run on the MERADCOM CDC 6600 computer at Fort Belvoir, Virginia.

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RANGE PERFORMANCE CALCULATIONS USING THE NVEOL–GEORGIA TECH RESEARCH INSTITUTE 0.1- TO 100-GHz RADAR PERFORMANCE MODEL

I. INTRODUCTION

Under an NVEOL-sponsored contract[1] the Georgia Institute of Technology Radar and Instrumentation Laboratory has modified a computer-based radar range performance model[2] in order that it may be exercised to analyze and predict the performance of US Army millimeter wavelength radar systems. The analytically enhanced radar range performance model has been delivered to NVEOL and has been installed onto the MERADCOM CDC 6600 Computer.[3] Because of computer word-length differences (hence, lowered computational accuracies), the model has not yet been made operational on the NVEOL IBM 4341 computer.

The computer radar model has a number of options that enables the user to calculate performance for different types of radars and conditions. This includes classical wide-beam scanning radars, raster scanning radars, air and ground scenario combinations, and moving or stationary targets and/or radars. Some of the important features are[4]:

- Performance predictions for classical wide-beam scanner radars or raster-scanning radars operating in 0.1- to 100-GHz band.
- Moving target indicator (MTI).
- Model for targets having distributed scatters.
- Multi-path propagation for the complex specular component from the ground or sea.
- Doppler processing and post-detection integration.
- Marcum-Swerling target and clutter statistical models.
- Simplistic atmospheric model for 0.1- to 100-GHz band.

Outputs provided by the program are probability of detection, signal-to-noise ratio, and range to target. Any one of these output parameters may be chosen as the dependent variable.

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1 US Army MERADCOM Contract DAAG 29-78-C-0011.

2 B. C. Appling, E. O. Rausch, and R. D. Haynes, "MRANGE, A Radar Simulation Program," Georgia Institute of Technology Engineering and Experiment Station, Atlanta, Georgia, Internal Memorandum, November 1979.

3 Model stored as file named RADAR, under MERADCOM user ID NV[illegible] 1701. Compiled program is on file named RA[illegible]ARB.

4 Georgia Tech Research Institute letter proposed RI-RAD-1025, 12 December 1979.

II. PURPOSE

The purpose of this report is to present three worked examples that illustrate how the model can be set up and used. The examples are:

- A classical wide-beam scanning radar tracking an airborne target.
- A ground raster-scanning radar tracking a target that descends almost vertically to the ground (representing a helicopter pop-up in reverse).
- An airborne raster-scanning radar tracking a moving ground target.

III. ILLUSTRATIVE EXAMPLES

The examples that will be presented were chosen to illustrate how the radar scenario parameters are used to define different types of surveillance, detection, and tracking problems. All the input/output parameters for the radar model are described in Appendix A.[5] The symbolic notation used will follow those defined and used in Appendix A.

Example 1 is a classical, non-coherent MTI radar which emits 100-W pulsed power (PT)[6] at a carrier frequency of 95 MHz (FM). The electro-magnetic radiation is horizontally polarized. The antenna is scanning the 360-degree horizon with a fixed tilt angle of 13.7 degrees (EL) at a rate of 120 degrees/s (SCNRTE). It is 6.0761 ft (AHFT) above the earth. Transmit antenna gain (GT) is equal to the receive centenna gain of 40 dB (GR). The 3-dB main lobe beamwidth is 0.2 degree elevation (BWDE) by 0.2 degree azimuth (BWDA). The antenna is stationary (VPLT = 0).

A 1-m² cross-section target (SIG) will fly along a straight-line descent path starting at a line-of-sight range of 10.005 nmi (-PD) from the radar. The relative descent slope of the target is a 5-ft drop (DELTAH) for each 20-ft (DELTAR) flown horizontally (the units for slope are not important). Closet line-of-sight distance between the radar and the target is 6076 ft (RO). Target height at RO is 6.0761 ft (HT).

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[5] B. Perry, B. C. Appling, et al., "Merge: An Analytic Radar Performance Model," Georgia Institute of Technology Engineering Experiment Station, Atlanta, Georgia, Internal Memorandum, March 1982.

[6] ( ) indicates the symbol in the model associated with the precedir numerical information.

The target has two scatterers (NPTS) located with respect to the target-cross-section center as follows:

	Relative Cross-Section (DISTSIG)	Locations X (SIGX)	Y (SIGY)	Z (SIGZ)
Reflector 1	1	10.0 ft	24.0 ft	0.0 ft
Reflector 2	1	0.0 ft	0.05 ft	34.0 ft

The radar constant false alarm probability is 10^{-6} (FA). False alarm due to clutter is 10^{-5} (PFAC). There is no rain (GAMMA=0) in the scenario.

Figure 1 shows the example geometry. Table 1 shows the values of the parameters that were abstracted from the above example and used to run the radar model. The values shown are those printed out by the model. Some self-explanatory values shown in Table 1 were not mentioned in the above text. Table 2 shows one of the pages of outputs from the model.

The fifth column of Table 2 shows atmospheric attenuation as a function of line-of-sight range. The sixth column shows the probability of detection as a function of line-of-sight range. For example, when the target is at 4.7 nmi, it is inside the main-lobe of the radar beam. The probability of detection changed from 0.0 to 0.8184 upon flying into the main-lobe beam. Computer calculated P_{Det} values corresponding to computer calculated signal-to-noise ratios agreed closely with P_{Det} values obtained using Meyer plots.[7]

All the outputs produced by the radar model are given in Appendix B. These are the outputs normally produced. Table B-1 (Appendix B) is (S/N) at the antenna receiver for the case when there is no atmospheric alteration. Tables B-2 and B-3 incorporate the effects of a range dependent pattern propagation factor without, and then with, atmospheric alteration. The last output, Table B-4, is the complete radar performance and thus includes clutter and doppler processing. The above sequence of outputs are often used to study the degrading effects that atmospherics and processors have on radar performance. Appendix B gives the set of input cards used to exercise the radar model for this example.

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[7] D. P. Meyer and H. A. Meyer, "Radar Target Detection, Handbook of Theory and Practice," Academic Press, 1973.

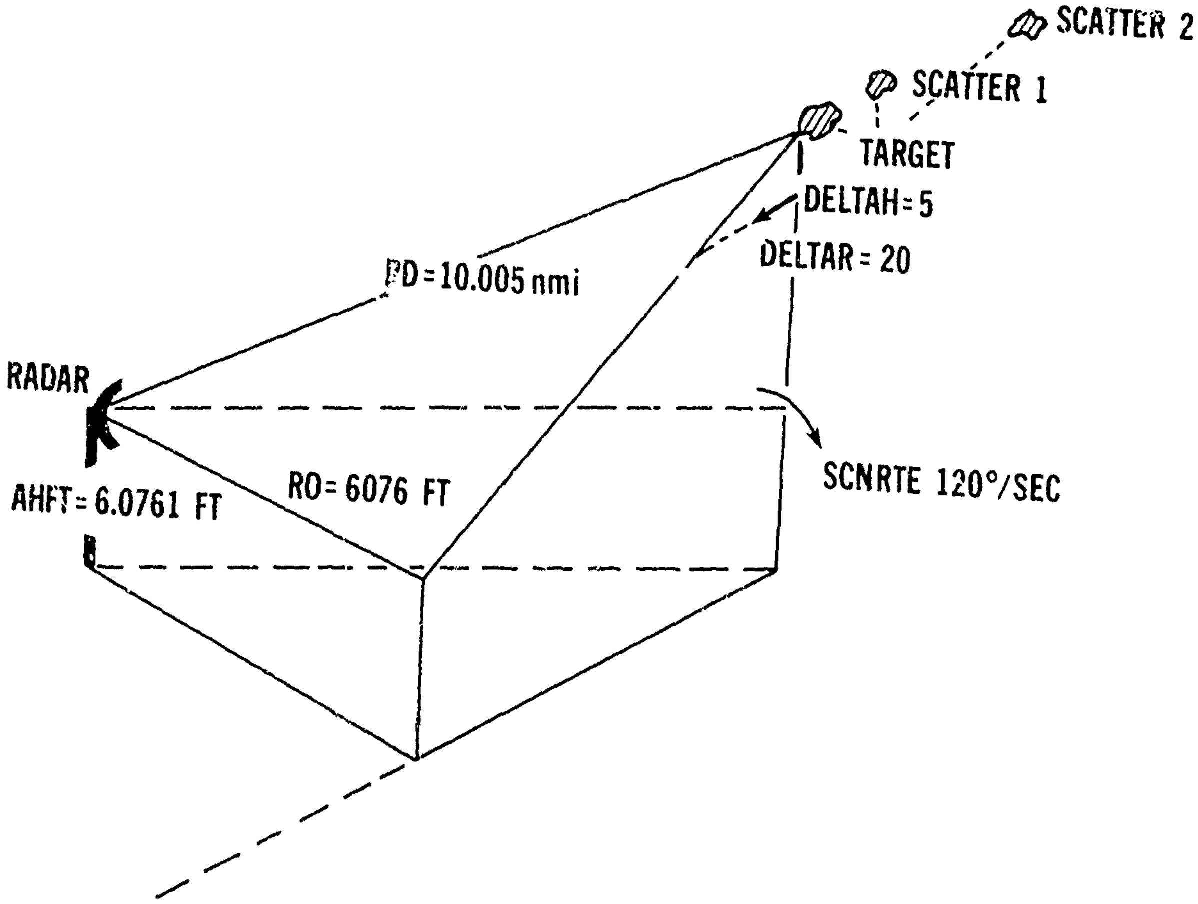

Figure 1. Geometry for Example 1.

Table 1. Input Parameters for Example 1

Parameter	Value
PULSE POWER, kW	.0100
PULSE LENGTH, μs	.6400
TRANSMIT ANTENNA GAIN, dB	40.0000
RECEIVE ANTENNA, GAIN, dB	40.0000
TARGET CROSS SECTION, m²	1.0000
FREQUENCY, MHz	9500.0000
ANTENNA OHMIC LOSS, dB	0.0000
PULSE REPITITION FREQUENCY	2000.0000
RECEIVE TRANSMISSION LINE LOSS, dB	0.0000
TRANSMIT TRANSMISSION LINE LOSS, dB	0.0000
SCANNING ANTENNA PATTERN LOSS, dB, INDICATES ELECTRONIC SCANNING IF NEGATIVE	0.0000
MISCELLANEOUS LOSSES, dB	5.0000
BANDWIDTH CORRECTION FACTOR, dB	0.0000
RECEIVER NOISE FACTOR (FIGURE), dB	6.0000
ATMOSPHERIC ATTENUATION, dB/km (−1 = 1COMP. CALC.)	−1.0000
DIELECTRIC CONSTANT REAL PART (−1 IF NO GROUND)	−1.0000
DIELECTRIC CONSTANT IMAGINARY PART (−1 AS ABOVE)	−1.0000
NUMBER OF PULSES INTEGRATED (−1 = COMP. CALC.)	−1
PROBABILITY OF DETECTION (NOTE≤D CAN SPECIFY INITIAL RANGE HERE IF PD IS NEGATIVE)	−10.005
FALSE-ALARM PROBABILITY, NEGATIVE POWER OF TEN	6.0000
SWERLING FLUCTUATION CASE (0 = NONFLUCT.)	0
TARGET ELEVATION ANGLE (DEGREES) FOR FIXED ANTENNA CASE OR ANTENNA ELEVATION OFFSET FOR TARGET TRACKING CASE	13.70
ANTENNA TILT- FIXED (= 0), OR FOLLOW TARGET (= 1)	0.0000
SOLAR AND GALACTIC NOISE	AVERAGE
RAIN RATE	0.00
ATTENUATION DUE TO RAIN, dB/km	0.0000
RANGE AT WHICH RAIN BEGINS, nmi	0.0000
RANGE AT WHICH RAIN ENDS, nmi	0.0000

Parameter	Value
ANTENNA HEIGHT, ft	6.0761
TARGET HEIGHT RELATIVE TO- HORIZONTAL AT BASE OF ANTENNA (= 0), OR EARTH'S SURFACE (= 1)	1.0000
BEAMWIDTH (ELEVATION), DEGREES	.2000
AZIMUTHAL BEAMWIDTH, DEGREES	.2000
SIDELOBES, dB	25.0000
WAVE HEIGHT, ft	100.0000
POLARIZATION (1 = VERTICAL, 2 = HORIZONTAL)	2
SCAN FREQUENCY, Hz	.3300
SCAN RATE OF ANTENNA, DEGREES/S	120.0000
TARGET SPEED PARALLEL TO RELATIVE MOTION PLANE	.5925
TARGET SPEED PERPENDICULAR TO RELATIVE MOTION PLANE	.0006
PLATFORM VELOCITY (PARLLEL TO TARGET), nmi	0.0000
CUMULATIVE PROBABILITY CUTOFF	.9000
RADAR IS- COHERENT (= 0), OR NONCOHERENT (= 1)	1
STANDARD DEVIATION OF CLUTTER	0.0000
STANDARD DEVIATION OF NOISE	0.0000
STANDARD DEVIATION OF SIGNAL	0.0000
HORIZONTAL COMPONENT OF TRAJECTORY SLOPE	20.0000
VERTICAL COMPONENT OF TRAJECTORY SLOPE	5.0000
TARGET HEIGHT AT CPA (ft)	6.0761
CPA RANGE OFFSET (ft)	6076.1000
RADAR TYPE (1 = PULSE DOPPLER, 2 = MTI)	2.0000
RESPONSE FUNCTION (−1 = SIN, 0 = TRIANGLE, 1 = TRAP)	2.0000
CLUTTER SPECTRUM (1) OR AVERAGE VALUE (0)	0
AVG. SURFACE CLUTTER/UNIT AREA, M**2/M**2	.0000
AVG. VOLUME CLUTTER/UNIT VOLUME, M**2/M**3	.0000
FIRST CORNER OF TRAP RESPONSE FUNCTION, Hz	70000.0000
SECOND CORNER OF TRAP RESPONSE FUNCTION, Hz	7.0000.0000
CLUT. IMPROV. FACTOR (NEG. = ELECT. SCAN.), dB	45.0000
PROBABILITY OF FALSE ALARM DUE TO CLUTTER	6.0000

Table 1. Input Parameters for Example 1

PULSE POWER, kW	.0100
PULSE LENGTH, μs	.6100
TRANSMIT ANTENNA GAIN, dB	40.0000
RECEIVE ANTENNA, GAIN, dB	40.0000
TARGET CROSS SECTION, m^2	1.0000
FREQUENCY, MHz	9500.0060
ANTENNA OHMIC LOSS, dB	0.0000
PULSE REPITITION FREQUENCY	2000.0000
RECEIVE TRANSMISSION LINE LOSS, dB	0.0000
TRANSMIT TRANSMISSION LINE LOSS, dB	0.0000
SCANNING ANTENNA PATTERN LOSS, dB, INDICATES ELECTRONIC SCANNING IF NEGATIVE	0.0000
MISCELLANEOUS LOSSES, dB	5.0000
BANDWIDTH CORRECTION FACTOR, dB	0.0000
RECEIVER NOISE FACTOR (FIGURE), dB	6.0000
ATMOSPHERIC ATTENUATION, dB/km (−1 = 1COMP. CALC.)	−1.0000
DIELECTRIC CONSTANT REAL PART (−1 IF NO GROUND)	−1.0000
DIELECTRIC CONSTANT IMAGINARY PART (−1 AS ABOVE)	−1.0000
NUMBER OF PULSES INTEGRATED (−1 = COMP. CALC.)	−1
PROBABILITY OF DETECTION (NOTE ≤ I) CAN SPECIFY INITIAL RANGE HERE IF PD IS NEGATIVE)	−10.005
FALSE-ALARM PROBABILITY, NEGATIVE POWER OF TEN	6.0000
SWERLING FLUCTUATION CASE (0 = NONFLUCT.)	0
TARGET ELEVATION ANGLE (DEGREES) FOR FIXED ANTENNA CASE OR ANTENNA ELEVATION OFFSET FOR TARGET TRACKING CASE	13.70
ANTENNA TILT- FIXED (=0), OR FOLLOW TARGET (=1)	0.0000
SOLAR AND GALACTIC NOISE	AVERAGE
RAIN RATE	0.00
ATTENUATION DUE TO RAIN, dB/km	0.0000
RANGE AT WHICH RAIN BEGINS, nmi	0.0000
RANGE AT WHICH RAIN ENDS, nmi	0.0000

ANTENNA HEIGHT, ft	6.0761
TARGET HEIGHT RELATIVE TO- HORIZONTAL AT BASE OF ANTENNA (=0), OR EARTH'S SURFACE (=1)	1.0000
BEAMWIDTH (ELEVATION), DEGREES	.2000
AZIMUTHAL BEAMWIDTH, DEGREES	.2000
SIDELOBES, dB	25.0000
WAVE HEIGHT, ft	100.0000
POLARIZATION (1 = VERT. 2 = HORIZONTAL)	2
SCAN FREQUENCY, Hz	.3300
SCAN RATE OF ANTENNA, DEGREES/S	120.0000
TARGET SPEED PARALLEL TO RELATIVE MOTION PLANE	.5925
TARGET SPEED PERPENDICULAR TO RELATIVE MOTION PLANE	.0006
PLATFORM VELOCITY (PARLLEL TO TARGET), nmi	0.0000
CUMULATIVE PROBABILITY CUTOFF	.9000
RADAR IS- COHERENT (=0), OR NONCOHERENT (=1)	1
STANDARD DEVIATION OF CLUTTER	0.0000
STANDARD DEVIATION OF NOISE	0.0000
STANDARD DEVIATION OF SIGNAL	0.0000
HORIZONTAL COMPONENT OF TRAJECTORY SLOPE	20.0000
VERTICAL COMPONENT OF TRAJECTORY SLOPE	5.0000
TARGET HEIGHT AT CPA (ft)	6.0761
CPA RANGE OFFSET (ft)	6076.1000
RADAR TYPE (1 = PULSE DOPPLER, 2 = MTI)	2.0000
RESPONSE FUNCTION (−1 = SIN, 0 = TRIANGLE, 1 = TRAP)	2.0000
CLUTTER SPECTRUM (1) OR AVERAGE VALUE (0)	0
AVG. SURFACE CLUTTER/UNIT AREA, M**2/M**2	.0000
AVG. VOLUME CLUTTER/UNIT VOLUME, M**2/M**3	.0000
FIRST CORNER OF TRAP RESPONSE FUNCTION, Hz	70000.0000
SECOND CORNER OF TRAP RESPONSE FUNCTION, Hz	70000.0000
CLUT. IMPROV. FACTOR (NEG. = ELECT. SCAN.), dB	45.0000
PROBABILITY OF FALSE ALARM DUE TO CLUTTER	6.0000

