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RADAR RETURN FROM THE VERTICAL
FOR GROUND AND WATER SURFACES

by

Charles S. Williams Jr.,

Charles H. Bidwell

and

Douglas M. Gragg

APRIL 1960

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PREFACE

A rather large number of people contributed to the collection and processing of the data that are presented in this report in Table I. The collection was carried out over the period 1953 to 1955 by personnel of Sandia Corporation; the aircraft and flight crew were furnished by the U.S. Air Force. The processing was done at the Physical Science Laboratory of New Mexico State University under contract with Sandia Corporation. (Some data flights were made as early as 1951, but we have not used this early data in Table I since there is some question about its reliability. Also, data were taken and processed for a frequency intermediate to the two frequencies found in Table I. The condition of the equipment used for this intermediate frequency places the resultant data in question and it has not been reported herein.)

The program was sponsored by Sandia Corporation and was under the general direction of Dr. R. K. Moore (now chairman of the Electrical Engineering Department at the University of New Mexico) until 1955. Messrs. F. J. Janza (now a graduate student at the University of New Mexico) and R. E. West of Sandia Corporation were principally responsible for the equipment, and participated extensively in the data-collecting flights. Mr. D. M. Gragg (now with Lockheed Missiles and Space Division) was responsible for the care and indexing of the voluminous data that was generated; he participated in some of the flights and also carried out certain mathematical analyses relative to interpretation of the data.

Dr. R. K. Moore, after leaving Sandia Corporation in 1955 for the Chairmanship of the Electrical Engineering Department at the University of New Mexico, continued to direct studies based on these data and aimed at finding the numerical values of the parameters of certain models that describe the phenomenon of vertical radar return from ground and water surfaces. The results of these studies are in a report by Edison, Moore and Warner; it is listed in the bibliography herein. Dr. Moore is continuing further studies in this general area.

The processing at the Physical Science Laboratory of New Mexico State University was, during most of the period, under the direction of Mr. Peter D. Welch. In addition to his responsibility for data analysis, he made many important contributions to the interpretation of the data. A number of his papers on this subject are listed in the bibliography.

The basic data presented herein were taken from the unpublished data reports prepared by the Physical Science Laboratory of New Mexico State University under contract to Sandia Corporation. Subsequent to the printing of many of these data reports, it was discovered that they had been based on erroneous antenna-gain figures. Hand-written corrections were then made on only one set; hence, anyone who examines any of these reports should take care that he has a corrected copy. The corrections are, in general, small compared to the experimental error and to the variations that exist in radar return from the ground; hence, the use of the uncorrected data reports would not have any appreciable effect on the conclusions that can be drawn from the data. Nonetheless, Table I herein was prepared from the corrected reports.

Mr. D. M. Gragg must be given special credit for putting the data in the form found in Table I. It was he who extracted the data from the some 500 original reports and put them in the tabular form. This was a trying task; his close association with the project from its inception was invaluable in accomplishing it. Mr. Gragg also wrote the terrain descriptions that appear in Sec. 1.6.

Mr. C. H. Bidwell was consulted continuously in preparing the outline of this report, and in the arrangement of the data in Table I. He reviewed the text with care and suggested many worthwhile changes and additions which have been incorporated. He is a coauthor of Part II.

Mrs. Elizabeth C. Edens took the data for the column "Minimum Time Interval for Independent Samples" in Table I from the some 65 original variance-spectra reports. She further verified many of the other tabular entries as a check against gross error. She prepared the final form of Table I and the final drafts of all figures that appear in the report. She also computed the "Angular Limits." (The angular limits given in Table I will be found to be different from the angular limits given in the original data reports. In both cases, these limits represent formal calculations rather than observations. For Table I, we used a different and simpler formula--and probably just as accurate.)

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Charles S. Williams, Jr.
May 1960

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RADAR RETURN FROM THE VERTICAL FOR GROUND AND WATER SURFACES

Introduction

From 1953 to 1955, a great many measurements of the strength of pulse radar return from the vertical for a variety of ground and water surfaces were made by personnel of the Sandia Corporation at 415 and 3800 Mcps. The radars were carried in a low-speed aircraft that made straight and level runs at various altitudes over 31 individual terrains that may be categorized into 17 general types. Low-gain antennas were used and they were directed straight down. The primary purpose of this report is to present these data in compact form.

Table I, p. 31, is a compilation of the experimental data. Part I describes the method of reducing the data to the form found in Table I and should be consulted for definitions of the tabulated quantities. In reducing the data, no operation was performed that required any assumption concerning the mechanism of reflection of electromagnetic energy from the terrain (except the assumption that response is proportional to excitation). Part I also includes visual descriptions of the various terrains.

Part II presents certain simple models of the return of electromagnetic energy from the ground. These models are presented to aid in understanding the experimental data. They cannot embrace all of the ways in which the energy can be returned; in fact, it is easy to find behavior in the data that none of the models can explain.

Part II further presents the median return from the vertical plotted against altitude above the terrain. These plots are taken from the data in Table I, but show the variation of the return with altitude in a more graphic form.

There seem to be certain contradictions in the data. For example, there is a case where the measured return from a water surface described as "quiet" behaves according to the criterion given herein for return from a scattering surface. In another case, the return from a water surface (ocean) described as having "swells" and "3- to 5-foot waves" meets the criterion for return from a smooth (i.e., specular) surface. For such cases, we can only suggest that a visual observation is not always a good measure of how a particular terrain

should be categorized according to its radar return characteristics. Of course, for the particular ocean example given, it is possible that the state of the surface changed between the time of visual observation and the time the run was made at the altitude that gave the aforementioned result.

The data presented here should give good estimates on the expected upper and lower limits of the strength of radar return from several types of terrain. However, since no good models exist to describe the process, one should be extremely cautious in seeking to extrapolate these data to greatly different heights, frequencies, or pulse widths. Interpolation should, of course, be fairly safe.

PART I

The Data

In Part I we present data obtained in experiments performed to ascertain the strength of radar reflections from the ground for vertical and near-vertical incidence. The data are presented almost in the same form in which they were taken. Of course, they have been modified to the extent that what originally appeared as a deflection on an oscilloscope is given as power density; further, they have been normalized so that as tabulated they represent (in logarithmic units) the returned power density per unit of transmitted power for an isotropic antenna. The important fact is that no modification has been made that would require any assumption except linearity about the mechanism of reflection of electromagnetic energy from the terrain.

1.1 Method of Taking the Data

The approximate characteristics of the two radars used in taking the data are given in the following table:

	<u>No. 1</u>	<u>No. 2</u>
Frequency f_0	415 Mcps	3800 Mcps
Pulse width τ	0.1 μ sec	0.2 μ sec
Repetition rate $1/T$	400 pps	2000 pps
Antenna gain G^1	5 db ¹	12 db ¹

More detail concerning the pulse shapes and antenna patterns is given in Part III in Figs. III-1 through III-5.

The radars were carried by a 130-knot aircraft that made straight and level runs, each of several seconds duration, over some 31 individual terrains that may be categorized into 17 general types. The antennas were directed straight down. Over most of the terrains, data

¹G represents the antenna power gain. The values given here in db are in reality $10 \log_{10} G$ and approximately represent the gain straight down.

were taken at four altitudes: approximately 600, 1200, 2100, and 3600 meters (2000, 4000, 7000, and 12,000 feet) above the ground. No attention was given to the effect of the polarization of the transmitted wave.

Each run over a terrain was long enough to provide about 2500 pulse returns; the envelopes of these RF returns were recorded individually on film. These films were subsequently analyzed to obtain the distribution of pulse amplitude within a run, and, for some runs, the pulse-to-pulse correlation was calculated. The latter is, of course, related to the velocity of the aircraft with respect to that portion of the terrain from which the return came and is also related to the radar frequency, f_0 . The return pulses were analyzed, not only at their peak values, but also at fixed delay points subsequent to the peak.

1.2 Definition of the Return Pulse

In Fig. I-1, two sample film strips are shown to illustrate the way in which the 2500 pulses of a run were recorded. A calibration related average RF power at receiver input to deflection on the oscilloscope. Hence, the pulse functions with which we shall deal represent power at receiver input averaged over successive RF cycles; that is, the k^{th} returned pulse in a run can be represented by

$$P_k(d) = [A_k(d)]^2 / 2Z_0 \text{ watts,} \quad (1.2-1)$$

where d is time delay from the start of the return pulse, Z_0 is the input impedance (real, and matched to the antenna) of the receiver in ohms, and $A_k(d)$ is the envelope of the RF voltage at receiver input. (The RF voltage of the k^{th} pulse at receiver input can be written $A_k(d) \cos(2\pi f_0 d + \phi_k)$, where f_0 is the carrier frequency and ϕ_k is a time-varying phase angle. The maximum frequencies contained in the spectra of the envelope A_k and the phase ϕ_k are very small compared to f_0 .)

Fig. I-2 represents the returned pulses $P_k(d)$ plotted against time delay d . The duration of the transmitted pulses is τ and the time interval between them is T . The subscript k designates the serial number of the pulse in the run of 2500 pulses. The variation from pulse to pulse is the result of the motion of the aircraft.

1.3 Geometry of the Pulse Reflection

The power at a fixed delay d in a returned pulse is reflected from an area that must lie within a certain annular area ΔA on the ground. (See Fig. I-3.) Let R_0 and R_1 be the

Fig. I-1 -- Sample film strips to illustrate the manner of recording the echo pulses received during a run. The large rectangular pulse at the left of each trace is a calibration pulse. The small pulse is the echo. Note the pulse-to-pulse variation of the echo.

Fig. I-2 -- A run of 2500 transmitted and returned pulses. The transmitted pulses occur in sequence at time intervals T , the repetition period of the radar. The variation from pulse to pulse is due to the motion of the aircraft carrying the radar.

Fig. I-3 -- The geometry of reflection of pulses of width τ from the terrain. The outer and inner ranges R_0 and R_1 that define the active annular area that may contribute to the returned pulse at delay d depend on d , but evidently must have the minimum value h .

distances from the radar to the outer and inner boundaries of the annulus.² The portion of returned power at delay d that is caused by the leading edge of the transmitted pulse has traveled $d + 2h/c$ sec (Fig. I-2) through a distance $2R_o$ at velocity c . Thus,

$$R_o = h + cd/2, \text{ (for } d > 0\text{).} \quad (1.3-1)$$

(For $d \leq 0$, the returned pulse does not exist, of course.) The portion of returned power at delay d that is caused by the trailing edge of the transmitted pulse has traveled $d + 2h/c - \tau$ seconds (Fig. I-2) through a distance $2R_i$ at velocity c . Thus,

$$R_i = h + c(d - \tau)/2, \text{ (for } d - \tau > 0\text{).} \quad (1.3-2)$$

(For $d - \tau < 0$, R_i must evidently have the value h and the annulus is a circle.)

If the terrain has the property of not reradiating energy at angles off the upward vertical beyond some limiting angle, then the area that contributes to the return at delay d will lie within ΔA but may not be identical to ΔA .

The annular area ΔA that produces the power $P_k(d)$ at some fixed delay d can also be defined by the outer and inner angles θ_o and θ_i that are given by

$$\cos \theta_o = h/R_o \quad (1.3-3)$$

and

$$\cos \theta_i = h/R_i. \quad (1.3-4)$$

1.4 Definition of the Tabulated Return

Now $P_1(d)$, $P_2(d)$, ..., $P_{2500}(d)$ may be considered as 2500 samples of a continuous function of time t as illustrated in Fig. I-4. (These are readings in the pulses taken at a fixed delay d .) We designate this function $W_d(t)$ and note that the samples are spaced at time intervals T , the pulse repetition period.³ This function $W_d(t)$ could be generated by continuously illuminating only the annular area associated with the delay d (and, of course, the height h and the pulse width τ). This area would be bounded by the angles θ_i and θ_o defined in Eqs. (1.3-3) and (1.3-4). As the annulus swept over the earth with the motion of the aircraft, $W_d(t)$ would vary with time t due to the changes in the character of the illuminated portion of the terrain.

² R_o and R_i evidently depend on d . Thus, the returns at two different delays d_1 and d_2 come from different annular areas; these two annular areas may, of course, overlap.

³There is a different function $W_d(t)$ for every value of delay d . The time d is position in each returned pulse while t measures time from the beginning of a run.

Samples of $W_d(t)$: $W_d(d + kT) \equiv P_{k+1}(d)$

Fig. I-4 -- A sequence of samples taken from the returned pulses at a fixed delay d from initial rise of each returned pulse. These may be considered as 2500 samples of a power function $W_d(t)$ taken at time intervals T . Such a function exists for every (different) delay d . The time t is measured from the initial rise of the first returned pulse.

Instead of dealing with the function $W_d(t)$ that represents returned power, we will tabulate (in logarithmic units) the power density

$$p_d(t) = \frac{W_d(t)}{\hat{P}_s G^2 \lambda^2 / 4\pi} \text{ watts/meter}^2 \text{ per watt} \quad (1.4-1)$$

which does not depend on transmitted power or antenna gain since we have divided $W_d(t)$ by the peak power $\hat{P}_s$ of the transmitted pulse, by the transmitting antenna gain G , and by the effective cross-section $G\lambda^2/4\pi$ of the receiving antenna (where $\lambda = c/f_o$ is the carrier wavelength).

It is important to note that the function $p_d(t)$ represents the return power density (watts per square meter) for a one-watt transmission, an isotropic antenna, a particular pulse width, and a given height above the terrain. It is, thus, the return that results from illuminating a particular circular or annular area ΔA that moves over the ground with the horizontal motion of the aircraft, it is not the return from a unit area. Now the area ΔA can readily be calculated; however, we have not tried here to find the return per unit area on the ground since any operation with ΔA would require the use of some theoretical model to explain reflection from the ground. In Part I, we are seeking to present experimental data only; we do not wish to modify such data by any operation that requires an assumption about the process by which energy is reflected from the terrain.

1.5 The Tabulated Quantities

Table I, p. 31, presents the data concerning the normalized return power density $p_d(t)$. This section defines the quantities that appear in the table.

Each "record" of $p_d(t)$ consists of 2500 samples taken at intervals T_s of time t . Such a record applies to a type of terrain and a specific terrain (described in some detail in Sec. 1.6), an RF carrier f_o , an altitude h above terrain, a transmitted pulse width τ , and a time position d in the pulse. (There is a different record of $p_d(t)$ for each value of time position d in the pulse; d is time delay from the initial rise of the return pulse.)⁴ From the measured values of d , τ , and h , the angular limits θ_i and θ_o of the annular area on the ground that may contribute to the return pulse at any specified delay d can be calculated from Eqs. (1.3-1), (1.3-2), (1.3-3), and (1.3-4).

⁴A group of 2500 actual returned pulses will produce several records of $p_d(t)$ --one for each position d in the pulses where amplitude readings are made.

The evaluation of each record of $p_d(t)$ has produced a probability distribution (and from the distribution comes the db difference between its first and third quartiles), and some records were further analyzed to obtain the ratio $(\text{mean})^2/(\text{variance})$ and the minimum time interval needed for independent samples. Since this time interval is inversely proportional to the velocity with respect to the terrain (as well as to the frequency f_0), the ground speed of the aircraft is given whenever the interval is given. The meaning of these quantities is described more precisely in the following subsections.

The "code" is a reference to Part III where more details concerning pulse shape and antenna pattern are given. The film or run number is the number that was assigned to each run and, hence, to each film during the time that the data were being taken and analyzed. (The letters H and L which are part of the run numbers indicate whether the radar frequency was "high," 3800 Mcps, or "low," 415 Mcps. The suffix R found with some run numbers means "reworked"; i.e., the film for the run was read a second time and the data so obtained were reported under the same run number with the R suffixed. In some cases we have tabulated the data from the first readings as well as from the "rework"; the differences between the two are an indication of the magnitude of the error in the data.) These run numbers can be used to associate the data here with the original data reports.

In each group of lines in Table I that pertains to a given altitude h , the first line results from readings taken at the peak of the returned pulse.⁵ Such readings should represent the return from the vertical, i.e., the inner angle θ_i should be zero. The fact that the tabulated values of θ_i are not always zero for such cases is an indication that errors have been introduced--probably because the transmitted pulse was not truly rectangular, and because of the difficulty in ascertaining just exactly where on the trace the return pulse begins to rise. (The tabulated angles θ_i and θ_o are formally calculated from the observed values of d , r , and h .) A constant correction may be applied to the tabulated values of θ_i and θ_o to make the θ_i that corresponds to vertical return equal to zero. One should not, of course, put too much faith in the values so obtained. As a matter of fact, the returns from angles other than vertical should be used only to give a crude idea of the variation of return with angle. These data were taken with a wide-beam antenna directed downward; such an antenna pattern is certainly not satisfactory for obtaining data concerning the variation of the return with angle from the vertical.

⁵To distinguish the data obtained by readings taken at the peak of the returned pulses from those obtained at subsequent points in the pulses, the probability distributions of the latter are printed in micro figures.

In some cases the tabulated return obtained by reading the returned pulses at peak is actually less than a subsequent reading. This is a result of dividing the actual reading by G^2 ; i.e., the drop in G^2 from vertical to the angle represented by the second line is sometimes greater than the fall from the peak of the returned pulse to the pulse reading corresponding to the second line. One should not seek to draw conclusions from these oddities; they are only an indication of the inaccuracies in the data.

1.5a Probability distribution -- The variations of $p_d(t)$ with time t can be described by a probability distribution. In Table I the levels that $p_d(t)$ exceeds 5, 25, 50, 75, and 95 percent of the time t are given in decibels (db) above a micromicrowatt per square meter per watt of power transmitted isotropically. That is, the tabulated distribution actually applies to the quantity

$$10 \log_{10} \left[\frac{p_d}{10^{-12}} \right] = 10 \log_{10} \left[\frac{(W_d) 10^{12}}{\hat{P}_s G^2 \lambda^2 / 4\pi} \right]$$

The median return (i.e., the 50-percent level) for vertical incidence⁶ is recorded in boldface in Table I since this is regarded as the most significant and useful information in the table. The other percentage levels for vertical incidence are recorded in the same type as the rest of the table. All percentage levels for other angles of incidence⁷ are recorded in micro figures for ease of distinction.

Although the probability distributions are recorded to the nearest tenth of a db, the relative accuracy of the points of a distribution is about 1 db while the absolute accuracy is about 3 db.⁸ That is, the difference between the tabulated values of any two percentage points of a given distribution is correct within 1 db while the tabulated values themselves are only within 3 db of the true values. The relative accuracy depends principally on the size of the sample from which the distribution is estimated. The absolute accuracy depends on all the factors whose inaccuracies contribute to the inaccuracy in determining the actual power represented by a certain deflection on the oscilloscope, viz., calibration, antenna gain, transmitter power and pulse shape, and receiver bandwidth.⁹

⁶The tabulated inner angle θ_i is not always zero for the tabular line that gives return from the vertical. This angle was formally calculated from the measured values of d , r , and h ; the fact that it is not zero probably indicates error in the measured data. See Sec. 1.5.

⁷The return for angles other than vertical was obtained by taking readings in the trailing portion of the pulses.

⁸There appears to be a constant error in the data that causes the 3800 Mcps returns to be 4 db greater on the average than the 415 Mcps returns. See Sec. 3.3.

⁹See Sec. 3.3.

1.5b Difference in db between first and third quartiles -- The first and third quartiles of the probability distribution are the 75- and 25-percent points, and we will designate them Q_1 and Q_3 watts, respectively. Now the ratio

$$Q_3/Q_1 = (\text{third quartile in watts})/(\text{first quartile in watts})$$

or the logarithm

$$\begin{aligned} 10 \log_{10} (Q_3/Q_1) &= 10 \log Q_3 - 10 \log Q_1 \\ &= \text{difference between first and third quartiles} \\ &\quad \text{expressed in db} \end{aligned}$$

is a statistical parameter of $p_d(t)$ that is a measure of the type of terrain. For a perfectly scattering terrain, the difference should be 6.8 db;¹⁰ for a perfectly specular terrain, it should have the value zero.¹¹ The tabulated difference is within about 1 db of the true difference of the quartile points.

1.5c (Mean)²/(variance) -- Among the other statistical parameters of $p_d(t)$ are

$\bar{p}_d$ = mean (or DC component) of $p_d(t)$,

σ_d = standard deviation (or rms value of AC component) of $p_d(t)$,

and

σ_d^2 = variance (or mean of square of AC component) of $p_d(t)$.

The ratio

$$\bar{p}_d^2/\sigma_d^2 = (\text{mean})^2/(\text{variance})$$

is also a measure of the type of terrain. For a perfectly scattering terrain, this ratio should have the value unity.¹² For a perfectly specular terrain, its value should be infinite, i.e., the variance should be zero.¹¹

1.5d Minimum time interval for independent samples -- The normalized auto-correlation function of the AC component of $p_d(t)$ is given by

$$\rho_d(\Delta t) = (1/\sigma_d^2) \left\{ \lim_{H \rightarrow \infty} (1/2H) \int_{-H}^H p_d(t) p_d(t + \Delta t) dt - \bar{p}_d^2 \right\}.$$

¹⁰ See Sec. 2.1.

