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QUANTITATIVE MEASUREMENTS OF RADAR ECHOES FROM AIRCRAFT IX. F-51

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4 March 1953

NAVAL RESEARCH LABORATORY, WASHINGTON, D.C.

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ABSTRACT

F-51 echo amplitudes, sampled at L, S, and X bands over periods of 10 seconds duration, show the marked influence of the four-bladed propeller. At favorable parts of the propeller rotation cycle, the echo from the propeller blades is generally stronger than the residual echo from the remainder of the aircraft. In cumulative distributions of echo amplitude for aspects outside the general region of broadside, the weaker echoes can be fitted with a Rayleigh distribution, but the higher signal levels, appearing about 20% of the time, are stronger than this Rayleigh distribution would predict, because of the strong propeller echo. As a result, 10% of the time the F-51 area exceeds 2.5, 5.5, and 11 square meters on L, S, and X bands, respectively. At non-broadside aspects (outside the azimuth range 70°-110°) the dominant fluctuation frequencies in the F-51 echo are caused by the periodically appearing propeller echo.

In the azimuth range 70°-110°, the propeller is rather edgewise to the radar, so that the propeller echo is relatively insignificant. Probably because of the curved fuselage and shaped air scoop, the echo in this region has about the same general behavior on all three frequencies, with the strongest echoes found at azimuths 90° and 98°, the latter arising from the tapered tail section of the fuselage.

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PROBLEM STATUS

This is an [redacted] on the problem; work continues.

AUTHORIZATION

NRL Problem R11-17

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INTRODUCTION

In eight previous reports,[1] - [8] characteristics of radar echoes from various aircraft were given. This report, the ninth of the series, gives the complete results obtained for the F-51.

Amplitude Distributions

The amplitude distributions plotted in Figs. 2 - 6 are representative 10 second (1200-pulse) samples of the airplane aspects (defined in Fig. 1) encountered. In these figures, cumulative distributions of echo pulse amplitudes are plotted, the ordinate being $10 \log_{10} \sigma$ (σ = radar area in square meters), the abscissa, the percent of time the amplitude of the observed echo exceeds the ordinate. For comparison, a straight line is drawn which corresponds to the theoretical cumulative distribution (Rayleigh distribution) of noise powers.

The distributions in Figs. 3, 4 and 6 follow the Rayleigh distribution with an accuracy sufficient for many purposes. Those in Figs. 2 and 5 have a characteristic deviation at high signal levels which is due to propeller modulation. (This will be discussed in greater detail in the section on Fluctuations.) Pictured in Fig. 7 are samples of the pulse-by-pulse film records illustrating the type of modulation frequently observed in the F-51 film records from which Figs. 2 and 5 were prepared. From Fig. 7 it is obvious why, in Figs.

2 and 5, a small percentage of the signals are so much larger than the remaining signals. Pulse-by-pulse records like those of Fig. 7 persisted throughout many aspect intervals of the F-51.

An attempt was made to explain the curious L-band distribution of Fig. 5 in terms of echoes from the four-bladed propeller. The blade was regarded as a flattened cylinder, and the nature of the propeller echo was then predicted from the flight geometry, the propeller blade length, and the wavelength through a theory basically similar to that used in the discussion (in Report VI) of the echo from the leading edge of the wing of the F-86. The aim was to relate the length of the blade with the appearance (on the L-band plot of Fig. 5) of strong propeller echoes about 27% of the time. The blade length consistent with this datum was found to be 2.6 feet, which seems to be a fair estimate of the effective length of a twisted F-51 propeller blade. A twist in the blade also accounts for the fact that the upswing of the L-band distribution plot of Fig. 5 is not found to an even more marked degree in the S- and X-band plots as a result of a sharper "flat-blade" echo at these frequencies.

Aspect Dependence

Each of Figs. 8 - 13 covers one flight of the aircraft and consists of four graphs. The uppermost graph of each figure consists of a plot of the aircraft's aspect, as defined in Fig. 1, versus range, in thousands of yards. The remaining three graphs (one for each of the three frequencies employed) of each figure consist of plots of radar area, expressed in decibels above one square meter, versus range in thousands of yards. Each graph consists of three sets of points, each set being connected by straight line segments. Each point represents one second of data, and data taken simultaneously are aligned vertically so that the uppermost point is the maximum, the middle point is the median, and the lowest point is the minimum radar area occurring in that second. The radar area as plotted contains variations due to interference lobes caused by ground reflections. At the center of each lobe, or integral number of lobes, is a circled x (⊗) indicating the median value (reduced to "free-space" value in accordance with the procedure described in the appendix to (2)) of the median radar area values for that lobe or integral number of lobes, and these median values were used in determining the median value of σ for each five degrees of azimuth as described below.

The data were divided into intervals, each of which spanned five degrees of azimuth. For each such interval the median of the median set of points was determined for each frequency. These "median median" values are plotted in Fig. 14.

The listed azimuths are calculated from the optically pointed radar's instantaneous azimuth and the true heading assigned to the

F-51 for the particular run. No azimuth corrections have been made, since the F-51 pilot apparently flew true headings, as instructed. Evidence supporting this is found in the apparent presence of an echo from the leading edge of the starboard wing on the X- and L-band data of Run 3, Fig. 9. Here the apparent leading edge echo appears at a nominal 357 1/2° azimuth, consistent with the approximate 3 1/2° sweep-back of the F-51 wing and with the fact that the antennas swung slowly to the right during this flight. Likewise, "broadside" echoes are found at nominal 90° and 98° azimuths, strong echoes at the latter azimuth being attributable to the conical structure of the underparts of the F-51 fuselage. (The half-angles of the "cones" are about 8°, with vertices to the rear, according to the F-51 drawings.)