Table 1. Input Parameters for Example 1 (continued)

LOWEST ANGLE RASTER SCAN ASSUMES (DEGREES)	0.0000	REQUIRED SIGNAL TO CLUTTER RATIO	0.0000
HIGHEST ANGLE RASTER SCAN ASSUMES (DEGREES)	0.0000	NUMBER OF POLES FOR FILTER	3.0000
RASTER SCAN INCREMENT (DEGREES)	0.0000		

THE TARGET MODEL CHOSEN CONSISTS OF MULTIPLE POINT SCATTERERS. THESE ARE DEFINED BY A CROSS SECTION AND A POSITION RELATIVE TO A REFERENCE SCATTERER AS SHOWN BELOW:

REFLECTOR	CROSS-SECTION	X(ft)	Y(ft)	Z(ft)
1	1.00000	10.00000	24.00000	0.00000
2	1.00000	0.00000	.05000	34.00000

Table 2. Output for Example 1

SIGNAL-TO-NOISE RATIO, dB AFTER PROCESSOR	EFFECTIVE SIGNAL-TO-NOISE RATIO, dB	SIGNAL-TO-CLUTTER RATIO, dB BEFORE PROCESSOR	SIGNAL-TO-CLUTTER RATIO, dB AFTER PROCESSOR	TROPOSPHERIC ATTENUATION dB	PROBABILITY OF DETECTION	CUMULATIVE PROBABILITY	RANGE IN nmi	RANGE IN km
−36.02	−36.02	16.17	16.17	.31	0.0000	0.0000	10.00	18.52
−36.01	−36.01	16.51	16.51	.30	0.0000	0.0000	9.62	17.82
−36.02	−36.02	16.86	16.86	.28	0.0000	0.0000	9.24	17.12
−33.75	−33.75	17.22	17.22	.27	.0000	.0000	8.86	16.41
−26.80	−26.80	17.61	17.61	.26	.0000	.0000	8.48	15.71
−24.87	−24.87	18.00	18.00	.25	.0000	.0000	8.10	15.00
−25.78	−25.78	18.42	18.42	.24	.0000	.0000	7.72	14.30
−22.92	−22.92	18.86	18.86	.23	.0000	.0000	7.34	13.60
−16.98	−16.98	19.32	19.32	.21	.0000	.0000	6.96	12.89
−14.98	−14.98	19.81	19.81	.20	.0000	.0000	6.58	12.19
−5.80	−5.80	20.32	20.32	.19	.0000	.0000	6.21	11.49
−6.81	−6.81	20.87	20.87	.18	.0000	.0000	5.83	10.79
5.06	5.06	21.45	21.45	.17	.0936	.0936	5.45	10.10
4.64	4.64	22.07	22.07	.16	.0646	.1521	5.07	9.40
8.75	8.75	22.73	22.73	.14	.8184	.8460	4.70	8.70
2.43	2.43	23.45	23.45	.13	.0083	.8473	4.33	8.01
−7.36	−7.36	24.23	24.23	.12	.0000	.8473	3.95	7.32
−36.02	−36.02	25.08	25.08	.11	0.0000	.8473	3.59	6.64
−36.02	−36.02	26.02	26.02	.10	0.0000	.8473	3.22	5.96
−36.02	−36.02	27.05	27.05	.09	0.0000	.8473	2.86	5.29
−36.02	−36.02	28.21	28.21	.08	0.0000	.8473	2.50	4.64
−36.02	−36.02	29.50	29.50	.07	0.0000	.8473	2.16	3.99
−36.02	−36.02	30.94	30.94	.06	0.0000	.8473	1.83	3.38
−36.02	−36.02	32.54	32.54	.05	0.0000	.8473	1.52	2.82
−36.02	−36.02	34.19	34.19	.04	0.0000	.8473	1.26	2.33

A simple equation[8] used to calculate the signal-to-noise ratio for a radiating radar is:

$$\left(\frac{S}{N}\right) = \frac{PG_tG_r\lambda^2\sigma^2_{TGT}}{(4\pi)^3R^4FkTB_n}\ \tau(2R).$$

where: P is radiated power.

G_t, G_r are transient and receive gain of radar antenna.

λ is wavelength of electro-magnetic radiation.

σ_{TGT} is target cross-section.

R is range to target.

F is noise figure of merit.

k is Boltzman's constant.

T is input temperature of receiver.

B_n is noise bandwidth.

τ is atmospheric transmission.

If the gains are each increased by 2, the resulting (S/N) ratio should increase by 4 (or 6 dB), all other conditions remaining the same. For the above described example 1, the antenna transmit and receive gains were each increased by 2. (The scatterers were deleted for this calculation in order to remove their signal contributions.) A plot of the (S/N) ratio for each case is shown in Figure 2. The curves are the same except that they are separated by 6 dB.

Example 2 is the case of a target pop-up in reverse. A stationary ground-based, raster-scanning MTI radar is viewing a section of the sky. The horizonal raster scans go from 0.36 degree above the horizon (TILTMIN) to 2.77 degrees above the horizon (TILTMAX) in 0.1-degree increments (ELINC), for a total of 25 raster lines per frame. It takes 0.16666 s to completely scan the frame (SCNFREQ).

The target has a cross-section of 1 m² (SIG) and has no distributed scatterers. Its initial line-of-sight range from the radar is 1.001 nmi (-PD). Its closest range to the radar is 6076.1 ft (RO) or 0.99933 nmi. Target height at RO is 6.0761 ft (HT).

[8] S. A. Hovanessian, "Radar Detection and Tracking Systems," Artech House, Inc., 1980, pages 1 through 8.

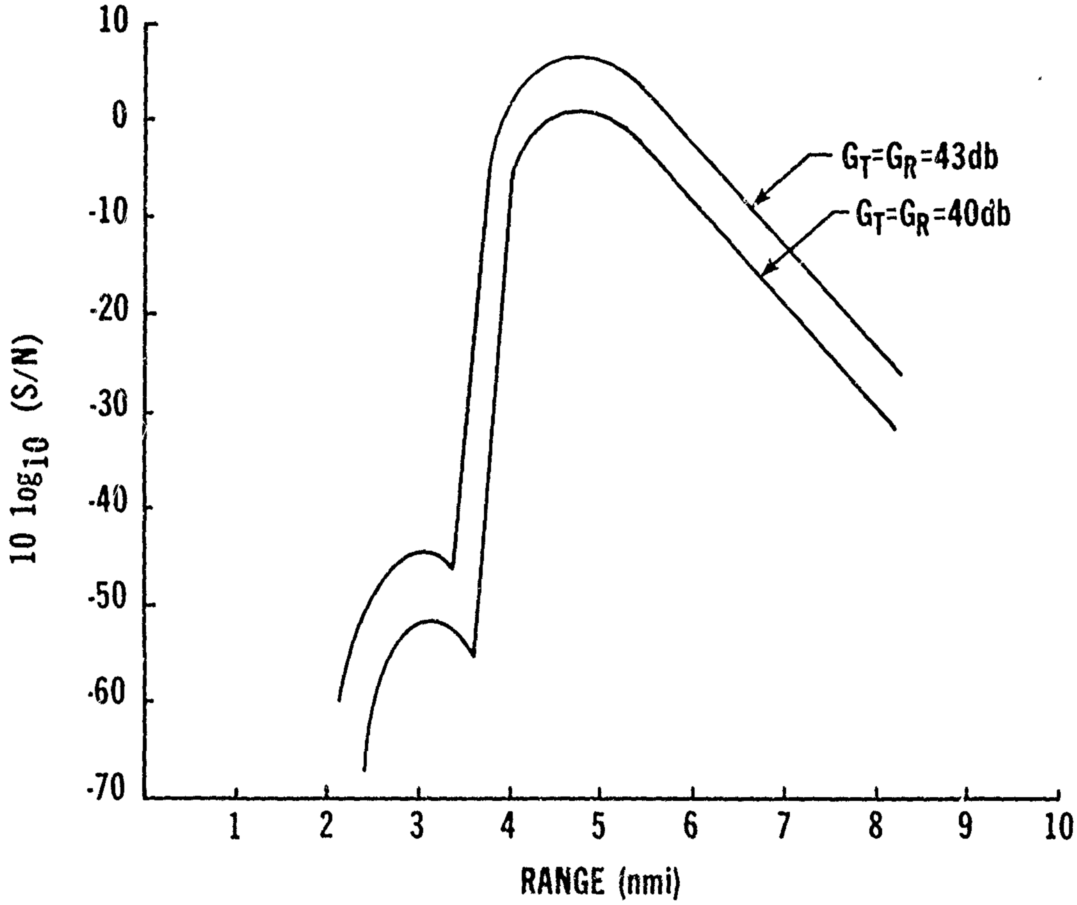

Figure 2. Graph showing the effect of increasing transmit and receiving antenna gain by a factor of two (or total of 6 dB). Data are shown for Example 1 when there are no scatterers and no atmospheric attenuation. The scatterers and atmospheric attenuation have been removed to simplify the graphic presentation.

Figure 3 shows the geometry for this example. Table 3 gives the data that were used to do this performance calculation. Table 4 shows the calculated (S/N) levels prior to the processor as well as probability of detection at different target heights. The probability of detection shown in column 4 (Table 4) is the highest value calculated for that frame. The actual raster line producing this maximum probability value is not printed out (this change will be made in the future).

Appendix C gives the set of input cards used to exercise the radar model for this case.

Example 3 represents an airborne radar surveying the battlefield. The radar platform is stationary (VPLT = 0) and is at a height of 60.761 ft (AHFT). The horizontal raster scans go from − 1.72 degrees (TILTMIN) down to − 3.00 degrees (TILTMAX) in 0.1-degree increments (ELINC). It takes 1.1 s to completely scan the frame (SCNFREQ).

The target has a cross-section of 5.25 m^2 (SIG) and has no distributed scatterers. Its initial line-of-sight range from the radar is 1.10 nmi (−PD). The horizontal component of target velocity towards the radar is 5 knots (VTGTI).

The geometry for this example is shown in Figure 4. Table 5 gives other data that were used to do this performance calculation. Table 6 shows the calculated (S/N) levels prior to the processor as well as probability of detection. Note that the probability of detection at a range of 1.10 nmi is 0. At ranges of 1.09 mi or closer, the probability of detection is 1.00.

Appendix D gives the set of input cards used to exercise the radar model.

IV. CONCLUSION

It is concluded that: The NVEOL—Georgia Tech Research Institute millimeter wavelength radar performance model has been put up on the MERADCOM CDC 6600 computer. Three examples that illustrate how the model is to be used have been presented. Each example represents a different type of radar or a different battlefield scenario.

The model in its present form has not been used to predict the performance of Army Startle sensors. It is uncertain how to treat the signal processing parts of these radars. This will be addressed internally in the near term and through a contract to be awarded to Georgia Tech during July 1982.

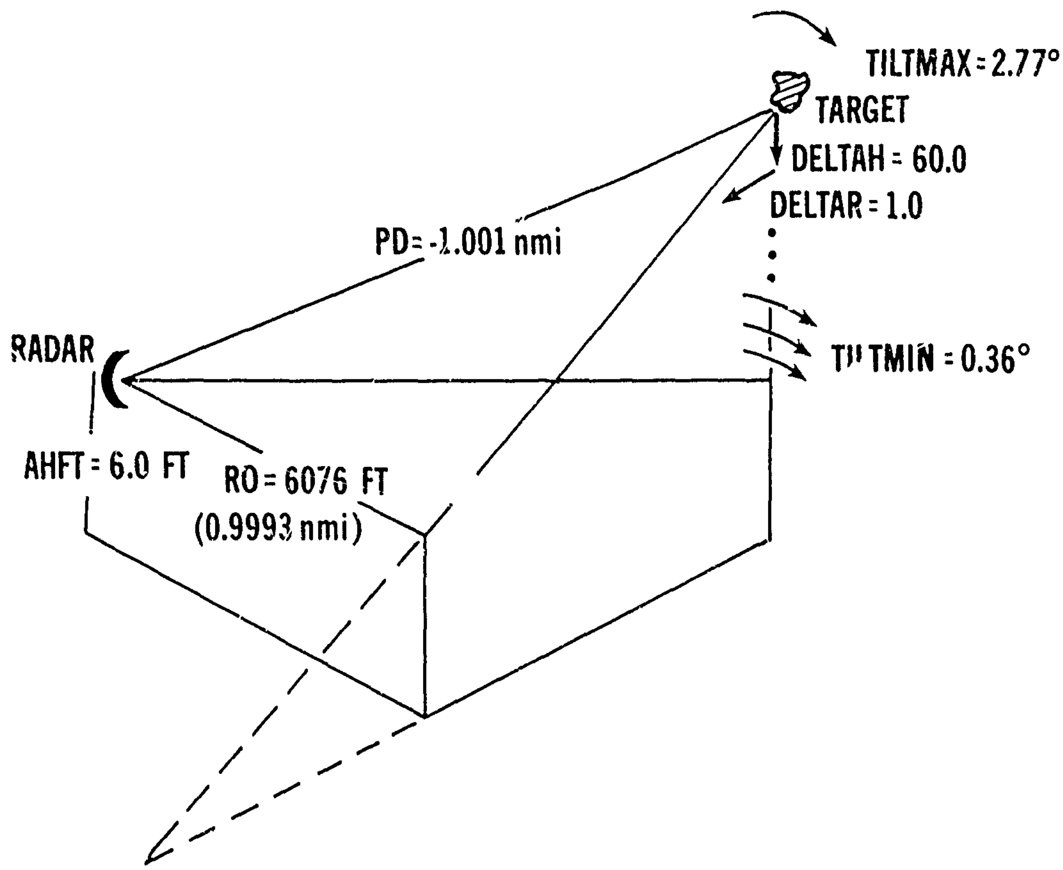

Figure 3. Geometry for Example 2.

Table 3. Input Parameters for Example 2

PULSE POWER, kW	.00400
PULSE LENGTH, μs	.1250
TRANSMIT ANTENNA GAIN, dB	45.0000
RECEIVE ANTENNA GAIN, dB	45.0000
TARGET CROSS SECTION, m²	1.0000
FREQUENCY, MHz	93930.0000
ANTENNA OHMIC LOSS, dB	0.0000
PULSE REPITITION FREQUENCY	40000.0000
RECEIVE TRANSMISSION LINE LOSS, dB	8.5000
TRANSMIT TRANSMISSION LINE LOSS, dB	0.0000
SCANNING ANTENNA PATTERN LOSS, dB, INDICATES ELECTRONIC SCANNING IF NEGATIVE	0.0000
MISCELLANEOUS LOSSES, dB	0.0000
BANDWIDTH CORRECTION FACTOR, dB	0.0000
RECEIVER NOISE FACTOR (FIGURE), dB	6.0000
ATMOSPHERIC ATTENUATION, dB/km (−1 = 1COMP. CALC.)	−1.0000
DIELECTRIC CONSTANT REAL PART (−1 IF NO GROUND)	4.0000
DIELECTRIC CONSTANT IMAGINARY PART (−1 AS ABOVE)	−.0060
NUMBER OF PULSES INTEGRATED (−1 = COMP. CALC.)	160
PROBABILITY OF DETECTION (NOTE ≤ D CAN SPECIFY INITIAL RANGE HERE IF PD IS NEGATIVE)	−1.001
FALSE-ALARM PROBABILITY, NEGATIVE POWER OF TEN	6.0000
SWERLING FLUCTUATION CASE (0 = NONFLUCT.)	0
TARGET ELEVATION ANGLE (DEGREES) FOR FIXED ANTENNA CASE OR ANTENNA ELEVATION OFFSET FOR TARGET TRACKING CASE	0.00
ANTENNA TILT- FIXED (=0), OR FOLLOW TARGET (=1)	2.0000
SOLAR AND GALACTIC NOISE	AVERAGE
RAIN RATE	0.00
ATTENUATION DUE TO RAIN, dB/km	0.0000
RANGE AT WHICH RAIN BEGINS, nmi	0.0000
RANGE AT WHICH RAIN ENDS, nmi	0.0000
LOWEST ANGLE RASTER SCAN ASSUMES (DEGREES)	.3600
HIGHEST ANGLE RASTER SCAN ASSUMES (DEGREES)	2.7700
RASTER SCAN INCREMENT (DEGREES)	.1000

ANTENNA HEIGHT, ft	6.0761
TARGET HEIGHT RELATIVE TO- HORIZONTAL AT BASE OF ANTENNA (=0), OR EARTH'S SURFACE (=1)	1.0000
BEAMWIDTH (ELEVATION), DEGREES	.5700
AZIMUTHAL BEAMWIDTH, DEGREES	.5700
SIDELOBES, dB	18.0000
WAVE HEIGHT, ft	.5000
POLARIZATION (1 = VERTICAL, 2 = HORIZONTAL)	1
SCAN FREQUENCY, Hz	.1666
SCAN RATE OF ANTENNA, DEGREES/S	60.0000
TARGET SPEED PARALLEL TO RELATIVE MOTION PLANE	.6000
TARGET SPEED PERPENDICULAR TO RELATIVE MOTION PLANE	.0006
PLATFORM VELOCITY (PARLLEL TO TARGET), nmi	0.0000
CUMULATIVE PROBABILITY CUTOFF	.9000
RADAR IS- COHERENT (=0), OR NONCOHERENT (=1)	0
STANDARD DEVIATION OF CLUTTER	0.0000
STANDARD DEVIATION OF NOISE	0.0000
STANDARD DEVIATION OF SIGNAL	0.0000
HORIZONTAL COMPONENT OF TRAJECTORY SLOPE	1.0000
VERTICAL COMPONENT OF TRAJECTORY SLOPE	60.0000
TARGET HEIGHT AT CPA (ft)	6.0761
CPA RANGE OFFSET (ft)	6076.1000
RADAR TYPE (1 = PULSE DOPPLER, 2 = MTI)	2.0000
RESPONSE FUNCTION (−1 = SIN, 0 = TRIANGLE, 1 = TRAP)	1.0000
CLUTTER SPECTRUM (1) OR AVERAGE VALUE (0)	1
AVG. SURFACE CLUTTER/UNIT AREA, M**2/M**2	.0000
AVG. VOLUME CLUTTER/UNIT VOLUME, M**2/M**3	.0000
FIRST CORNER OF TRAP RESPONSE FUNCTION, Hz	1055.0000
SECOND CORNER OF TRAP RESPONSE FUNCTION, Hz	14071.0000
CLUT. IMPROV. FACTOR (NEG. = ELECT. SCAN.), dB	10.0000
PROBABILITY OF FALSE ALARM DUE TO CLUTTER	6.0000
REQUIRED SIGNAL TO CLUTTER RATIO	0.0000
NUMBER OF POLES FOR FILTER	2.0000

Table 4. Output for Example 2; No Atmospheric Attenuation

OUTPUT BELOW (S/N, PROBABILITY OF DETECTION) IS FREE SPACE VALUE, (ZERO WEIGHTING).