¹¹ See Sec. 2.2.

¹² See Sec. 2.1.

It is the linear correlation coefficient between values of the AC component, $p_d(t) - \bar{p}_d$, of $p_d(t)$ separated by the time interval Δt , and, therefore, it has the value unity when Δt is zero. As Δt increases, the correlation between values of $p_d(t) - \bar{p}_d$ so separated will decrease. When the separation is sufficient, the correlation becomes small enough to say that such values of $p_d(t) - \bar{p}_d$ are independent. Herein, we have defined the minimum time interval t_i needed before independence is reached as the value of Δt such that $\rho(\Delta t)$ is less than 0.25 for all greater values. Thus, the equations

$$\rho(t_i) = 0.25$$

and

$$\rho(\Delta t) < 0.25, \text{ for } \Delta t > t_i$$

define t_i .¹³ It is true that the separation t_i does not provide strict independence of the values of $p_d(t) - \bar{p}_d$, but, for practical purposes, they can be assumed independent.

The Fourier transform of $p_d(t)$ is the variance spectrum of $p_d(t)$. The spread of the variance spectrum is a result of the spreading of the returned RF spectrum by the Doppler effect.¹⁴ For horizontal flight, it can be shown¹⁴ that the maximum possible frequency in the variance spectrum of $p_d(t)$ is $4f_o(v/c) \sin \theta_o$, where f_o is the transmitted RF carrier, v the ground speed of the aircraft, c the velocity of propagation, and θ_o the outer angle that bounds the annulus that reflects the return received at time position d in the pulse. Thus, from the sampling theorem,¹⁵ the minimum possible time between totally independent samples of $p_d(t) - \bar{p}_d$ is $1/[8f_o(v/c) \sin \theta_o]$. Now the time t_i that we have tabulated is not equal to this since it does not provide total independence and, also, since the actual maximum variance frequency is not usually equal to the maximum possible variance frequency. However, t_i should be approximately inversely proportional to f_o , v , and $\sin \theta_o$.¹⁶ For this reason we have tabulated the aircraft ground speed v in addition to f_o and θ_o ; the true speed should be within 20 percent of the tabulated value.

¹³ In a few cases it has been necessary to take $\rho(t_i) = 0.50$ as the criterion; such cases are designated by a double asterisk in Table I.

¹⁴ Peter D. Welch, "Progress Report on Interpretation and Prediction of Radar Terrain Return Fading Spectra," AER 14-W, Physical Science Laboratory, New Mexico College of Agriculture and Mechanic Arts, May 1955; p. 9.

¹⁵ Julius S. Bendat, Principles and Applications of Random Noise Theory, John Wiley and Sons, Inc., New York (1958); p. 55.

¹⁶ The dependence of t_i on frequency f_o can be seen in Table I. The value of t_i averaged over all entries of 415 Mcps is 42 msec while the value averaged over all 3800 Mcps entries is 2.2 msec.

Note that our data relative to the time between independent samples apply only to horizontal flight. We have no information on the time between independent samples for vertical descent.

1.6 Terrain: Categories and Descriptions

The 31 specific terrains over which data were taken are described below under the Specific Terrain numbers used in Table I. They are grouped into the categories that are listed as Types A, B, etc., in Table I. The lower-case letter "a" represents a second trip to the location in a different season of the year. In those cases where the first trip did not yield useful data, it is not reported here.

Many of these terrains are described in greater detail in certain Technical Memoranda of Sandia Corporation (designated SCTM). Such references are given here with the description of the terrain. These memoranda contain both aerial photographs and photographs taken on the ground to aid in describing the various terrains.

It is difficult to fly twice over exactly the same piece of terrain. Thus, on making runs at different altitudes, or at a later time over what purports to be the same terrain, it is rare that the returns do come from precisely the same piece of ground.

The categories and terrain descriptions are:

Type A. Water, smooth

No. 7a Elephant Butte Reservoir. Located in south-central New Mexico near Truth or Consequences. Reservoir about 1 mile wide and 7 miles long. Water relatively calm during data runs; only a few occasional ripples. Runs made in January but seasonal changes are very minor. See SCTM 225-55-(54) by D. M. Gragg.

No. 11a Salton Sea. Located in southern desert region of California. Water surface very much larger than greatest area illuminated by antenna. Water quiet during time of runs. Very minor seasonal changes.

Type B. Water, ocean

No. 9 Pacific Ocean near Long Beach, California. Swells; little turbulence; a few whitecaps on the 3- to 5-foot waves; 7-mph wind inshore. Flight paths at right angle to wavefronts.

- No. 9a Pacific Ocean near Santa Ana Island, California. Conditions similar to those in No. 9. No effective seasonal change.

Type C. Water, frozen lakes

- No. 14 Lake Bemidji. Located in northern Minnesota. Lake frozen to a depth of 10 to 12 inches. Covered with approximately 10 inches of dry snow. Several cars and winter fisherman shacks dotted about the lake. Expanse of smooth, snow-covered ice well beyond area illuminated by antenna. See SCTM 163-55-(54) by D. M. Gragg.
- No. 18 A lake near Alexandria, Minnesota. Frozen, snow-covered, and relatively large. Not studied in great detail by ground visit.

Type D. Water, rippled

- No. 11 Salton Sea. On this first visit, lake was disturbed by light breeze giving ripples and small waves up to about a foot in height.
- No. 16 Caballo Reservoir. Located just south of Elephant Butte Reservoir. Light ripples due to breeze; no waves. Broader expanse of water than Elephant Butte Reservoir.
- No. 38 Lake Superior. Winter; heavy winds and high waves with whitecaps. No ice except in patches near shore; not included in area illuminated by antenna.
- No. 14a Lake Bemidji. Water lightly ruffled by winds; caused approximately one-foot waves. See SCTM 163-55-(54) by D. M. Gragg.

Type E. Farmland

- No. 2a Near Osborn, Missouri. Gently rolling farmland with heavy summer growth of deep grass. Lightly wooded in spots. Very little moisture present in soil. See SCTM 59-55-(54) by D. M. Gragg.
- No. 3a Near Cameron, Missouri. In same general region as No. 2a. Gently rolling farmland with heavy summer growth of deep grass with a single-line railroad track running along flight path. Little if any moisture along a creek bed running parallel to tracks. See SCTM 60-55-(54) by D. M. Gragg.

- No. 4a Near Sioux City, Iowa. Cultivated farmland, freshly plowed, crossed by roads and a wide and deep drainage ditch full of still water; a few trees along ditch; ten-strand power line at right angle to ditch near edge of illuminated area. Summer. See SCTM 64-55-(54) by D. M. Gragg.
- No. 13a Near Wahpeton, South Dakota. Completely cultivated farmland, freshly plowed. Illuminated area probably did not cover any roads; very homogeneous. A few shocks of dried vegetation in one section with stubble. Summer. See SCTM 62-55-(54) by R. K. Moore.
- No. 15a Near Bemidji, Minnesota. Freshly plowed farmland and a field of stubble; bordered on three sides by heavily wooded area; crossed by road; one farmhouse. Moisture present due to rains but not excessive. See SCTM 162-55-(54) by D. M. Gragg.
- No. 24 In the Imperial Valley of California. Cultivated and irrigated farmland covered with heavy growth of pasture grass and some grasslike crops. Irrigation regular enough to imply ground probably rather wet; ground visit not made for check.

Type F. Orchard

- No. 5 Near Las Cruces, New Mexico. Irrigated field and pecan orchard in heavy foliage split by paved highway. Trees were regularly spaced on 20-foot squares, 10 to 15 feet high. Ground showed through between trees and was heavily ridged by plowing. Recent irrigation had moistened field but not orchard area. Flight path parallel to highway. See SCTM 226-55-(54) by D. M. Gragg.
- No. 5a Same as No. 5 above but at later time in year. Seasonal changes practically nonexistent; orchard and field still in foliage. Moisture content very low on this second visit. See SCTM 226-55-(54) by D. M. Gragg.
- No. 10 Near El Toro, California. Regularly spaced trees on 20-foot squares; height about 25 feet; ground showed through between trees; moisture content relatively higher than New Mexico orchard but not excessive. See SCTM 258-55-(54) by D. M. Gragg.

Type G. Farmland, with snow

- No. 12 Near Magdalena, New Mexico. Lightly snow-covered rangeland with rather sparse growth of dried clumps of buffalo grass. Snow not deep; windswept into shallow drifts with ground visible in many places. Two windmills and water tanks at ends of flight path. See SCTM 254-55-(54) by D. M. Gragg.
- No. 13 Near Wahpeton, South Dakota. Wide expanse of snow of 8-inch depth ridged slightly by winds; broken only by protruding fence posts, a few farmhouses, telephone poles, and bare tree trunks. See SCTM 62-55-(54) by R. K. Moore.
- No. 15 Near Bemidji, Minnesota. Snow layer of 10-inch depth on field--a rather wide, unbroken expanse. Bordered by wooded area with snow on branches of evergreen trees. See SCTM 162-55-(54) by D. M. Gragg.
- No. 37 South of Presque Isle, Maine. Wide expanse of 24- to 30-inch snow, broken occasionally by bare trees and containing one or two small copses of pine trees. Snow surface followed general contours of gently rolling countryside; in layers, some of ice due to several snowfalls and thaws. Crust on top. See SCTM 9-56-(14) by D. M. Gragg.

Type H. Forest

- No. 20 Near Pine Island, Minnesota. Very homogeneous area of tall pines mixed with many deciduous trees. Ground did not show through at all. Countryside had variations of elevation of up to 50 feet, thus treetops were not all level; variations not apparent from the air. Surface of trees not broken by cultural objects of any sort over a very large area. See SCTM 218-54-(54) by R. K. Moore.

Type J. Forest, with snow

- No. 20a Near Pine Island, Minnesota. 12- to 18-inch layer of dry snow on the ground and as much on limbs of trees as they would naturally hold. No winds to remove snow. Ground showed through in a few isolated areas where deciduous trees had lost foliage. Surface had almost same appearance from the air as in summer except for the white haze added by snow. Very homogeneous. See SCTM 218-54-(54) by R. K. Moore.

- No. 35 South of Presque Isle, Maine. 24 to 60 inches of layered snow and ice on ground in wooded area with several patches of open ground showing through. Trees mostly pines with snow on branches; many bare deciduous trees having very little, if any, snow on limbs. Icy crust on snow at time of data runs. See SCTM 265-55-(54) by D. M. Gragg.

Type K. City, residential, with snow

- No. 22a Minneapolis, Minnesota. An area of large houses, apartments, schools with open playgrounds, many trees, and cleared paved roads covered by 6 to 12 inches of dry snow. Very homogeneous residential area. Roofs steeply pitched in most cases, although apartments and large buildings were flat-roofed; all roofs with snow. See SCTM 58-55-(54) by D. M. Gragg.

- No. 33 Presque Isle, Maine. 24 to 48 inches of layered ice and snow; rather small town with houses more widely separated than large city. Several flat-topped buildings in business section and cleared railroad tracks along side of town. Scattered but still homogeneous area. See SCTM 264-55-(54) by D. M. Gragg.

- No. 34 Superior, Wisconsin. 15 to 24 inches of dry snow in an area primarily residential. Streets cleared and snow off most roofs. One open park area of approximately 6 square blocks. See SCTM 267-55-(54) by D. M. Gragg.

Type L. City, residential

- No. 22 Minneapolis, Minnesota. Houses, schools with open playgrounds, flat-topped apartments, stores, churches, paved streets with street-car rails; all thickly interspersed with trees and a few parks. Summer growth of trees, lawns, and shrubs. See SCTM 58-55-(54) by D. M. Gragg.

- No. 32 Santa Ana, California. Large area thickly covered with houses of flat roofs and roofs of low pitch; paved streets; all centered around one large supermarket with a large paved parking area containing a few cars. See SCTM 8-56-(14) by D. M. Gragg.

Type M. City, commercial, with snow

- No. 21a St. Paul, Minnesota. 6 to 8 inches of dry snow on area containing many large, metal, pitched-roof industrial buildings. Service lots with pipes, machinery, cars, etc. Railroad yards included with several side tracks among industrial buildings. River wound through side of illuminated area and contained many ice floes. Streets had been cleared and snow had melted partly from roofs. See SCTM 57-55-(54) by D. M. Gragg.

Type N. City, commercial

- No. 1 Kansas City, Missouri. Winter; light patches of snow hardly evident. Runs made from downtown area along a boulevard to industrial section, railroad tracks, and river. Buildings tall and flat-topped downtown, metal in industrial area. Trees along boulevard covered the pavement, but many paved side streets showed. Some residences in area. Very few open areas or parks. See SCTM 61-55-(54) by D. M. Gragg.
- No. 21 Minneapolis and St. Paul, Minnesota. Industrial area with pitched-roof metal buildings, railroad yards, river, paved streets, and a few trees. Summer. See SCTM 57-55-(54) by D. M. Gragg.

Type P. Dry desert, some vegetation

- No. 17 West of Belen, New Mexico. Semiarid region covered with dry clumps of buffalo grass. Abandoned dirt runways almost regrown with native grass and weeds. Great deal of bare, sandy, rocky surface. See SCTM 266-55-(54) by D. M. Gragg.
- No. 6 Dry desert west of Albuquerque, New Mexico. Semiarid, flat area with scattered native grasses and sparse shrubs. Sandy, rocky soil with some areas of solid outcropping of sandstone. Very little moisture. See SCTM 164-55-(54) by D. M. Gragg.

Type R. Dry desert, bare

- No. 8 Near Salton Sea, California. Dry desert region; sandy, rocky, veined with arroyos; crossed by two-lane highway with three concrete bridges across deeper arroyos. Very dry. See SCTM 228-55-(54) by D. M. Gragg.

- No. 31 Near Salton Sea, California. Desert region; sandy, rocky, veined with arroyos; no cultural objects in illuminated area. Very dry.

Type S. Sand hills

- No. 30 North of Yucca Lake, Nevada. Wind-blown sand in deep ridges covering all other features to give pure sandy surface. Expanse wide enough to cover all of illuminated area in low-altitude runs; in high-altitude runs, illuminated area may have included a dry salt-lake bed to south. Slight moisture 5 to 6 inches below surface from recent rain. See SCTM 263-55-(54) by D. M. Gragg.

Type T. Salt flats

- No. 29 Yucca Lake, Nevada. Completely flat, dry, salt-lake bed. Sandy, salty surface with moisture evident in shallow depressions and below ground. Rocky patch with small metal machines and one car in center of area. Wide expanse of uniform surface. See SCTM 263-55-(54) by D. M. Gragg.

TABLE I

Probability Distributions of Returned Power Density
from the Near-Vertical for Various Ground and Water Surfaces

TABLE I

TABLE I																		
Type of Terrain	Specific Terrain	Transmitted Pulse Width, τ (μ sec)	Radar Frequency, f_o (Mcps)	Altitude above Terrain, h (meters)	Time Position in Return Pulse, d (μ sec)	Angular Limits, θ_1 and θ_2 (deg), calculated formally from Eqs. (1.3-3) and (1.3-4)	PROBABILITY DISTRIBUTION of $10 \log_{10} (P_d/10^{-12})$ (i.e., of returned power density in db above one μ watt/meter ² per watt transmitted isotropically)					Difference in db between First and Third Quartiles	$(\text{Mean})^2/(\text{Variance})$ $\bar{P}_d^2/\sigma_d^2$	Minimum Time Interval For Independent Samples, t_i (millisec)	Aircraft Ground Speed, v (meters/sec)	Code	Film or Run No.	
							95% above:	75% above:	50% above:	25% above:	5% above:							
A	7a	0.113	415	579	.170	9.8-16.7	43.9	45.1	45.8	46.3	47.3	1.2				Ic	16-10L	
				1067	.170	7.2-12.4	36.5	37.4	37.6	37.9	38.3	0.5					16- 8L	
				1067	.170	7.2-12.4	29.7	30.2	30.4	30.7	31.2	0.5					16- 7L	
					.353	14.7-17.7	39.9	41.6	42.0	42.5	43.0	0.6					↓	
					.555	19.7-21.9	30.1	32.0	33.1	34.0	35.1	2.0					16- 6L	
				2179	.170	5.1- 8.8	31.9	32.0	33.4	33.7	34.5	1.0					16- 4H	
		0.160	3800	1052	.120	0.0-10.5	36.8	37.5	38.2	38.7	39.1	1.2				IIIb	16- 4H	
					.225	7.8-14.3	36.7	37.4	38.1	38.7	39.2	1.3					16- 3H	
				1067	.120	0.0-10.5	35.8	36.5	37.1	37.8	38.4	1.3					16- 1H	
					.225	7.7-14.2	35.7	36.5	37.1	37.8	38.4	1.3					16- 2H	
				2164	.120	0.0- 7.3	34.4	35.1	35.3	35.4	35.6	0.3	140.58	.33	56		↓	
					.225	5.5-10.1	34.1	34.5	35.0	35.2	35.5	0.7	99.12	.39	56		16- 2H	
	11a	0.113	415	608	.18	10.3-16.8	32.8	40.3	43.9	46.8	50.5	6.5				Ic	37-27L	
					.24	14.1-19.2	35.0	42.0	45.4	47.9	51.2	5.9					↓	
					.36	19.5-23.3	29.5*	37.8	41.5	44.5	47.5	6.7					37-26L	
						25.0-27.9			38.2*	41.8	45.3						↓	
				1216	.18	7.3-11.9	27.6	33.6	37.4	40.5	43.4	6.9	1.26	97**	64		37-25XL	
					.38	14.5-17.2	22.4*	27.2	31.1	34.2	36.9	7.0	0.81	84	64		37-25L	
			0.200	3800		.61	19.5-21.5			25.8*	27.7*	31.1					IVb	37-20H
					2104	.131	2.9- 7.8	22.3	29.2	32.8	35.1	37.2	5.9					↓
					3601	.19	4.6- 7.2	17.0	23.0	26.7	29.9	33.8	6.9					37-19H
						.47	9.8-11.2	7.9*	15.7	20.0	23.1	26.6	7.4					37-18H
					615	.21	4.0-17.9		45.4	49.8	53.4	57.2	8.0					37-17H
						.29	11.9-20.9		45.9	51.1	54.4	58.1	8.5					↓
		0.200	3800		.40	17.5-24.3		40.1*	45.1	49.4	52.7	9.3*				Id		12-10LR
				1184	.23	5.0-13.7	29.9*	38.7	43.5	47.0	50.4	8.3					↓	
					.41	13.1-18.0		34.3*	39.6	43.4	46.6	9.1*					37-18H	
				2092	.22	3.1-10.2	23.7*	32.8	37.5	40.7	44.4	7.9	0.86	1.6	64		↓	
					.35	8.4-12.7	24.2*	32.5	37.0	39.8	43.7	7.3	1.03	0.98	64		↓	
					.62	13.9-16.8		25.6*	29.4*	34.3	38.9						37-17H	
9	0.113	415	664	.16	8.3-15.2	30.6	37.5	40.2	40.9	41.3	3.4				Id	12-10LR		
				.32	17.2-21.2	26.9	31.7	35.4	37.9	39.6	6.2					↓		
				.44	21.4-24.5	22.0	27.4	31.8	33.6	35.5	6.2					↓		
			671	.184	10.2-16.1	29.6	35.6	37.9	39.4	41.1	3.8					↓		
				.278	15.3-19.7	26.1	32.1	34.9	36.9	39.0	4.8					↓		
																↓		