The plots of Figs. 8 - 13 also contain step "curves" (1db steps) of constant echo power drawn at the minimum detectable radar signal levels. At non-broadside aspects, the general trend of the plotted S-band medians closely parallels the corresponding constant-power curve. That is, at non-broadside aspects, the median power of the F-51 echo on S-band appears to be independent of the radar range. One might think that this is a coincidence since the db correction for range is in a one-to-one correspondence with azimuth for straight-line F-51 flights (except for head-on runs). However, the same tendency is found in the head-on S-band run of Figs. 8, 9, 10, where the aspect change is relatively small. One cannot attribute the apparent range independence of the median echo power to faulty analysis, to judge from the evidence of the S-band plot of Fig. 8. The identical data are plotted as read from the film, i.e., on an echo-power-vs.-time basis; in Fig. 9, Report I. This plot is seen to agree with the S-band radar-area-vs.-time plot of the present Fig. 8. The "range-independence" of the S-band echo was not noticed at the earlier time, owing to the propeller's effect in setting the general level of the maximums, and because of the somewhat fragmentary nature of the plot.

There may be a similar tendency for median echo powers to be independent of range at L and X bands, but evidence for this is inconclusive owing to the lobe structure at L band, and to the generally weak median signals at X band.

Also noticeable in Figs. 9, 12, and 13 is the fact that the db separation between plotted maxima and medians far exceeds the separation between medians and minima in certain sections of the plots. The effect is especially marked at azimuths 330° and 130°, and is somewhat apparent at 50°. This is the same effect as discussed in relation to Fig. 5 and arises from the fact that, at these azimuths, the relatively strong echo from the propeller is observed once in about five radar pulses (see Fig. 7). The propeller echo thus determines the db level of the plotted maxima, but does not appear often enough to affect the median or minimum echo levels. The latter arise from the remainder of the F-51, and are separated by about the same number of db as are the median and minimum echo-levels of the B-45 for similar aspects (See Figs. 9 and 13, Report VIII).

When the propeller echo is strong, its level should be independent of the average echo from the rest of the F-51. In Figs. 9, 12, and 13, this is corroborated by a comparison of the second-to-second variations of the plotted maxima with the simultaneous variations of the plotted medians. Where maxima lie many db above the medians (because of the propeller echo) the simultaneous variations of the two plots are relatively uncorrelated, but where the maxima are relatively close to the medians, (and the propeller echo is relatively small) the two plots are correlated, rising and falling together from second to second.

The dominance of the propeller echo is especially marked at aspects 130°, 50°, and 330°, on all three frequencies. The propeller echo is strongest when the flat portion of the blade is normal to the ray from the radar. If the roughly flat sides of the blades made an angle of about 50° with the plane of rotation, the strongest propeller echoes would be observed at azimuths 50°, 130°, 230°, and 310°. No observations were made at 230° or at 310°, where the echo might have been even stronger than that observed at 330°.

The fact that strong propeller echoes are found over many degrees of azimuth is attributable to the twist and curvature of the blade. Likewise, there is no azimuth where the propeller echo power increases as the square of the radar frequency, which would be the case if the blade were flat.

As the median echo power levels are relatively unaffected by the propeller's presence, the median-median data of Fig. 14 represent the trends of L-, S-, and X-band echoes from the F-51 fuselage. The dominant feature of the aspect dependence of the fuselage echo is a two-humped broadside echo, the humps occurring at approximately 90° and 98°. The two-humped broadside echoes are of somewhat the same shape on all three frequencies, corresponding to the curved and tapered F-51 fuselage. Theoretically, the echo from a large surface is independent of frequency, the echo power being proportional to the product of the principal radii of curvature at the point where the ray is normal to the surface. On this principle, the echo should be maximum on all three frequencies at the observed 90° and 98°, according to the F-51 drawings.

Frequency Dependence

To obtain representative measures of the radar area of the F-51, the following procedure was carried out for each frequency employed. From Fig. 14, a single number for the radar area was obtained on each frequency for each five-degree azimuth interval by averaging all the "median-median" areas (in square meters) in that azimuth interval, without regard to the elevation angles involved. The results are plotted in Fig. 15. The following four estimates of the average radar area of the F-51 were then obtained, using the "average-median-median" data of Fig. 15. In the first estimate, the Fig. 15 data at each frequency were averaged (in square meters) over the 18 five-degree intervals containing data on all three frequencies. This estimate included the azimuth intervals 85° - 90° and 95° - 100°, and the lower limits of the L-band values for these intervals were used in obtaining the L-band average.

	L	S	X
Square meters	> 1.35	4.85	8.28
db > 1 m^2	>-0.2	6.9	9.2

When the broadside azimuth intervals 85° - 90°, and 95° - 100° were excluded from consideration, a second estimate was obtained by averaging the areas (in square meters) over the remaining 16 intervals containing data on all three frequencies:

	L	S	X
Square meters	0.89	2.29	4.57
db > 1 m^2	-0.5	3.6	6.6

This is the appropriate measure of the frequency dependence. (The F-51 had a "double broadside" with the median echo unsaturated on all three frequencies in the interval 90° - 95°; hence this interval is included in all of the estimates.)

A third estimate was obtained by calculating, for each frequency, the average (in square meters) of all the "average median-median" radar areas plotted in Fig. 15: This estimate included the azimuth intervals 85° - 90° and 95° - 100°; and the lower limits of the L-band values for these intervals were used in obtaining the L-band average.

	L	S	X
Square meters	> 0.94	3.59	8.28
db>1 m^2	>-0.2	5.6	9.2

A fourth estimate was obtained by calculating, for each frequency, the average (in square meters) of all "average median-median" areas of Fig. 15 except those in azimuth intervals 85° - 90° and 95° - 100°.

	L	S	X
Square meters	0.61	1.78	4.57
db>1 m^2	-2.1	2.5	6.6

In all four estimating procedures, the "average" radar area increases consistently with frequency. There seems to be no good theoretical reason for this fact.