SWERLING FLUCTUATION CASE	SIGNAL-TO-NOISE RATIO, dB BEFORE PROCESSOR	TROPOSPHERIC ATTENUATION, dB	PROBABILITY OF DETECTION	TARGET HEIGHT IN ft	RANGE IN nmi	RANGE IN km.
0	2.84	0.00	1.0000	277.84	1.001	1.8538
0	2.84	0.00	1.0000	265.68	1.000	1.8537
0	2.85	0.00	1.0000	253.53	1.000	1.8535
0	2.85	0.00	1.0000	241.37	1.000	1.8534
0	2.85	0.00	1.0000	229.21	1.000	1.8532
0	2.85	0.00	1.0000	217.06	1.000	1.8531
0	2.85	0.00	1.0000	204.90	1.000	1.8530
0	2.85	0.00	1.0000	192.75	1.000	1.8529
0	2.85	0.00	1.0000	180.59	1.000	1.8528
0	2.85	0.00	1.0000	168.44	1.000	1.8527
0	2.86	0.00	1.0000	156.28	1.000	1.8526
0	2.86	0.00	1.0000	144.13	1.000	1.8525
0	2.86	0.00	1.0000	131.97	1.000	1.8524
0	2.86	0.00	1.0000	119.82	1.000	1.8523
0	2.86	0.00	1.0000	107.66	1.000	1.8523
0	2.86	0.00	1.0000	95.51	1.000	1.8522
0	2.86	0.00	1.0000	83.35	1.000	1.8521
0	2.86	0.00	1.0000	71.19	1.000	1.8521
0	2.86	0.00	1.0000	59.04	1.000	1.8521
0	2.86	0.00	1.0000	46.88	1.000	1.8520
0	2.86	0.00	1.0000	34.73	1.000	1.8520
0	2.86	0.00	1.0000	22.57	1.000	1.8520

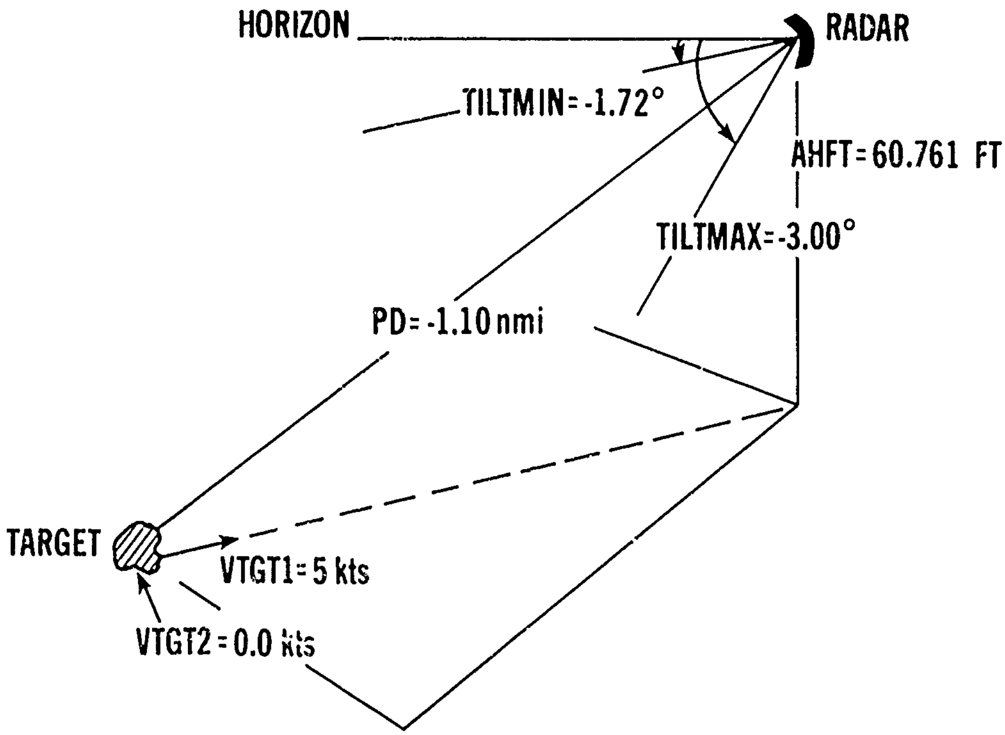

Figure 4. Geometry for Example 3.

Table 5. Input Parameters for Example 3

PULSE POWER, kW	.2100
PULSE LENGTH, μs	.2000
TRANSMIT ANTENNA GAIN, dB	55.0000
RECEIVE ANTENNA, GAIN, dB	55.0000
TARGET CROSS SECTION, m²	5.2500
FREQUENCY, MHz	93930.0000
ANTENNA OHMIC LOSS, dB	0.0000
PULSE REPITITION FREQUENCY	33400.0000
RECEIVE TRANSMISSION LINE LOSS, dB	10.1000
TRANSMIT TRANSMISSION LINE LOSS, dB	0.0000
SCANNING ANTENNA PATTERN LOSS, dB, INDICATES ELECTRONIC SCANNING IF NEGATIVE	0.0000
MISCELLANEOUS LOSSES, dB	0.0000
BANDWIDTH CORRECTION FACTOR, dB	0.0000
RECEIVER NOISE FACTOR (FIGURE), dB	6.0000
ATMOSPHERIC ATTENUATION, dB/km (−1 = 1COMP. CALC.)	−1.0000
DIELECTRIC CONSTANT REAL PART (−1 IF NO GROUND)	4.0000
DIELECTRIC CONSTANT IMAGINARY PART (−1 AS ABOVE)	.0060
NUMBER OF PULSES INTEGRATED (−1 = COMP. CALC.)	40
PROBABILITY OF DETECTION (NOTE≤D CAN SPECIFY INITIAL RANGE HERE IF PD IS NEGATIVE)	−1.100
FALSE-ALARM PROBABILITY, NEGATIVE POWER OF TEN	6.0000
SWERLING FLUCTUATION CASE (0 = NONFLUCT.)	0
TARGET ELEVATION ANGLE (DEGREES) FOR FIXED ANTENNA CASE OR ANTENNA ELEVATION OFFSET FOR TARGET TRACKING CASE	0.00
ANTENNA TILT- FIXED (=0), OR FOLLOW TARGET (=1)	2.0000
SOLAR AND GALACTIC NOISE	AVERAGE
RAIN RATE	0.00
ATTENUATION DUE TO RAIN, dB/km	0.0000
RANGE AT WHICH RAIN BEGINS, nmi	0.0000
RANGE AT WHICH RAIN ENDS, nmi	0.0000
LOWEST ANGLE RASTER SCAN ASSUMES (DEGREES)	0.0000
HIGHEST ANGLE RASTER SCAN ASSUMES (DEGREES)	−2.0000
RASTER SCAN INCREMENT (DEGREES)	.1000
ANTENNA HEIGHT, ft	60.7610
TARGET HEIGHT RELATIVE TO- HORIZONTAL AT BASE OF ANTENNA (=1), OR EARTH'S SURFACE (=1)	1.0000
BEAMWIDTH (ELEVATION), DEGREES	.5700
AZIMUTHAL BEAMWIDTH, DEGREES	.5700
SIDELOBES, dB	22.0000
WAVE HEIGHT, ft	.5000
POLARIZATION (1 = VERTICAL, 2 = HORIZONTAL)	2
SCAN FREQUENCY, Hz	1.1000
SCAN RATE OF ANTENNA, DEGREES/S	396.0000
TARGET SPEED PARALLEL TO RELATIVE MOTION PLANE	.10.0000
TARGET SPEED PERPENDICULAR TO RELATIVE MOTION PLANE	0.0000
PLATFORM VELOCITY (PARLLEL TO TARGET), nmi	0.0000
CUMULATIVE PROBABILITY CUTOFF	.9000
RADAR IS- COHERENT (=0), OR NONCOHERENT (=1)	0
STANDARD DEVIATION OF CLUTTER	0.0000
STANDARD DEVIATION OF NOISE	0.0000
STANDARD DEVIATION OF SIGNAL	0.0000
HORIZONTAL COMPONENT OF TRAJECTORY SLOPE	100.0000
VERTICAL COMPONENT OF TRAJECTORY SLOPE	0.0000
TARGET HEIGHT AT CPA (ft)	6.0761
CPA RANGE OFFSET (ft)	6076.1000
RADAR TYPE (1 = PULSE DOPPLER, 2 = MTI)	2.0000
RESPONSE FUNCTION (−1 = SIN, 0 = TRIANGLE, 1 = TRAP)	1.0000
CLUTTER SPECTRUM (1) OR AVERAGE VALUE (0)	1
AVG. SURFACE CLUTTER/UNIT AREA, M**2/M**2	0.0000
AVG. VOLUME CLUTTER/UNIT VOLUME, M**2/M**3	.0000
FIRST CORNER OF TRAP RESPONSE FUNCTION, Hz	1055.0000
SECOND CORNER OF TRAP RESPONSE FUNCTION, Hz	14071.0000
CLUT. IMPROV. FACTOR (NEG. = ELECT. SCAN.), dB	16.0000
PROBABILITY OF FALSE ALARM DUE TO CLUTTER	6.0000
REQUIRED SIGNAL TO CLUTTER RATIO	0.0000
NUMBER OF POLES FOR FILTER	2.0000

Table 6. Output for Example 3; No Atmospheric Attenuation

OUTPUT BELOW IS WEIGHTED WITH A PPF AND ATROP. ATTEN. FACTOR. CLUTTER AND DOPPLER PROCESSING IS ALSO INCLUDED. CUMULATIVE PROBABILITY IS ALSO CALCULATED.

SIGNAL-TO-NOISE RATIO, dB AFTER PROCESSOR	EFFECTIVE SIGNAL-TO-NOISE RATIO, dB	SIGNAL-TO-CLUTTER RATIO, dB BEFORE PROCESSOR	SIGNAL-TO-CLUTTER RATIO, dB AFTER PROCESSOR	TROPOSPHERIC ATTENUATION dB	PROBABILITY OF DETECTION	CUMULATIVE PROBABILITY	RANGE IN nmi	RANGE IN km
−36.02	−36.02	−33.26	−36.02	1.60	.0000	.0000	[illegible]	2.04
28.01	22.49	−33.20	22.49	1.59	1.0000	1.0000	[illegible]	2.02
27.68	22.55	−33.14	22.55	1.58	1.0000	1.0000	[illegible]	2.01
27.26	22.60	−33.09	22.60	1.57	1.0000	1.0000	1.08	2.00
26.78	22.66	−33.04	22.66	1.56	1.0000	1.0000	1.07	1.99
26.31	22.71	−32.99	22.71	1.55	1.0000	1.0000	1.07	1.97
25.87	22.76	−32.94	22.76	1.54	1.0000	1.0000	1.06	1.96
25.22	22.53	−32.89	22.53	1.53	1.0000	1.0000	1.05	1.95
24.50	22.14	−32.85	22.14	1.52	1.0000	1.0000	1.05	1.94
23.81	21.73	−32.80	21.73	1.52	1.0000	1.0000	1.04	1.93
23.15	21.28	−32.76	21.28	1.51	1.0000	1.0000	1.04	1.92
22.48	20.80	−32.72	20.80	1.50	1.0000	1.0000	1.03	1.92
21.80	20.27	−32.69	20.27	1.50	1.0000	1.0000	1.03	1.91
21.07	19.69	−32.65	19.69	1.49	1.0000	1.0000	1.03	1.90
20.29	19.06	−32.62	19.06	1.48	1.0000	1.0000	1.02	1.89
19.44	18.35	−32.59	18.35	1.48	1.0000	1.0000	1.02	1.89
18.50	17.57	−32.56	17.57	1.47	1.0000	1.0000	1.02	1.88
17.48	16.70	−32.54	16.70	1.47	1.0000	1.0000	1.01	1.87
16.34	15.71	−32.51	15.71	1.47	1.0000	1.0000	1.01	1.87
15.06	14.58	−32.49	14.58	1.46	.9999	1.0000	1.01	1.87
13.61	13.26	−32.48	13.26	1.46	.9861	1.0000	1.01	1.86
11.92	11.68	−32.46	11.68	1.46	.7921	1.0000	1.00	1.86
9.87	9.73	−32.45	9.73	1.46	.3131	1.0000	1.00	1.86
7.25	7.19	−32.44	7.19	1.45	.0455	1.0000	1.00	1.85
3.56	3.56	−32.43	3.56	1.45	.0025	1.0000	1.00	1.85

Other future internal and external efforts to improve upon the model include:

- Extend model's prediction capability to include 100 GHz to 300 GHz band.This requires incorporation of the Atmospheric Science Laboratory's atmospheric model and modifications to the existing multi-path scattering part of the model.

- Make model much easier for user to interactively work with by:

  (1) Establishing a library of data files for existing or prototyped radars and targets.

  (2) Incorporating automated graphics capability.

  (3) Enabling user to do multi-runs and automated system sensitivity and analysis.

- Incorporate uniform units of measure (presently, there is a mix of metric and English).

The above are expected to be accomplished over the next fiscal year through internal and external programs.

REFERENCES

1. US Army MERADCOM Contract DAAG 29-78-C-0044.

2. B. C. Appling, E. O. Rausch and R. D. Haynes, "MERANGE: A Radar Simulation Program," Georgia Institute of Technology Engineering Experiment Station, Atlanta, Georgia, Internal Memorandum, November 1979.

3. B. Perry, B. C. Appling, et al, "Merge: An Analytic Radar Performance Model," Georgia Institute of Technology Engineering Experiment Station, Atlanta, Georgia, Internal Memorandum, March 1982.

4. Georgia Tech Research Institute letter proposed No. RI-RAD-1025, 12 December 1979.

5. S. A. Hovanessian, "Radar Detection and Tracking Systems," Artech House, Inc., 1980, pages 1 through 8.

6. D. P. Meyer and H. A. Meyer, "Radar Target Detection, Handbook of Theory and Practice," Academic Press, 1973.

APPENDIX A*

DESCRIPTION OF RADAR PERFORMANCE MODEL AND ITS INPUT/OUTPUT PARAMETERS

THE SURVEILLANCE ROUTINE

1.1 INTRODUCTION

This program is a FORTRAN IV formulation of several integrated component programs. Since MERGE is an integrated composite of several "stand-alone" component programs, much of the documentation for the RANGE portion of MERGE is taken from documents which describe the component programs. This is especially true of NRL Report 7448, *A FORTRAN COMPUTER Program to Calculate the Range of a Pulse Radar*, by L. V. Blake.

The Surveillance routine is primarily intended to determine the detection range performance of a conventional surveillance radar. The routine can be started in either of two ways. One method requires that the user specify the range at which he would like the target to start. The program will then calculate the signal-to-noise ratio (S/N) and the probability of detection (PD) due to a maximum allowed false alarm probability (PFA). The second method requires that the user specify a *minimum* probability of detection at which he would like the target to start. Now the program will calculate the S/N and the corresponding range due to a PFA. The target's range is then decremented at a rate corresponding to the surveillance scan rate and target velocity. The S/N is computed for each decremented range and the resulting PD's are computed. The computations are continued until the minimum increment of range is reached. A table of PD's and S/N's versus range is then printed. The contents of this table are then modified by a pattern propagation factor and printed in a second table. The contents of the second table are in turn modified by medium attenuation and printed in a third table. A fourth table takes these results and accounts for the effect clutter and various types of Doppler response functions.

The fundamental underlying philosophy of program MERGE is that it must be kept as flexible as possible. As an example, the user can specify the starting range *or* he can specify a minimum probability of detection that he would like the target to start at. Another example of this flexibility is that the user can specify *or* calculate attenuation due to rain, atmospheric attenuation; and the number of pulses integrated. These and all of the other options available to the user are outlined in the subsection on input parameters (par 1.3).

* B. Perry, B. C. Appling, et al., "Merge: An Analytic Radar Performance Model, Section 1," Georgia Institute of Technology Engineering Experiment Station, Atlanta, Georgia, Internal Memorandum, March 1982.

1.2 BRIEF HISTORY ON RANGE PROGRAMS

The essential nucleus of the Surveillance Routine is based upon a series of previous programs, the most notable of which is RGCALC. The following is a brief history of the development of these radar performance programs.

Some years ago, a computer program was developed for the calculation of maximum radar range by a contractor for the Scientific and Technical Intelligence Center of the Office of Naval Intelligence (ONI-STIC-50). The work was completed about 1966. This program was based on NRL Report 5868, an earlier edition of NRL Report 6930. It utilized some curves published in that report by reading a finite number of data points into the computer and interpolating between them; this was done for the "visibility factor" (minimum-detectable signal-to-noise ratio), the antena noise temperature, and the atmospheric absorption loss. Because of this, the program was limited to calculating the range for 0.5 probability-of-detection for a nonfluctuating target in the frequency range of 100 MHz to 10 GHz.