B	9	0.113	415	671	.407	20.2-23.5 25.0-27.6	24.0 17.1	27.6 22.1	30.3 25.1	32.5 27.6	35.2 29.6	4.9 5.5				Id	12- 9L
				1286	.17 .30 .47 .70	6.6-11.3 11.8-14.9 16.2-18.5 20.6-22.4	23.9 22.0 17.8 9.2*	32.2 28.2 22.8 16.4	36.1 31.4 25.8 20.0	38.6 34.2 28.0 22.9	40.2 36.9 30.9 25.9	6.4 6.0 5.2 6.5					12-12LR
				1295	.184 .253 .424 .673	7.3-11.7 10.2-13.7 15.1-17.6 20.1-21.9 25.0-26.5	25.0 23.7 16.0*	30.2 28.7 22.5 15.4*	33.8 31.2 25.7 18.7 13.5*	37.1 34.0 28.4 21.7 16.5	40.3 37.8 31.2 25.5 19.9	6.9 5.3 5.9 6.3*	1.17 1.20 1.49	12 8.4 7.0	67 67 67 67		12-11L
				2210	.19 .39 .68 1.10	5.9- 9.2 11.0-13.0 15.7-17.1 20.4-21.5	19.9 15.9 10.0*	27.0 20.3 14.5*	30.1 23.5 17.4 13.4*	33.0 26.0 19.9 16.1	36.3 29.1 23.0 18.8	6.0 5.7 5.4*					12-13LR
				2216	.20 .39 .68	6.2- 9.4 11.0-13.0 15.6-17.0	18.4 7.6*	25.3 12.7*	28.8 15.9 12.2*	31.8 18.7 15.9	35.1 22.1 18.9	6.5 6.0*					12-14LR
				3795	.184 .510 1.015 1.750	4.3- 6.9 10.1-11.4 15.1-16.0 20.1-20.7	15.4 12.7* 5.9*	21.1 16.0 5.9*	24.6 19.1 10.0*	27.5 22.5 13.5*	30.9 22.5 17.0 13.5*	6.4 6.4* 7.6*	1.05 1.13 0.92	26 17 7.7	63 63 63		12-15L
				3804	.17 .55 1.06 1.79	3.8- 6.7 10.5-11.8 15.4-16.3 20.3-20.9	15.0 6.6*	19.9 12.2* 7.1*	23.2 15.9 10.5* 8.0*	26.4 17.7 13.4* 10.5*	30.2 20.6 17.0 13.0	6.5 5.5* 6.3*					12-16LR
	0.206	3800		643	.153	0.0-15.1	30.6	37.1	38.0	38.1	38.4	1.0				IIa	12- 8H
				646	.225 .288 .402	5.4-18.1 11.1-20.4 17.0-23.8	32.8 33.4 29.7	37.6 39.0 34.5	38.2 40.1 37.5	38.5 40.7 39.8	39.1 41.9 41.9	0.9 1.7 5.3					12- 7H
				1256	.162	0.0-11.2	20.0	24.0	27.3	30.0	32.8	6.0					12- 6H
				1273	.225 .424 .666	3.8-13.0 12.9-17.7 18.5-22.0	24.3 22.4 16.9	29.2 26.8 20.7	32.6 29.3 23.4	35.2 31.7 26.0	37.4 34.5 28.7	6.0 4.9 5.3					12- 5H
				2179	.225 .354 .635 1.05	2.9-10.1 8.2-12.5 13.8-16.6 19.0-21.2	17.3 16.8 11.2 10.7	23.8 22.5 17.7 14.1	28.3 26.0 20.8 16.2	31.8 29.2 23.4 18.5	34.8 32.8 26.3 21.9	8.0 6.7 5.7 4.4					12- 3H
				2195	.224	2.8-10.0	17.9	24.1	28.7	32.4	35.3	8.3					12- 4H
				3795	.225 .514 1.007	2.3- 7.6 8.9-11.4 14.2-15.9	25.7 21.1 14.2	30.9 24.2 16.8	33.7 26.9 16.8	35.7 28.9 18.8	37.7 31.4 21.5	4.8 4.7 4.6	2.46 2.01 1.64	1.5 1.8 1.2	65 65 65		12- 1H
				3801	.203	0.0- 7.2	26.4	30.8	34.4	36.4	38.3	5.6					12- 2H
	9a	0.200	3800	611	.179	0.0-16.7	34.9*	43.0	46.7	49.4	53.5	6.4				IVb	39-54H
				612	.22 .29 .40	5.7-18.4 11.9-21.0 17.6-24.4	29.7* 32.0*	40.5 42.4 36.0*	45.3 47.2 44.2	48.4 50.4 48.3	52.3 53.9 51.7	7.9 8.0 10.3*					39-55H
				1188	.23 .42	5.0-13.6 13.3-18.2	26.6*	37.0 29.2*	40.7 35.8	43.8 39.1	47.8 42.7	6.8 9.9*	0.93 0.85	3.1 1.7	64 64		39-57H

Footnotes:

* Obtained from an oscilloscope deflection of less than one millimeter; hence, value given is questionable.

** Value of t_i obtained from relation $p(t_i) = 0.50$;
other entries obtained from $p(t_i) = 0.25$.

TABLE I (continued)

Type of Terrain	Specific Terrain	Transmitted Pulse Width, τ (μ sec)	Radar Frequency, f_o (Mcps)	Altitude above Terrain, h (meters)	Time Position in Return Pulse, d (μ sec)	Angular Limits, θ_i and θ_o (deg), calculated formally from Eqs. (1.3-3) and (1.3-4)	PROBABILITY DISTRIBUTION of $10 \log_{10} (p_d/10^{-12})$ (i.e., of returned power density in db above one μ watt/meter ² per watt transmitted isotropically)					Difference in db between First and Third Quartiles	$(\text{Mean})^2 / (\text{Variance})$ $\bar{p}_d^2 / \sigma_d^2$	Minimum Time Interval For Independent Samples, t_1 (milli-sec)	Aircraft Ground Speed, v (meters/sec)	Code	Film or Run No.
							95% above:	75% above:	50% above:	25% above:	5% above:						
B	9a	0.200	3800	1190	.169	0.0-11.7	28.6	37.8	41.8	44.7	48.3	6.9				IVb	39-56H
				2114	.23 .35	3.7-10.3 8.3-12.6	19.4* 15.5*	30.0 26.6*	34.3 32.9	37.6 35.6	41.1 39.4	7.6 9.0*	0.89 0.80	2.5 1.7	64 64		39-58H
C	14	0.113	415	747	.0842	0.0-10.5	28.9	35.1	36.0	36.8	37.4	1.7				Ic	18-32L
				1341	.0842	0.0- 7.8	26.6	32.7	34.5	35.7	36.8	3.0					18-30L
		0.160	3800	732	.155 .260 .398	0.0-14.3 11.5-18.3 17.5-22.4	31.3 31.6* 21.1*	38.2 38.2 27.9*	41.0 41.0 31.1*	43.0 43.0 39.7*	44.6 44.8 36.7	4.8 4.8 6.4*				IIIb	18-33H
				2164	.155 .303 .593	0.0- 8.4 8.1-11.6 13.9-16.1	22.7 17.6*	30.4 26.2	33.8 29.6	35.5 31.9	37.6 34.9 15.0*	5.1 5.7					18-37H
				3231	.155 .420 .833	0.0- 6.9 8.9-11.2 14.1-15.7	19.2	27.3 11.0*	31.3 16.9*	33.9 20.0	36.4 24.1 14.0*	6.6 9.0*					18-39H
	18	0.113	415	1999	.186 .304 .562 .954	6.0- 9.6 9.7-12.1 14.7-16.4 19.8-21.0	25.6 22.6 10.5*	26.7 24.6 19.5*	27.5 25.9 16.1 10.8*	28.3 27.0 18.8 12.7*	29.4 28.8 21.6 14.4*	1.6 2.4 5.3*				Ic	31-19L
D	11	0.113	415	707	.184 .274 .405	9.9-15.7 14.8-19.1 19.7-22.9	29.4 29.0 24.9	38.3 39.9 29.2	40.7 36.2 31.8	42.9 38.5 33.5	44.6 40.7 37.0	4.6 4.6 4.3					13- 2L
				747	.16 .29 .44	7.8-14.3 15.1-19.1 20.2-23.2	28.1 26.9 21.6	36.4 33.9 26.9	40.3 36.9 30.4	42.4 39.4 33.1	44.9 41.4 36.5	6.0 6.1 6.2					13- 1LR
				1338	.184 .252 .421 .667	7.2-11.5 10.1-13.5 14.8-17.3 19.7-21.5	19.6 17.9	26.3 24.4 16.4*	29.8 26.6 19.7 10.9*	32.6 28.8 22.7 14.1*	35.5 31.6 25.7 17.9	6.3 4.4 6.3* 8.7*				Id	13- 3L
				1338	.17 .26 .43 .68	6.5-11.1 10.3-13.7 15.1-17.4 19.9-21.7	26.0 23.7 16.0	34.3 29.8 21.8 9.3*	38.3 35.7 25.6 14.4*	41.1 36.6 26.4 18.9	44.4 39.5 31.5 22.6	6.8 6.8 6.6 9.0*					13- 4LR
				2362	.16 .36 .68 1.13	4.5- 8.2 10.1-12.1 15.1-16.5 20.1-21.1	17.9 12.2*	23.2 19.1 9.5*	27.3 22.7 14.8* 10.9*	31.2 25.9 17.8 14.1*	35.7 28.6 20.8 16.5	8.0 6.2 8.3*					13- 5LR
				2365	.184 .348	5.5- 8.8 9.9-11.9	17.0* 14.9*	24.0 21.6	27.6 24.6	30.3 26.8	34.0 30.0	6.3 5.2	3.47 5.11	17 8.5	67 67		13- 6L

D	11	0.113	415	2365	.656 1.109	14.8-16.2 19.8-20.9		11.6* 5.5*	15.6* 9.9*	18.9 19.1*	22.8 16.8*	7.3* 7.6*	5.11	8.1	67 67	Id	13- 6L ↓	
				3877	.16 .51 1.03	3.5- 6.4 10.0-11.3 15.1-15.9	9.5*	18.3 9.2*	22.9 19.3*	26.8 16.2 19.4	30.8 19.4 19.2	8.5 7.0*				13- 8LR ↓		
				3886	.184 .498 1.008 1.757	4.2- 6.8 9.9-11.1 14.8-15.7 19.9-20.5		22.5	26.5 7.7*	28.6 19.5* 8.1*	31.5 19.9 19.7*	6.1				13- 7L ↓		
		0.206	3800	1317	.225 .273 .436 .683	3.8-12.8 7.0-14.1 13.0-17.7 18.5-21.9	21.6 26.4 26.9 17.8	30.9 34.9 31.5 22.2	35.8 38.0 35.0 24.8	38.8 40.1 37.7 27.4	40.6 41.7 40.3 30.5	7.9 5.8 6.2 5.2				IIa	13-13H ↓	
				1335	.23 .35 .52	4.2-12.9 10.2-15.8 15.0-19.1	24.0 25.4 18.7	30.7 31.5 29.6	35.4 35.6 27.6	39.6 38.9 31.1	43.6 42.3 34.8	8.9 7.4 7.5					13-14HR ↓	
				2271	.225 .361 .657	2.8- 9.8 8.2-12.4 13.8-16.6	15.6 11.4	22.3 17.9	25.5 21.4	30.5 24.4 8.8	33.9 28.0 11.8	8.2 6.5	0.87 0.88 1.17					13-11H ↓
				2274	.225	2.8- 9.8	20.2	26.9	31.0	34.6	37.8	7.7					13-12H ↓	
				3868	.225 .521 1.023 1.770	2.2- 7.6 8.9-11.5 14.3-16.0 19.6-20.8	18.9 15.1	24.2 20.5	27.2 29.1 15.2	30.1 25.8 18.8	34.2 29.2 22.3 20.2	5.9 5.3					13- 9H ↓	
				3889	.30 .60 1.12	4.9- 8.7 9.9-12.2 15.0-16.5	14.3 12.7* 10.0*	19.6 17.1 19.9*	23.7 20.2 16.5*	26.9 29.2 18.7*	30.6 27.5 21.4	7.3 6.1 4.8*					13-10HR ↓	
	16	0.113	415	488	.14	7.3-16.5	45.2	46.3	47.1	47.5	48.5	1.2				Ic	19- 5L ↓	
				1128	.14	4.9-11.0	35.4	36.1	36.6	37.1	37.8	1.0					19- 4L ↓	
				1128	.14	4.9-11.0	36.7	37.0	37.2	37.5	37.9	0.5					19- 3L ↓	
				2103	.14	3.6- 8.1	30.6	31.3	31.9	32.4	33.2	1.1					19- 2L ↓	
				2103	.14	3.6- 8.1	30.4	31.6	32.3	33.3	33.8	1.7					19- 1L ↓	
	38	0.113	415	1139	.21 .40 .62	9.1-13.3 15.5-18.2 20.4-22.4	32.5 28.5*	36.8 33.5 28.4*	39.9 36.2 32.5*	42.8 38.9 35.7	46.0 42.3 38.6	6.0 5.4 7.3*	1.16 1.32	19 7.3	65 65 65	Ic	50-20L ↓	
	14a		415	649	.191 .211 .334	10.8-16.7 12.1-17.5 17.9-21.8 25.0-27.7	37.4 38.4 36.8 30.1*	40.9 42.5 40.7 36.1	42.9 44.2 42.6 39.2	44.5 45.9 44.4 41.4	46.9 46.2 47.0 44.9	3.6 3.4 3.7 5.3					26-23L ↓	
				1185	.215 .336 .564	9.1-13.2 13.5-16.4 18.9-21.0	33.1 31.9 26.6*	36.0 36.4 29.8	37.8 38.5 32.9	39.3 40.3 34.7	42.2 43.3 37.8	3.3 3.9 4.9					26-19L ↓	
				2094	.219 .273 .548	7.0-10.1 8.6-11.2 14.1-15.8	27.7 26.8	30.1 30.1 22.2	31.7 32.0 25.6	33.3 33.8 27.9	35.8 36.6 31.2	3.2 3.7 5.7					26-17L ↓	
				3591	.231 .429	5.7- 8.0 9.2-10.8	22.7 16.8	24.5 21.1	25.6 23.4	26.9 25.2	28.8 28.0	2.4 4.1	4.56 1.59	22 13	67 67		26-13L ↓	
				3594	.256	6.2- 8.4	24.9	26.4	27.4	28.5	30.1	2.1					26-15L ↓	
				575	.235 .335	11.2-19.5 17.0-23.1	39.5 40.9	46.6 46.6	51.3 50.9	55.5 52.5	61.6 55.5	8.9 5.9					IIb	26-11H ↓
		0.160	3800	1407	.221	6.5-12.3	33.0*	38.2	41.3	44.1	47.7	5.9					26- 9H ↓	
				1411	.234 .417	7.2-12.7 13.2-16.7	31.9* 35.8	37.8 38.7	41.6 38.7	44.7 41.4	48.3 44.7	6.9 5.6	0.91 1.22	1.8 0.76	67 67		26- 7H ↓	
				2075	.257 .302 .572 .973	6.8-10.9 8.2-11.9 13.8-16.2 19.2-20.9	28.9 30.9 24.7*	36.8 37.2 30.8	40.6 40.2 39.8	44.0 44.1 36.6	48.4 47.9 40.2	7.2 6.9 5.8					26- 5H ↓	
				3478	.178	2.3- 7.1	23.5	29.2	32.5	35.0	38.6	5.8					26- 3H	

TABLE I (continued)

TABLE I (continued)																		
Type of Terrain	Specific Terrain	Transmitted Pulse Width, τ (μ sec)	Radar Frequency, f_o (Mcp2)	Altitude above Terrain, h (meters)	Time Position in Return Pulse, d (μ sec)	Angular Limits, θ_i and θ_o (deg), calculated formally from Eqs. (1.3-3) and (1.3-4)	PROBABILITY DISTRIBUTION of $10 \log_{10} (p_d/10^{-12})$ (i.e., of returned power density in db above one μ watt/meter ² per watt transmitted isotropically)					Difference in db between First and Third Quartiles	$(\text{Mean})^2 / (\text{Variance})$ T_d^2 / σ_d^2	Minimum Time Interval For Independent Samples, t_i (milli-sec)	Aircraft Ground Speed, v (meters/sec)	Code	Film or Run No.	
							95% above:	75% above:	50% above:	25% above:	5% above:							
D	14a	0.160	3800	3514	.239 .445 .905 1.38	4.7- 8.2 8.9-11.1 14.3-15.7 18.1-19.2	22.7* 19.2*	28.9 25.9*	32.4 29.1 19.9*	35.0 31.8 23.8* 20.2*	33.0 29.0 27.3 24.2*	6.1 5.9*			IIIb	26- 1H		
E	2a	0.113	415	560	.140 .185 .288 .395	6.9-15.5 11.0-17.4 16.9-21.5 21.2-24.8 25.0-28.0 30.0-32.3 35.0-36.9	30.4 30.6 31.6 31.1 23.0 24.9*	34.1 34.9 36.2 36.8 34.5 27.5*	37.1 37.4 38.6 39.5 37.6 29.9 26.5*	40.1 39.6 40.6 41.6 40.1 32.7 28.5	45.4 42.7 43.0 44.0 42.7 35.5 31.5	6.0 4.7 4.4 4.8 5.6 5.2*			Ic	25-37L		
				581	.185 .288 .395	11.0-17.4 16.9-21.5 21.2-24.8 25.0-28.0 30.0-32.3 35.0-36.9	30.6 31.6 31.1 23.0 24.9*	34.9 36.2 36.8 34.5 27.5*	37.4 38.6 39.5 37.6 29.9 26.5*	40.1 40.6 41.6 40.1 32.7 28.5	42.7 43.0 44.0 42.7 35.5 31.5	4.7 4.4 4.8 5.6 5.2*		25-35L				
				1379	.185 .293 .467	7.2-11.4 11.2-14.3 15.6-17.9	19.9 13.2 18.2*	25.2 24.2 21.3	27.5 27.1 24.0	29.2 29.2 26.2	31.5 31.4 29.2	4.0 5.0 4.9	1.94 1.88 1.53	120 20 11		74 74 74	25-39L	
				2129	.185 .365 .637 1.044	5.8- 9.2 10.7-12.9 15.3-16.9 20.2-21.3	8.1* 13.2 13.5* 16.8*	19.6 15.8 9.9*	23.2 13.2 13.5* 16.8*	25.4 23.1 17.4* 19.0*	28.4 26.6 21.3 21.9	5.8 7.3 7.5*				25-41L		
				3566	.185 .506 .974	4.5- 7.1 10.4-11.7 15.2-16.1		17.6 9.3 6.9*	21.2 13.8 9.0	23.9 17.3 11.9	26.6 21.1 15.1	6.3 8.0 4.4*				25-45L		
	0.160	3800	594	.238 .299 .401	11.3-19.3 15.0-21.6 19.5-24.7	31.6 33.4 36.3	40.6 40.0 36.3	44.3 43.6 38.8	46.6 45.6 41.2	49.6 48.0 44.3	6.0 5.6 4.9	1.33 1.62 1.32	2.3 1.2 0.54	67 67 67		IIIb	25-51H	
			2086	.238 .367 .642	6.1-10.5 9.9-13.0 14.9-17.0	19.8 13.7 21.9	25.8 24.5 21.9	28.9 27.7 24.4	31.5 30.0 27.0	35.4 33.1 30.3	5.7 5.5 5.1	0.99 1.27 1.40	1.8 0.92 0.59	76 76 76		25-49H		
			3523	.238 .508 .973 1.661	4.7- 8.1 9.8-11.8 14.9-16.2 20.0-20.9	18.5 17.8 13.0* 13.8*	23.3 20.4 15.9* 16.0*	26.9 20.4 13.4 16.0*	29.7 22.6 20.6 19.7*	32.7 25.3 23.3 21.0	6.4 4.8 5.3* 4.9*					25-47H		
			3a	0.113	415	606	.185 .293 .406	10.7-17.0 16.8-21.2 21.2-24.7 25.0-27.9 30.0-32.2	24.9* 30.7	31.9 22.8 36.5 34.9 26.9*	38.9 39.9 39.8 38.5 28.7	43.9 43.8 43.2 42.2 32.5	7.0 7.1 7.8				Ic	25-34L
						608	.140	6.6-14.8	25.1	30.7	35.4	39.9	47.3	9.2				25-36L
				1416	.185 .296	7.1-11.2 10.6-13.7	19.6 18.7*	26.1 25.8	29.4 29.0	32.4 31.7	36.4 35.0	6.3 5.9				25-38L		