The data initially entering the above averages were the median radar areas plotted in Figs. 8 - 13. It has been stated earlier that these medians do not show the influence of the propeller echo, which is a dominant feature of the F-51 as a radar echoer. The propeller effect shows up on about 1/5 of the radar echoes. This is probably sufficiently often to made the F-51 detectable at considerably longer ranges than one would estimate through use of the foregoing averages. For an estimate of this enhancement, one may take the medians of the propeller-affected F-51 echoes as somewhat representative. With propeller effects in 1/5 of the echoes, this median radar area echo then corresponds to the radar area at a 10% abscissa in a comulative distribution plot. Propeller effects are not observed at near-broadside aspects, so that one can form an estimate of the median propeller effect from the non-broadside distributions in Figs. 2, 3, 4, and 5. From these, one estimates that the median propeller-affected echo averages about 7 db above the over-all median echo on all frequencies compared to 5 db in the theoretical Rayleigh distribution. Averaging the data of Fig. 15 over all a spect intervals containing data on all three frequencies, <u>except</u> the "near-broadside" band of aspects between 70^o and 110^o, average median-median radar areas of -3.1, 0.4, and 3.5 db>1 m^2 for L, S, and X bands, respectively are obtained for aspects of the F-51 where propeller echo is a dominant feature. Adding 7 db to these figures, one arrives at the following conclusion: <u>Ten percent of the time</u>, for aspects outside of the azimuth interval 70^o - 110^o, the F-51 radar area exceeds 3.9, 7.4, and 10.5 db>1 m^2. These figures are perhaps pertinent to detection of the F-51 on a PPI screen.

<u>Fluctuations of the F-51 Echo</u>

Spectrums of selected 5-second samples of F-51 echoes were prepared according to the procedure described in Report VII. The necessary plots of video voltage vs. time are shown in Figs. 16 - 18, and the spectrums for aspects near head-on, near broadside, and toward the tail are shown in Figs. 19 - 23, respectively. The head-on and tailward spectrums are dominated by the discrete frequencies 19, 27, and 46 cps and 23 and 47 cps, respectively. As these spectral components are found at all three radar frequencies, they must arise from the propeller modulation, or directly from the propeller echo itself. On the tailward spectrums, there is also a frequency component at about 25 cps, which increases in relative strength with radar frequency.

The broadside spectrums of Fig. 22 do not seem to contain identifiable discrete frequency components, and the bulk of each spectrum lies at low frequencies where the spectrum analyzer starts to cut off (See Fig. 7, Report VII). To display the low-frequency components to better advantage, the following expedient was adopted: The voltage on the original loop of magnetic tape (used as spectrum analyzer input in preparation of, say, the last plot of Fig. 22) was transferred to a second loop of magnetic tape of the same length, but moving at 1/4 the speed. This second tape then contains a nominal 20 seconds of radar data, consisting of the original 5 seconds of data repeated four times. With tapes of this type as inputs to the spectrum analyzer, the plots of Fig. 23 were prepared. Here the cutoff of the spectrum analyzer lies at the same distance (in inches) from the zero frequency abscissa, but effectively at 1/4 the cutoff frequency obtained with the first tape.

Owing to the periodic nature of the voltage on the second tapes, only integer multiples of 1/5 cps are properly deducible. These discrete frequencies are almost resolved by the analyzer, and the fine structure of the plots of Fig. 23 is due to this resolution. For instance, there are five humps in the S-band spectrum between the 1.5 cps and the 2.5 cps abscissas; these humps represent the spectrum analyzer's attempt to resolve the five discrete frequencies in the input tape in this frequency interval. After these artificially introduced ripples are smoothed out, the S-band spectrum consists primarily of two broad humps, centered at about 0.4 and 1.0 cps. The humps are not quite sharp enough (compared with the calibration pulses to the far right) to be interpreted as arising from interference between the echoes from two different portions of the F-51. The 0.4 cps S-band hump probably corresponds to a hump at 1.3 cps at X-band, and the 1.0 cps S-band hump, to one at about 0.4 cps at L-band. A second L-band hump at lower frequency might well be cut off by the analyzer. This, and the general tendency for the bulk of the spectrum to be displaced to higher frequencies for higher radar frequencies, is in agreement with the theory outlined in Report VIII.

The propeller blades are viewed somewhat edgewise at near-broadside aspects, where the fuselage echo is at its strongest. Thus spectral frequencies arising from the propeller's effect are not prominent near broadside.

The spectrum analyzer at best gives an averaged picture of the radar echo, and throws away information about the phase relation of various frequency components that may be found in the original radar data. To discuss in greater detail the effect of the propeller, it is best to refer to the pulse-by-pulse radar observations, samples of which are found in Fig. 7.

It has been stated that the propeller echo is at a maximum when the flattened sides of the propeller blades are normal to the radar ray at some point of the rotation. This condition prevails at about azimuths 30° and 130°. The pulse-by-pulse records of Fig. 18, made at about 135° azimuth, show a relatively strong echo occurring (for varying time intervals) at every fifth radar pulse. The (1/5) x 120 = 24 cps dominant propeller echo frequency is reflected in the heavy concentration of spectral powers in this general neighborhood in Figs. 19 - 21.

The basic 24 cps periodicity of the appearance of the propeller echo in the radar data, taken at 120 pulses per second, is an effect of the four-bladed propeller's rate of revolution. For this periodicity, the propeller must present the same strongly echoing aspect to the radar every fifth radar pulse and present weakly echoing aspects during the intervening four pulses. For this cycle, the slowest possible propeller rotation rate is 18° per radar pulse period, giving 90° of rotation per five radar pulses. Also possible are rotation rates N(18°) per pulse period when N is any integer relatively prime to five. Taking N = 7 or N = 8 gives a rotation rate of 2520 or 2880 rpm, either being in reasonable agreement with the nominal 2700 rpm for an F-51 at cruising speed. Regularities in the fading of the propeller echoes can be attributed to steady propeller rotation at some rate differing slightly from one of the above estimates. In general this fading would be aperiodic, owing to incommensurability of the pulse and the rotation rates.

Conclusions

F-51 echo amplitudes, sampled at L, S, and X bands over periods of 10 seconds duration, show the marked influence of the four-bladed propeller. At favorable parts of the propeller rotation cycle, the echo from the propeller blades is generally stronger than the residual echo from the remainder of the aircraft. In cumulative distributions of echo amplitude for aspects outside the general regions of broadside, the weaker echoes can be fitted with a Rayleigh distribution, but the higher signal levels, appearing about 20% of the time, are stronger than this Rayleigh distribution would predict, because of the strong propeller echo. As a result, 10% of the time the F-51 area exceeds 2.5, 5.5, and 11 square meters on L, S, and X bands, respectively. At non-broadside aspects (outside the azimuth range 70° -110°) the dominant fluctuation frequencies in the F-51 echo are caused by the periodically appearing propeller echo.