Another computer program has been described by Boothe. This program computes the probability-of-detection as a function or range, rather than computing the range for a specified probability. However, the maximum range for specified probability is found by computing probability for decreasing range values until the desired probability is reached. The program also makes use of atmospheric absorption curves from NRL Report 5868, entered as data into the computer; consequently it is limited to the frequency range 100 MHz to 10 GHz, plus perhaps a few "spot" frequencies up to 100 GHz. The report does not state the method used for evaluating antenna noise temperature, and a program listing is not given. The effect of target aspect variation on cross section is taken into account deterministically, rather than statistically using Swerling's theory. The signal-to-noise ratio and the resulting probability-of-detection are calculated at ranges that decrease in steps corrersponding to the observation interval of a target approaching the radar. The target is assumed to be changing aspect according to some known prescription during this approach, and the corresponding cross section variation is calculated (a missile target is assumed in Boothe's analysis). As the target approaches, the probability of a detection increases, and when the probability reaches the specified value, the range is printed out or otherwise recorded. Either single scan or cumulative probability of detection can be specified.

D. M. White has described a comprehensive program to analyze radar performance in a dynamic situation, computing signal-to-noise ratio and detection probability as a function of time and target position, taking into account the effects of multipath interference, clutter echoes from the sea or rain, and target motion. In short, the program simulates in as much detail as is practical the complete radar-target engagement for a single target. This program utilizes a subroutine written by L. F. Fehlner of the John Hopkins Applied Physics Laboratory, and described by Fehlner in a previous report, to calculate the probability-of-detection for a specified signal-to-noise ratio, false-alarm number, number of pulses integrated, and target fluctuation characteristic. Any one of five fluctuation cases can be specified: the nonfluctuating case and the four Swerling fluctuation cases. White mentions other programs that have been written by Kirkwood and by Nolen.

Killinger has developed a computer program that calculates the ratio of signal-to-noise plus clutter as a function of target range. Probabilities of detection and false alarm are also computed. Maximum detection range can be found for a specified signal-to-noise plus clutter ratio.

The philosophy of RGCALC is somewhat different from those discussed above. It is not intended to simulate the radar performance in a dynamic situation. Instead, it is intended to provide, for a specified target size, fluctuation model, and detection probability, a single number that will serve as an index of the radar's range capability—a "figure of merit." The geophysical environment is taken into account as realistically as possible, except that the effects of clutter, rain, and multipath interference are omitted. The factors that are believed to be more realistically or accurately calculated than in other programs are the system noise temperature (or more specifically, the tropospheric, solar, and galactic contributions to the antenna temperature) and the tropospheric absorption loss (due to collision-broadened absorption resonances of the oxygen and water vapor molecules). The antenna noise temperature and the atmospheric attenuation are computed directly, rather than by interpolation using data entered from precalculated curves or tables; consequently, the permissible range of frequency is much greater than for most programs using precalculated temperature and absorption data.

RGCALC computes the detection range for either a steady (nonfluctuating) target or any of the four Swerling fluctuation cases (or for all five cases) for a specified probability-of-detection and a specified false alarm probability. Fehler's subroutine (which is named MARCUM) has been incorporated into the NRL program, with slight modifications, for this purpose. The principal modification has been to provide for calculations on the basis of false alarm probability, rather than MARCUM's false alarm number. Another modification ensures that the bias-level calculation is not repeated when successive calls are made to the subroutine with the same false alarm and number-of-pulses parameters. This saves an appreciable amount of computing time in the iterative procedure used to determine the signal-to-noise ratio for a specified probability of detection (Subroutine MARCUM actually does the inverse problem of computing probability of detection for a specified signal-to-noise ratio). Because of these and other changes, the subroutine as actually used in the NRL program has been renamed MARSWR, but it is basically Fehlner's MARCUM subroutine. The calculation is made assuming a square law detector, whereas most radar receivers employ a linear-rectifier detector, but the difference in performance of the two detector types is about 0.2 dB at most, depending on number of pulses integrated.

Target amplitude distributions other than those represented by the Swerling cases have recently been observed, particularly at higher transmit frequencies. In addition, clutter distributions are not limited to the Gaussian case assumed in the Swerling models. One of the distributions observed can be described by a log-normal function. For this case, the probability of false alarm is given by the equation.

$$P_{FA} = \frac{1}{2}\left[1 - \text{erf}\left(\frac{T/C}{2N\,\sigma_c}\right)\right]$$

where

T = detector threshold

N = number of independent samples

C = clutter signal level

σ_c = the standard deviation of the clutter amplitude, and

erf = the error function.

The probability of detection is given by,

$$P_d = \frac{1}{2}\left[1 + \text{erf}\;\frac{1/2\;N\ln(S/C) - T/C}{\left[2\sigma_s^2 + \frac{\exp(2\sigma_c^2 + 2\sigma_s^2)}{S/C}\right]^{1/2}}\right]$$

where

S = signal strength

σ_s = standard deviation of the signal.

These types of distribution are discussed in more detail elsewhere.* When the log-normal target and clutter model has been chosen, the above equations are used in place of the MARSWR routine. It should be noted that log-normal distributed targets and clutter severely reduce the detection capability. This model results in a "worst case" detection performance. It should thus be employed only when there is good reason to believe that the Swerling cases do not apply.

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* B. Perry, B. C. Appling, et al., "Merge; An Analytical Radar Performance Model, Section 1, Appendix A," Georgia Institute of Technology Engineering Station, Atlanta, Georgia, Internal Memorandum, March 1982.

1.3 INPUT PARAMETERS

Table 1 contains a list of all of the input parameters arranged in the sequence in which they are entered. Note that one must set up *three* separate data files as if running the entire MERGE program to run the surveillance portion of MERGE. This is because the surveillance routine borrows a few parameters from the Track routine to help prevent redundancy. The first file is used by the top level MERGE logic. The second file provides the parameters for the RANGE portion of the program, and the third table is primarily for the ERROR routine. Since the RANGE routine uses a few of the parameters from the ERROR file and is also affected by the top level MERGE logic, the input files will be discussed in the following manner: The first and second files will be discussed in full, and the parameters borrowed from the ERROR portion of the program will be discussed briefly. For a more detailed explanation of the ERROR parameters other than that shown in Table A-1, refer to the documentation of the ERROR portion of the program.

1.3.1 INPUTS FOR MERGE TOP LEVEL LOGIC

The first parameter (variable name NORNG) is used to determine which portion of MERGE the user wishes to employ. The user may use either the RANGE part or the ERROR part of MERGE by specifying "S" (for surveillance) or "T" (for track), respectively. A third option available is to run both; in this case, the RANGE portion is run first to simulate a surveillance radar. When the cumulative probability of detection reaches the user-specified value, the corresponding range is automatically handed to the ERROR portion of the program. This part then simulates a tracking radar following the target to a specified minimum range. The parameter NORNG should be specified as "B" to run both sections.

The second parameter (variable name YESNO) is purely for user convenience. This parameter determines whether the parameter list is printed. This option provides a very good means of checking the input data, but it takes a long time and is sometimes not necessary; hence the option. A "Y" will result in a printed parameter list, and an "N" will not.

Parameter number three (variable name IGRND) tells the program whether the radar is looking at a target on, or close to the ground, or in the air. Specify "S" for target on the surface or "A" for a target in the air.

1.3.2 INPUTS FOR RANGE PORTION OF MERGE

Name. This parameter has no effect on any computations in the program. It is to be used as a label so that the user has a means of quickly distinguishing one output from another. The label may be any alphanumeric character string up to forty characters long.

Peak Transmitter Power. This is the peak pulse power of the radar in kilowatts.

Table A-1. Input Parameters for Range Portion of MERGE

Line 1	NAME	—	Name of System (up to 40 characters)
Line 2	PT	kW	Peak Power
	TAU	μs	Pulse Width
	GT	dB	Transmit Antenna Gain
	GR	dB	Receive Antenna Gain
	SIG	m**2	Target Cross Section
	FM	MHz	Carrier Frequency
	ALA	dB	Antenna Ohmic Loss
	PRF	Hz	Pulse Repetition Frequency
Line 3	ALR	dB	Receive Transmission Line Loss
	ALT	dB	Transmit Transmission Line Loss
	ALP	dB	Scanning Antenna Pattern Loss (pg. 2-49 Skolnik) (negative number indicates electronic scanning)
	ALX	dB	Miscellaneous Losses
	CB	dB	Bandwidth Correction Factor
	ANF	dB	Receiver Noise Figure
	ATLF	dB/km	Attenuation Loss Factor, enter -1 for program to calculate it
	DICONR	—	Real Dielectric Constant, enter -1 if no ground
	DICONI	—	Imaginary Dielectric Constant, enter -1 if no ground
Line 4	NP	—	Number of Pulses Integrated, enter -1 for program to calculate NP. NOTE: PD must be negative for NP=-1
	PD	nmi.	Probability of Detection, or initial starting range if PD is a negative number
	FA	Negative Power	Probability of False alarm due to noise (negative power of ten)
	KA	—	Swerling Fluctuation Case, KA=0 is nonfluctuating, KA=-1 is log-normal
	EL	Degrees	Tilt of Antenna With Respect to Horizontal; or, Offset if ELFLAG=1
	ELFLAG	—	0—Fixed Antenna tilt 1—Follow Target With offset specified by EL 2—Raster Scan

Table A-1 (continued)

	NS	—	Solar and galactic Noise; -1, 0, 1 for minimum, average, maximum
	RRATE	mm/h	Rain Rate
	GAMMA	dB/km	Rain Attenuation, enter -1 for program to calculate it
	RMINR	nmi.	Range at which rain begins
	RMAXR	nmi.	Range at which rain ends
Line 5	TILTMIN	Degrees	Lowest Angle Raster Scan Assumes
	TILTMAX	Degrees	Greatest Angle Raster Scan Assumes
	ELINC	Degrees	Increment through which raster changes in elevation
Line 6	AHFT	ft	Antenna Height
	HTFLAG	—	0 – if target height is relative to horizontal at base of antenna 1 – if target height is relative to earth's surface
	BWDE	Degrees	Elevation Beamwidth
	BWDA	Degrees	Azimuthal Beamwidth
	SLDB	dB	Difference between sidelobe value and main peak value
	WHFT	ft	Wave height or maximum roughness factor
	IPOL	—	Polarization; 1 = vertical, 2 = horizontal
Line 7	SCNFREQ	Hz	Scan Frequency
	SCNRTE	Degrees/s	Scan Rate of Antenna
	VTGTI	Knots	Velocity of target parallel to plane of relative motion
	VTGR2	Knots	Velocity of target perpendicular to plane of relative motion
	VPLT	Knots	Platform Velocity
	PCREQ	—	Required Cumulative Probability
Line 8	COHO	—	0, 1, 2, for coherent, non-coherent, noncoherent Doppler
	SIGC	dB	Standard Deviation of Clutter
	SIGN	dB	Standard Deviation of Noise
	SIGS	dB	Standard Deviation of Target Signal

Table A-1 (continued)

Line 9	RDTYP	—	1, 2: Pulse Doppler, MTI
	TYPRF	—	Type of Response Function, -1=Sinusoid, 0=Triangle, +1=Trapezoid, 2=Rolloff
	IFSIG	—	1=Input Spectrum, 0=Input Average Value For Clutter Cross Section
	DSIG	m**²/m**²	Average Surface Clutter RCs per m**²
	DNUE	m**²/m**³	Average Volume Clutter RCs per m**³
	F1	Hz	1st corner of trapezoid or rolloff response function
	CLTI	dB	Clutter Improvement Factor, if negative program will account for clutter starvation
	PFAC	Negative power	Probability of false alarm due to clutter (negative power of ten)
	SCR	dB	Required signal-to-clutter ratio
	P	—	Number of Digital MTI Filters (number of poles)
Line 10	NPTS	—	Number of additional scatterers in distributed targets
Line 11	DISTSIG	—	Distributed target relative cross section array
Line 12	SIGX	ft	Distributed target X-coordinate position array
Line 13	SIGY	ft	Distributed target Y-coordinate position array
Line 14	SIGZ	ft	Distributed target Z-coordinate position array
Line 15	SCRCS	*	Surface clutter radar cross section array
Line 16	SCFREQ	*	Surface clutter radar frequency array
Line 17	VCRCS	*	Volume clutter radar cross section array
Line 18	VCFREQ	*	Volume clutter radar frequency array
Line 19	PDFAC	*	Pulse Doppler response function array
			*The first number in the one dimensional arrays; SCRCS, SCFREQ, VCFCS, VCFREQ, and PDFAC must be an integer value set equal to the # of points in the entire array (first point inclusive). Also, *both* SCFREQ and VCFREQ must be input, *OR both* SCFREQ and VCFREQ must *not* be input. Also, the frequency arrays should never have reoccurring values.

Pulse Length. See NRL Report 6930, p. 11. The symbol τ represents the duration between 3 dB points of the transmitted RF pulse, in microseconds. If the radar is of the pulse-compression type, the uncompressed pulse length applies, assuming that P_t is the power of the uncompressed pulse. The basic rule is that the product P_τ must equal the transmitted pulse energy. (More specifically, the pulse power in watts, multiplied by the pulse length in seconds, must equal the transmitted pulse energy in watt-seconds.)

Antenna Gain. See NRL Report 6930, p. 12. The power gains of the transmitting antenna (G_t) and receiving antenna (G_r) are in decibels. Power gain G is to be distinguished from directive gain D; these quantities are related by $G = kD$, where k is the radiation efficiency. The radiation efficiency is a measure of ohmic or heat loss in the antenna and should not be confused with aperture efficiency which measures the relationship between the directive gain actually obtained and that which would have been obtained if the aperture were uniformly illuminated.

Target Cross Section. See NRL Report 6930, p. 13. The parameter SIG represents the radar cross section of the target in square meters. For comparison of the performance of competing systems, the value SIG = 1 m^2 is often used.

Frequency. See NRL Report 6930, p. 14. This parameter is the transmitted radiation frequency in megahertz.

Antenna Ohmic Loss. (L_a) See NRL Report 6930, p. 48. This is the ohmic loss of the antenna expressed in decibels. Even though this loss is taken into account by the fact that G represents the power gain, rather than the directive gain, of the antenna, it must also be entered separately because of its contribution to the system noise. (Its inclusion in the power gain accounts only for its effect on the transmitted and received signal power.) If there are separate transmitting and receiving antennas, L_a refers to the receiving antenna only. This quantity is negligible for many types of antennas, particularly for parabolic reflector types, for which the approximation $L_a = 0$ dB is usually justifiable. Certain types of array antennas, especially those that employ frequency or phase scanning, may have appreciable ohmic loss.

Pulse Repetition Frequency. This is the average pulse repetition frequency of the radar in Hertz.

Receiving Line Loss. (L_r) See NRL Report 6930, p. 70. This is the loss of the receiving transmission line in decibels. This loss usually includes duplexer or circulator losses; the prefatory remark concerning partitioning of the receiving system applies.

Transmitting Line Loss. (L_t) See NRL Report 6930, p. 70. This is the loss of the transmitting portion of the transmission line in decibels (not usually identical to L_r). Duplexer loss is usually included. The remark concerning partitioning of the system applies.

Antenna-Pattern Scan Loss. (L_p) See NRL Report 6930, p. 70. This loss reflects the facts that (a) the number of pulses integrated for a scanning radar is somewhat arbitrarily taken to be the number of pulses occurring while the target is within the half-power beamwidth of the antenna, and (b) the beam does not have full uniform gain within this beamwidth and zero gain elsewhere. For a nonscanning radar aimed directly at a target, $L_p = 0$ dB. For a simple azimuth-scanning radar, $L_p \approx 1.6$ dB. For a simultaneously azimuth- and elevation-scanning radar, $L_p \approx 3.2$ dB is a reasonable assumption, although this result is based on a crude, rather than a sophisticated analysis.

Miscellaneous Loss. (L_x) See NRL Report 6930, pp. 82-84. Among the possible losses that may be included here are collasping loss, signal-processing loss, array-fill-time loss, beam-squint loss, polarization-rotation loss, and rain-absorption loss (if the rainstorm extent is less than the radar-to-target range). The decibel value of this loss is obtained by directly adding the decibel values of individual contribution losses.

Bandwidth Factor. (C_β) See NRL Report 6930, p. 14. This is the decibel loss resulting from a mismatch, in the North-filter sense, between the pulse characteristics and the receiver filter transfer characteristic. For a simple pulse radar, this relationship can be analyzed adequately in terms of pulse length, pulse shape, and filter bandwidth. For most radars of this type, it is reasonable to assume $C_\beta = 0$ dB in the absence of specific knowledge to the contrary. For pulse-compression radars, there is usually some loss associated with the compression filter; this loss ranges from perhaps 0.5 dB to several decibels, depending on the technique employed and the compression ratio. As is done with the loss factors, C_β is to be entered as a positive decibel number.

Receiver Noise Factor. (F_n) (Also called receiver noise figure; although "figure" is perhaps the most common usage, IEEE standards give preference to "factor".) See NRL Report 6930, p. 30. The receiver noise factor and receiver noise temperature are alternative ways of expressing the same property of the receiver, but the noise factor has been chosen here because it is the quantity more commonly given in receiver specifications. The noise factor has been described as a measure of the noise produced by a practical receiver as compared with the noise of an ideal receiver. For any practical receiver, the noise factor must be measured directly. The decibel value of the noise factor is to be entered.

Attenuation Loss Factor. This factor is the attenuation of the atmosphere expressed in decibels per kilometer. This factor may be specified or, if a "−1" is input for this parameter, the program will calculate the atmospheric attenuation. The program calculation is considered valid to 100 GHz.

Dielectric Constant (Real Component). The program automatically computes the dielectric constant for seawater. It is necessary to specify the dielectric constant for any other surface. The real component of the dielectric constant may be computed from:

$$\epsilon' = \frac{K}{\epsilon_0},$$

where:

ϵ' = Real component of dielectric constant

K = Permittivity

ϵ_0 = Dielectric constant of free space.