E	3a	0.113	415	1416	.472	15.5-17.7	16.8*	21.7	25.5	28.4	31.9	6.7				Ic	25-38L
				2091	.185	5.8- 9.3		24.1	28.5	32.5	37.8	8.4					25-40L
					.363	10.8-12.9			25.7	29.3	32.9						25-42L
				2126	.140	3.6- 8.0	16.5	22.8	26.6	30.3	34.9	7.5					25-44L
		0.160	3800	3517	.185	4.5- 7.2	9.6	15.7	18.0	20.1	23.8	4.4				IIb	25-50H
					.502	10.4-11.7	9.6*	8.4*	11.9	15.1	18.7	6.7*					25-48H
					.972	15.3-16.2		6.4*	9.0*	12.2	15.6	5.8*					25-46H
					1.647	20.2-20.9		9.1*	11.2*	13.7	16.7	4.6*					
				661	.238	10.7-18.4	33.2	39.6	43.2	46.2	49.3	6.6					
					.306	14.5-20.7	34.9	40.9	43.6	46.1	49.8	5.8					
				2074	.238	6.1-10.5	22.8	27.8	30.8	33.6	36.8	5.8					
					.368	9.9-13.1	22.9	26.5	29.2	31.6	35.9	5.1					
					.639	14.9-17.1	16.9*	22.2	24.7	26.9	30.9	4.7					
					1.040	19.9-21.6		18.4*	21.0*	23.6	27.2	5.2*					
				3564	.238	4.7- 8.1	19.1	24.2	27.6	30.6	34.2	6.4					
					.513	9.8-11.8	16.9*	18.9	21.4	23.5	26.9	4.6					
					1.673	20.0-20.9		19.1*	15.2*	17.5	21.2	4.4*					
	4a	0.113	415	606	.140	6.6-14.9	18.6*	26.2	31.0	35.7	40.9	9.5				Ic	23- 6L
				621	.185	10.6-16.8	23.2	29.9	34.2	36.5	39.0	6.6					23- 7L
					.296	16.7-21.0	24.4	30.7	34.2	36.6	39.2	5.9					
					.411	21.1-24.5	25.9*	31.2	34.7	37.0	40.9	5.8					
						25.0-27.9	25.0*	30.5	33.4	36.2	39.2	5.7					
						30.0-32.2			25.7*	28.7	32.9						
				1177	.185	7.7-12.3	17.6	23.7	26.9	29.3	31.4	5.6	1.69	53	58		23- 5L
					.276	11.6-15.0		22.7	25.9	28.0	30.9	5.3	1.84	52	58		
					.420	15.8-18.3			23.9	25.7	28.3		1.44	35	58		
					.646	20.5-22.5			24.6	26.9	28.9						
						25.0-26.6		20.8	23.1	25.9	28.6	5.1					
				2136	.140	3.6- 8.0	11.4	15.9	19.0	22.1	26.3	6.2					23- 3L
				2136	.185	5.8- 9.2	13.0	18.7	22.4	25.1	28.1	6.4	1.13	90	59		23- 4L
					.364	10.7-12.8		15.2	18.4	20.9	23.9	5.7	1.27	88	59		
					.645	15.4-16.9			19.8*	16.1*	19.5				59		
						25.0-25.8											
				3635	.140	2.7- 6.1	5.1	10.1	13.5	17.0	22.4	6.9					23- 1L
				3640	.140	2.7- 6.1	6.5	12.1	14.7	17.0	22.3	4.9					23- 2L
		0.160	3800	573	.238	11.5-19.7	28.1	32.3	36.1	39.0	41.8	6.7				IIb	23-13H
					.296	15.1-21.8	28.2	33.0	36.4	38.9	42.9	5.9					23-12H
					.396	19.6-25.0	27.6*	31.6	34.1	36.4	39.8	4.8					23-11H
				620	.193	7.2-17.2	27.4	33.0	36.7	39.6	42.7	6.6					
				1211	.238	8.0-13.7	16.4*	23.4	26.6	29.6	33.0	6.2					
					.438	14.8-18.5	12.6*	19.5	23.8	26.4	29.6	6.9					
					.663	19.7-22.5	9.9*	14.5*	19.9*	23.7	27.4	9.2*					
				2081	.193	4.0- 9.5	13.6	18.1	21.6	24.6	28.5	6.5					23- 9H
				2098	.238	6.0-10.5		21.4	26.0	29.3	32.0	7.9	1.18	20**	69		23-10H
					.369	9.8-13.0			19.1	21.6	24.5		0.89	0.90	69		
					.641	14.8-17.0				22.0					69		
				3612	.238	4.6- 8.1	8.7	14.9	18.3	21.6	26.7	6.7					23- 8H
					.516	9.8-11.7	4.7*	9.8	13.9	15.9	19.3	6.1					
					.991	14.9-16.1		7.1*	9.2	11.6	15.0	4.5*					
					1.698	19.9-20.9		8.9*	12.4	12.1	15.0	3.2*					
	13a	0.113	415	576	.181	10.7-17.2	31.7	35.1	37.1	39.2	41.9	4.1				Ic	31-17L
					.344	19.4-23.4	32.4	36.2	38.2	39.8	41.8	3.6					28- 1L
						25.0-28.1	30.2	34.0	36.6	38.9	41.7	4.9					
				594	.171	9.7-16.5	30.3	36.1	39.8	43.1	45.6	7.0					
					.198	11.7-17.7	31.4	37.6	41.6	44.8	47.3	7.2				IIb	
					.309	17.7-21.9	31.9	36.9	39.8	42.9	44.9	5.1					
						25.0-28.0	28.9	34.0	36.8	38.8	40.9	4.8				Ic	

TABLE I (continued)

Type of Terrain	Specific Terrain	Transmitted Pulse Width, τ (μ sec)	Radar Frequency, f_0 (Mcps)	Altitude above Terrain, h (meters)	Time Position in Return Pulse, d (μ sec)	Angular Limits, θ_i and θ_o (deg), calculated formally from Eqs. (1.3-3) and (1.3-4)	PROBABILITY DISTRIBUTION of $10 \log_{10} (P_d/10^{-12})$ (i.e., of returned power density in db above one μ Watt/meter ² per watt transmitted isotropically)					Difference in db between First and Third Quartiles	$(\text{Mean})^2 / (\text{Variance})$ $\bar{P}_d^2 / \sigma_d^2$	Minimum Time Interval For Independent Samples, t_i (millisec)	Aircraft Ground Speed, v (meters/sec)	Code	Film or Run No.
							95% above:	75% above:	50% above:	25% above:	5% above:						
E	13a	0.113	415	594		30.0-32.3		26.4	28.1	30.1	33.9	3.7				Ic	28- 1L
				1146	.204	8.8-13.1	23.3	27.0	29.4	31.9	35.2	4.9					31-18L
					.366	14.6-17.4	24.0	27.4	29.7	32.0	34.8	4.6					↓
					.584	19.6-21.7		24.9*	26.4	27.9	30.1	3.6*					28-13La
				1202	.166	6.6-11.6	17.4	25.3	29.1	32.0	37.3	6.7					28-13Lb
				1202	.166	6.6-11.6	28.2	32.4	34.5	36.3	38.1	3.9					28-14La
				1214	.194	8.1-12.4	17.5	23.9	27.6	30.6	33.7	6.7					↓
					.342	13.5-16.4	19.8*	24.7	27.4	30.2	33.1	5.5					28-14Lb
					.572	18.9-20.9		18.4	23.2	26.4	29.3	8.0					↓
				1214	.194	8.1-12.4	24.5	29.5	31.4	33.2	35.6	3.7					28-2La
					.342	13.5-16.4	25.1	29.5	31.5	32.9	34.5	3.4					28-2Lb
					.572	18.9-20.9		18.4	23.2	26.4	29.3	8.0					28-12L
				1227	.198	8.3-12.5	24.8	29.1	31.6	33.1	35.2	4.0					↓
				1227	.198	8.3-12.5	28.9	32.8	34.5	36.4	39.4	3.6					28-11L
				2107	.193	6.1- 9.5	18.3	23.3	26.2	28.9	32.0	5.6					↓
					.272	8.6-11.2	17.8	23.4	26.5	29.1	32.1	5.7					28-10L
					.552	14.1-15.8		9.0*	15.1*	20.0	24.9	11.0*					↓
				3604	.216	5.3- 7.6		21.1	23.7	26.1	29.1	5.0					28- 7H
					.429	9.3-10.7	7.7*	16.9	19.5	21.8	24.2	5.5					↓
		0.160	3800	3630	.168	3.9- 6.7	11.5	20.0	22.5	24.7	27.3	4.7					28- 6H
				567	.223	10.4-19.2	29.7	35.9	40.0	43.7	49.0	7.8					↓
					.330	16.9-23.1	32.5	38.1	41.5	44.7	48.9	6.6					28- 5H
				1197	.219	6.9-13.3	22.4	28.6	32.1	35.5	39.5	6.9					↓
					.368	12.9-17.1	22.8	28.9	31.1	33.7	37.9	5.4					28- 4H
					.593	18.5-21.4	16.8*	22.2*	25.6	28.1	31.6	5.9*					↓
				1207	.158	0.0-11.3	22.5	29.4	33.0	35.9	40.4	6.5					28- 3H
				2088	.217	5.2-10.1	18.5*	24.4	28.0	30.8	33.7	7.6	1.19	1.4	84		↓
					.303	8.2-11.8	18.9*	23.6	27.9	30.0	32.9	6.4	1.25	1.1	84		28- 8H
					.574	13.8-16.2		18.5*	21.5	24.4	27.9	5.9*	1.12	0.49	84		↓
				2125	.160	0.0- 8.6		23.8	27.2	29.7	33.0	5.9					26-24L
	15a	0.113	415	3631	.211	3.7- 7.6	13.7	20.2	24.3	27.8	32.7	7.6				Ic	↓
					.456	8.9-11.0	11.6*	16.0	18.8	21.5	24.5	5.5					↓
					.942	14.3-15.7		11.5*	14.4*	16.7	20.1	5.2*					↓
				1.640		19.5-20.5			19.0*	14.0*	16.7						↓
				625	.182	10.4-16.6	26.0	32.2	35.8	38.5	40.7	6.3					↓
					.206	12.0-17.6	26.9	33.6	37.4	40.1	42.2	6.5					↓
					.323	17.8-21.8	28.1*	33.0	36.4	39.3	41.9	6.3					↓
						25.0-27.9		33.9*	36.8	39.3	42.3	5.4*					26-22L
				1176	.193	8.1-12.6	15.3	23.3	26.5	29.3	35.9	6.0					

E	15a	0.113	415	1178	.230 .334 .560	9.8-13.7 13.4-16.4 18.9-21.0	18.1 19.0 16.4	25.0 25.7 21.4	29.3 29.5 25.0	33.3 32.8 31.4	39.8 36.4 31.4	8.3 7.1 6.7				Ic	26-20L
				2107	.245 .275 .550 .954	7.8-10.6 8.7-11.2 14.1-15.8 19.3-20.5	15.8 16.8 12.9*	21.2 21.9 16.7 13.8*	23.8 24.6 19.3 16.3	26.3 27.0 22.0 18.7	29.6 30.3 24.6 20.9	5.1 5.1 5.3 4.3*					26-18L
				3608	.263	6.4-8.4	6.7	12.9	16.3	18.8	21.7	5.9					26-16L
				3621	.225 .429	5.5-7.8 9.2-10.7	5.3 9.4	13.1 9.4	16.2 13.7	18.6 16.2	22.1 19.5	5.5 6.8	0.67 0.66	170 150	88 88		26-14L
				572	.243 .332	11.8-19.9 16.9-23.1	30.4* 32.4*	35.7 37.6	38.5 39.9	40.8 42.2	43.5 45.0	5.1 4.6					26-12H
	24	0.160	3800	1393	.224 .414 .680	6.7-12.5 13.2-16.8 18.7-21.3	17.9* 23.6* 21.9*	25.3 27.5 24.5*	29.2 27.5 26.6*	32.2 30.6 26.6*	35.7 33.8 29.9	6.9 7.0* 4.7*	0.91 1.06 0.92	2.8 0.59 0.22	76 76 76	IIb	26-8H
				1401	.240	7.5-12.9	16.7*	21.6	24.9	28.1	31.4	6.5					26-10H
				2069	.226 .300 .568 .969	5.6-10.3 8.1-11.8 13.8-16.2 19.1-20.9	16.3* 16.9* 15.2*	22.1 21.7 17.3*	24.7 24.2 20.3	27.1 26.7 23.0	30.7 30.2 25.4	5.0 5.0 5.7*					26-6H
				3483	.211	3.8-7.7		12.9*	16.2	19.2	22.3	6.3*					26-4Ha
				3483	.211	3.8-7.7	10.7*	15.7	19.0	21.2	24.2	5.5					26-4Hb
				3493	.196 .443 .904	3.1-7.4 8.9-11.1 14.3-15.7	9.7* 12.1* 11.9*	13.7 14.6* 14.0*	17.2 16.9 15.1*	20.1 19.8 18.0	22.7 19.8 18.0	6.4 4.8* 3.2*					26-2H
		0.113	415	552	.18 .33	10.8-17.5 19.2-23.4 25.0-28.2	35.9 35.3 31.8	40.3 39.0 37.5	41.4 41.5 40.2	42.6 43.0 42.2	44.2 44.6 44.6	2.3 4.0 4.7					37-29La
				552	.18 .33	10.8-17.5 19.2-23.4 25.0-28.2	41.2 37.8 31.8	42.7 40.2 37.5	44.0 41.9 40.2	45.8 44.1 42.2	48.2 46.2 44.6	3.1 3.9 4.7					37-29Lb
				1182	.19 .38 .60	8.0-12.4 14.7-17.4 19.6-21.7	31.3 25.0 14.9*	34.0 29.8 26.4*	36.0 32.5 28.4*	37.7 34.4 24.9	39.6 36.5 28.7	3.7 4.6 10.6*	3.26 2.82	180** 160	64 64 64		37-30L
				2076	.19 .31 .58 .98	6.0-9.4 9.6-12.0 14.7-16.3 19.8-20.9	27.6 24.4 8.9*	30.2 27.8 8.9*	31.6 29.5 13.0*	32.9 30.7 17.6	34.4 32.2 13.5*	2.7 2.9 8.7*	5.75 2.79	160 59*	64 64 64		37-31L
				3575	.20 .46	4.9-7.4 9.7-11.2	24.1 11.3	26.5 15.7	28.0 17.9	29.2 19.6	31.0 21.2	2.7 3.9					37-32L
		0.200	3800	567	.191	0.0-17.8	26.6	34.7	38.8	41.8	45.5	7.1					37-44H
				614	.24 .29 .40	8.0-19.2 11.9-21.0 17.6-24.4	29.4 30.2 29.0	35.6 36.6 34.8	39.6 40.5 38.0	43.0 43.8 40.7	47.0 47.0 43.5	7.4 7.2 5.9					37-43Ha
				614	.24 .29 .40	8.0-19.2 11.9-21.0 17.6-24.4	33.5 33.5 29.0	40.6 40.9 34.8	43.8 44.1 38.0	46.3 46.5 40.7	49.5 49.4 43.5	5.7 5.6 5.9					37-43Hb
				1142	.21 .40 .62	2.9-13.3 13.0-18.2 18.6-22.4	15.6* 22.0* 22.5*	24.3 27.1 27.2*	29.6 27.1 27.2*	32.5 30.7 32.2	35.7 34.2 32.2	8.2 8.7*	1.16 0.81	6.4 1.0	64 64 64		37-42H
				2043	.23 .35 .61	3.8-10.5 8.5-12.9 13.9-16.8	9.4* 10.3* 7.6*	21.7 20.4 14.2*	26.3 25.9 20.4	29.3 28.8 25.6	33.0 31.9 29.6	7.6 8.4 11.4*	1.01 1.10 0.78	2.0** 1.3 0.86	64 64 64		37-41H
				1018	.162 .200 .329 .521	6.9-12.4 9.1-13.7 14.3-17.5 19.4-21.8	4.1 4.9 1.1	13.3 14.4 8.0 3.4	17.7 18.9 11.2 7.2	21.3 22.5 14.0 10.7	25.7 26.7 17.6 14.8	8.0 8.1 6.0 7.3					9-10L

TABLE I (continued)

Type of Terrain	Specific Terrain	Transmitted Pulse Width, τ (μ sec)	Radar Frequency, f_o (Mcps)	Altitude above Terrain, h (meters)	Time Position in Return Pulse, d (μ sec)	Angular Limits, θ_i and θ_o (deg), calculated formally from Eqs. (1.3-3) and (1.3-4)	PROBABILITY DISTRIBUTION of $10 \log_{10} (p_d/10^{-12.2})$ (i.e., of returned power density in db above one μ watt/meter ² per watt transmitted isotropically)					Difference in db between First and Third Quartiles	$(\text{Mean})^2 / (\text{Variance})$ $\bar{P}_d^2 / \sigma_d^2$	Minimum Time Interval For Independent Samples, t_i (millisec)	Aircraft Ground Speed, v (meters/sec)	Code	Film or Run No.
							95% above:	75% above:	50% above:	25% above:	5% above:						
T	5	0.113	415	1018		25.0-26.7		9.2	3.0	6.0	9.6	9.2				Id	9-10L
						30.0-31.4			-4.9	1.1	5.7						9- 9L
					.225	8.2-11.5	7.2	13.1	16.3	19.1	29.6	6.0					
					.300	10.5-13.3	1.6	8.4	11.6	14.4	17.7	6.0					
				2505	.509	15.2-17.2		0.2	4.7	7.6	10.8	7.4					
					.819	20.1-21.5		1.4	2.7	5.7	10.1	7.1					
						25.0-26.1		1.1	4.7	6.7	10.7	5.6					9- 6L
					.162	4.4- 7.9	8.4*	12.9	18.7	20.9	23.3	8.0					
					.347	9.5-11.6		4.9	8.4	11.1	14.3	6.2					
					.675	14.7-16.0		2.6*	3.1*	6.5*	9.8*	9.1*					
					1.186	20.0-21.0		7.6*	11.6*	17.4	23.0	9.8*					
						25.0-25.8		1.4*	3.1*	6.5*	9.4*	7.9*					
		0.206	3800	927	.225	4.5-15.2		19.3	22.7	25.7	29.4	6.4				IIa	9-11H
					.242	6.2-15.8		19.2	22.8	25.4	29.0	6.2					
					.347	12.1-18.8		18.4	22.1	25.2	28.3	6.8					
					.517	17.8-22.7	19.9	18.5	21.2	24.3	27.7	5.8					
				1588	.225	3.4-11.7	9.9	15.3	18.9	21.5	26.4	6.2					9- 8H
					.297	7.5-13.4	10.1	14.5	17.1	19.9	23.0	5.4					
					.497	13.3-17.2	8.7	13.2	16.2	18.6	21.8	5.4					
					.797	18.7-21.6	9.0	13.4	16.6	18.7	21.9	5.3					
				2615	.228	2.9- 9.2	7.3	12.2	15.2	17.4	21.3	5.2					9- 7H
					.391	8.3-12.0	7.9	12.0	15.1	17.6	21.1	5.6					
					.740	14.0-16.4	3.2	10.1	13.9	15.4	18.1	5.3					
					1.241	19.3-21.0	5.2	9.4	12.7	15.6	18.2	6.2					
	5a	0.113	415	518	.184	11.5-18.3	26.8	32.8	37.1	40.5	43.3	7.7				Id	14- 7L
					.232	14.8-20.4	26.8	32.5	36.1	38.9	41.8	6.4					
					.325	19.6-23.9	23.3	28.6	31.2	33.7	35.8	5.1					
						25.0-28.4	21.6	26.2	28.7	30.7	32.8	4.5					
						35.0-37.1		19.1*	17.8	20.6	24.4	7.5*					
						45.0-46.3		5.8*	10.9*	13.1	17.1	7.3*					
				549	.184	11.2-17.8	30.5	35.7	40.7	43.3	45.6	6.6					14- 8L
					.184	7.6-12.3	13.2	22.1	25.3	28.1	31.1	6.0					14- 3L
					.376	14.6-17.4		15.1	18.7	21.9	25.1	6.8					
					.599	19.6-21.7		12.8*	16.9	20.0	23.3	7.2*					
				1181		25.0-26.6	9.1*	16.1	20.6	24.1	27.4	8.0*					14- 4L
					.184	7.6-12.3	18.7	25.2	28.3	31.2	34.7	6.0					14- 2L
					.184	5.6- 9.0		19.3	22.5	24.7	27.9	5.4					
					.155	4.3- 8.3			24.6	26.6	29.6		1.52	78**	63		14- 1L
					.329	9.9-12.0	12.5*	17.5	20.9	23.9		7.8*	0.96	87	63		