In the azimuth range 70°-110°, the propeller is rather edgewise to the radar, so that the propeller echo is relatively insignificant. Probably because of the curved fuselage and shaped air scoop, the echo in this region has about the same general behavior on all three frequencies, with the strongest echoes found at azimuth 90° and 98°, the latter arising from the tapered tail section of the fuselage.

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1) "Quantitative Measurements of Radar Echoes from Aircraft, I. B-36, B-45, F-51, and F-86," NRL Letter Report, Serial C-3460-73A/50 dated 24 October 1950.

2) "Quantitative Measurements of Radar Echoes from Aircraft, II. Formation of Three F-86's, B-29, F-80 with wing tanks, and F-80 without wing tanks", NRL Letter Report, Serial C-3460-18A/51 dated 12 February 1951.

3) "Quantitative Measurements of Radar Echoes from Aircraft, III. B-36 Amplitude Distributions and Aspect Dependence," NRL Letter Report, Serial C-3460-94A/51 dtd 19 June 1951.

4) "Quantitative Measurements of Radar Echoes from Aircraft, IV. F-86 Amplitude Distributions and Aspect Dependence," NRL Letter Report, Serial C-3460-138A/51 dtd 5 September 1951.

5) "Quantitative Measurements of Radar Echoes from Aircraft, V. Correction of X-band Values," NRL Letter Report, Serial C-3460-132A/52 dtd 24 October 1952.

6) "Quantitative Measurements of Radar Echoes from Aircraft, VI. Corrected F-86 Amplitude Distributions and Aspect Dependence," NRL Letter Report, Serial C-3460-143A/52 dtd 15 December 1952.

7) "Quantitative Measurements of Radar Echoes from Aircraft, VII, B-36 and F-86 Spectrums," NRL Memorandum Report No. 107 dtd 15 January 1953

8) "Quantitative Measurements of Radar Echoes from Aircraft, VIII. B-45", NRL Memorandum Report No. 116 dated 28 January 1953.

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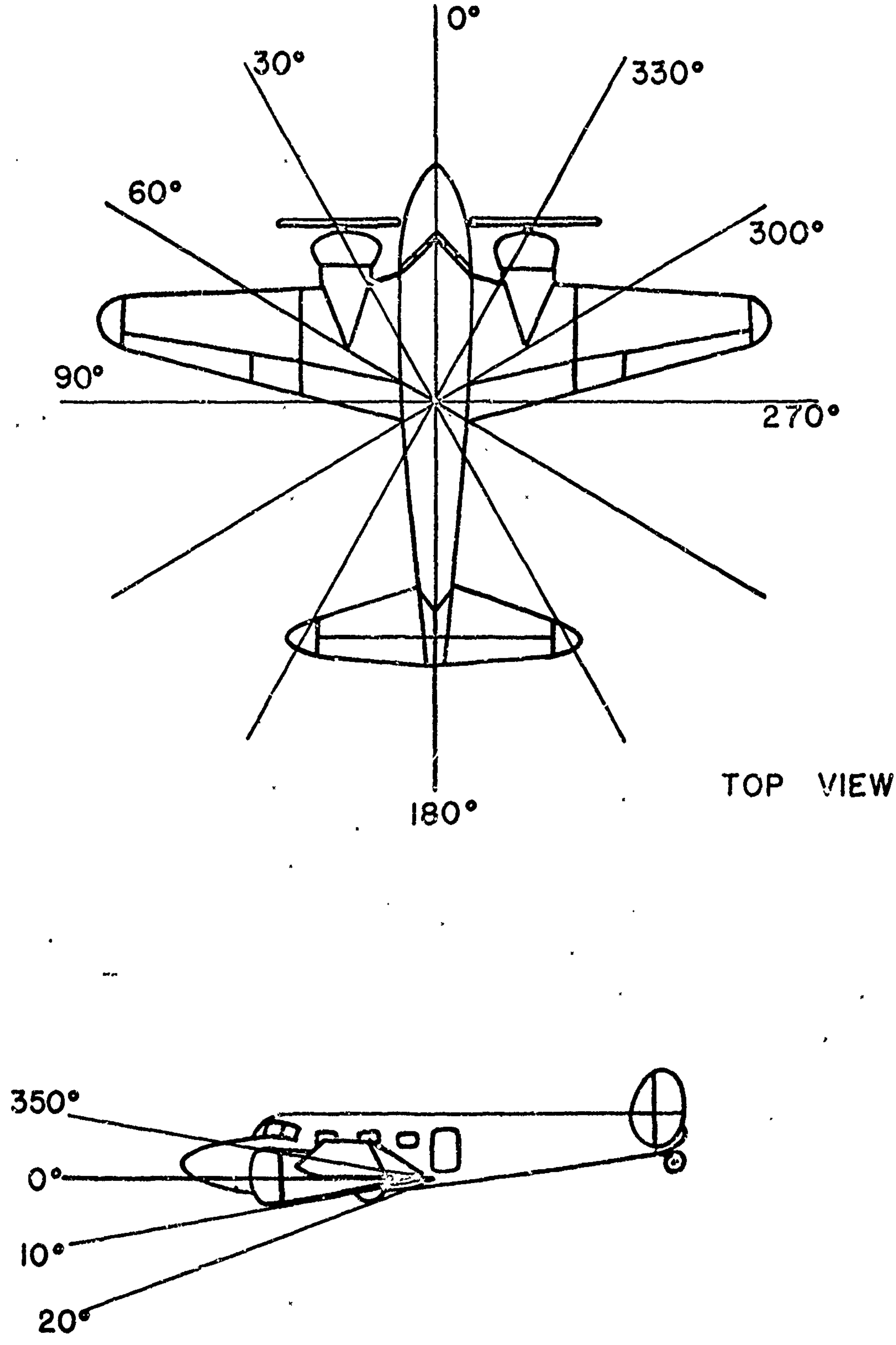