Dielectric Constant (Imaginary Component). The imaginary component of the complex dielectric constant must be specified for any surface other than seawater. The imaginary dielectric component is:

$$\epsilon'' = \frac{\sigma}{\omega \epsilon_0},$$

where:

ϵ'' = Imaginary component of dielectric constant

σ = Surface conductivity

ω = $2\pi f$, where f is the radar frequency

ϵ_0 = Dielectric component of free space.

Number of Pulses. (M) See NRL Report 6930, pp. 71 and 72. If this number is determined by a signal processor, it must be calculated by the user according to the characteristics of the processor. When it is determined by the scanning action of the radar antenna, it may be specified by the user or calculated by the program (enter a -1 for the program to calculate it). Note than one *must specify* a starting range (as opposed to a starting PD) before the program can calculate the number of pulses (see Probability of Detection). The appropriate formula for an azimuth scanning antenna is:

$$M = \frac{\phi \cdot PRF}{6 \cdot RPM \cdot \cos \theta_e},$$

where Φ is the azimuthal half-power beamwidth, degrees; PRF is the pulse repetition frequency, hertz; RPM is the rotation rate of the antenna, revolutions per minute; and θ_e is the elevation angle of the target degrees. (The term $\cos \theta_e$ is significant only when a target is at an elevation angle of about 10 degrees or more. For vertical-fan-beam radars, the range is usually calculated at an elevation angle low enough so that $\cos\theta_e \approx 1$.)

For simultaneous azimuth- and elevation-scanning radars, assuming a sawtooth-motion elevation scan and a uniform-speed-rotation azimuth scan, the appropriate formula is:

$$M = \frac{\phi \cdot \theta \cdot PRF}{6\ w_v \cdot t_v \cdot RPM \cdot \cos \theta_e}$$

in which Φ, PRF, RPM, and θ_e have the same definitions as before, Θ is the vertical beamwidth, w_v is the vertical scanning speed in degrees per second at the target elevation angle, and t_v is the vertical-scan period in seconds, including the dead time if any.

The number of pulses to be used for radars of other scan types must be analyzed on an individual basis as discussed in NRL Report 6930.

The number of pulses is entered as an integer (I-format). If the number calculated from the above formula is not an integer, it should be rounded off to the nearest integer. (The subroutine that calculates detection probability requires an integer for the number of pulses integrated).

Probability of Detection. (P_d) See NRL Report 6930, pp. 18 and 19. This probability is used to determine the maximum unattenuated range from which the scenario commences; *or*, the user may specify the starting range by placing a negative sign in front of the number. For example, to start the target at 10 nmi this parameter would be input as a "−10." Probability is given here in the mathematical sense of a number between 0 and 1 (not as a percentage figure). Values larger than 0.99 should not be entered because computational difficulties result. Also, values smaller than the false-alarm probability P_{fa} are meaningless; for practical purposes, P_d should be at least an order of magnitude larger than P_{fa}. (Ordinarily, it is many orders of magnitude larger.) Typical values of P_d of interest ranges from about 0.1 to 0.95.

False-Alarm Exponent. ($\log_{10} P_{fa}$) See NRL Report 6930, pp. 18-19. Given a fixed detection threshold in the radar receiver, there is a statistical likelihood that the noise level will exceed the threshold and cause a false detection. These false alarms are undesirable, and usual values for the probability of false alarm reflect this. Typical values of false-alarm probability range from 10^{-4} to 10^{-12}. The number to be entered is the positive value of the exponent (power of ten). Thus, for $P_{fa} = 10^{-6}$, enter the number 6.0.

Swerling Fluctuation Case. (KA) See NRL Report 6930, p. 28. Six cases are considered, with 0 representing the nonfluctuating target and integers 1 through 4 representing the four Swerling cases as defined in NRL Report 6930 (and elsewhere). If the numbers 0, 1, 2, 3, or 4 are entered, the corresponding fluctuation case will be used for probability of detection calculations. If a −1 is entered for this parameter, a log-normal target and clutter distribution is assumed. The characteristics of this type of distribution have previously been discussed, and the actual implementation is shown in subroutine LOGNOR.

Tilt of Antenna. (EL) The definition of this parameter changes depending on the value assumed by the parameter ELFLAG. If ELFLAG is set equal to "0," then EL is the actual tilt of the antenna with respect to horizontal. When ELFLAG is set to "1," the antenna follows the target, so EL is now the amount by which the center of the beam is offset from the actual centroid of the target in elevation as the antenna follows the target. If ELFLAG is "2," then the routine conducts a raster scan and EL is meaningless. Note that EL may be either +/− degrees. ELFLAG is dimensionless.

Elevation Flag. (ELFLAG) As mentioned above, three choices are available for describing the antenna elevation angle. If ELFLAG is set to "0," the antenna elevation is fixed; if it equals "1," then the antenna follows the target; if it is set to "2," a raster scan is employed.

Galactic Noise Code. (NS) See NRL Report 6930, p. 49, Fig 11. The noise received from the galaxy to which the solar system belongs varies depending on the part of the galaxy toward which the antenna is pointed. This direction is not usually predictable. A −1 for minimum, 0 for average, and +1 for maximum galatic noise may be specified.

Rain Rate. (RRATE) Entering a negative one for GAMA will cause the value entered for RRATE (mm/hr) to be used in the computation of attenuation due to rain. The computation is considered valid from 1 to 100 GHz.

Attenuation Due to Rain. (GAMA) (See Rain Rate). If a number other than −1 is entered for GAMA, this number will be used in lieu of the program computation as the *one-way* attenuation in decibels per kilometer.

Leading Edge of Rain Cell. (RMINR) This parameter specifies the edge of the rain cell closest to the antenna in nmi. Note that this cannot be negative.

Trailing Edge of Rain Cell. (RMAXR) RMAXR specifies the edge of the rain cell furthest from antenna. RMAX must always be greater than RMIN.

Raster Scan. (TILTMIN, TILTMAX, ELINC) When ELFLAG is set equal to "2," the routine implements a raster scan as follows. The antenna assumes a minimum tilt as specified [illegible] TILTMIN in degrees. The radar scans across the scenario at this angle and determines a S/N and a PD. The tilt is then incremented according to the elevation increment specified by ELINC in degrees, the antenna scans, and the radar calculates a new set of S/Ns and PDs. This incrementing procedure continues until the tilt of the antenna reaches the maximum tilt specified by TILMAX in degrees. After a raster scan is completed the peak S/N encountered and a cumulative probability over the entire window are printed out. Note that when running the raster scan routine, SCNFREQ is the frequency of the entire window (how often each window is completed), not of each individual scan. SCNRTE is the scan rate of each individual scan in the window.

Antenna Height. (AHFT) This is the antenna height in feet above the horizontal plane, tangent to the earth's surface at the base of the antenna; or, the height above the earth's surface, according to parameter HTFLAG.

Target Height Flag. (HTFLAG) If HTFLAG = 0, all height calculations will be done with respect to the horizontal at the base of the antenna (flat earth). If HTFLAG = 1, all calculations will be done with respect to the earth's surface. It should be noted that there is a significant difference between these two at long ranges.

Elevation Beamwidth. (BWDE) This is the elevation beamwidth expressed in degrees, as measured between the one-way 3 dB power points.

Azimuthal Beamwidth. (BWDA) This is the azimuthal beamwidth expressed in degrees, as measured between the one-way 3 dB power points.

Peak Sidelobe Ratio. (SLDB) This is a positive number representing the amount in decibels by which the peak sidelobe is less than the peak of the main lobe.

Wave Height or RMS Roughness. (WHFT) This is the root-mean-square deviation of the wave height from the mean position for over-the-sea computations. For overland computation, this is the root-mean-square roughness factor. In either case, the parameter is expressed in feet. This parameter is utilized in multipath calculations.

Polarization. (IPOL) An input value of 1 selects vertical transmit polarization, whereas an input value of 2 is used for horizontal polarization.

Scan Frequency. (SCNFREQ) This parameter defines the number of revolutions the radar antenna will make per second. Or, if the antenna does not complete a full revolution, SCNFREQ is the number of times the beam passes by the target per second.

Scan Rate of Antenna. (SCNRTE) This parameter is used to determine the amount of time the target is actually in the beam (dwell time). SCNRTE should be entered in degrees per second and may be (+) or (−). Dwell time calculations also allow for the increase or decrease of the amount of time the target spends in the beam due to platform motion.

Target Velocity. (VTGT1, VTGT2) VTGT1 is the horizontal component of the target velocity parallel to the plane of relative motion in nmi/hr. If the platform velocity is zero, then VTGT1 is just the radial velocity to the specified range offset. VTGT2 is the horizontal component of the target velocity perpendicular to the plane of relative motion in nmi/hr. Note that VTGT2 *cannot* be zero. When using VTGT1 as a radial velocity to the range offset, set VTGT2 equal to a very small value.

Platform Velocity. (VPLT) This parameter defines the velocity of platform in knots.

Required Cumulative Probability. (PCREQ) When the final calculations have reached a range that corresponds to a cumulative probability which exceeds PCREQ then the previous range will be used as the maximum detection range in the ERROR calculations.

Coherent Radar Flag. (COHO) This parameter serves as a switch for various logic pathways within the program. COHO = 0 means the radar is coherent. COHO = 1 means the radar is non-coherent. COHO = 2 means the radar is non-coherent MTI.

Standard Deviation of Clutter. (SIGC) Target amplitude distribution characteristics are not limited to the Swerling models, nor are clutter distributions always Gaussian. Several other forms have recently been observed; one form is called a log-normal distribution. The nature of the distribution is discussed in the section on subroutine LOGNOR. The standard deviation of clutter parameter (in dB) must be entered when the log-normal distribution model is being employed.

Standard Deviation of Noise. (SIGN) This is a dummy parameter used in the log-normal distribution model. This model is only valid for log-normal target and clutter distributions. The case of a log-normal target in Gaussian noise has not been derived, so the results of the model are only valid for a target in clutter. This dummy parameter is necessary to avoid errors in the program while performing signal-to-noise calculations. Thus, the detection performance versus noise is invalid, but the detection performance in clutter which follows it is correct.

Standard Deviation of Target Signal. (SIGS) Along with the standard deviation of clutter, this parameter is used in probability of detection calculations for the log-normal distribution model which is described later.

Response Function Selector. (RDTYP) This parameter selects the desired type of response function 1 = pulse Doppler, 2 = MTI.

MTI Response Function Selector. (TYPRF) This parameter selects different types of MTI response functions: −1 = sinusoid function; 0 = triangular function, +1 = trapezoid function; 2 = rolloff filter.

Clutter Input Flag. (IFSIG) This parameter serves as a switch for setting various logic pathways within the program. A zero means the clutter spectrum was not input. A one means a clutter spectrum was entered.

Average Surface Clutter Cross-Section. (DSIG) This input is required if no clutter frequency spectrum is input and if the radar is either non-coherent or MTI and coherent. The cross section must have the units of m^2/m^2.

Average Volume Clutter Cross-Section. (DNUE) This input is required if no clutter frequency spectrum is input and if the radar is either non-coherent or MTI and coherent. The cross section must have units m^2/m^3.

First Trapezoid Knee. (F1) This parameter determines the frequency (in Hz) at which the first trapezoidal knee for the MTI trapezoid response function occurs.

Second Trapezoid Knee. (F2) This parameter determines the frequency (in Hz) at which the second trapezoidal knee for the MTI trapezoid response function occurs.

MTI Improvement Factor. (CLTI) This factor is a required input if the radar is MTI. CLTI is entered in dB. If CLTI is entered as a negative number, its absolute value is used and the program will account for clutter starvation.

Probability of False Alarm Due to Clutter. (PFAC) This is the desired probability of false alarm in the presence of clutter. The input is the negative LOG_{10} of the value; e.g., enter 6.0 if PFAC = 10^{-6}.

Required Signal-to-Clutter Ratio. This parameter is the ratio of the average target cross section to the average clutter cross section for a given PFAC and a PD = 0.5. The two parameters, PFAC and SCR, are part of a user option that allows for nonstandard clutter amplitude distributions. Most probability of detection calculations assume a Gaussian clutter distribution. If this model is adequate, then the two parameters are not necessary and range performance calculations proceed normally. If the clutter distribution is known to be different from a Gaussian, the program calculations can still be used to perform accurate range performance prediction if the two parameters above are employed properly, as shown below. The clutter and target are modelled by specified probability density distributions which are a function of radar cross section; i.e., $f_c(\sigma)$ and $f_t(\sigma)$:

(1) calculating a threshold T such that

$$\int_T^{\infty} f_c(\sigma)d\sigma = \text{PFAC and} \int_T^{\infty} f_t(\sigma)d\sigma = 0.5$$

(2) by computing the average of $f_c(\sigma)$; i.e., A_c.

SCR is then given by SCR = T/A_c. SCR is entered into the program in dB.

Number of Scatterers. (NPTS) The program is capable of modelling an extended target via the use of a number of point scatterers. The signal returned from these scatterers is combined coherently, including multipath effects, for use in S/N and S/C calculations. If a distributed target is not desired, then NPTS = 0 and the following four lines are skipped. In this case, line 15 in Table A-1 would become line 11, etc. If a distributed target is desired, then NPTS represents the number of *additional* scatterers in the target model.

Distributed Target Cross Section Array. (DISTSIG) For the case of a distributed target, this line contains the relative cross sections of the additional scatterers. Note that the cross sections are not in m^2, but are a ratio of the scatterer size to that of the reference scatterer whose cross section was entered previously as SIG.

X-Coordinate Distributed Target Array. (SIGX) The position of the additional scatterers are defined by X, Y, and Z coordinates relative to the reference scatterer. This parameter is the X-coordinate position array.

Y-Coordinate Distributed Target Array. (SIGY) See above.

Z-Coordinate Distributed Target Array. (SIGZ) See above.

Surface Clutter Radar Cross Section. (SCRCS) This parameter defines a one-dimensional array which contains the cross section (in m^2/m^2) of surface clutter as a function of frequency. The first value must always be the total number of points in the array (first point inclusive). An SCRCS input must be accompanied by a VCRCS input.

Surface Clutter Frequency. (SCFREQ) This parameter defines a one-dimensional array which contains the frequencies (in Hz) of a surface clutter spectrum. The first value must always be the total number of points in the array (first point inclusive).

Volume Clutter Radar Cross-Section. (VCRCS) This parameter defines a one-dimensional array which contains the cross section (in m^2/m^3) of volume clutter as a function of frequency. The first value must be the total number of points in the array (first point inclusive). A VCRCS input must be accompanied by an SCRCS input.

Volume Clutter Frequency. (VCFREQ) This parameter defines a one-dimensional array which contains the frequencies (in Hz) of a surface clutter spectrum. The first value must be the total number of points in the array (first point inclusive).

Pulse Doppler Response Factor. (PDFAC) This parameter defines a one-dimensional array that contains values of the pulse Doppler response function at discrete frequencies separated by equal frequency intervals. The value of the frequency interval is given by:

$$F = PRF/(PDFAC(1) - 1)$$

where PRF is the pulse repetition frequency and PDFAC(1) − 1 is the number of Doppler response values. The first value in the array (PDFAC(1)) must always be the number of points in the array (first point inclusive). The value of the pulse Doppler response function must be between 0 and 1.

Parameters Borrowed from Error. Four parameters are borrowed from the error portion of the program. The position of these parameters in the error file are given in Table A-2. DELTAR and DELTAHT give the climb or descent of the target. The target drops DELTAHT nautical miles for every DELTAR nautical miles of ground travel due to target motion. RO gives the range offset along the ground at the closest point of approach. HT gives the height of the target at CPA.

1.4 OUTPUTS

There are three basic components to the RANGE output. First, the input parameters are listed. Second, some preliminary calculation results are displayed. Finally, the four radar detection performance tables are output. Table A-3 depicts an example input parameter list. These values were used to generate the following outputs.

A copy of the preliminary outputs is given in Table A-4. First is a list of noise temperatures of the systems components and of the overall system. Next is a single line of output giving the Swerling fluctuation case, the signal-to-noise ratio, and the tropospheric attenuation for the farthest range of interest. The last of the preliminary outputs is a list of radial velocities for each of the range increments used in the following tables. These radial velocities are used to calculate the Doppler frequencies at these ranges.

Table A-5 depicts the first of the four main tables. This table gives the signal-to-noise ratio and probability of detection as a function of decreasing range. These values are free space values; the effects of multipath interference, the antenna pattern, tropospheric attenuation, and clutter have been left out. This table gives a good indication of the basic detection capability of the radar.

Table A-6 gives the same values as Table A-5 except that the signal-to-noise ratio includes the effect of the pattern propagation factor. This factor represents a combination of the antenna pattern and multipath interference. The probabilities of detection reflect the change in the signal-to-noise ratio. In addition, if electronic scanning is specified, it is taken into account in this table.