F	5a	0.113	415	2217	.614 1.034	14.7-16.2 19.7-20.8 25.0-25.8				10.6* 9.9*	15.9 15.0		0.36	2.3	63 63 63	Id	14- 1L
		0.206	3800	533	.225	5.9-19.9	22.3	31.4	35.3	37.7	39.2	6.3				IIa	14-10H
				549	.225	5.8-19.6	21.3	29.2	33.6	36.2	38.4	7.0					14- 9H
					.268	10.5-21.3	23.8	31.2	35.1	37.6	40.2	6.4					↓
					.365	16.6-24.6	24.9	29.5	32.9	36.3	39.8	6.8					14-12H
				1204	.225	4.0-13.4	18.5	24.4	27.8	30.7	34.0	6.3					14-11H
				1234	.225	3.9-13.2		22.4	25.6	28.3	30.9	5.9	1.57	6.5	67		↓
					.415	12.8-17.8	19.0	20.7	23.5	25.8	28.9	5.1	1.52	0.74	67		14-14H
					.645	18.3-22.0		17.9	22.9	24.5	27.3	6.6	1.60	0.19	67		14-13H
				2164	.225	2.9-10.1	11.3	18.3	22.1	25.2	29.4	6.9					↓
				2179	.225	2.9-10.0		16.8	20.6	23.2	27.5	6.4					12-23L
					.350	8.0-12.4		14.8	18.0	20.3	23.4	5.5					↓
					.630	13.7-16.6		12.1	15.0	17.8	21.2	5.7					12-24LR
					1.045	19.0-21.1		13.3	14.9	17.1	20.4	3.8					↓
	10	0.113	415	689	.184	10.0-15.9	18.4	25.6	28.5	30.9	33.4	5.3	5.26	35	63	Id	12-21L
					.268	14.7-19.1	17.8	23.4	26.9	28.9	31.6	5.5	5.60	18	63		↓
					.396	19.6-23.0	15.5*	20.6	23.4	25.6	29.1	5.0	5.39	9.8	63		12-22LR
						25.0-27.6	8.0*	17.6	20.1	22.7	27.1	5.1			63		↓
						30.0-32.0	5.1*	12.8*	17.0	20.1	23.8	7.3*			63		12-20LR
						40.0-41.2	2.6*	10.0*	14.9*	18.3	21.5	8.3*			63		↓
				704	.18	9.6-15.6	20.0	27.4	31.3	34.4	37.2	7.0					12-19L
					.28	15.1-17.5	18.5	24.7	28.3	30.9	34.5	6.2					↓
					.42	20.2-23.4	14.0*	19.1	23.0	25.9	29.1	6.8					12-18L
				1244	.184	7.5-12.0	13.5*	20.5	23.2	25.4	27.7	4.9					↓
					.248	10.3-13.8		18.1	21.4	24.1	27.2	6.0					12-17L
					.413	15.2-17.7		16.8	20.6	23.6	27.3	6.8					↓
					.652	20.1-22.0		16.0	19.9	22.9	25.6	6.9					15- 9L
						25.0-26.5		10.0*	14.9*	17.7	21.9	7.7*					↓
						30.0-31.1		11.7*	16.0	19.3	22.4	7.6*					15- 8L
						35.0-35.9		9.1*	13.6*	17.9							↓
				1317	.17	6.5-11.2	17.7	23.2	26.1	28.6	31.3	5.4					15- 2L
					.26	10.4-13.8	15.7	21.0	23.8	26.9	29.2	5.3					↓
					.43	15.2-17.6	8.8*	14.4	18.0	20.6	23.6	6.2					17- 9LR
					.68	20.1-21.9		8.7*	12.7	15.8	19.1	7.1*					↓
				2106	.17	5.1- 8.9	7.8*	13.7	17.5	20.7	24.6	7.0					↓
					.34	10.2-12.5	6.0*	11.3	14.3	16.8	20.8	5.5					15- 9L
					.61	15.0-16.6		8.5	12.9	15.6	19.3	7.1					↓
				2109	.184	5.7- 9.2		16.6	19.8	22.4	24.6	5.8	5.43	84	67		15- 8L
					.340	10.2-12.5		11.5*	14.8	17.3	19.5	5.8*	5.18	13	67		↓
					.617	15.1-16.7		3.7*	7.9*	11.1*	14.5	7.4*	3.19	3.4	67		15- 2L
					1.033	20.2-21.3		1.7*	5.5*	8.7*	12.3	7.0*			67		↓
				3621	.184	4.4- 7.1		15.3	17.4	19.5	22.4	4.2					17- 9LR
					.471	9.8-11.2		4.8*	9.5*	13.1	15.9	8.3*					↓
					.947	14.8-15.8			3.0*	6.9*	10.9*						↓
					1.643	19.9-20.6		0.8*	5.2*	8.2*	11.2*	7.4*					↓
				3658	.184	4.4- 7.0		11.3	14.2	16.1	18.3	4.8					↓
G	12	0.113	415	762	.184	9.6-15.2		28.3	31.6	34.0	36.4	5.7				Ic	15- 9L
					.284	14.7-18.7		27.0	30.8	33.0	36.0	6.0					↓
					.426	19.6-22.7		21.9	27.5	30.6	34.2	8.7					15- 8L
				777	.184	9.4-15.0		28.0	31.7	35.1	37.7	7.1					↓
				1661	.184	6.5-10.4		21.6	25.7	28.4	31.3	6.8					15- 2L
					.278	9.8-12.7		15.6*	21.6	25.6	29.2	10.0*					↓
					.492	14.8-16.8			12.2*	15.5*	20.8*						↓
					.804	19.7-21.2			12.5*	14.6*	17.8*						↓
	13	0.113	415	716	.114	1.2-12.4	36.8	39.8	41.2	41.9	43.0	2.1					↓

TABLE I (continued)

Type of Terrain	Specific Terrain	Transmitted Pulse Width, τ (μ sec)	Radar Frequency, f_o (Mcps)	Altitude above Terrain, h (meters)	Time Position in Return Pulse, d (μ sec)	Angular Limits, θ_i and θ_o (deg), calculated formally from Eqs. (1.3-3) and (1.3-4)	PROBABILITY DISTRIBUTION of $10 \log_{10} (P_d/10^{12})$ (i.e., of returned power density in db above one μ Watt/meter ² per watt transmitted isotropically)					Difference in db between First and Third Quartiles	$(\text{Mean})^2 / (\text{Variance})$ $\bar{P}_d^2 / \sigma_d^2$	Minimum Time Interval For Independent Samples, t_i (millisec)	Aircraft Ground Speed, v (meters/sec)	Code	Film or Run No.
							95% above:	75% above:	50% above:	25% above:	5% above:						
G	13	0.113	415	716	.230 .366	12.5-17.4 18.2-21.7	34.2 32.1	38.9 37.5	40.9 40.9	42.5 43.4	43.9 45.3	3.6 5.9				Ic	17-9LR
				1067	.170 .350 .552	7.2-12.4 14.5-17.6 19.5-21.9		19.0* 14.9*	24.0* 21.0* 21.8*	27.5* 26.1* 25.5*	30.6* 30.1* 32.9*	8.5* 11.2*					17-12L
				1128	.105 .180 .325 .541	0.0-9.6 7.6-12.4 13.4-16.5 17.4-21.1	19.0* 15.0* 15.7	25.7* 25.9* 22.9*	30.0* 29.5* 26.7*	32.5 32.4* 30.1*	35.1 34.9 33.5*	6.8* 7.1* 7.2*					17-11LR
				2149	.170 .327 .609 1.017	5.1-8.8 9.8-12.1 14.9-16.4 19.8-21.0			23.3* 20.0* 14.6* 15.7*	26.5 23.2* 18.1* 19.8*	29.6 26.4 21.0* 23.1*		1.13 1.03 1.27 0.94	35** 66 1.1 1.1	58 58 58 58		17-13L
				2164	.099 .285 .567 .984	0.0-6.7 8.8-11.3 14.2-15.8 19.4-20.6	14.7* 12.2*	20.0* 15.7* 14.3* 15.6*	23.9 19.2* 16.3* 18.2*	26.9 22.8* 18.1* 19.9*	29.6 26.7 21.2* 22.7*	6.9* 7.1* 3.8* 3.3*					17-14LR
				3581	.118 .463 .901 1.591	1.2-5.7 10.6-11.2 14.5-15.5 19.7-20.4	8.0*	13.5 5.6* 3.3*	17.2 9.3* 6.9*	20.1 11.7* 9.8*	22.8 14.6 12.2*	6.6 6.1* 6.5*					17-15LR
				3581	.170 .467 .937 1.625	4.0-6.8 9.8-11.2 14.8-15.8 19.9-20.6	6.9*	12.5* 5.4* 3.6*	16.0 8.8* 6.1*	18.7 12.0* 6.4*	21.4 16.1* 12.2*	6.2* 6.6* 4.8*					17-16L
		0.160	3800	732	.160 .303 .440	0.0-14.5 13.7-19.7 19.0-23.5	27.3 25.8 22.5*	31.3 30.7 29.1	34.5 33.9 31.9	36.3 35.6 34.5	37.8 37.9 37.2	5.0 4.9 5.4					17-24H
				732	.135 .263 .400	0.0-13.3 11.7-18.4 17.6-22.4	25.6 28.4 28.1	31.8 34.5 32.4	35.4 37.7 35.4	37.3 39.5 37.7	38.9 41.1 40.5	5.5 5.0 5.3					17-23HR
				1311	.143 .394 .640	0.0-10.3 13.1-16.9 18.6-21.3	21.3 20.8*	27.2 25.8 24.1	30.6 28.4 26.5	33.2 30.7 29.0	35.9 33.9 32.5	6.0 4.9 4.9					17-22HR
				2164	.167 .308 .590 1.008	1.8-8.7 8.2-11.7 13.8-16.1 19.2-20.8	18.3 16.6 16.5	23.3 22.5 20.2	25.8 25.1 22.8	27.8 27.2 25.9	29.4 29.2 27.7	4.5 4.7 5.1					17-20HR
				3581	.145	0.0-6.3	12.8	17.9	21.3	23.9	26.5	6.0					17-17HR

G	13	0.160	3800	3581	.452 .922 1.614	8.9-11.1 14.3-15.7 19.5-20.5	11.9	15.7 19.1 14.4*	18.5 15.7 16.5	20.9 18.1 18.5	23.9 21.7 20.6	5.2 5.0 4.1				IIIb	17-17HR ↓ 17-18H ↓		
				3597	.160 .492 .961 1.654	0.0- 6.6 9.5-11.5 14.6-15.9 19.7-20.7		17.5 12.1 6.8*	20.6 17.1 11.6*	23.3 20.2 15.9 15.7*	26.3 22.9 20.3 20.7	5.8 8.1 9.1*							
				15	0.113	415	716	.0842 .2121 .3521	0.0-10.7 11.5-16.7 17.7-21.4 25.0-27.5 30.0-31.9	9.9* 16.4*	25.5* 26.9* 25.9* 23.9* 18.4*	29.4 31.2 30.6* 29.9* 25.0*	33.0 34.6 33.9 33.8 28.5*	36.6 35.2 38.9 37.9 32.9*	7.5* 7.7* 8.6* 9.9* 10.1*			Ic	18-31L ↓ 18-29L ↓
							1356	.0842 .1821 .3592 .6171	0.0- 7.8 7.1-11.4 13.2-15.9 18.7-20.6		8.7* 15.2* 8.8*	15.6* 20.0* 16.8*	19.6 24.0 20.7* 15.1*	25.2 28.8 25.9 20.6*	10.9* 8.8* 11.9*				
		0.160	3800	701	.155 .255 .383	0.0-14.5 11.4-18.5 17.3-22.4		31.1 31.2	34.9 34.9 30.7*	37.5 37.7 34.4	40.6 40.5 37.6	6.4 6.5	1.24 1.26 0.81	1.8 1.1 0.53	54 54 54	IIIb	18-34H ↓ 18-36H ↓		
				1295	.155	0.0-10.8	17.7	24.5	28.3	31.1	33.9	6.6				Ic	52-57L ↓		
	37	0.113	415	2040	.121	2.0- 7.6	13.1*	16.9	20.0	23.1	27.6	6.2					IVb	51-41H ↓	
				0.200	3800	1998	.27 .41 .67 1.05	5.9-11.4 10.1-14.0 15.0-17.8 19.9-22.0	18.4 20.8 19.9 15.9*	23.3 24.9 24.2 22.5	26.2 28.1 26.7 25.2	28.6 31.2 29.7 27.9	32.1 34.4 33.3 29.9	5.3 6.3 5.5 4.8				51-45H ↓	
						2006	.23 .41 .67 1.06	3.8-10.5 10.1-14.0 15.0-17.7 20.0-22.1	16.8* 16.9* 10.9* 19.5*	22.8 22.4 20.0* 20.4*	25.8 25.4 23.4 24.3	28.9 28.1 26.2 27.8	32.1 31.5 28.9 27.8	6.1 5.7 6.2* 10.8*	0.94 1.14 1.00	67 67 67 67			
				H	20	0.113	415	560	.201 .296	12.3-18.4 17.6-22.1 25.0-28.1 30.0-32.5	17.0* 28.9 22.9* 18.4*	24.5 32.5 31.2 25.6	28.2 32.5 35.0 31.6	31.1 35.3 38.0 35.0	34.3 38.1 41.7 38.7	6.6 6.4 6.8 9.4			
	1109	.211 .356 .570	9.3-13.5 14.5-17.4 19.6-21.8 25.0-26.6 30.0-31.2					10.8* 14.5* 16.6* 17.2* 18.2*	15.1 18.1 20.2 22.3 21.0	17.8 20.9 22.9 24.3 23.1	20.4 23.5 24.3 26.1 24.6	24.4 26.6 27.9 29.4 27.0	5.3 5.4 4.1 3.8 3.6	1.09 1.32 1.86	13 9.5 5.5	47 47 47 47 47			
	1120	.173	7.3-12.2					10.9*	15.2	18.0	20.5	23.3	5.3						
	1188	.171	6.9-11.8						16.0	19.4	22.0	25.2	6.0						
	2080	.188 .314 .586 .986	6.0- 9.4 9.7-12.0 14.8-16.3 19.8-21.0					4.3* 6.6* 6.9* 12.1	9.1 10.5 11.2 14.8	11.9 13.1 13.7 14.8	13.5 15.2 15.6 16.7	16.4 18.0 18.1 19.6	4.4 4.7 4.4 4.6	1.73 2.00 2.02	22 14 8.5	38 38 38 38			
	2083	.211 .273 .548 .951	6.8- 9.9 8.7-11.3 14.1-15.8 19.4-20.6 25.0-26.0					1.1* 3.0* 2.0* 8.7* 6.4*	8.6 10.1 10.1 13.5 14.0	12.1 13.3 13.5 13.5 14.0	14.7 15.8 15.9 16.3 17.9	17.7 18.7 19.1 19.7 20.8	6.1 5.7 5.8 7.6* 11.5*	1.31 1.32 1.17 0.98	13 8.5 3.5 2.0	80 80 80 80 80			
	3605	.194	4.7- 7.3					.5	5.0	8.0	10.5	13.7	5.5						
3612	.144	2.9- 6.2	3.9*					2.8	6.4	9.0	12.5	6.2							
0.200	3800	496	.229 .350					7.6-20.7 16.9-25.3	24.1 28.0	29.5 33.3	33.0 36.6	35.9 39.4	42.0 44.0	6.4 6.1	0.53 0.98	0.86 0.54	49 49	IVb	30- 6H ↓
		517	.211 .278					9.8-19.5 14.8-22.2	24.0	29.6 31.4	32.9 34.6	35.6 37.2	38.9 40.1	6.0 5.8				IIIb	29-29H ↓
0.200	3800	1088	.145					0.0-15.8	22.3	28.1	31.8	34.6	38.0	6.5					29-30H ↓
			.241					6.1-14.6	17.0*	22.6	26.6	29.8	32.6	7.2	1.28	1.1	44	IVb	30- 5H

TABLE I (continued)

Type of Terrain	Specific Terrain	Transmitted Pulse Width, τ (μ sec)	Radar Frequency, f_0 (Mcps)	Altitude above Terrain, h (meters)	Time Position in Return Pulse, d (μ sec)	Angular Limits, θ_1 and θ_2 (deg), calculated formally from Eqs. (1.3-3) and (1.3-4)	PROBABILITY DISTRIBUTION of $10 \log_{10} (P_d/10^{-12})$ (i.e., of returned power density in db above one μ watt/meter ² per watt transmitted isotropically)					Difference in db between First and Third Quartiles	$(\sigma_{\text{mean}})^2 / (\sigma_d^2)$	Minimum Time Interval For Independent Samples, t_1 (millisec)	Aircraft Ground Speed, v (meters/sec)	Code	Film or Run No.
							95% above:	75% above:	50% above:	25% above:	5% above:						
H	20	0.200	3800	1088	.392	13.0-18.4		24.6	27.9	30.6	33.7	6.0	1.37	0.59	44	IVb	30- 5H
					.600	18.6-22.5	19.8	23.1	26.3	29.4	32.7	6.3	1.27	0.54	44		30- 4H
					.181	0.0-12.4	17.0*	21.5	25.4	28.4	31.9	6.9					30- 3H
					.173	0.0- 9.3	10.7*	15.4	18.8	21.6	25.2	6.2					30- 1H
J	20a	0.113	415	655	.21	11.9-17.4	20.4*	25.5	29.2	32.1	34.9	6.6				Ic	49- 7L
					.29	16.0-20.3	22.8*	28.0	31.3	34.1	37.3	6.1					49- 6L
					.41	20.6-23.9	23.2*	28.4	31.8	34.4	37.9	6.0					49- 5L
					.19	7.8-12.4	6.7*	12.5	16.1	19.3	23.7	6.8	0.68	15	58		49- 4L
				1242	.42	15.4-17.8	8.7*	14.3	17.6	20.5	24.8	6.2	0.70	6.4	58		49- 3H
					.66	20.3-22.1	6.8*	13.9	17.9	20.7	24.3	6.8			58		49- 2H
					.20	6.3- 9.5	5.5*	9.7	12.5	15.5	18.5	5.8	1.29	12	89		49- 1H
					.35	10.3-12.5	7.2*	11.4	14.1	16.7	19.9	5.3	1.39	5.9	89		49- 10H
					.54	13.8-15.4	4.0*	10.9	13.8	16.9	19.5	5.4	0.70	3.6	89		49- 9H
					1.05	20.1-21.2		9.7	14.3	16.7	19.5	7.0			89		49- 8H
				3665	.21	5.1- 7.5	1.3	3.0	5.9	8.6	11.8	5.6					49- 7H
					.45	9.5-10.9	0.4	4.0	6.9	9.2	12.9	5.2					49- 6H
					.83	13.7-14.7	0.7*	3.4	6.4	8.9	11.4	5.5					49- 5H
					.99	15.1-16.0	0.5*	3.2	6.0	8.2	11.4	5.0					49- 4H
	0.200	3800	1165	1165	.25	6.5-14.3	11.7*	19.7	22.5	24.8	28.4	5.1				IVb	49-10H
					.47	14.9-19.4	13.4*	20.4	23.9	25.9	28.3	5.5					49- 9H
					.69	19.8-23.3		18.5	22.1	24.4	27.3	5.9					49- 8H
					.26	5.3-10.9	9.4	14.3	17.7	20.2	23.4	5.9					49- 7H
	35	0.113	415	1178	.42	10.1-13.8	10.7	15.2	19.2	20.5	25.7	5.3				Ic	52-54L
					.47	11.1-14.6	9.9	15.0	17.9	20.2	25.2	5.2					52-56L
					.84	16.9-19.3	7.9*	12.3	15.7	18.2	21.7	5.9					52-58L
					1.10	19.9-21.9		10.9*	14.8	17.8	20.9	6.9*					52-59L
	0.200	3800	1165	1165	.22	2.3- 7.7	1.5*	6.7	9.8	12.4	15.1	5.7				IVb	52-54L
					.34	6.1- 9.6	2.9*	7.8	10.6	13.2	16.4	5.4					52-56L
					.80	12.6-14.5		4.4	8.0	10.6	14.0	6.2					52-58L
					1.05	14.9-16.5		4.7*	8.3	10.8	14.3	6.1*					52-59L
	0.200	3800	1165	1165	1.76	20.0-21.2		6.3	10.0	15.3	19.3	7.0					52-54L
					.22	9.4-13.4	19.6	24.0	27.1	30.2	34.6	6.2	0.82	14	58	Ic	52-56L
					.41	15.5-18.1	20.2	24.2	27.0	29.8	33.1	5.6	1.06	5.8	58		52-58L
					.63	20.2-22.2	19.6*	24.4	26.8	28.8	32.5	4.4			58		52-59L
	0.113	415	415	1178	.151	4.3- 8.5	14.0	18.0	20.8	23.5	27.5	5.5					52-54L
					.21	5.2- 7.6	6.1*	12.5	15.5	17.9	21.0	5.4					52-56L
					.49	10.2-11.6	5.7*	11.0	14.1	16.9	20.0	5.9					52-58L
					.96	15.1-16.0		9.5*	12.9	15.2	18.7	5.7*					52-59L