Definition of aspect angles

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Figure 1

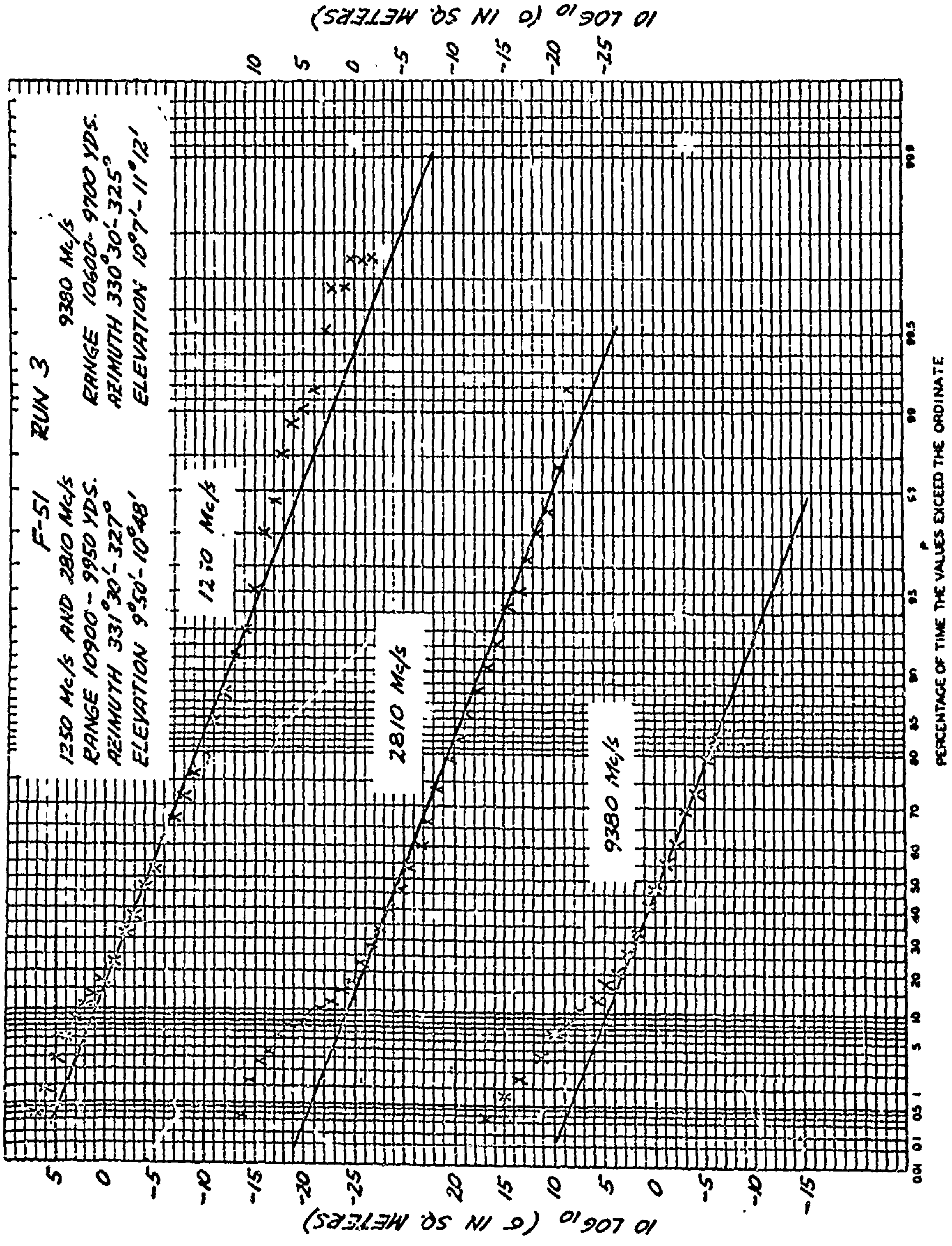

F-51 RUN 3
1230 Mc/s AND 2810 Mc/s
RANGE 10900 - 9950 YDS.
AZIMUTH 331°30' - 327°
ELEVATION 9°50' - 10°48'
9380 Mc/s
RANGE 10600 - 9700 YDS.
AZIMUTH 330°30' - 325°
ELEVATION 10°7' - 11°12'
1230 Mc/s
2810 Mc/s
9380 Mc/s
10 LOG10 (σ IN SQ. METERS)
PERCENTAGE OF TIME THE VALUES EXCEED THE ORDINATE