Table A-2. Error Parameters Used in Range Portion of MERGE

Line 1-3			Not used in RANGE
Line 4	RMIN	–	Not used in RANGE
	RMAX	–	Not used in RANGE
	DELTAR	nmi.	Range increment
	HT	ft	Target altitude
	DELTAHT	ft	Altitude increment
	RO	ft	Range offset at CPA
	ITRAJ	–	Not used in RANGE
Line 5			Not used in RANGE

Table A-3. Printed RANGE Input Parameters

RADAR NAME OR DESCRIPTION—

RFINFDD (RUN # 2, RCS=14.14)

RADAR AND TARGET PARAMETERS (INPUTS)—

PULSE POWER, kW	200.0000
PULSE LENGTH, μs	.2000
TRANSMIT ANTENNA GAIN, dB	38.0000
RECEIVE ANTENNA, GAIN, dB	38.0000
TARGET CROSS SECTION, m²	14.1400
FREQUENCY, MHz	9256.0000
ANTENNA OHMIC LOSS, dB	0.0000
PULSE REPITITION FREQUENCY	600.0000
RECEIVE TRANSMISSION LINE LOSS, dB	0.0000
TRANSMIT TRANSMISSION LINE LOSS, dB	0.0000
SCANNING ANTENNA PATTERN LOSS, dB. INDICATES ELECTRONIC SCANNING IF NEGATIVE	−.0010
MISCELLANEOUS LOSSES, dB	14.4000
BANDWIDTH CORRECTION FACTOR, dB	0.0000
RECEIVER NOISE FACTOR (FIGURE), dB	9.9000
ATMOSPHERIC ATTENUATION, dB/km (−1=1COMP. CALC.)	−1.0000
DIELECTRIC CONSTANT REAL PART (−1 IF NO GROUND)	30.0000
DIELECTRIC CONSTANT IMAGINARY PART (−1 AS ABOVE)	1.0000
NUMBER OF PULSES INTEGRATED (−1=COMP. CALC.)	330
PROBABILITY OF DETECTION (NOTE≤D CAN SPECIFY INITIAL RANGE HERE IF PD IS NEGATIVE)	−120.000
FALSE-ALARM PROBABILITY, NEGATIVE POWER OF TEN	6.0000
SWERLING FLUCTUATION CASE (0=NONFLUCT.)	
TARGET ELEVATION ANGLE (DEGREES) FOR FIXED ANTENNA CASE OR ANTENNA ELEVATION OFFSET FOR TARGET TRACKING CASE	−1.60
ANTENNA TILT- FIXED (=0), OR FOLLOW TARGET (=1)	0.0000
SOLAR AND GALACTIC NOISE	AVERAGE
RAIN RATE	10.00
ATTENUATION DUE TO RAIN, dB/km	.1608
RANGE AT WHICH RAIN BEGINS, nmi	60.0000
RANGE AT WHICH RAIN ENDS, nmi	100.0000

ANTENNA HEIGHT, ft	10000.0000
TARGET HEIGHT RELATIVE TO- HORIZONTAL AT BASE OF ANTENNA (=0), OR EARTH'S SURFACE (=1)	1.0000
BEAMWIDTH (ELEVATION), DEGREES	5.5000
AZIMUTHAL BEAMWIDTH, DEGREES	.5500
SIDELOBES, dB	40.0000
WAVE HEIGHT, ft	100.0000
POLARIZATION (1=VERTICAL, 2=HORIZONTAL)	2
SCAN FREQUENCY, Hz	.0110
SCAN RATE OF ANTENNA, DEGREES/S	1.0000
TARGET SPEED PARALLEL TO RELATIVE MOTION PLANE	7.0000
TARGET SPEED PERPENDICULAR TO RELATIVE MOTION PLANE	7.0000
PLATFORM VELOCITY (PARLLEL TO TARGET), nmi	200.0000
CUMULATIVE PROBABILITY CUTOFF	.9000
RADAR IS- COHERENT (=0), OR NONCOHERENT (=1)	2
RADAR TYPE (1=PULSE DOPPLER, 2=MTI)	2.0000
RESPONSE FUNCTION (−1=SIN, 0=TRIANGLE, 1=TRAP)	2.0000
CLUTTER SPECTRUM (1) OR AVERAGE VALUE (0)	0
AVG. SURFACE CLUTTER/UNIT AREA, M**2/M**2	.0032
AVG. VOLUME CLUTTER/UNIT VOLUME, M**2/M**3	0.0000
FIRST CORNER OF TRAP RESPONSE FUNCTION, Hz	80.0000
SECOND CORNER OF TRAP RESPONSE FUNCTION, Hz	520.0000
CLUT. IMPROV. FACTOR (NEG.=ELECT. SCAN.), dB	−50.0000
PROBABILITY OF FALSE ALARM DUE TO CLUTTER	6.0000
REQUIRED SIGNAL TO CLUTTER RATIO	20.0000
NUMBER OF POLES FOR FILTER	4.0000
RNGA BEFORE ITERATE SUBROUTINE = 120.	
RNGA AFTER ITERATE SUBROUTINE = 103.5373991118	

Table A-4. Preliminary RANGE outputs.

CALCULATED QUANTITIES (OUTPUTS) --

NOISE TEMPERATURES, DEGREES KELVIN --

ANTENNA (TA)	105.0
RECEIVING TRANSMISSION LINE (TR)	0.0
RECEIVER (TE)	2544.0
TE X LINE-LOSS FACTOR = TEI	2544.0
SYSTEM (TA+TR+TEI)	2649.0
TWO-WAY ATTENUATION THROUGH ENTIRE TROPOSPHERE-dB	2.9

SWERLING FLUCTUATION CASE	SIGNAL-TO-NOISE RATIO, dB	TROPOSPHERIC ATTENUATION, DECIBELS	RANGE, NAUTICAL	
			nmi	km.
1	-23.15	2.56	120.0	(222.240)

RADIAL VELOCITY IN KNOTS (VR) = 9.111443005793
RADIAL VELOCITY IN KNOTS (VR) = 9.178329995819
RADIAL VELOCITY IN KNOTS (VR) = 9.247985234057
RADIAL VELOCITY IN KNOTS (VR) = 9.320220448123
RADIAL VELOCITY IN KNOTS (VR) = 9.394687228238
RADIAL VELOCITY IN KNOTS (VR) = 9.470807727913
RADIAL VELOCITY IN KNOTS (VR) = 9.547677574119
RADIAL VELOCITY IN KNOTS (VR) = 9.623930410226
RADIAL VELOCITY IN KNOTS (VR) = 9.697550248886
RADIAL VELOCITY IN KNOTS (VR) = 9.765614591315
RADIAL VELOCITY IN KNOTS (VR) = 9.82394956301
RADIAL VELOCITY IN KNOTS (VR) = 9.866681578028
RADIAL VELOCITY IN KNOTS (VR) = 9.885685334514
RADIAL VELOCITY IN KNOTS (VR) = 9.869967977246
RADIAL VELOCITY IN KNOTS (VR) = 9.805113095192
RADIAL VELOCITY IN KNOTS (VR) = 9.673054880628
RADIAL VELOCITY IN KNOTS (VR) = 9.452655636438
RADIAL VELOCITY IN KNOTS (VR) = 9.121728537017
RADIAL VELOCITY IN KNOTS (VR) = 8.661038195432
RADIAL VELOCITY IN KNOTS (VR) = 8.060072219644

Table A-5. RANGE Output

OUTPUT BELOW (S/N, PROB. OF DETECT.) IS FREE SPACE VALUE. (ZERO WEIGHTING).

SWERLING FLUCTUATION CASE	SIGNAL-TO-NOISE RATIO, dB BEFORE PROCESSOR	TROPOSPHERIC ATTENTUATION, DECIBELS	PROBABILITY OF DETECTION	RANGE IN	
				nmi	km
1	−23.16	0.00	.0000	120.04	(222.31)
1	−22.44	0.00	.0000	115.18	(213.31)
1	−21.70	0.00	.0000	110.35	(204.37)
1	−20.92	0.00	.0000	105.56	(195.50)
1	−20.13	0.00	.0000	100.82	(186.71)
1	−19.30	0.00	.0000	96.12	(178.02)
1	−18.44	0.00	.0000	91.49	(169.43)
1	−17.55	0.00	.0000	86.92	(160.97)
1	−16.63	0.00	.0001	82.43	(152.66)
1	−15.67	0.00	.0004	78.03	(144.51)
1	−14.69	0.00	.0014	73.74	(136.56)
1	−13.68	0.00	.0041	69.58	(128.85)
1	−12.65	0.00	.0110	65.57	(121.43)
1	−11.61	0.00	.0255	61.74	(114.34)
1	−10.56	0.00	.0518	58.13	(107.66)
1	−9.53	0.00	.0923	54.78	(101.46)
1	−8.54	0.00	.1457	51.75	(95.84)
1	−7.62	0.00	.2066	49.08	(90.90)
1	−6.81	0.00	.2672	46.85	(86.77)
1	−6.16	0.00	.3193	45.12	(83.56)
1	−5.70	0.00	.3567	43.94	(81.38)

Table A-6. RANGE Output

S-N RATIO ADJUSTED FOR ELECTRONIC SCANNING GAIN LOSS
OUTPUT BELOW (S/N, PROB. OF DETECT.) IS WEIGHTED
WITH A PATTERN PROPAGATION FACTOR DEPENDENT ON
RANGE. TROPOSPHERIC ATTEN. WEIGHTING FACTOR = ZERO.

SWERLING FLUCTUATION CASE	SIGNAL-TO-NOISE RATIO, dB BEFORE PROCESSOR	TROPOSPHERIC ATTENTUATION, DECIBELS	PROBABILITY OF DETECTION	RANGE IN	
				nmi	km
1	−32.06	0.00	0.00	120.04	(222.31)
1	−30.96	0.00	.00	115.18	(213.31)
1	−29.84	0.00	.00	110.35	(204.37)
1	−28.69	0.00	.00	105.56	(195.50)
1	−27.49	0.00	.00	100.82	(186.71)
1	−26.24	0.00	.00	96.12	(178.02)
1	−24.96	0.00	.00	91.49	(169.43)
1	−23.62	0.00	.00	86.92	(160.97)
1	−22.24	0.00	.00	82.43	(152.66)
1	−20.82	0.00	.00	78.03	(144.51)
1	−19.35	0.00	.00	73.74	(136.56)
1	−17.85	0.00	.00	69.58	(128.85)
1	−16.32	0.00	.00	65.57	(121.43)
1	−14.78	0.00	.00	61.74	(114.34)
1	−13.25	0.00	.01	58.13	(107.66)
1	−11.75	0.00	.02	54.78	(101.46)
1	−10.32	0.00	.06	51.75	(95.84)
1	−9.02	0.00	.12	49.08	(90.90)
1	−7.88	0.00	.19	46.85	(86.77)
1	−6.97	0.00	.25	45.12	(83.56)
1	−6.34	0.00	.30	43.94	(81.38)

Table A-7 takes tropospheric attenuation into account. The tropospheric attenuation includes rain, whether specified or computed. Cumulative probability of detection is also provided in this table.

Table A-8 takes clutter and Doppler processing into account. This table gives the same outputs as Table A-7, except that it also prints the signal to clutter ratio both before and after processing.

1.5 SUBROUTINE DESCRIPTIONS

This section provides the documentation for the logic and calculations as implemented in the various subroutines. The documentation is in the form of narrative descriptions, equations and references.

1.5.1 SUBROUTINE HIERARCHY

The top level executive logic of MERGE manages the combined MRANGE and ERROR radar analysis program. The flowchart of this logic is shown on page 45. MRANGE, which this section describes, is therefore the second level in the macro-level program hierarchy. The following descriptions of subroutines are organized according to the hierarchy under which they are employed. Where a subroutine is used by more than one level of higher order subroutine or where the subroutine occupies multiple hierarchical levels, the description is limited to the first occurrence in the program logic. An alphabetical listing of the subroutines is located elsewhere along with their flowcharts.

* B. Perry, B. C. Appling, et al., "Merge, An Analytical Radar Performance Model, Section 1, Appendix C," Georgia Institute of Technology Engineering Station, Atlanta, Georgia, Internal Memorandum, March 1982.

Table A-7. RANGE Output

OUTPUT BELOW IS WEIGHTED WITH A PPF AND A
TROP. ATTEN. FACTOR. CUMULATIVE PROB. IS ALSO CALC.

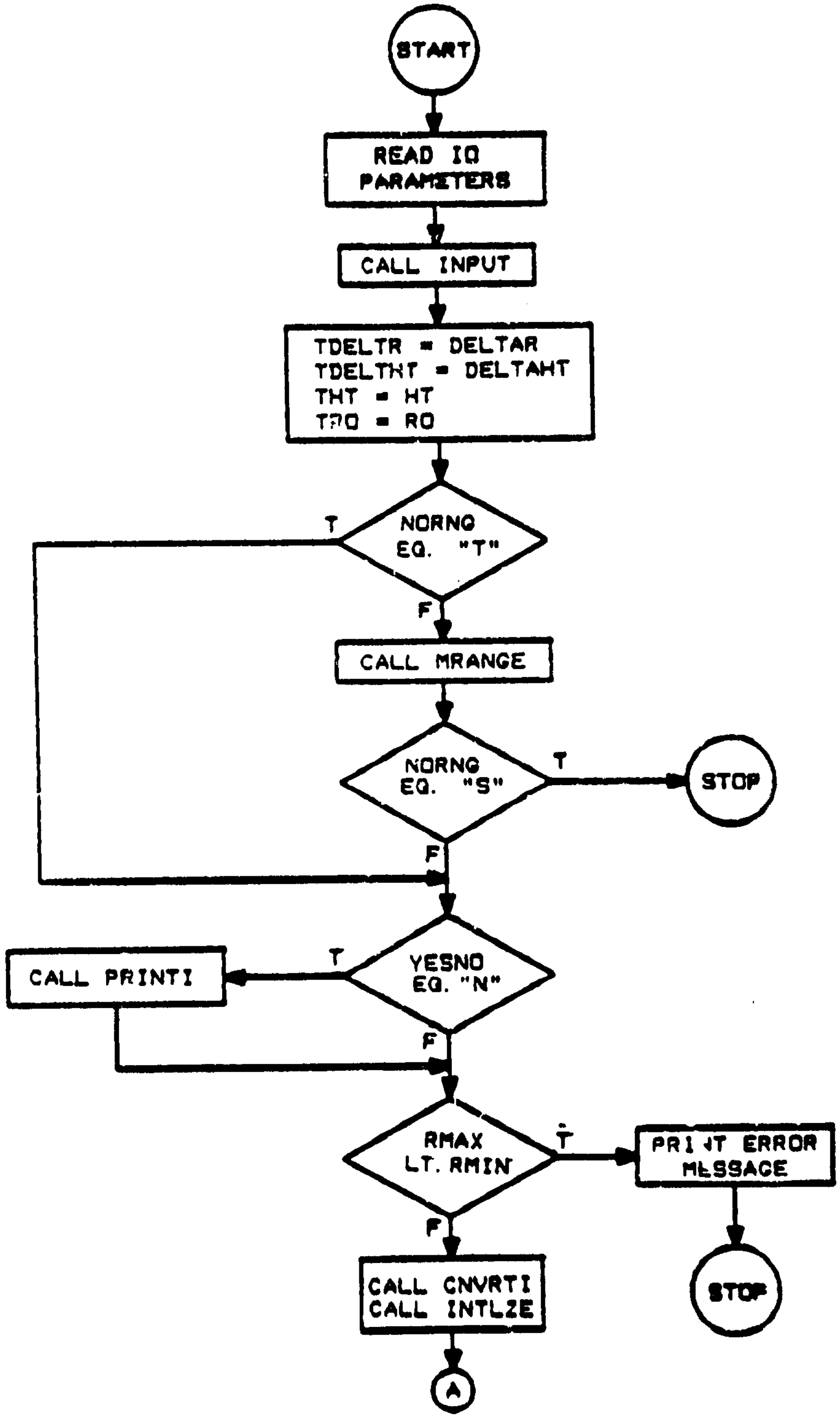
SWERLING FLUCTUATION CASE	SIGNAL-TO-NOISE RATIO, dB BEFORE PROCESSOR	TROPOSPHERIC ATTENTUATION, DECIBELS	PROBABILITY OF DETECTION	CUMULATIVE PROBABILITY	RANGE IN nmi	RANGE IN km
1	−81.44	26.39	0.0000	0.0000	120.04	(222.31)
1	−57.24	26.28	0.0000	0.0000	115.18	(213.31)
1	−56.02	26.18	0.0000	0.0000	110.35	(204.37)
1	−54.76	26.08	0.0000	0.0000	105.56	(195.50)
1	−53.46	25.98	0.0000	0.0000	100.82	(186.71)
1	−49.81	23.57	0.0000	0.0000	96.12	(178.02)
1	−45.66	20.71	0.0000	0.0000	91.49	(169.43)
1	−41.51	17.89	0.0000	0.0000	86.92	(160.97)
1	−37.36	15.12	0.0000	0.0000	82.43	(152.66)
1	−33.22	12.40	.0000	.0000	78.03	(144.51)
1	−29.11	9.76	.0000	.0000	73.74	(136.36)
1	−25.04	7.19	.0000	.0000	69.58	(128.85)
1	−21.03	4.72	.0000	.0000	65.57	(121.43)
1	−17.13	2.35	.0001	.0001	61.74	(114.34)
1	−14.49	1.24	.0018	.0018	58.13	(107.66)
1	−12.92	1.17	.0086	.0105	54.78	(101.46)
1	−11.43	1.11	.0290	.0392	51.75	(95.84)
1	−10.07	1.05	.0693	.1058	49.08	(90.90)
1	−8.88	1.00	.1256	.2181	46.85	(86.77)
1	−7.94	.96	.1846	.3625	45.12	(83.56)
1	−7.28	.94	.2314	.5100	43.94	(81.38)

Table A-8. RANGE output.