J	35	0.113	415	3549	1.65	20.1-20.8		10.0*	14.1	16.9	19.9	6.3*				Ic	52-59L
		0.200	3800	1141	.25	6.6-14.5	16.8*	24.0	27.2	29.9	33.1	5.9	1.02	0.81	72	IVb	51-47H
					.47	15.0-19.6	18.6*	24.6	27.6	30.1	33.4	5.5	1.34	0.54	72		↓
					.69	20.0-23.5		23.0*	26.6	29.2	32.0	6.3*			72		51-44H
				2107	.21	2.2-9.8	9.2*	18.3*	21.2	23.6	26.8	5.3*					↓
					.42	10.1-13.8		18.4*	22.0	24.9	27.0	5.9*					51-38H
					.60	13.5-16.4		15.6*	20.7	23.9	26.9	7.7*					↓
					1.10	20.0-21.9			19.5*	23.4*	26.2						46- 8H
				3888	.170	0.0- 6.6	4.3*	11.2	15.0	17.9	21.1	6.7					↓
																	46- 6H
K	22a	0.200	3800	1091	.26	7.3-15.1	27.1	33.6	37.5	40.7	44.8	7.1	0.90	3.1	58		↓
					.46	15.1-19.9	25.9	30.2	33.5	36.4	40.1	6.2			58		46- 4H
					.66	19.9-23.5	22.6*	27.0	30.1	32.7	35.7	5.7			58		↓
				2021	.23	3.8-10.5		24.1	27.6	30.2	33.4	6.1	1.20	2.9	58		46- 3H
					.41	10.1-13.9	17.4*	22.4	25.6	28.1	31.4	5.7	1.41	0.65	58		↓
					.67	14.9-17.7		17.9*	21.5*	24.5	26.2	6.6*	0.79	0.43	58		↓
					1.06	19.9-22.0			20.6*	23.5	27.1				58		46- 3H
				3508	.24	3.4- 8.2	11.2*	17.8	21.8	24.7	27.9	6.9					↓
					.55	9.9-12.3	9.0*	13.8*	16.9	19.8	23.0	6.0					46- 3H
					1.02	15.0-16.6		10.8*	14.4*	17.4*	20.5	6.6*					↓
					1.69	19.9-21.2			14.8*	17.6*	20.6						↓
				3534	.23	2.9- 8.0	12.2*	18.2	21.7	24.6	27.7	6.4					↓
					.56	10.0-12.3		14.6*	17.9	20.2	22.8	5.6*					↓
					1.03	15.0-16.6		10.9*	13.8*	16.9*	19.9	6.6*					↓
					1.71	20.0-21.2			14.1*	17.0*	20.1*						↓
	33	0.113	415	616	.167	9.3-16.1	9.4	16.0	20.0	23.7	27.9	7.7				Ic	52-53L
				1253	.169	6.7-11.4	13.5*	18.6	21.0	23.2	26.3	4.6					52-55L
				2137	.169	5.1- 8.8	16.3	21.9	25.9	28.6	31.9	6.7					52-58L
				3639	.163	3.7- 6.7	9.7	13.7	17.1	20.3	24.1	6.6					52-60L
		0.200	3800	2111	.25	4.8-10.7	17.4*	23.8	27.0	29.9	33.4	6.1	0.94	1.7	58	IVb	51-46H
					.42	10.1-13.8	17.9*	23.6	26.9	29.5	32.5	5.9	1.41	0.70	58		↓
					.60	13.5-16.4	12.7*	21.0	24.6	27.1	29.9	6.1	0.91	0.62	58		↓
					1.09	19.9-21.8		13.9*	20.9*	24.2	27.2	10.3*			58		↓
	34	0.113	415	1123	7.3	9.7-13.7	25.2	30.9	34.7	38.2	42.7	7.3	0.75	38	65	Ic	50-19L
					.39	15.4-18.1	24.6	29.1	31.9	34.5	37.8	5.4	1.41	9.8	65		↓
					.61	20.3-22.4	23.8*	27.9	30.8	33.5	36.9	5.6			65		50-21L
		0.200	3800	3559	.20	5.0- 7.4	11.0	16.4	20.0	23.1	26.4	6.7					↓
					.49	10.2-11.5	5.4*	11.9	14.9	16.9	20.9	5.6					50-18H
					.96	15.1-16.0		2.4*	9.9	12.5	15.7	10.1*					↓
L	22	0.113	415		1.65	20.1-20.8		9.0*	13.0	15.4	17.7	6.4*					50-17H
				1127	.26	7.2-14.8	23.0	29.2	32.6	35.8	39.6	6.6	0.96	1.6	65	IVb	↓
					.47	15.1-19.7	23.5	28.6	31.5	33.9	37.5	5.3	0.59	0.70	65		50-18H
					.68	20.0-23.5	19.5*	25.8	28.6	31.1	33.9	5.3			65		↓
				3579	.23	2.9- 7.9	10.7	17.9	21.6	24.4	27.9	6.5					50-17H
					.57	10.0-12.4	7.5*	13.5	16.8	19.9	22.1	5.8					↓
					1.04	15.0-16.6		6.7*	12.2	16.1	20.1	9.4*					↓
					1.73	20.0-21.2		8.9*	12.9*	15.2	18.7	6.3*					↓
				561	.193	11.7-18.0	26.0	32.3	35.4	38.0	41.4	5.7				Ic	32-31L
					.338	19.4-23.5	29.6	35.1	36.9	40.4	43.1	5.3					↓
						25.0-28.1	31.8*	35.5	38.4	41.0	43.9	5.5					32-29La
						30.0-32.4	30.7*	32.9*	35.2	37.6	40.5	4.7*					32-29Lb
				1129	.168	6.9-12.0	13.2	19.7	23.5	26.9	31.6	7.2					32-27L
				1129	.168	6.9-12.0	21.2	26.9	30.1	33.2	36.7	6.3	1.39	47	60		↓
				1146	.204	8.8-13.1	16.7	23.2	27.0	30.2	33.8	7.0	0.91	47	67		32-25L
					.366	14.6-17.4	17.4	24.9	27.4	29.7	32.4	5.4	1.44	36	67		↓
					.586	19.7-21.7	15.8*	23.9	23.7	26.3	28.9	6.0			67		↓
				2349	.206	6.2- 9.3	10.6	15.9	19.2	21.9	25.3	6.0	0.94	48	63		↓
					.336	9.6-11.7	10.6	15.6	18.7	21.2	24.1	5.6	1.26	18	63		↓

TABLE I (continued)

TABLE I (continued)																	
Type of Terrain	Specific Terrain	Transmitted Pulse Width, τ (μ sec)	Radar Frequency, f_0 (Mcps)	Altitude above Terrain, h (meters)	Time Position in Return Pulse, d (μ sec)	Angular Limits, θ_1 and θ_2 (deg), calculated formally from Eqs. (1.3-3) and (1.3-4)	PROBABILITY DISTRIBUTION of $10 \log_{10} (P_d/10^{-12})$ (i.e., of returned power density in db above one μ watt/meter ² per watt transmitted isotropically)					Difference in db between First and Third Quartiles	$(\text{Mean})^2 / (\sigma_d^2)$	Minimum Time Interval For Independent Samples, t_i (millisec)	Aircraft Ground Speed, v (meters/sec)	Code	Film or Run No.
							95% above:	75% above:	50% above:	25% above:	5% above:						
L	22	0.113	415	2349	.642 1.106	14.7-16.1 19.9-20.9	8.7*	12.0 12.5	14.5 14.9	16.6 17.5	19.2 20.4	4.6 5.0	1.05	5.2	63 63	Ic IVb 	

M	21a	0.200	3800	3504	.55 1.01 1.68	9.9-12.3 14.9-16.5 19.9-21.1	15.9 9.8*	20.8 15.0 12.8*	24.4 18.9 15.4*	27.4 21.0 18.2	30.5 24.1 21.1	6.6 6.0 5.4*				IVb	46- 1H
				3533	.24 .56 1.03 1.71	3.4- 8.2 10.0-12.3 15.0-16.6 20.0-21.2	13.9 8.8*	19.7 19.7 19.9* 10.6*	23.1 16.9 19.9* 15.1*	26.0 19.9 16.5 15.5*	29.9 22.1 19.6 19.4	6.3 5.6 5.9*					46- 2H
N	1	0.113	415	600	.185 .291 .401	10.8-17.1 16.8-21.2 21.1-24.6 25.0-28.0 30.0-32.3 35.0-36.9 40.0-41.4 44.0-45.2	25.5 29.4 31.1 22.9	33.3 35.2 35.7 36.5 30.3 23.0 23.4 25.2	37.8 38.5 38.6 39.4 34.9 28.4 27.7 27.9	41.2 41.5 41.5 42.0 37.4 32.1 31.3 30.7	44.9 45.6 45.9 45.8 40.5 36.4 36.1 34.7	7.9 6.3 5.8 5.5 7.1 9.1 7.9 5.5	0.94 0.80 0.88	28 13 9.0	80 80 80 80 80 80 80	Ic	24-25L
				.668 1195	.140 .185 .268 .423	6.3-14.2 7.7-12.2 11.2-14.6 15.7-18.3 25.0-26.6 30.0-31.2 33.0-34.0	23.6	30.7 27.3 27.1 20.2* 20.0* 21.0*	35.1 30.2 30.4 28.7 25.0 23.5 21.0*	38.7 33.4 32.9 31.6 29.1 27.0 24.4	42.5 38.1 36.7 34.6 33.6 31.2 28.7	8.0 6.1 5.8 8.9* 7.0*		64 62 19	80 80 80 80 80		24-26L 24-24L
		0.160	3800	2149	.140	3.5- 8.0	14.5	19.4	23.2	26.3	30.3	6.9					24-23L
				2178	.185 .368 .650	5.7- 9.1 10.7-12.8 15.4-16.8 18.0-19.2	11.5 10.5 6.9*	17.2 17.0 19.4 19.4*	20.4 19.9 16.4 17.0	23.5 22.4 19.0 19.7	27.7 25.2 22.0 22.6	6.3 5.4 5.6 6.3*					24-22L
		0.160	3800	3577	.140	2.7- 6.2	10.1	15.3	19.7	22.9	29.1	7.6					24-20L
				3579	.185 .512 .976	4.5- 7.1 10.4-11.7 15.2-16.1 18.0-18.7	9.8*	14.4 7.9* 19.4 11.6*	17.7 10.5 15.6 14.9	20.7 12.3 17.6 16.0	24.7 14.7 20.6 18.9	6.3 4.4* 4.2 4.4*					24-21L
		0.160	3800	635	.193	7.1-17.0	29.9	39.3	43.5	47.0	52.5	7.7					24-15H
				645	.238 .310 .428	10.8-18.6 14.9-21.1 19.7-24.6	30.4 31.9 31.1	37.9 36.3 36.0	41.8 41.9 39.5	44.8 44.7 42.3	49.0 48.3 45.0	6.9 6.4 6.3					24-14H
		0.160	3800	1166	.238 .426 .651	8.1-14.0 14.8-18.5 19.8-22.7	25.2 20.9*	33.3 28.1 23.7*	37.8 32.1 28.0*	41.2 35.4 31.5	45.3 39.1 35.4	7.9 7.3 7.8*					24-16H
				2102	.238 .369 .641	6.0-10.5 9.8-13.0 14.8-17.0		27.3 24.0	31.0 28.0	33.9 31.1	36.8 34.2	6.6 7.1	1.14 1.03	2.0 0.76	63 63 63		24-17H
		0.160	3800	2135	.193	3.9- 9.4	17.1*	27.7	31.7	34.6	37.9	6.9					24-18H
				3536	.238 .508 .978 1.668	4.7- 8.1 9.8-11.8 14.9-16.2 20.0-20.9	17.1* 10.0*	23.5 17.2* 9.9*	26.7 21.9 14.5* 14.1*	29.4 24.3 19.2* 17.4*	33.2 27.4 29.6 21.9*	5.9 7.1* 9.3*					24-19H
	21	0.113	415	522	.190 .320	11.9-18.5 19.3-23.7 25.0-28.4 30.0-32.7	26.8 31.7 34.0 31.9	33.3 37.5 37.7 35.1	36.6 40.3 41.3 37.7	39.8 42.5 43.6 40.1	43.9 46.1 46.3 43.0	6.5 5.0 5.9 5.0					32-30L
				1125	.165	6.7-11.9	15.9	21.8	26.1	29.7	33.8	7.9					32-28L
		0.113	415	1128	.213 .362 .576	9.3-13.5 14.6-17.4 19.6-21.7	15.7 18.7	22.9 25.2 24.3	26.3 27.8 27.3	29.8 30.8 29.5	34.3 34.0 32.4	6.9 5.6 5.2	0.71 0.92	36 21	51 51 51		32-26L
				2352	.209 .336	6.3- 9.3 9.6-11.7	8.3 9.9	14.6 15.9	18.2 18.7	20.9 21.3	24.4 24.3	6.3 6.0	0.98 1.34	37 24	57 57		32-24L

TABLE I (continued)

TABLE I (continued)																				
Type of Terrain	Specific Terrain	Transmitted Pulse Width, τ (μ sec)	Radar Frequency, f_o (Mcps)	Altitude above Terrain, h (meters)	Time Position in Return Pulse, d (μ sec)	Angular Limits, θ_i and θ_o (deg), calculated formally from Eqs. (1.3-3) and (1.3-4)	PROBABILITY DISTRIBUTION of $10 \log_{10} (P_d/10^{-12})$ (i.e., of returned power density in db above one μ watt/meter ² per watt transmitted isotropically)					Difference in db between First and Third Quartiles	$\frac{(\text{Mean})^2}{P_d^2 / \sigma_d^2}$	Minimum Time Interval For Independent Samples, t_i (millisec)	Aircraft Ground Speed, v (meters/sec)	Code	Film or Run No.			
							95% above:	75% above:	50% above:	25% above:	5% above:									
N	21	0.113	415	2352	.642	14.7-16.1	7.2 *	11.9 *	14.5	17.0	20.0	5.7*	1.42	7.1	57	Ic	32-24L			
					1.100	19.8-20.9						6.4*							32-20L	
				3506	.199	5.0- 7.4	5.2	11.0	14.3	17.1	20.4	6.1								
					.452	9.7-11.2	4.2	8.9	12.1	14.6	17.0	5.7								
					.922	14.9-15.8		4.9 *	7.3	9.8	12.7	5.5*								
					1.590	19.9-20.5		5.9 *	8.2*	10.4	12.9	5.1*								
				3510	.162	3.7- 6.7	6.9	12.7	16.5	19.4	22.8	6.7								32-22L
					.221	6.3-19.9	35.1*	40.4	43.8	46.5	49.5	6.1								32-32H
					.362	17.1-25.1	98.4*	49.4	46.2	48.5	51.4	5.1								32-34H
				0.200	3800	1114	.170	0.0-12.1	25.0*	30.9	34.4	37.1					40.6	6.2		
	1116	.227	4.9-14.0			24.7*	31.5	35.7	38.9	42.4	7.4	0.96	2.7	56	32-38Ha					
		.398	13.1-18.3			26.9*	31.3	35.0	38.0	41.9	6.7	1.23	0.84	56	32-38Hb					
		.612	18.6-22.5				27.6*	30.7	33.9	37.7	6.3			56						
	2034	.237	4.2-10.6			24.5	28.4	32.8	36.2	39.6	7.8	0.78	3.9	56						
		.350	8.5-12.9			22.4	28.9	33.2	36.2	39.2	7.3	1.26	2.5	56						
		.610	13.9-16.9			18.7*	22.9*	25.0	27.8	31.2	5.5*			56						
	2034	1.006	19.3-21.4				22.8*	24.7*	27.7					56						
		.237	4.2-10.6			19.8*	25.7	29.6	33.1	37.7	7.4	0.96	7.7	56						
		.350	8.5-12.9			20.4 *	26.7	30.4	33.5	37.2	6.8	1.49	16	56						
		.610	13.9-16.9			18.7*	22.9*	25.0	27.8	31.2	5.5*			56						
		1.006	19.3-21.4				22.8*	24.7*	27.7					56						
	3475	.233	3.1- 8.1			15.6*	22.1	26.3	29.6	33.1	7.5				32-42H					
		.494	9.1-11.7			14.4 *	17.6*	20.8	23.5	26.6	5.9*									
		.952	14.4-16.1				16.6*	18.5*	22.1											
	3476	.169	0.0- 6.9				21.8	25.9	29.5	33.2	7.7				32-40H					
	P	17	0.113	415	625	.0842	0.0-11.4	14.5	17.8	20.6	23.1	26.1	5.3				Ic	20- 6L		
.0842						0.0-11.4	12.9	19.1	21.6	23.3	25.6	4.2				20- 5L				
.0842						0.0- 8.2	15.9	21.6	24.5	26.4	29.1	4.8				20- 4L				
1219					.0842	0.0- 8.2	12.1	21.1	24.9	27.2	30.2	6.1				20- 3L				
					.14	3.6- 8.1	11.9	17.0	20.1	22.8	25.7	5.8				20- 1L				
																20- 2L				
2113					.0842	0.0- 6.2	10.1	16.4	19.7	22.3	25.3	5.9				20-11H				
					.155	0.0-15.8	26.0*	35.8	40.4	43.7	46.8	7.9				20-12H				
					.155	0.0-15.7	26.2*	34.1	38.2	41.6	45.0	7.5								
0.160		3800		597	.229	10.6-19.0	26.8*	34.2	38.4	41.9	45.5	7.7				IIb				
					.340	16.9-22.9	22.5*	30.0	33.1	37.1	40.9	7.1								
				1189	.155	0.0-11.2	20.1	27.4	31.8	35.1	38.6	7.7					20- 9H			
					.155	0.0-11.1	17.2*	26.9	31.0	34.4	37.8	7.5					20-10H			
					.215	6.6-13.0	18.7 *	28.0	31.9	35.9	38.9	7.3								
				1219	.369	12.9-16.9		22.4*	26.5	30.2	33.7	7.8*								

P	17	0.160	3800	1219	.600	18.5-21.4				22.9 *	27.0				IIIb	20-10H
				2082	.155 .295 .577 .977	0.0- 8.5 8.0-11.7 13.9-16.2 19.2-20.9	15.1 16.9	22.8 21.9 12.2	26.9 25.5 17.6	30.4 28.4 21.0 11.2	34.4 30.7 24.9 16.5	7.6 6.5 8.8			↓	20- 8H
6		0.206	3800	2141	.155	0.0- 8.4	14.6	23.0	26.7	29.5	32.7	6.5			↓	20- 7H
				630	.144 .225 .290 .409	0.0-14.8 5.5-18.3 11.4-20.7 17.5-24.3	21.5 21.1 21.1	27.6 26.8 26.6 23.4	31.6 30.6 29.7 26.6	34.9 33.8 32.7 29.2	38.4 36.9 36.1 32.6	7.3 7.0 6.1 5.8			↓	10- 1H
				649	.147 .225 .288 .405	0.0-14.7 5.4-18.1 11.1-20.4 17.0-23.9	20.9 21.9 20.8 20.5	27.2 27.6 28.5 25.3	31.6 31.5 31.5 28.4	35.4 34.8 34.9 30.4	38.7 38.2 37.5 33.9	8.2 7.2 5.8 5.1			↓	10- 2H
				1848	.155 .225 .317 .554 .904	0.0- 9.0 3.2-10.8 7.6-12.9 13.5-16.8 18.8-21.3	14.0 12.6	21.1 19.9 17.7	24.2 23.5 21.9 15.9 15.5	26.8 26.1 24.1 18.9 17.4	30.3 28.9 27.1 22.6 20.9	5.7 6.2 6.4			↓	10- 4H
				1864	.165 .225 .355 .639 1.056	0.0- 9.3 3.2-10.8 8.8-13.5 14.9-18.0 20.6-22.8	16.2 16.4	22.1 22.0 19.9 19.0	25.6 25.4 22.4 16.0 16.7	28.2 27.9 25.1 19.1 18.9	31.4 30.9 28.9 22.4 21.9	6.1 5.9 5.8 6.1			↓	10- 3H
				2612	.174 .225 .396 .735 1.234	0.0- 8.1 2.7- 9.2 8.4-12.1 13.9-16.4 19.2-21.0	11.0 10.8 7.6	16.3 15.6 12.7 6.9 7.0	19.8 19.0 15.6 10.8 9.5	22.6 21.7 18.1 19.8 10.5	25.6 24.6 21.4 16.9 15.7	6.3 6.1 5.4 7.5 3.5			↓	10- 5H
R	8	0.113	415	607	.184 .263 .380	10.6-17.0 15.4-20.1 20.2-23.9 25.0-27.9	20.4 21.9 19.2 8.4*	29.8 27.9 23.9 17.1	33.1 30.8 26.7 21.4	35.9 33.1 27.7 24.3	40.0 35.9 31.4 26.7	6.1 5.2 3.8 7.2			↓	11-15L
				613	.22 .31 .42	13.0-18.4 17.4-21.6 21.5-24.9	22.9 21.7 18.8	29.9 26.7 23.9	33.8 30.0 26.5	36.3 32.6 29.2	39.3 35.5 31.9	6.4 5.9 5.9			↓	11-16L
				1242	.15 .29 .45 .69	5.4-10.8 11.7-14.9 16.1-18.5 20.8-22.6	19.2 15.9 9.7*	26.0 20.9 14.1*	29.7 23.9 17.2 8.6*	32.9 26.4 19.7 11.7 *	37.0 30.0 22.8 14.3 *	6.9 6.1 5.6* 5.7*			↓	11-14LR
				1242	.207	8.6-12.7	18.0	24.1	27.5	30.5	33.7	6.4			↓	11-14L
				1311	.184 .255 .430 .682	7.3-11.6 10.3-13.7 15.2-17.6 20.1-21.9	17.4 10.5	24.0 20.9 14.1 10.9	27.1 24.2 16.9 12.7	29.5 26.5 18.7 14.7	32.4 29.2 22.5 17.4	5.5 5.6 4.6 3.8			↓	11-13L
				3825	.151	3.2- 6.2	3.8	10.9	15.3	18.8	22.4	7.9			↓	11-10L
				3840	.184 .511 1.019 1.752	4.3- 6.9 10.0-11.4 15.0-15.9 20.0-20.6	3.5	11.0	14.7 9.9 0.8 -0.4	17.9 6.0 3.5 2.1	21.7 10.2 6.7 5.8	6.9			↓	11- 9L
		0.206	3800	655	.24 .38 .49	7.1-18.6 15.9-23.1 20.1-25.9	22.3 20.5 16.9 *	26.7 25.2 19.0*	30.3 28.9 20.9	33.4 30.9 23.9	36.9 34.0 26.4	6.7 5.7 4.3*			↓	11- 8HR
				655	.196	0.0-16.9	17.9	26.4	30.3	34.6	38.5	8.2			↓	11- 8H
				686	.225 .296 .420	5.2-17.6 11.3-20.1 17.2-23.7	20.3 17.9	27.5 23.5 10.9	31.5 26.2 14.2	35.2 29.1 18.7	38.6 32.5 23.5	7.7 5.6 7.8			↓	11- 7H