Figure 2

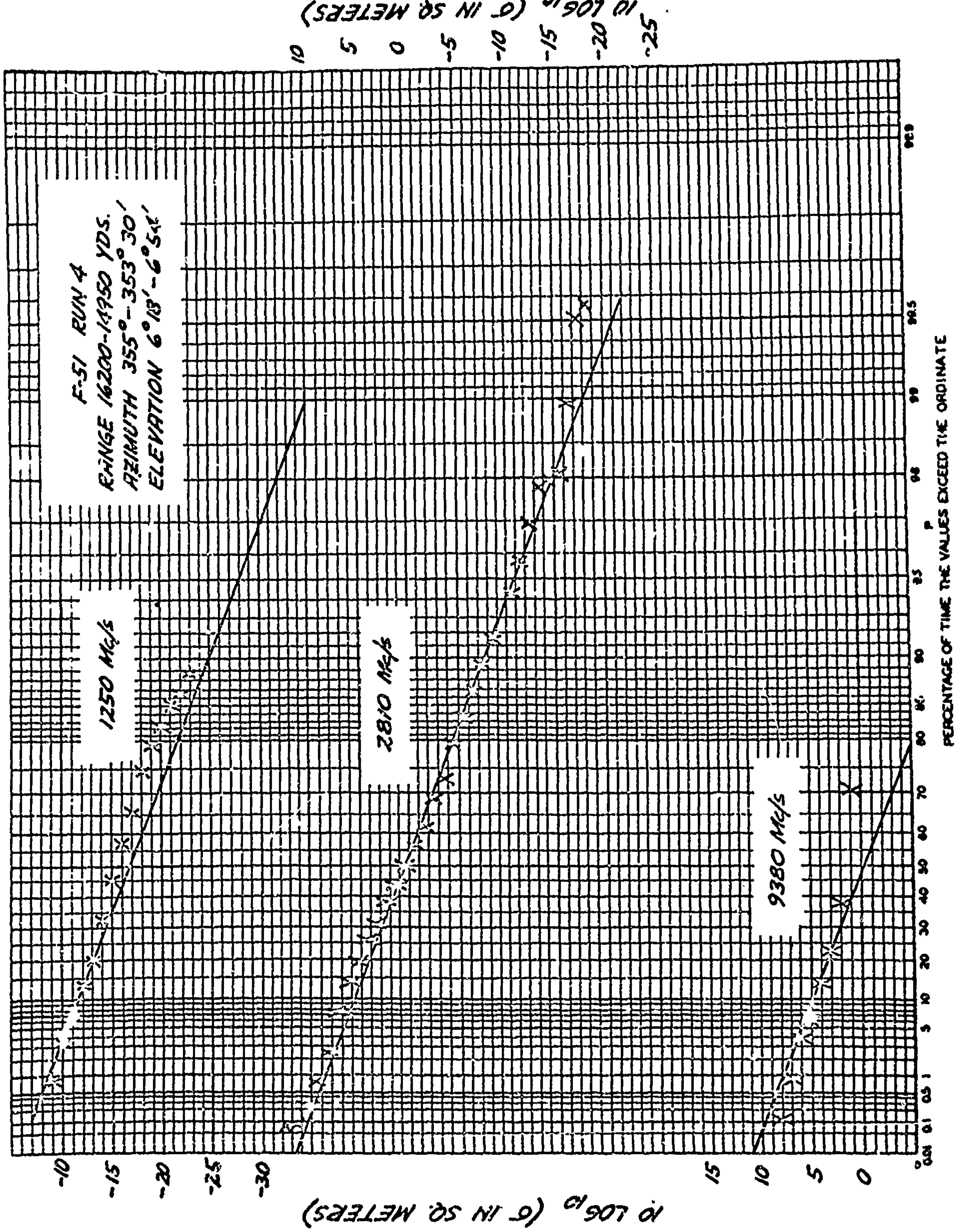
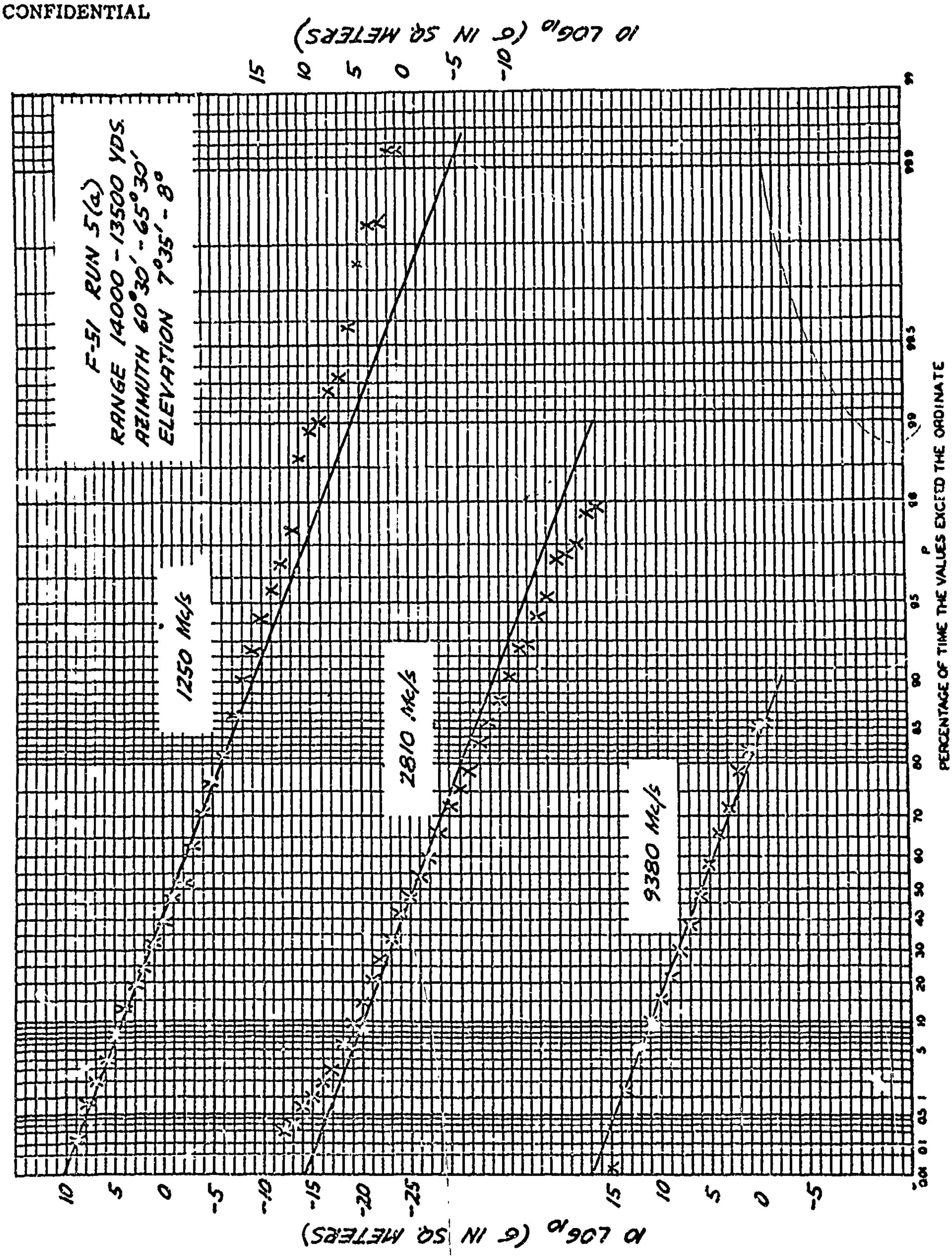