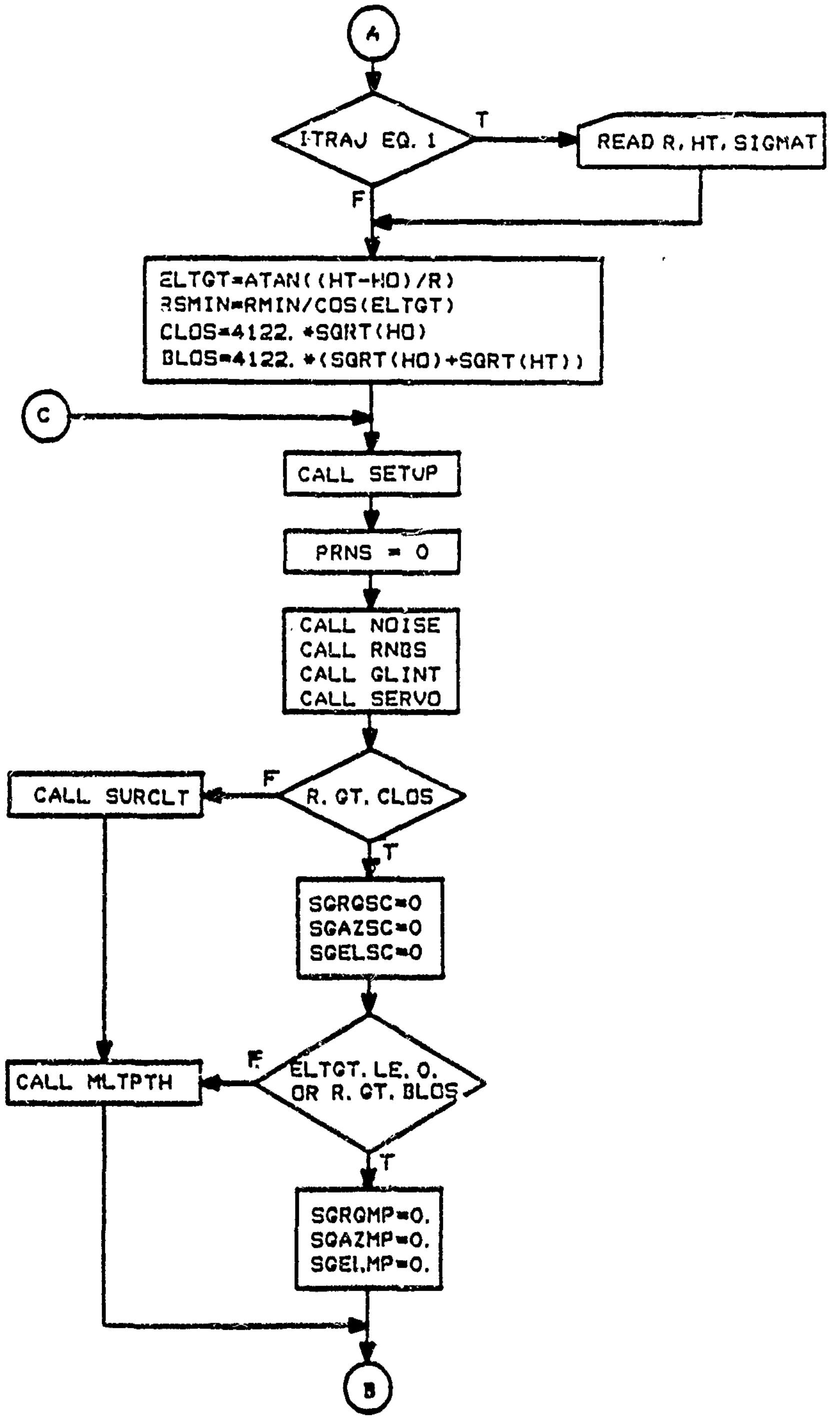
OUTPUT BELOW IS WEIGHTED WITH A PPF AND A TROP. ATTEN. FACTOR. CLUTTER AND DOPPLER PROCESSING IS ALSO INCLUDED. CUMULATIVE PROBABILITY IS ALSO CALCULATED. CLUTTER STARVATION ACCOUNTED FOR

SIGNAL-TO-NOISE RATIO, dB AFTER PROCESSOR	EFFECTIVE SIGNAL-TO-NOISE RATIO, dB	SIGNAL-TO-CLUTTER RATIO, dB BEFORE PROCESSOR	SIGNAL-TO-CLUTTER RATIO, dB AFTER PROCESSOR	TROPOSPHERIC ATTENUATION dB	PROBABILITY OF DETECTION	CUMULATIVE PROBABILITY	RANGE IN nmi	RANGE IN km
−36.02	−36.02	−11.31	38.69	26.39	0.0000	0.0000	120.04	222.31
−36.02	−36.02	−11.15	38.85	26.28	0.0000	0.0000	115.18	213.31
−36.02	−36.02	−10.98	39.02	26.18	0.0000	0.0000	110.35	204.37
−36.02	−36.02	−10.81	39.19	26.08	0.0000	0.0000	105.56	195.50
−36.02	−36.02	−10.63	39.37	25.98	0.0000	0.0000	100.02	186.71
−36.02	−36.02	−10.45	39.55	23.57	0.0000	0.0000	96.12	178.02
−36.02	−36.02	−10.26	39.74	20.71	0.0000	0.0000	91.49	169.43
−36.02	−36.02	−10.06	39.94	17.89	0.0000	0.0000	86.92	160.97
−36.02	−36.02	−9.85	40.15	15.12	0.0000	0.0000	82.43	152.66
−36.02	−36.02	−9.63	40.37	12.40	0.0000	0.0000	78.03	144.51
−36.02	−36.02	−9.40	40.60	9.76	0.0000	0.0000	73.74	136.56
−36.02	−36.02	−9.17	40.83	7.19	0.0000	0.0000	69.58	120.05
−30.77	−30.77	−8.92	41.08	4.72	.0000	.0000	65.57	121.43
−23.88	−23.88	−8.67	41.33	2.35	.0000	.0000	61.74	114.34
−19.57	−19.57	−8.41	41.59	1.24	.0000	.0000	58.13	107.66
−17.23	−17.23	−8.15	41.85	1.17	.0001	.0001	54.78	101.46
−15.10	−15.10	−7.89	42.11	1.11	.0009	.0010	51.75	95.84
−13.23	−13.23	−7.64	42.36	1.05	.0064	.0074	49.08	90.90
−11.63	−11.63	−7.41	42.59	1.00	.0250	.0322	46.85	86.77
−10.44	−10.44	−7.22	42.78	.96	.0557	.0862	45.12	83.56
−9.64	−9.64	−7.08	42.92	.94	.0875	.1561	43.94	81.30

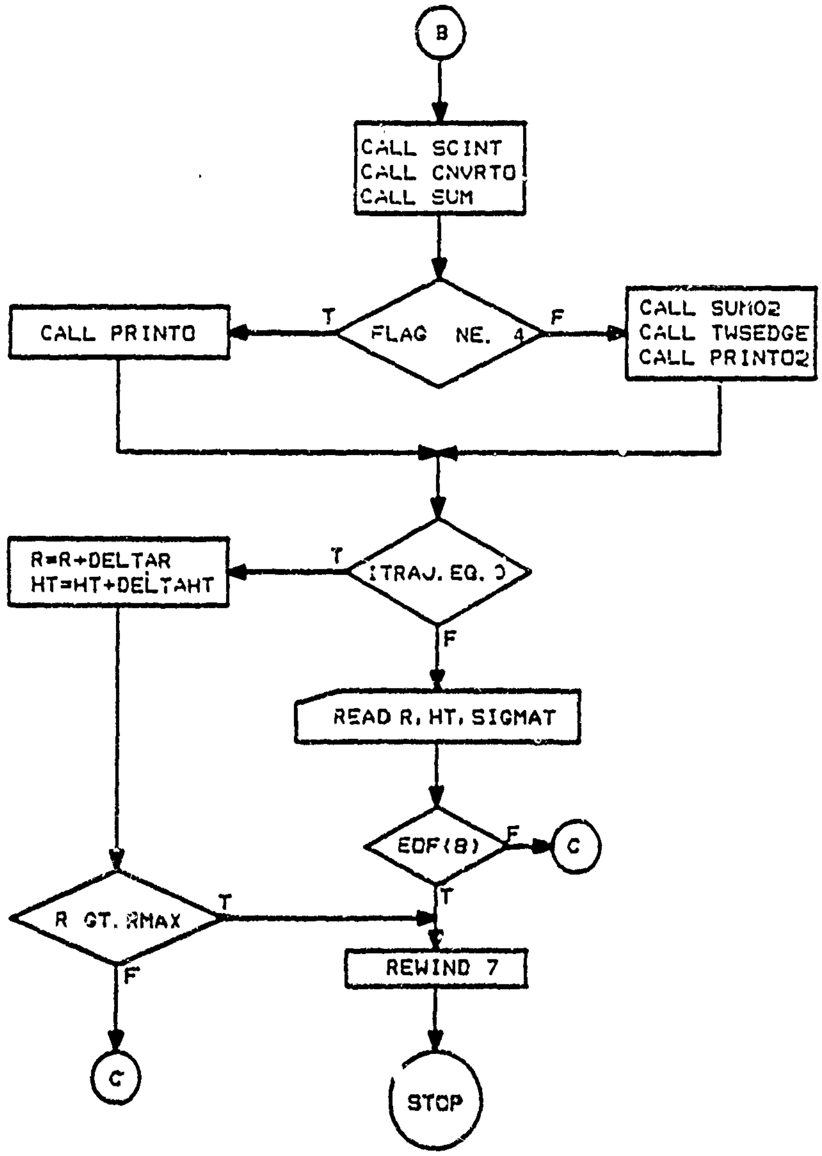
****
RMAX FROM SUBROUTINE HRANGE = 120.
NOTE: THIS IS THE HORIZONTAL RANGE FROM CPA (nmi)
****



Flowchart of the top level MERGE logic.



Flowchart of the top level MERGE logic (continued).



Flowchart of the top level MERGE logic (continued).

APPENDIX B

COMPUTER DATA FILE INPUT*/OUTPUT FOR EXAMPLE 1

File Data 6

100= S
110= T
120= A

File DATA 10

100=DISTRIBUTED RANDON TARGET-THREE SCATTERS
110=.01,.64,40,40,1,9500,0,2000
120=0,0,0,5,0,6,−1,−1,−1
130=−1,−10.0048767,6,0,13.7,0,0,0,0,0,0
140=0,0,0
150=6.07613,1,.2,.2,25,100,2
160=.33,120,.59248,.00059248,0,.9
170=1,0,0,0
180=2,2,0,1E-6,1E-7,7E3,7E4,45,6,0,3
190=2
200=1,1
210=10,0
220=24,.05
230=0,34
240=3,1,2
250=3,1,2
260=3,1,2
270=3,1,2
280=3,1,2

File DATA 11

100= 100,41.1,1.76,1.76,.2118,1.875,4E-15,3,0,0,1,0,0,16,1.57,1,0
110= 53256.0,100,40,0,90,500,40,20,16000,1,1,2,6,1,4,6,3
120= .305,7.9,.305,2337,5,.1,0,0,0,0,0
130= 1,1.004993,20,6.0761,5,6076.1,0
140= 20,2.8,10,0,0,0,0

* Also, see Table 1 (Example 1 of main report) for radar model print-out of these data input. Note that the data files must be stored *unsequenced.*

The following commands were used on the remote terminal to retrieve the data files and the radar model, and then to run the program. The output was batched to NVEOL's COPE terminal. Note that the file containing the radar model, RADAR, was not compiled.

```
PFN IS
DATA10
..ATTACH, DATA6,ID=NVT1701

PFN IS
DATA6
AT CY= 001 SN=SYSTEM
..ATTACH,RADAR,ID=NVT1701


PFN IS
RADAR
AT CY= 003 SN=SYSTEM
..EDIT,RADAR
REWIND, DATA11,DATA10,DATA6

..
..RUN,FTN

—

  STOP
  132400 MAXIMUM EXECUTION FL.
  24.391 CP SECONDS EXECUTION TIME.

BATCH,OUTPUT,PRINT,TA,MAYO
IMAY051 SENT TO OUTPUT QUEUE
```

The outputs shown below are those automatically put out by the radar model for example 1 of main report. A detailed explanation of the outputs is given in Appendix A.

PLEASE SELECT WHICH SYSTEM YOU WOULD LIKE TO RUN
(T = TRACK, S = SURVEILLANCE, B = BOTH)
DO YOU WANT THE INPUT PRINTED ! (Y OR N)
DO YOU WANT SHORT RANGE SURVEILLANCE (SURFACE TO SURFACE) OR LONG RANGE (SURFACE TO AIR) SURVEILLANCE ! (S = SURFACE).
RADAR NAME OR DESCRIPTION—

DISTRIBUTED RANDON TARGET-THREE SCATTERS

RADAR AND TARGET PARAMETERS (INPUTS)—

PULSE POWER, kW	.0100
PULSE LENGTH, μs	.6100
TRANSMIT ANTENNA GAIN, dB	40.0000
RECEIVE ANTENNA, GAIN, dB	40.0000
TARGET CROSS SECTION, m²	1.0000
FREQUENCY, MHz	9500.0000
ANTENNA OHMIC LOSS, dB	0.0000
PULSE REPITITION FREQUENCY	2000.0000
RECEIVE TRANSMISSION LINE LOSS, dB	0.0000
TRANSMIT TRANSMISSION LINE LOSS, dB	0.0000
SCANNING ANTENNA PATTERN LOSS, dB, INDICATES ELECTRONIC SCANNING IF NEGATIVE	0.0000
MISCELLANEOUS LOSSES, dB	5.0000
BANDWIDTH CORRECTION FACTOR, dB	0.0000
RECEIVER NOISE FACTOR (FIGURE), dB	6.0000
ATMOSPHERIC ATTENUATION, dB/km (−1 = ICOMP. CALC.)	−1.0000
DIELECTRIC CONSTANT REAL PART (−1 IF NO GROUND)	−1.0000
DIELECTRIC CONSTANT IMAGINARY PART (−1 AS ABOVE)	−1.0000
NUMBER OF PULSES INTEGRATED (−1 = COMP. CALC.)	−1
PROBABILITY OF DETECTION (NOTE ≤ D CAN SPECIFY INITIAL RANGE HERE IF PD IS NEGATIVE)	−10.005
FALSE-ALARM PROBABILITY, NEGATIVE POWER OF TEN	6.0000
SWERLING FLUCTUATION CASE (0 = NONFLUCT.)	0
TARGET ELEVATION ANGLE (DEGREES) FOR FIXED ANTENNA CASE OR ANTENNA ELEVATION OFFSET FOR TARGET TRACKING CASE	13.70
ANTENNA TILT- FIXED (= 0), OR FOLLOW TARGET (= 1)	0.0000
SOLAR AND GALACTIC NOISE	AVERAGE
RAIN RATE	0.00
ATTENUATION DUE TO RAIN, dB/km	0.0000
RANGE AT WHICH RAIN BEGINS, nmi	0.0000
RANGE AT WHICH RAIN ENDS, nmi	0.0000
LOWEST ANGLE RASTER SCAN ASSUMES (DEGREES)	0.0000
HIGHEST ANGLE RASTER SCAN ASSUMES (DEGREES)	0.0000
RASTER SCAN INCREMENT (DEGREES)	0.0000
ANTENNA HEIGHT, ft	6.0761
TARGET HEIGHT RELATIVE TO- HORIZONTAL AT BASE OF ANTENNA (= 0), OR EARTH'S SURFACE (= 1)	1.0000
BEAMWIDTH (ELEVATION), DEGREES	.2000
AZIMUTHAL BEAMWIDTH, DEGREES	.2000
SIDELOBES, dB	25.0000
WAVE HEIGHT, ft	100.0000
POLARIZATION (1 = VERTICAL, 2 = HORIZONTAL)	2

SCAN FREQUENCY, Hz	.3300
SCAN RATE OF ANTENNA, DEGREES/S	120.0000
TARGET SPEED PARALLEL TO RELATIVE MOTION PLANE	.5925
TARGET SPEED PERPENDICULAR TO RELATIVE MOTION PLANE	.0006
PLATFORM VELOCITY (PARLLEL TO TARGET), nmi	0.0000
CUMULATIVE PROBABILITY CUTOFF	.9000
RADAR IS- COHERENT (=0), OR NONCOHERENT (=1)	1
STANDARD DEVIATION OF CLUTTER	0.0000
STANDARD DEVIATION OF NOISE	0.0000
STANDARD DEVIATION OF SIGNAL	0.0000
HORIZONTAL COMPONENT OF TRAJECTORY SLOPE	20.0000
VERTICAL COMPONENT OF TRAJECTORY SLOPE	5.0000
TARGET HEIGHT AT CPA (ft)	6.0761
CPA RANGE OFFSET (ft)	6076.1000
RADAR TYPE (1 = PULSE DOPPLER, 2 = MTI)	2.0000
RESPONSE FUNCTION (−1 = SIN, 0 = TRIANGLE, 1 = TRAP)	2.0000
CLUTTER SPECTRUM (1) OR AVERAGE VALUE (0)	0
AVG. SURFACE CLUTTER/UNIT AREA, M**2/M**2	.0000
AVG. VOLUME CLUTTER/UNIT VOLUME, M**2/M**3	.0000
FIRST CORNER OF TRAP RESPONSE FUNCTION, Hz	7000.0000
SECOND CORNER OF TRAP RESPONSE FUNCTION, Hz	70000.0000
CLUT. IMPROV. FACTOR (NEG. = ELECT. SCAN.), dB	45.0000
PROBABILITY OF FALSE ALARM DUE TO CLUTTER	6.0000
REQUIRED SIGNAL TO CLUTTER RATIO	0.0000
NUMBER OF POLES FOR FILTER	3.0000

THE TARGET MODEL CHOSEN CONSISTS OF MULTIPLE POINT SCATTERERS. THESE ARE DEFINED BY A CROSS SECTION AND A POSITION RELATIVE TO A REFERENCE SCATTERER AS SHOWN BELOW:

REFLECTOR	CROSS-SECTION	X (ft)	Y (ft)	Z (ft)
1	1.00000	10.00000	24.00000	0.00000
2	1.00000	0.00000	.05000	34.00000

RNGA BEFORE ITERATE SUBROUTINE = 10.0048767
RNGA AFTER ITERATE SUBROUTINE = 9.829352641912

CALCULATED QUANTITIES (OUTPUTS) --

NOISE TEMPERATURES, DEGREES KELVIN --

ANTENNA (TA)	51.1
RECEIVING TRANSMISSION LINE (TR)	0.0
RECEIVER (TE)	864.5
TE X LINE-LOSS FACTOR = TEI	864.5
SYSTEM (TA + TR + TEI)	915.7
TWO-WAY ATTENUATION THROUGH ENTIRE TROPOSPHERE-dB	.5

SWERLING FLUCTUATION CASE	SIGNAL-TO-NOISE RATIO, dB	TROPOSPHERIC ATTENUATION, DECIBELS	RANGE, NAUTICAL nmi	km
0	-11.67	.31	10.0	(18.529)

DUE TO PROGRAM LIMITATIONS, THE NUMBER OF HITS ON THE TARGET HAS BEEN RESTRICTED TO 25 (OR LESS). THEREFORE THE NUMBER OF HITS ON THIS TARGET HAS BEEN DECREASED BY A FACTOR OF 768. BECAUSE OF THIS LIMITATION, THE CUMULATIVE PROBABILITY SHOWN IN THE FOLLOWING TABLES IS INVALID.