TABLE I (continued)																		
Type of Terrain	Specific Terrain	Transmitted Pulse Width, τ (μ -sec)	Radar Frequency, f_o (Mcps)	Altitude above Terrain, h (meters)	Time Position in Return Pulse, d (μ -sec)	Angular Limits, θ_i and θ_o (deg), calculated formally from Eqs. (1.3-3) and (1.3-4)	PROBABILITY DISTRIBUTION of $10 \log_{10} (P_d/10^{-12})$ (i.e., of returned power density in db above one μ watt/meter ² per watt transmitted isotropically)					Difference in db between First and Third Quartiles	$(\text{mean})^2 / (\text{variance})$ P_d^2 / σ_d^2	Minimum Time Interval For Independent Samples, t_i (millisec)	Aircraft Ground Speed, v (meters/sec)	Code	Film or Run No.	
							95% above:	75% above:	50% above:	25% above:	5% above:							
R	8	0.205	3800	1280	.225	3.8-13.0	16.7	24.1	27.4	29.8	32.8	5.7				IIa	11- 6H	
					.426	12.9-17.7												11- 5HR
					.669	18.5-22.0												11- 5H
				1341	.25	5.7-13.4	18.2	23.8	27.9	31.6	36.9	7.8					11- 4HR	
					.37	10.9-16.2	17.7*	23.2	26.8	29.9	35.9	6.7					11- 4H	
					.206	0.0-12.1	17.0	24.3	28.4	31.5	35.0	7.2					11- 3H	
				2249	.21	1.4- 9.5	13.7*	19.5	23.5	26.7	30.6	7.2					11- 1H	
					.45	10.3-13.9	10.9*	14.2*	17.0	19.6	23.1	5.4*					11- 2HR	
					.74	15.1-17.6			13.7*	15.1*	17.6*						11- 2H	
				2249	.213	1.8- 9.6		19.7	23.3	26.2	30.2	6.5					36-15H	
	2268	.225	2.9- 9.8			19.3	23.2	26.0	29.7	6.7				36-14H				
		.361	8.2-12.4			19.4	16.2	19.9	23.2	5.9				36-11H				
		.656	13.8-16.6				11.9	14.5	17.9					36-16H				
	1.087	19.1-21.1				14.2	17.4					42-32L						
	31	0.200	3800	3871	.225	2.2- 7.5	6.4	11.2	14.1	16.8	19.9	5.6	1.20	1.5	65	IVb	42-34L	
					.521	8.9-11.4		4.6	7.7	9.9	13.1	5.3	1.33	0.62	65		42-28La	
					1.024	14.2-15.9		1.0	4.6	7.0	10.0	6.0	1.51	0.31	65		42-28Lb	
				1.771	19.5-20.6			5.9	7.2	9.9				65	42-26L			
				3886	.28	4.3- 8.4	7.8	13.0	16.1	18.6	22.1	5.6					42-24L	
					.61	10.1-12.3		8.2*	10.1	12.1	14.9	3.9*						
1.12					15.0-16.5			9.2*	10.1*	11.7								
3886				.282	4.4- 8.4	5.9	12.3	16.9	18.8	23.7	6.5							
584				.20	0.0-18.0	26.0*	34.9	39.2	42.2	45.5	7.3							
				.39	17.5-24.7	26.4*	31.5*	35.5	39.9	42.7	7.8*							
	1117	.23	5.1-14.1	22.5*	32.8	36.7	39.5	43.2	6.7	1.12	2.1	64						
		.40	13.1-18.4	17.1*	29.6	33.5	36.5	40.0	6.9	1.12	1.2	64						
2018	.22	3.2-10.3	17.2	26.3	30.2	33.4	36.7	7.1										
	.34	8.2-12.7	17.7	25.2	28.7	31.2	34.9	6.0										
3555	.61	14.0-16.9		12.0*	15.8*	20.4	25.4	8.4*										
	.22	2.4- 7.8	11.4*	20.6	24.5	27.2	30.6	6.6										
		.50	9.1-11.7		11.9*	15.4	18.8	22.9	6.9*									
S	30	0.113	415	619	.135	5.9-14.5	27.9*	36.9	39.2	40.7	42.6	3.8				Ic	42-32L	
				1223	.134	4.1-10.3	26.0	30.6	32.7	34.2	36.1	3.6					42-34L	
				1230	.165	6.4-11.4	27.5	31.3	33.0	34.8	36.9	3.5					42-28La	
				1230	.165	6.4-11.4	24.3	27.8	29.9	31.7	33.8	3.9					42-28Lb	
				2402	.165	4.6- 8.2	22.9	25.1	26.2	27.3	28.7	2.2					42-26L	
				2403	.165	4.6- 8.2	22.1	24.2	25.5	26.5	27.9	2.3					42-24L	

S	30	0.200	3800	601	.202	1.8-17.8	33.7	39.3	42.2	45.2	48.8	5.9				IVb ↓	42-42H
				602	.192	0.0-17.4	33.1	40.0	43.0	46.0	50.3	6.0					42-44H
				1195	.203	1.6-12.8	26.6	33.4	36.7	39.6	43.5	6.2					42-40H
				1203	.168	0.0-11.6	28.3	33.3	36.2	38.6	41.7	5.3					42-46H
				2343	.201	0.8- 9.2	21.0	27.5	30.8	33.6	37.3	6.1					42-38H
				2384	.186	0.0- 8.7	19.7	26.1	29.4	32.6	36.2	6.5					42-36H
T	29	0.113	415	615	.18	10.3-16.7	40.6	41.8	42.3	42.9	43.8	1.1				Ic ↓	42-31L
					.24	14.1-19.1	43.0	43.9	44.6	45.2	46.9	1.3					↓
					.36	19.4-23.2	32.6*	36.3	38.7	40.4	42.5	4.1					42-29L
				633	.150	7.6-15.0	40.3	41.5	42.2	42.8	43.9	1.3					42-33L
				1195	.170	6.8-11.7	35.4	36.3	37.1	37.6	38.5	1.3					42-27L
				1218	.179	7.3-11.9	37.4	37.9	38.2	38.3	38.7	0.4					42-25L
		0.200	3800	2397	.153	4.1- 7.9	30.6	31.3	31.8	32.1	32.9	0.8				IVb ↓	42-23L
				2397	.190	5.6- 8.8	28.5	29.0	29.4	30.1	30.7	1.1					42-43H
				583	.198	0.0-17.9	45.6	48.4	49.5	50.4	51.8	2.0					42-39H
				1198	.203	1.6-12.8	19.5	20.3	20.9	21.3	22.0	1.0					42-45H
				1207	.182	0.0-12.0	41.9	42.9	43.5	43.9	44.7	1.0					42-35H
				2389	.193	0.0- 8.9	33.2	35.0	36.1	36.7	38.2	1.7					

Footnotes:

* Obtained from an oscilloscope deflection of less than one millimeter; hence, value given is questionable.

** Value of t_1 obtained from relation $\rho(t_1) = 0.50$; other entries obtained from $\rho(t_1) = 0.25$.

PART II

Terrain Models

The principal intent of this report is to present experimental data concerning radar return from the terrain. We will make no attempt to give a complete explanation of the behavior of the return. There are, however, certain simple models for the return of electromagnetic energy from the earth that we will present in this part, and, in Table I, there is at least one case that fits each model. However, many cases can be found in Table I that will not fit any of the models we present, but we shall not try to rationalize the discrepancies.

2.1 Scattering Terrain

Here, by definition, a scattering terrain consists of a large collection of point scatterers densely distributed over a surface in such a way that the RF phases of the returns from the individual scatterers are random with respect to each other. Moreover, the phase relation that exists among all the returns at any one instant can change to a completely independent arrangement after the time t_1 (defined in Sec. 1.5d) has elapsed; that is, the average power due to the sum of all the individual returns can take on independent values every t_1 sec. Hence, the total RF voltage return from such a terrain is the same as the voltage produced by summing the voltage outputs of a large number of incoherent RF oscillators whose frequencies are distributed over a frequency range of $1/(4 t_1)$ cps. It follows that the total RF voltage varies according to a Gaussian distribution¹⁷ and has bandwidth $1/(4 t_1)$ cps, that its envelope varies according to a Rayleigh distribution¹⁸ while the square of its envelope (proportional to the power averaged over successive RF cycles) varies according to an exponential distribution.¹⁹ Thus, over a scattering terrain, $p_d(t)$ will vary with t according to an

¹⁷Julius S. Bendat, Principles and Applications of Random Noise Theory, John Wiley and Sons, Inc., New York (1958); p. 99.

¹⁸Bendat, op. cit., pp. 134-136.

¹⁹Charles S. Williams, Jr., "Output Signal-to-Noise Ratio in Pulse Systems with AGC and Saturation," Sandia Corporation Technical Memorandum SCTM 44-58-(14), February 1958; p. 38.

exponential distribution at any delay d and will have independent values every t_i sec. Then, because of the properties of the exponential distribution,

$$10 \log_{10}(Q_1/Q_3) = 6.8 \text{ db},$$

where Q_1 and Q_3 are the upper and lower quartiles of the distribution (and are power units), and

$$\begin{aligned} \bar{p}_d^2/\sigma_d^2 &= (\text{mean})^2/(\text{variance}) \\ &= 1 \end{aligned}$$

at any value of delay d .

The variation of the return from pulse to pulse is the sole criterion needed to distinguish a scattering terrain. Hence, in Table I, if the db difference between the quartiles is near 6.8, or if the ratio $(\text{mean})^2/(\text{variance})$ is near 1.0, we may conclude that the terrain is a scattering type. We will make no real attempt to explain the many cases where the db difference between quartiles is too low to represent the scattering case and too high to represent the specular case (see Sec. 2.2). We will note, however, that, if a portion of a run were over scattering terrain while the remainder were over specular terrain, the db difference between the quartiles of the resulting distribution would lie between the values that correspond to these two types of terrain, viz., 6.8 and 0.0. We will further note that a scattering terrain is necessarily rough in terms of a wavelength of the radiation (in order to meet the definition given above) while a specular terrain is smooth; hence, a terrain whose roughness lies between these two extremes will produce a distribution of return power of db quartile difference between 0.0 and 6.8.

Since the individual returns from a collection of scattering elements are incoherent, the total return power on the average is equal to the sum of the average powers from the various elements. Hence, for a scattering terrain, we could obtain the average return power density per unit area on the ground as a function of θ (for a given height and an isotropic transmission of unit power) from the relation²⁰

$$I(\theta) = \bar{p}_d/\Delta S \quad (2.1-1)$$

provided the area ΔS (at angle θ from the downward vertical and symmetric about the origin) were known.²⁰ The area ΔS is not necessarily the same as the area ΔA defined in Sec. 1.3 and Fig. I-3. The latter is the area illuminated by the pulse while ΔS is only that

²⁰The average $\bar{p}_d$ of p_d is not tabulated. However, for practical purposes it is little different from the median--the 50-percent level.

part of ΔA that contributes to the return at delay d . (The portion of ΔA that contributes to the return at delay d depends on the scattering pattern of the terrain elements.)

2.1a Return from a Lambert surface -- Each area element of a Lambert surface obeys Lambert's law, i.e., it scatters the power incident upon it (except for the power absorbed by the element) in a cosine pattern; further, by definition of a scattering surface, the return from the many area elements is incoherent. (Many diffuse surfaces scatter light in this manner.) Thus, an isotropic radiator that emits a one-watt pulse of duration τ sec at a height h meters above a plane Lambert surface will on the average²¹ receive a returned power density

$$\bar{p}_d = \int_{\theta=\theta_i}^{\theta_o} \frac{4K_{\text{scat.}} \cos^2 \theta}{(4\pi R^2)^2} dA \text{ watts/m}^2 \text{ per watt,} \quad (2.1a-1)$$

where $K_{\text{scat.}}$ is the ratio of reradiated power to incident power of each area element and has maximum value unity. We arrive at this integral as follows:

$$\text{power incident on } dA = \frac{1}{4\pi R^2} \cos \theta \, dA;$$

power scattered by dA in upper hemisphere

$$= (K_{\text{scat.}}) (\text{power incident on } dA)$$

$$= \frac{K_{\text{scat.}}}{4\pi R^2} \cos \theta \, dA;$$

$4 \cos \theta$ = scattering pattern of dA in upper hemisphere;

$$(\text{power scattered by } dA)(\text{scattering pattern of } dA)/(4\pi R^2)$$

$$= \frac{4K_{\text{scat.}} \cos^2 \theta}{(4\pi R^2)^2} dA$$

= returned power density due to dA ;

²¹The returns from a scattering surface will vary from pulse to pulse due to motion over the surface. The pulse readings $p_d(t)$, $p_d(t + T)$, $p_d(t + 2T)$, etc., at a fixed delay d in the pulses can be averaged to obtain $\bar{p}_d$.

the total returned power density is then obtained by summing over all elements dA from $\theta = \theta_i$ to $\theta = \theta_o$, where θ_i and θ_o are given by Eqs. (1.3-3) and (1.3-4).²² We note that the function $f(\theta)$ defined by Eq. (2.1-1) is

$$f(\theta) = \frac{4K_{\text{scat.}} \cos^2 \theta}{(4\pi R^2)^2}$$

for a Lambert surface. (R is a function of θ through the relation $\cos \theta = h/R$.)

The value of $\bar{p}_d$ is a maximum for $d = r$; thus, the peak of the average returned pulse, subject to the condition $cr/2 \ll h$,²³ is

$$\begin{aligned} \bar{p}_r &= \text{maximum of } \bar{p}_d \text{ with respect to } d \\ &= K_{\text{scat.}} [cr/4\pi h^3] [1 - (5cr/4h)]. \end{aligned} \quad \left. \vphantom{\begin{aligned} \bar{p}_r &= \text{maximum of } \bar{p}_d \text{ with respect to } d \\ &= K_{\text{scat.}} [cr/4\pi h^3] [1 - (5cr/4h)]. \end{aligned}} \right\} (2.1a-2)$$

We note that the peak of this average return from a scattering Lambert terrain varies directly as the pulse width r and inversely as the cube h^3 of the height, provided the term $5cr/4h$ can be neglected compared to unity. These effects result because in this case the reflecting area ΔS corresponds to the illuminated area ΔA and, for the return at $d = r$, it is proportional both to r and to h .

Surfaces with a scattering law not greatly different from Lambert's law behave similarly to a Lambert surface. For example, if the scattering pattern is $6 \cos^2 \theta$ in the upper hemisphere, we find, for isotropic transmission of a one-watt pulse of duration r sec at height h meters above a plane, that the peak of the average returned power-density pulse is

$$\bar{p}_r = K_{\text{scat.}} [3cr/8\pi h^3] [1 - (3cr/2h)] \quad (2.1a-3)$$

Note that, in this case, too, the peak of the average return varies directly with r and inversely with h^3 , provided we can neglect $3cr/2h$ with respect to unity.

2.1b Return from another type of scattering surface -- Let us consider a model where the scattering pattern of the terrain elements is constant over a right circular cone of half-angle α directed upward, and is zero elsewhere. (Thus, the scattering pattern has the value $1/[\sin^2(\alpha/2)]$ inside the cone.) We form an integral similar to Eq. (2.1a-1) for the average

²²See also Fig. I-3.

²³Note that cr is the pulse length in space.

returned power density at height h meters for a one-watt isotropic transmission of duration τ sec:

$$\bar{p}_d = \int_{\theta=\theta_i}^{\min \text{ of } (\theta_o, \alpha)} \frac{K_{\text{scat.}} \cos \theta}{(4\pi R^2)^2 \sin^2(\alpha/2)} dA \quad (2.1b-1)$$

where for the upper limit on θ we use the lesser of θ_o or α . Of course, when $\theta_i > \alpha$, the return will be zero.

The maximum of $\bar{p}_d$ with respect to d occurs for $d = r$; this corresponds to $\theta_i = 0$. (For $\alpha < \text{arcsec}(1 + c\tau/2h)$, i.e., for α less than the value of θ_o that corresponds to $d = r$, the maximum is reached before d reaches the value r , but this maximum is held until d goes just beyond r .) In order to examine terrains appreciably different from Lambert surfaces, we will consider those cases where α is quite small, i.e., where $\alpha < \text{arcsec}(1 + c\tau/2h)$. We then find

$$\bar{p}_r = \frac{K_{\text{scat.}} (1 - \cos^3 \alpha)}{24\pi h^2 \sin^2(\alpha/2)} \quad (2.1b-2)$$

We have, then, for this case, that the peak average return does not depend on the pulse width τ and varies inversely as the square h^2 of the height. (In the past there has been a tendency to consider variation with $1/h^2$ as evidence of return from specular terrain; this shows how such a variation may occur with a scattering terrain.²⁴ There are, in fact, one or two cases in the data where a scattering terrain has an inverse square variation with height h .)

2.2 Specular Return

By definition, specular return is that which would result if the transmission were made from a mirror-image point in the earth. (We assume that this is the return that would come back from a perfectly smooth and uniform infinite surface.) Thus, for a one-watt isotropic

²⁴ Charles S. Williams, Jr., "Some Doubts Concerning the Specular-Plus-Scatter Theory of Radar Return," Sandia Corporation SCDC No. 842, presented at a Symposium of Radar Return at the University of New Mexico, 11 and 12 May 1959. This paper describes how a scattering surface may be constructed that will obey the $1/h^2$ law.

transmission of duration τ sec at height h meters, the specularly-returned power density is

$$\left. \begin{aligned} p_d &= \frac{K_{\text{spec}}}{4\pi(2h)^2}, & (0 \leq d \leq \tau), \\ &= 0, & (\text{otherwise}). \end{aligned} \right\} \quad (2.2-1)$$

Since, for specular return, the terrain is smooth and uniform, $p_d(t)$ is constant with t , i.e., there is no variation from pulse to pulse. The entire distribution of p_d is, therefore, concentrated at a single value with the result that σ_d is zero while the ratio Q_1/Q_3 of the quartiles is unity. Hence,

$$10 \log_{10} (Q_1/Q_3) = 0 \text{ db}$$

and

$$\bar{p}_d^2 / \sigma_d^2 = \infty$$

for a specular terrain. In Table I, if the db difference between quartiles is around a db or less, or if $\bar{p}_d^2 / \sigma_d^2$ is appreciably greater than unity, we can reasonably suppose that the terrain is specular.

2.3 Variation of Median Return from Vertical with Altitude and Type of Terrain

In the models described in Secs. 2.1a, 2.1b, and 2.2, where the variation of the peak of the mean return with altitude is proportional to $1/h^3$, it is also proportional to the pulse width τ ; where the variation is proportional to $1/h^2$ (whether the terrain be scattering or specular), the peak mean return is independent of τ . We do not state this as a rule that can always be followed; we only draw your attention to the results given by the models.

Each of Figs. II-1 through II-17, pages 63 to 79, corresponds to a certain terrain type and the plotted values are, in logarithmic units, the 50-percent points²⁵ of the probability distributions of the return p_d from the vertical (i.e., the return for the lowest values of θ_1 and d for each run).²⁶ The frequency f_0 and pulse width τ of the data radar are also given. For comparison, each figure also shows the theoretical variation of the peak mean return for

²⁵In the cases of interest here, the median return differs little from the mean return.

²⁶We have noted in Sec. 1.5 that θ_1 should be zero for the return from the vertical, but that as tabulated it frequently is not zero due to data errors.

a specular terrain with a given loss and for a scattering terrain (that obeys Lambert's law) with a given loss. It is not intended to suggest that a particular terrain type obeys a particular law; the theoretical returns are given only for comparison.