F-51 RUN 4
RANGE 16200-14950 YDS.
AZIMUTH 355°-353°30'
ELEVATION 6°18'-6°54'
1250 Mc/s
2810 Mc/s
9380 Mc/s
PERCENTAGE OF TIME THE VALUES EXCEED THE ORDINATE
10 LOG10 (σ IN SQ. METERS)
10 LOG10 (σ IN SQ. METERS)

Figure 3



10 LOG10 (σ IN SQ METERS)
F-51 RUN 5(a)
RANGE 14000 - 13500 YDS.
AZIMUTH 60°30' - 65°30'
ELEVATION 7°35' - 8°
1250 Mc/s
2810 Mc/s
9380 Mc/s
PERCENTAGE OF TIME THE VALUES EXCEED THE ORDINATE

Figure 4

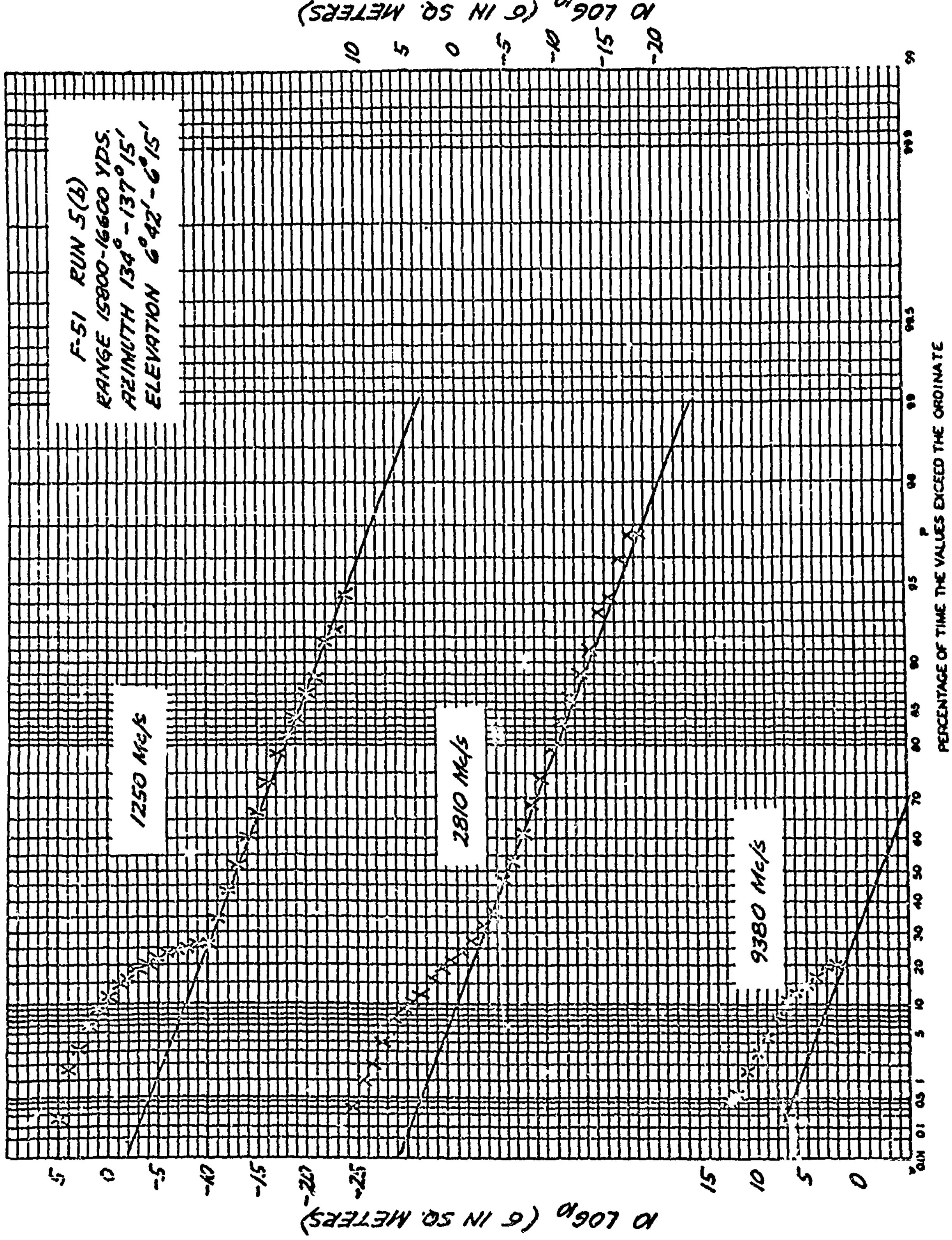

F-51 RUN 5(b)
RANGE 15800-16600 YDS.
AZIMUTH 134°-137°15'
ELEVATION 6°42'-6°15'
1250 Mc/s
2810 Mc/s
9380 Mc/s
10 LOG10 (σ IN SQ. METERS)
PERCENTAGE OF TIME THE VALUES EXCEED THE ORDINATE
10 LOG10 (σ IN SQ. METERS)