RADIAL VEL = .5893342865488 (KNOTS) ** DOPPLER FREQ. = 19.20138414359 (Hz)
RADIAL VEL = .5890662648508 (KNOTS) ** DOPPLER FREQ. = 19.1926515996 (Hz)
RADIAL VEL = .5887628416372 (KNOTS) ** DOPPLER FREQ. = 19.18276562179 (Hz)
RADIAL VEL = .5884175318473 (KNOTS) ** DOPPLER FREQ. = 19.17151491726 (Hz)
RADIAL VEL = .5880223019438 (KNOTS) ** DOPPLER FREQ. = 19.15863774148 (Hz)
RADIAL VEL = .5875671063617 (KNOTS) ** DOPPLER FREQ. = 19.14380679505 (Hz)
RADIAL VEL = .5870392545085 (KNOTS) ** DOPPLER FREQ. = 19.12660859967 (Hz)
RADIAL VEL = .5864225340888 (KNOTS) ** DOPPLER FREQ. = 19.10651493474 (Hz)
RADIAL VEL = .5856959781094 (KNOTS) ** DOPPLER FREQ. = 19.08284266455 (Hz)
RADIAL VEL = .5848321012441 (KNOTS) ** DOPPLER FREQ. = 19.05469627646 (Hz)
RADIAL VEL = .583794330001 (KNOTS) ** DOPPLER FREQ. = 19.02088415192 (Hz)
RADIAL VEL = .582533180839 (KNOTS) ** DOPPLER FREQ. = 18.97979404386 (Hz)
RADIAL VEL = .5809804461719 (KNOTS) ** DOPPLER FREQ. = 18.92920364805 (Hz)
RADIAL VEL = .5790401248758 (KNOTS) ** DOPPLER FREQ. = 18.86598510568 (Hz)
RADIAL VEL = .576573872949 (KNOTS) ** DOPPLER FREQ. = 18.78563096419 (Hz)
RADIAL VEL = .5733769231547 (KNOTS) ** DOPPLER FREQ. = 18.68146960367 (Hz)
RADIAL VEL = .5691368177897 (KNOTS) ** DOPPLER FREQ. = 18.54332068924 (Hz)
RADIAL VEL = .5633599012268 (KNOTS) ** DOPPLER FREQ. = 18.35510018923 (Hz)
RADIAL VEL = .5552347312703 (KNOTS) ** DOPPLER FREQ. = 18.09037011476 (Hz)
RADIAL VEL = .5433667151872 (KNOTS) ** DOPPLER FREQ. = 17.70369256853 (Hz)
RADIAL VEL = .5252402342805 (KNOTS) ** DOPPLER FREQ. = 17.11310496654 (Hz)
RADIAL VEL = .4960983563587 (KNOTS) ** DOPPLER FREQ. = 16.16361941069 (Hz)
RADIAL VEL = .4466759474789 (KNOTS) ** DOPPLER FREQ. = 14.55336411101 (Hz)
RADIAL VEL = .359629514101 (KNOTS) ** DOPPLER FREQ. = 11.71726235388 (Hz)

OUTPUT BELOW (S/N, PROBABILITY OF DETECTION) IS FREE SPACE VALUE. (ZERO WEIGHTING).

Table B-1.

SWERLING FLUCTUATION CASE	SIGNAL-TO-NOISE SIGNAL-TO-NOISE RATIO, dB BEFORE PROCESSOR	TROPOSPHERIC ATTENUATION dB	PROBABILITY OF DETECTION	TARGET HEIGHT IN ft	RANGE IN nmi	(km)
0	−11.66	0.00	.0000	14672.27	10.00	(18.52)
0	−10.99	0.00	.0000	14107.83	9.62	(17.82)
0	−10.29	0.00	.0000	13543.39	9.24	(17.12)
0	−9.56	0.00	.0000	12978.95	8.86	(16.41)
0	−8.80	0.00	.0000	12414.51	8.42	(15.71)
0	−8.00	0.00	.0000	11850.07	8.10	(15.00)
0	−7.17	0.00	.0000	11285.62	7.72	(14.30)
0	−6.29	0.00	.0000	10721.18	7.34	(13.60)
0	−5.37	0.00	.0000	10156.74	6.96	(12.89)
0	−4.40	0.00	.0000	9592.30	6.58	(12.19)
0	−3.37	0.00	.0001	9027.86	6.21	(11.49)
0	−2.28	0.00	.0002	8463.42	5.83	(10.79)
0	−1.12	0.00	.0004	7898.98	5.45	(10.10)
0	.12	0.00	.0010	7334.53	5.07	(9.40)
0	1.46	0.00	.0034	6770.09	4.70	(8.70)
0	2.89	0.00	.0129	6205.65	4.33	(8.01)
0	4.46	0.00	.0550	5641.21	3.95	(7.32)
0	6.16	0.00	.2247	5076.77	3.59	(6.64)
0	8.03	0.00	.6533	4512.33	3.22	(5.96)
0	10.10	0.00	.9777	3947.89	2.86	(5.29)
0	12.40	0.00	1.0000	3383.44	2.50	(4.64)
0	14.99	0.00	1.0000	2819.00	2.16	(3.99)
0	17.88	0.00	1.0000	2254.56	1.83	(3.38)
0	21.06	0.00	1.0000	1690.12	1.52	(2.82)
0	24.36	0.00	1.0000	1125.68	1.26	(2.33)

Table B-2.

OUTPUT BELOW (S/N, PROBABILITY OF DETECTION) IS WEIGHTED WITH A PATTERN PROPAGATION FACTOR DEPENDENT ON RANGE. TROPOSPHERIC ATTENUATION WEIGHTING FACTOR=ZERO.

SWERLING FLUCTUATION CASE	SIGNAL-TO-NOISE RATIO,dB BEFORE PROCESSOR	TROPOSPHERIC ATTENUATION, dB	PROBABILITY OF DETECTION	RANGE IN nmi.	RANGE IN km.
0	−43.85	0.00	0.00	10.00	(18.52)
0	−35.71	0.00	0.00	9.62	(17.82)
0	−38.86	0.00	0.00	9.24	(17.12)
0	−33.48	0.00	.00	8.86	(16.41)
0	−26.54	0.00	.00	8.48	(15.71)
0	−24.62	0.00	.00	8.10	(15.00)
0	−25.55	0.00	.00	7.72	(14.30)
0	−22.70	0.00	.00	7.34	(13.60)
0	−16.77	0.00	.00	6.96	(12.89)
0	−14.78	0.00	.00	6.58	(12.19)
0	−5.61	0.00	.00	6.21	(11.49)
0	−6.64	0.00	.00	5.83	(10.79)
0	5.23	0.00	.11	5.45	(10.10)
0	4.79	0.00	.07	5.07	(9.40)
0	8.89	0.00	.85	4.70	(8.70)
0	2.56	0.00	.01	4.33	(8.01)
0	−7.24	0.00	.00	3.95	(7.32)
0	−59.85	0.00	0.00	3.59	(6.64)
0	−41.41	0.00	0.00	3.22	(5.96)
0	−49.52	0.00	0.00	2.86	(5.29)
0	−51.17	0.00	0.00	2.50	(4.64)
0	−61.96	0.00	0.00	2.16	(3.99)
0	−83.76	0.00	0.00	1.83	(3.38)
0	−92.90	0.00	0.00	1.52	(2.82)
0	−71.82	0.00	0.00	1.26	(2.33)

Table B-3

OUTPUT BELOW IS WEIGHTED WITH A PPF AND A TROP. ATTEN. FACTOR. CUMULATIVE PROBABILITY IS ALSO CALCULATED.

SWERLING FLUCTUATION CASE	SIGNAL-TO-NOISE RATIO. dB BEFORE PROCESSOR	TROPOSPHERIC ATTENUATION dB	PROBABILITY OF DETECTION	CUMULATIVE PROBABILITY	RANGE IN	
					nmi	km
0	-44.15	.31	0.0000	0.0000	10.00	(18.52)
0	-36.01	.30	0.0000	0.0000	9.62	(17.82)
0	-39.14	.28	0.0000	0.0000	9.24	(17.12)
0	-33.75	.27	.0000	.0000	8.86	(16.41)
0	-26.80	.26	.0000	.0000	8.48	(15.71)
0	-24.87	.25	.0000	.0000	8.10	(15.00)
0	-25.78	.24	.0000	.0000	7.72	(14.30)
0	-22.92	.23	.0000	.0000	7.34	(13.60)
0	-16.98	.21	.0000	.0000	6.96	(12.89)
0	-14.98	.20	.0000	.0000	6.58	(12.19)
0	-5.80	.19	.0000	.0000	6.21	(11.49)
0	-6.81	.18	.0000	.0000	5.83	(10.79)
0	5.06	.17	.0936	.0936	5.45	(10.10)
0	4.64	.16	.0646	.1521	5.07	(9.40)
0	8.75	.14	.8184	.8460	4.70	(8.70)
0	2.43	.13	.0083	.8473	4.33	(8.01)
0	-7.36	.12	.0000	.8473	3.95	(7.32)
0	-59.96	.11	0.0000	.8473	3.59	(6.64)
0	-41.51	.10	0.0000	.8473	3.22	(5.96)
0	-49.61	.09	0.0000	.8473	2.86	(5.29)
0	-61.25	.08	0.0000	.8473	2.50	(4.64)
0	-62.02	.07	0.0000	.8473	2.16	(3.99)
0	-83.81	.06	0.0000	.8473	1.83	(3.38)
0	-92.95	.05	0.0000	.8473	1.52	(2.82)
0	-71.86	.04	0.0000	.8473	1.26	(2.33)

Table B-4.

OUTPUT BELOW IS WEIGHTED WITH A PPF AND A TROP. ATTEN. FACTOR. CLUTTER AND DOPPLER PROCESSING IS ALSO INCLUDED. CUMULATIVE PROBABILITY IS ALSO CALCULATED.

SIGNAL-TO-NOISE RATIO, dB AFTER PROCESSOR	EFFECTIVE SIGNAL-TO--NOISE RATIO, dB	SIGNAL-TO-CLUTTER RATIO, dB BEFORE PROCESSOR	SIGNAL-TO-CLUTTER RATIO, dB AFTER PROCESSOR	TROPOSPHERIC ATTENUATION dB	PROBABILITY OF DETECTION	CUMULATIVE PROBABILITY	RANGE IN nmi	RANGE IN km
−36.02	−36.02	16.17	16.17	.31	0.0000	0.0000	10.00	18.52
−36.01	−36.01	16.51	16.51	.30	0.0000	0.0000	9.62	17.82
−36.02	−36.02	16.36	16.86	.28	0.0000	0.0000	9.24	17.12
−33.75	−33.75	17.22	17.22	.27	.0000	.0000	8.86	16.41
−26.80	−26.80	17.61	17.61	.26	.0000	.0000	8.48	15.71
−24.87	−24.87	18.00	18.00	.25	.0000	.0000	8.10	15.00
−25.78	−25.78	18.42	18.42	.24	.0000	.0000	7.72	14.30
−22.92	−22.92	18.86	18.86	.23	.0000	.0000	7.34	13.60
−16.98	−16.98	19.32	19.32	.21	.0000	.0000	6.96	12.89
−14.98	−14.98	19.81	19.81	.20	.0000	.0000	6.58	12.19
−5.80	−5.80	20.32	20.32	.19	.0000	.0000	6.21	11.49
−6.81	−6.81	20.87	20.87	.18	.0000	.0000	5.83	10.79
5.06	5.06	21.45	21.45	.17	.0936	.0936	5.45	10.10
4.64	4.64	22.07	22.07	.16	.0646	.1521	5.07	9.40
8.75	8.75	22.73	22.73	.14	.8184	.8460	4.70	8.70
2.43	2.43	23.45	23.45	.13	.0083	.8473	4.33	8.01
−7.36	−7.36	24.23	24.23	.12	.0000	.8473	3.95	7.32
−36.02	−36.02	25.08	25.08	.11	0.0000	.8473	3.59	6.64
−36.02	−36.02	26.02	26.02	.10	0.0000	.8473	3.22	5.96
−36.02	−36.02	27.05	27.05	.09	0.0000	.8473	2.86	5.29
−36.02	−36.02	28.21	28.21	.08	0.0000	.8473	2.50	4.64
−36.02	−36.02	29.50	29.50	.07	0.0000	.8473	2.16	3.99
−36.02	−36.02	30.94	30.94	.06	0.0000	.8473	1.83	3.38
−36.02	−36.02	32.54	32.54	.05	0.0000	.8473	1.52	2.82
−36.02	−36.02	34.19	34.19	.04	0.0000	.8473	1.26	2.33

Table B-5.
RMAX FROM SUBROUTINE MRANGE = 10.0048767
NOTE: THIS IS THE HORIZONTAL RANGE FROM CPA (NMI)

RADAR PARAM   DIMENSIONS IN PAREN, NO PAREN FOR DIMENSIONLESS PARAM

PEAK POWER (kW)   100.0
ANTENNA GAIN (dB)   41.1
AZ 3dB BW (DEGREES)   1.8
EL 3dB BW (DEGREES)   1.8
PULSEWIDTH (μs)   .21
WAVELENGTH (CM)   1.88
THERMAL FACTOR (WATTS/MHz)   .4E-14
IF BANDWIDTH (MHz)   3.0
TRANSMIT LINE LOSS (dB)   0.0
RECEIVE LINE LOSS (dB)   0.0
PATTERN LOSS (dB)   1.0
IF MISMATCH LOSS (dB)   0.0
CROSSOVER LOSS (dB)   0.0
AVG SIDELOBE (dB)   16.0
ANGLE TRACK CONSTANT   1.57
PRF (PPS)   53256.0
HITS/SCAN
OR NO. OF PULSES DURING DWELL TIME (SEARCH OR EDGE SYSTEMS)   100.0
RANGE TRACK CONSTANT   40.0
COLLAPSING LOSS (dB)   0.0
SERVO ANGULAR ACCELERATION CONSTANT (SE -2)   90.0
SERVO ANGULAR VELOCITY CONSTANT (SE -1)   500.0
SERVO RANGE ACCELERATION CONSTANT (SE -2)   40.0
ANTENNA HEIGHT (ft)   20.0
FREQ (MHz)   16000.0
ELEV TYPE   1
AZ TYPE   1
IPOL   2
NOISE FIGURE (dB)   6.0
SCAN FREQUENCY (Hz)   1.0
RANGE SERVO BANDWIDTH (Hz)   4.0
ANGLE SERVO BANDWIDTH (Hz)   6.0
NUMBER OF INDEPENDENT LOOKS   1.0
BEAMSTEP GRANULATION   0.0000

APPENDIX C

COMPUTER DATA FILE INPUT* FOR EXAMPLE 2

File DATA 6

```
100= S
110= Y
120= A
```

File DATA 10

```
100= HELICOPTER POP UP
110= .004,.125,45,45,1,93930,0,40000
120= 8.5,0,0,0,0,6,-1,4,.006
130= 160,-1.001,6,0,0,2,0,0,0,0,0
140= .36,2.77,.1
150= 6.07613,1,.57,.57,18,.5,1
160= .1666,60,.6,.0006,0,.9
170= 0,0,0,0
180= 2,1,1,1E-6,1E-7,1055,14071,10,6,0,2
190= 0
200= 3,1,2
210= 3,1,2
220= 3,1,2
230= 3,1,2
240= 3,1,2
```

File DATA 11

```
100= 100,41.1,1.76,1.76,.2118,1.875,4E-15,3,0,0,1,0,0,16,1.57,1,0
110= 53256.0,100,40,0,90,500,40,20,16000,1,1,2,6,1,4,6,3
120= .305,7,9,.305,2337,5,.1,0,0,0,0,0
130= 1,1.004993,1,6.0761,60,6076.1,0
140= 20,2.8,10,0,0,0,0
```

---

* Also, see Table 3 (Example 2 of main report) for radar model print-out of these data input. Note that data files must be stored *unsequenced.*

APPENDIX D

COMPUTER DATA FILE INPUT* FOR EXAMPLE 3

File DATA 6

```
100= S
110= Y
120= A
```

File DATA 10

```
100= RADAR ON HELICOPTER
  110= .21,.200,55,55,5.25,93930,0,33400
  120= 10.1,0,0,0,0,6,-1,4,.006
  130= 40,-1.1,6,0,0,2,0,0,0,0,0
  140= -2.5,-5,.1
  150= 300,1,.57,.57,22,.5,2
  160= 1.1,396,10,0,0,.9
  170= 0,0,0,0
  180= 2,1,1,0,1E-7,1055,14071,16,6,0,2
  190= 0
  200= 3,1,2
  210= 3,1,2
  220= 3,1,2
  230= 3.1,2
  240= 3,1,2
```

File DATA 11

```
100= 100,41.1,1.76,1.76,.2118,1.875,4E-15,3,0,0,1,0,0,16,1.57,1,0
110= 53256.0,100,40,0,90,500,40,20,16000,1,1,2,6,1,4,6,3
120= .305,7.9,.305,2337,5,.1,0,0,0,0[,0
130= 1,1.004993,100,6.0761,0,6076.1,0
140= 20,2.8,10,0,0,0,0
```

The following commands were used on the remote terminal to fetch the data files and the radar model and then to run the program. The output was batched to NVEOL's COPE terminal. Note that the file containing the radar model, RADARB, is the compiled version.

* Also, see Table 5 (Example 3 of main report) for radar model print-out of these data input. Note that data files must be stored *unsequenced.*

```
ATTACH,DATA11,CY=1,ID=NVT1701

PFN IS
DATA11
. .ATTACH,DATA10,CY=1,ID=NVT1701

PFN IS
DATA10
. .ATTACH,DATA6,CY=1,ID=NVT1701

PFN IS
DATA6
. .ATTACH,RADARB,ID=NVT1701

PFN IS
RADARB
AT CY= 001 SN=SYSTEM
. .REWIND,DATA11,DATA10,DATA6,RADARB
RADARB

. .

 STOP
 132200 MAXIMUM EXECUTION FL.
 23.176 CP SECONDS EXECUTION TIME.

. ._

BATCH,OUTPUT,PRINT,TA,MAY0

IMAY051 SENT TO OUTPUT QUEUE
```

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