The theoretical returns from a Lambert scattering terrain are plotted from the equation

$$10 \log_{10} [p_r] = 10 \log_{10} [K_{\text{scat}}] - 10 \log_{10} [c\tau/4\pi h^3],$$

which follows from Eq. (2.1a-2) by neglecting the term $5c\tau/4h$. The notation "-10 db scat." means -10 db with respect to a lossless Lambert scatter return, i.e., $10 \log_{10} [K_{\text{scat}}] = -10$, etc. These plots assume a pulse width τ of $0.2 \mu\text{sec}$. The actual pulse widths used in taking the data varied from 0.1 to $0.2 \mu\text{sec}$; this should not make more than a two-to-one, or 3 db, difference and this is probably less than the experimental error.

The theoretical returns from a specular surface are plotted from

$$10 \log_{10} [p_d] = 10 \log_{10} [K_{\text{spec}}] - 10 \log_{10} [4\pi(2h)^2],$$

which follows from Eq. (2.2-1). The notation "-10 db spec" means -10 db with respect to a lossless specular return, i.e., $10 \log [K_{\text{spec}}] = -10$, etc.

The points in Figs. II-1 through II-17 fall in such a way that it is difficult to evaluate the variation of the return with height for a specific terrain. This irregularity is partly due to data errors but is principally caused by the impossibility of having the return come from the same piece of ground at different altitudes. This would be impossible even if exactly the same flight path were followed, and, of course, the flight path varied.²⁷ These conditions would not matter if the terrain were truly homogeneous (as assumed in the models), but such homogeneity does not ordinarily exist. Nonetheless, Figs. II-1 through II-17 indicate in a general way that the return variation with altitude lies between $1/h^2$ and $1/h^3$.

²⁷ In one case, a second run over the same terrain at the same altitude gave a result that was about 7 db different from that given by the first run. Of course, this may have been due to an unreported change in moisture content rather than to a variation in flight path.

It has been suggested that a variation of, say, $1/h^{2.5}$, indicates the presence of a "specular component" along with a scatter return.²⁸ It has been shown²⁹ that such a specular-plus-scatter model is not consistent with the data. Moreover, since scattering models have been described that produce both $1/h^3$ and $1/h^2$ variations (in Secs. 2.1a and 2.1b), it would be easy to elaborate a scattering model with a variation between those extremes. The correct criterion for scattering is the value of $\bar{p}_d^2/\sigma_d^2$ or $10 \log_{10} (Q_3/Q_1)$; where the former is near unity or the latter near 6.8 db, the return is a scattered return. However, the scattering is not according to Lambert's law (or a similar law) when the variation is different from $1/h^3$ (if the condition $cr/2 \ll h$ is met); e.g., see Eq. (2.1b-2).

We also note (e.g., Fig. II-5) that some of the returns are greater than that for lossless scatter, i.e., for "0 db scat." Again, this does not prove that the return is not a scattered return. It need only indicate that the scattering is not according to the law that was used in calculating the theoretical scattered returns.

2.4 Summary

The models we have presented are too simple to yield any information about the time interval between independent samples of the varying component of the return. (The interval is denoted t_i in Table I and described in Sec. 1.5d.) This interval is of interest since, if one seeks to remove the variation by integration or summing of returns, it gives some idea of the time needed to acquire a desired number of independent samples. It further gives some idea of the duration of fades. This time interval, like the strength of the return, varies appreciably from one terrain to another so that it can only be used in a statistical sense. We have noted in Sec. 1.5d, however, that it does have a known dependence on the carrier frequency and on the velocity with respect to the terrain. The time between independent samples is really of no interest for specular return since there is no variation from pulse to pulse, i.e., the "independence" applies to the varying component of the return which is zero in this case.

²⁸C. H. Bidwell, "Application of Terrain Return Knowledge to the Design of Fuzing Radars," Sandia Corporation Technical Memorandum SCTM 219-57-(14), September 1957. Also, R. K. Moore, "Resolution of Vertical Incidence Radar Return into Random and Specular Components," University of New Mexico, Engineering Experiment Station Technical Report EE-6, July 1957; p. 13.

²⁹Charles S. Williams, Jr., "Some Doubts Concerning the Specular-Plus-Scatter Theory of Radar Return," Sandia Corporation SCDC No. 842, May 1959.

The data presented in Table I and in Figs. II-1 through II-17 can be used in a general way to set bounds on the strength of the return from the ground at near-vertical incidence. In the application, however, since these data represent return power density (watts/meter²) for an isotropic transmission of one watt of a given duration, the calculation must account for the transmitter power, the gain of the transmitting antenna and the effective cross section of the receiving antenna (both as functions of direction), and the transmitted pulse width. This is usually done for a scattering terrain by forming an integral that represents the sum of the powers from the area elements dA . Such an integral requires the use of a function similar to $f(\theta)$, defined by Eq. (2.1-1), which gives the return per unit area of the ground. The difficulty in finding the function $f(\theta)$ from the data is described in Sec. 2.1; in evolving a method of estimating $f(\theta)$, Secs. 2.1a and 2.1b should be considered.

The integral just described will give only the mean return from a scattering surface; the variation of the power return from time to time (at a fixed height) will vary according to an exponential distribution. Of course, such an integral cannot be used at all for the return from a specular surface since the returns from the various area elements in this case have fixed phase relations and are not incoherent. For a specular surface, Eq. (2.2-1) is used, where the range of K_{spec} is estimated from the data; there is no pulse-to-pulse variation.

A very significant feature of the return from the ground is the large variation from one terrain to another even when the terrains belong to the same category, e.g., see Fig. II-5 for "Farmland." This range of variation is so great that it is unnecessary to seek any really refined method of determining the return. After all, it would be a rare practical application where one knew in advance precisely which piece of ground was of interest--or, if the terrain were known specifically, it would be rare to have data concerning it.

All applications of these data involve interpolation or extrapolation of the parameters that describe the conditions under which the data were obtained. We would urge caution in extrapolation to appreciably different heights, frequencies, or pulse widths.

An example of the application of the data appears in the Sandia Corporation Technical Memorandum SCTM 219-57-(14), "Application of Terrain Return Knowledge to the Design of Fuzing Radars," by C. H. Bidwell, dated September 1957, and classified secret. The data are used therein to estimate the upper and lower limits of the strength of the return for a type of radar fuze of interest to Sandia Corporation and certain military organizations. Although the specular-plus-scatter model described in the memorandum is invalid for any kind of extrapolation, the estimates of the upper and lower limits of the return are satisfactory since

they represent interpolations and do not essentially depend on the model. Further, the methods of accounting for variations of the return due to factors besides the terrain are of interest and are pertinent to most fuze applications.

Fig. II-1 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-2 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-3 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-4 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-5 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-6 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-7 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-8 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-9 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-10 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-11 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-12 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function height h above terrain

Fig. II-13 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-14 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-15 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-16 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

Fig. II-17 -- Median return from straight down (in decibels above one micromicrowatt per square meter per watt of power transmitted isotropically) as a function of height h above terrain

PART III

Appendix

3.1 Transmitted Pulse Shape; Receiver Bandwidth

In deriving the data for Table I, we assumed that the transmitted pulse was rectangular and of width τ , and that the receiver bandwidth was such that it did not distort the returned pulses. Neither assumption is true, but a method has been devised to correct for the latter.³⁰ The method consisted of deriving an "effective" transmitted pulse (by use of the actual transmitted pulse and the receiver bandwidth). The use of the effective transmitted pulse rather than the actual transmitted pulse makes it unnecessary further to consider the effect of the receiver bandwidth.

Figs. III-1, III-2, III-3, and III-4 show both the actual transmitted pulses and effective transmitted pulses of the various radars used in obtaining the data, as well as the bandwidths of the receivers. The four effective pulses are designated Types I, II, III, and IV; in Table I, under "Code," the pulse applicable to each run is given by one of these Roman numerals. These effective transmitted pulses are, of course, not rectangular; the pulse widths τ given in Table I and elsewhere in this report are their half-power widths. The peak pulse power $\hat{P}_s$ used in determining p_d through Eq. (1.4-1) is the peak of the effective transmitted pulse.

3.2 Antenna Gain Pattern

The antenna patterns of the data radars are given in Fig. III-5. These four patterns are designated "a", "b", "c", and "d"; in Table I, under "Code," the pattern applicable to each run is given by one of these four lower-case letters. The data of Table I has been reduced to eliminate the effect of the antenna gain. In doing so, the return from an area limited by the inner and outer angles³¹ θ_i and θ_o was divided by the square of the antenna gain³² at the

³⁰ Janza, Hessemer, and Williams, "Pulse Response of Terrain Return Program Receivers," Sandia Corporation Technical Memorandum SCTM 208-54-(54), September 1954.

³¹ See Fig. I-3 for a definition of θ_i and θ_o .

³² See Eq. (1.4-1).

mid-angle $(\theta_0 + \theta_1)/2$. This is, of course, an approximation; it is a reasonable one since the gain patterns do not change abruptly with the angle θ .

The antenna gain is given as a function of θ only since, as best as it could be determined, the gain was symmetric about the downward vertical in all four cases. Although every effort was made to measure the gain accurately, it is probable that the actual gain varied from the plotted values by 1 or 2 db. (It may have been worse; see last paragraph of Sec. 3.3.) Moreover, for values of θ greater than about 20 degrees, the patterns are not at all accurate; however, it is not likely that any significant lobes existed beyond 20 degrees.

3.3 Sources of Error

The calibration that established the relation between received power and deflection on the oscilloscope was carried out in flight just before and just after each run. Therefore, it can be assumed that the calibration error is negligible compared to the error introduced by other causes.

In Sec. 3.1 we noted that the effective transmitted pulse was not rectangular, although in deriving certain items for Table I it was assumed so, and of a width τ equal to the half-power width of the effective transmitted pulse. This assumption introduces error into the determination of the area ΔA on the terrain that may contribute to the return at a particular delay d . It further causes error in that the actual area ΔA is not illuminated uniformly while the area used in calculations is assumed to be uniformly illuminated by virtue of assuming a rectangular pulse.

In Sec. 3.2 we noted that there is probably an error of several db in the antenna patterns. In addition to this error, an error is introduced in deriving the data for Table I by assuming the antenna gain constant across the area ΔA associated with the return at a particular delay.

Error is introduced into the delay time d in the pulse because of the difficulty in determining the zero delay point, i.e., the initial rise of the pulse. The point of initial rise should exactly correspond to the altitude h ; however, it is easy to see that the determination of this point is affected by the shape of the effective transmitted pulse, the character of the terrain, and the noise and sensitivity of the receiver.

The average of all tabulated median returns at vertical incidence is about 4 db greater for 3800 Mcps than for 415 Mcps; the comparisons are made at equal altitudes, of course. This may indicate a constant error of 4 db in one or the other--possibly due to error in measuring antenna gain. It is not impossible, of course, that on the average the ground responds better at higher frequencies. However, it is more plausible to expect a weaker return at the higher frequency since the terrain is rougher in terms of a wavelength.

Fig. III-1 -- Effective transmitted pulse, Type I, and the actual transmitted pulse it was derived from by use of receiver bandwidth

Fig. III-2 -- Effective transmitted pulse, Type II, and the actual transmitted pulse it was derived from by use of receiver bandwidth

Fig. III-3 -- Effective transmitted pulse, Type III, and the actual transmitted pulse it was derived from by use of receiver bandwidth

Fig. III-4 -- Effective transmitted pulse, Type IV, and the actual transmitted pulse it was derived from by use of receiver bandwidth

Fig. III-5 -- Antenna gain G as a function of angle θ off downward vertical

BIBLIOGRAPHY

The following references were cited in the footnotes as authority for particular points, but are not concerned with the topic of radar return:

Julius S. Bendat, Principles and Applications of Random Noise Theory, John Wiley and Sons, Inc., New York (1958).

Charles S. Williams, Jr., "Output Signal-to-Noise Ratio in Pulse Systems with AGC and Saturation," Sandia Corporation Technical Memorandum SCTM 44-58-(14), February 1958.

Janza, Hessemer, and Williams, "Pulse Response of Terrain Return Program Receivers," Sandia Corporation Technical Memorandum SCTM 208-54-(54), September 1954.

The following references were cited in the footnotes and are specifically concerned with vertical radar return from ground and water surfaces:

Peter D. Welch, "Progress Report on Interpretation and Prediction of Radar Terrain Return Fading Spectra," SCR - 212, Physical Science Laboratory, New Mexico College of Agriculture and Mechanic Arts (now New Mexico State University), May 1955.

Charles S. Williams, Jr., "Some Doubts Concerning the Specular-Plus-Scatter Theory of Radar Return," Sandia Corporation SCDC No. 842, presented at a Symposium of Radar Return held at the University of New Mexico, May 11 and 12, 1959.

C. H. Bidwell, "Application of Terrain Return Knowledge to the Design of Fuzing Radars," Sandia Corporation Technical Memorandum SCTM 219-57-(14), September 1957, Secret. (We believe the specular-plus-scatter model presented in this memorandum to be invalid for any kind of extrapolation; however, the reported estimates of the upper and lower limits of the strength of the return are satisfactory since they represent interpolations and do not essentially depend on the model.)

R. K. Moore, "Resolution of Vertical Incidence Radar Return into Random and Specular Components," University of New Mexico Engineering Experiment Station Technical Report EE-6, July 1957. (We believe that the conclusions drawn in this report concerning the partition of the return power into specular and scattered components are erroneous.)

The following references were not cited in the text but contain interesting material pertinent to vertical radar return from ground and water surfaces:

- Vera LaFleur and Peter D. Welch, "Tabulation and Preliminary Analysis of D.C./A.C. Ratios for Spectra Analyses from Flight Series 11 through Flight Series 52," SCR-213, Physical Science Laboratory, New Mexico College of Agriculture and Mechanic Arts (now New Mexico State University), January 1956. (This report is the source of the $(\text{mean})^2/(\text{variance})$ ratios--called DC/AC ratio in the reference--given in Table I.)
- Peter D. Welch, "A Bibliographic Outline of Work Performed on the Sandia Corporation's Terrain Return Program under Sandia Purchase Orders EL-586, EL-2167, 54-1451, 54-3052," SCR-216, Physical Science Laboratory, New Mexico College of Agriculture and Mechanic Arts (now New Mexico State University), July 1956. (This report covers the period 1 July 1951 through 30 June 1956; this is the period during which the data presented in Table I were gathered and processed. This bibliography does not list by AER number the approximately 490 reports issued on the probability distributions of the radar returns nor the approximately 65 reports on the variance spectra and autocorrelation functions of the returns. However, it does list the flight series reports, and the latter can be further consulted to associate the AER numbers of the data reports with the film numbers given in Table I. These numerous data reports are the source of most of the data in Table I.)
- Peter D. Welch, "Second Progress Report on Interpretation and Prediction of Radar Terrain Return Fading Spectra," SCR-214, Physical Science Laboratory, New Mexico College of Agriculture and Mechanic Arts (now New Mexico State University), February 1956. (This report is of special interest in that it gives methods of estimating the pulse-to-pulse variance spectra, and, hence, the time between independent samples, for nonhorizontal flight paths.)
- Peter D. Welch, "Third Progress Report on Interpretation and Prediction of Radar Terrain Return Fading Spectra," SCR-215, Physical Science Laboratory, New Mexico College of Agriculture and Mechanic Arts (now New Mexico State University), May 1956. (This report gives the procedures for calculating the spectra described in AER 18-B cited just above.)
- Peter D. Welch, "The Covariance Spectrum of Two Points on a Radar Terrain Return Pulse," SCR-217, Physical Science Laboratory, New Mexico College of Agriculture and Mechanic Arts (now New Mexico State University), July 1956. (This is applicable where integration is done within the pulse as opposed to pulse-to-pulse integration.)
- Janza and West, "Accurate Radar Attenuation Measurements Achieved by Inflight Calibration," Trans IRE Professional Group on Instrumentation, October 1955. (This report describes the methods that were used in the collection of the data reported in Table I in order to obtain accurate measurements.)

Edison, Moore, and Warner, "Radar Return at Near-Vertical Incidence--Summary Report," Technical Report EE-24, Engineering Experiment Station, University of New Mexico, September 1959. (This report is based on the same experimental data that went into Table I. It is considerably less extensive than Table I except that it does present a few examples of variance spectra, i.e., transforms of the autocorrelation functions. It is more extensive in terms of conclusions drawn from the data. For example, it presents the variation of the scattering cross section of the terrain with angle from the vertical for a number of terrain types. This is a computed function that we believe to be of dubious validity. In the first place, the original data were not satisfactory at angles off the vertical. Further, the computation of the function depends on the specular-plus-scatter model of the terrain and, as stated earlier herein, we think that this model is unsound.)

The Technical Memoranda of Sandia Corporation describing the various terrains in detail are:

- D. M. Gragg, "Target of Terrain Return Program - Elephant Butte Lake and Caballo Reservoir, New Mexico," Sandia Corporation Technical Memorandum SCTM 225-55-(54), October 1955.
- D. M. Gragg, "Target of Terrain Return Project - Lake Bemidji, Minnesota," Sandia Corporation Technical Memorandum SCTM 163-55-(54), August 1955.
- D. M. Gragg, "Target of Terrain Return Project - Site 2, Farmland near Osborn, Missouri," Sandia Corporation Technical Memorandum SCTM 59-55-(54), April 1955.
- D. M. Gragg, "Target of Terrain Return Project - Site 6, Wooded Farmland with Railroad near Cameron, Missouri," Sandia Corporation Technical Memorandum SCTM 60-55-(54), May 1955.
- D. M. Gragg, "Target of Terrain Return Project - Site 8, Flat Farmland near Sioux City, Iowa," Sandia Corporation Technical Memorandum SCTM 64-55-(54), May 1955.
- R. K. Moore, "Target of Terrain Return Project - Wahpeton, North Dakota," Sandia Corporation Technical Memorandum SCTM 62-55-(54), May 1955.
- D. M. Gragg, "Target of Terrain Return Project - Field near Woods near Bemidji, Minnesota," Sandia Corporation Technical Memorandum SCTM 162-55-(54), August 1955.
- D. M. Gragg, "Target of Terrain Return Program - Orchard and Field near Las Cruces, New Mexico," Sandia Corporation Technical Memorandum SCTM 226-55-(54), October 1955.
- D. M. Gragg, "Target of Terrain Return Project - Orchard near El Toro, California," Sandia Corporation Technical Memorandum SCTM 258-55-(54), December 1955.

- D. M. Gragg, "Target of Terrain Return Project - Snow-covered Rangeland Northwest of Magdalena, New Mexico," Sandia Corporation Technical Memorandum SCTM 254-55-(54), December 1955.
- D. M. Gragg, "Target of Terrain Return Project - Snowfield S.E. of Presque Isle, Maine," Sandia Corporation Technical Memorandum SCTM 9-56-(14), January 1956.
- R. K. Moore, "Target of Terrain Return Project - Pine Island, Minnesota," Sandia Corporation Technical Memorandum SCTM 218-54-(54), September 1954.
- D. M. Gragg, "Target of Terrain Return Project - Forest South of Presque Isle, Maine," Sandia Corporation Technical Memorandum SCTM 265-55-(54), December 1955.
- D. M. Gragg, "Target of Terrain Return Project - Residential Section, Minneapolis, Minnesota," Sandia Corporation Technical Memorandum SCTM 58-55-(54), April 1955.
- D. M. Gragg, "Target of Terrain Return Project - Residential Section, Presque Isle, Maine," Sandia Corporation Technical Memorandum SCTM 264-55-(54), December 1955.
- D. M. Gragg, "Target of Terrain Return Project - Residential Section, Superior, Wisconsin," Sandia Corporation Technical Memorandum SCTM 267-55-(54), December 1955.
- D. M. Gragg, "Target of Terrain Return Project - Residential Section, Santa Ana, California," Sandia Corporation Technical Memorandum SCTM 8-56-(14), January 1956.
- D. M. Gragg, "Target of Terrain Return Project - Industrial Section, St. Paul, Minnesota," Sandia Corporation Technical Memorandum SCTM 57-55-(54), April 1955.
- D. M. Gragg, "Target of Terrain Return Project - Site 1, Kansas City, Missouri," Sandia Corporation Technical Memorandum SCTM 61-55-(54), April 1955.
- D. M. Gragg, "Target of Terrain Return Project - Dry Mesa and Abandoned Runways near Belen, New Mexico," Sandia Corporation Technical Memorandum SCTM 266-55-(54), December 1955.
- D. M. Gragg, "Target of Terrain Return Project - Dry Mesa West of Albuquerque, New Mexico," Sandia Corporation Technical Memorandum SCTM 164-55-(54), August 1955.
- D. M. Gragg, "Target of Terrain Return Project - Desert near Salton Sea, California," Sandia Corporation Technical Memorandum SCTM 228-55-(54), October 1955.

D. M. Gragg, "Target of Terrain Return Project - Yucca Lake, Nevada and Sand Hills North of Yucca Lake," Sandia Corporation Technical Memorandum SCTM 263-55-(54), December 1955.