Figure 5

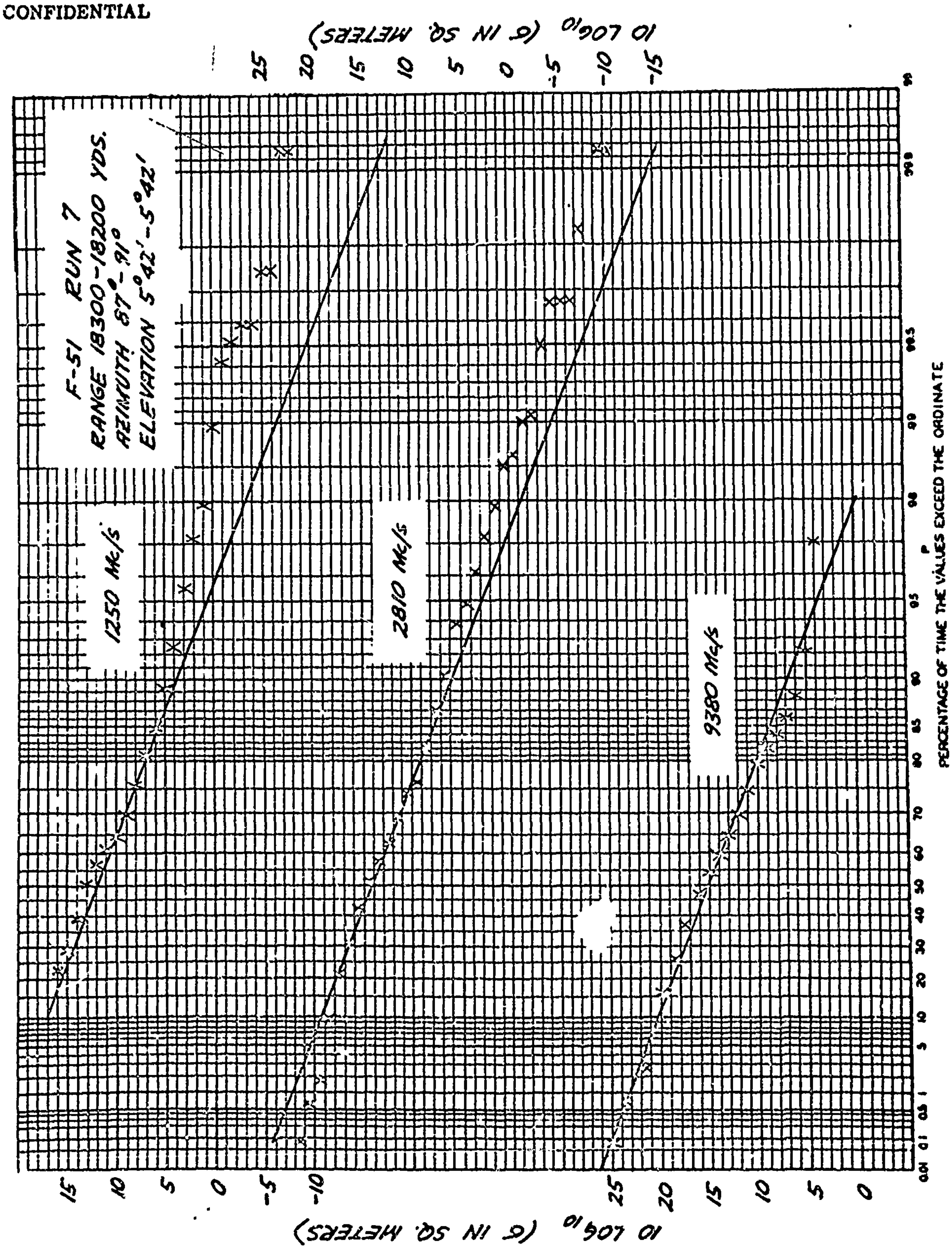

F-51 RUN 7
RANGE 18300-18200 YDS.
AZIMUTH 87°-91°
ELEVATION 5°42'-5°42'
1250 Mc/s
2810 Mc/s
9380 Mc/s
10 LOG10 (σ IN SQ. METERS)
PERCENTAGE OF TIME THE VALUES EXCEED THE ORDINATE

Figure 6

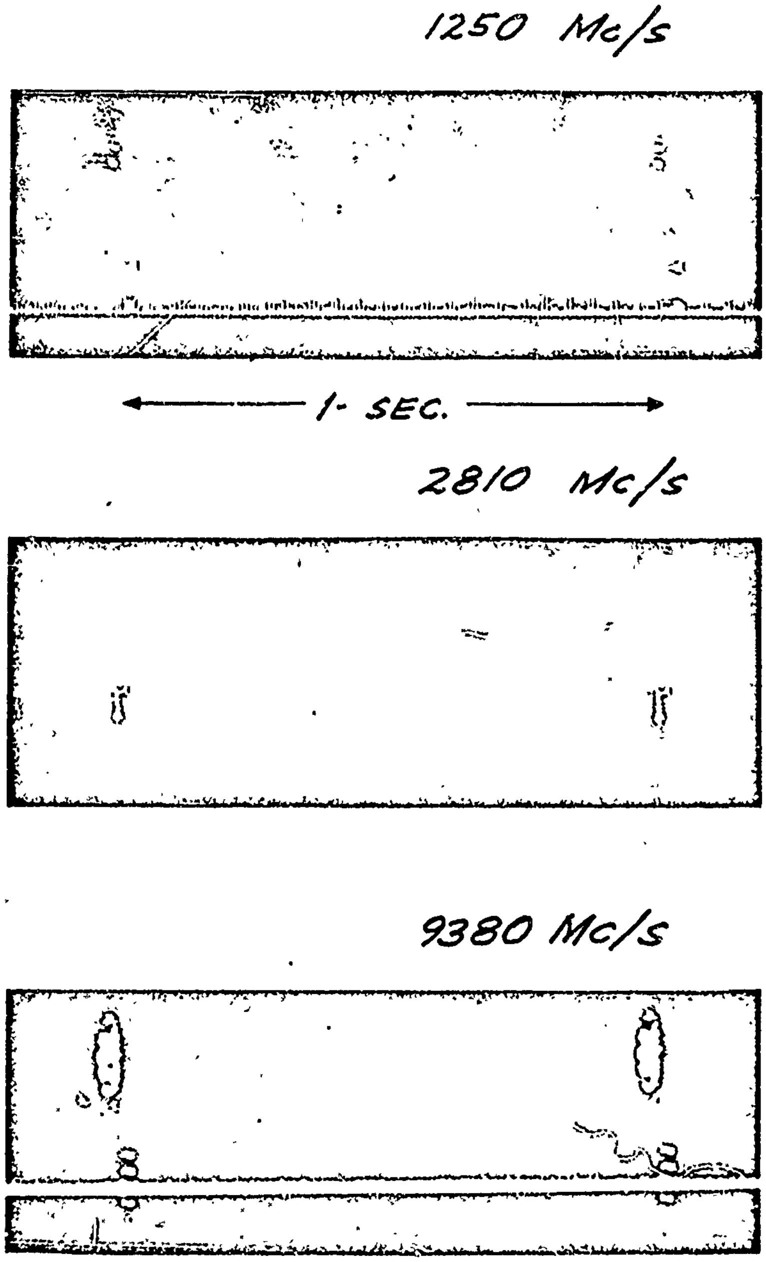
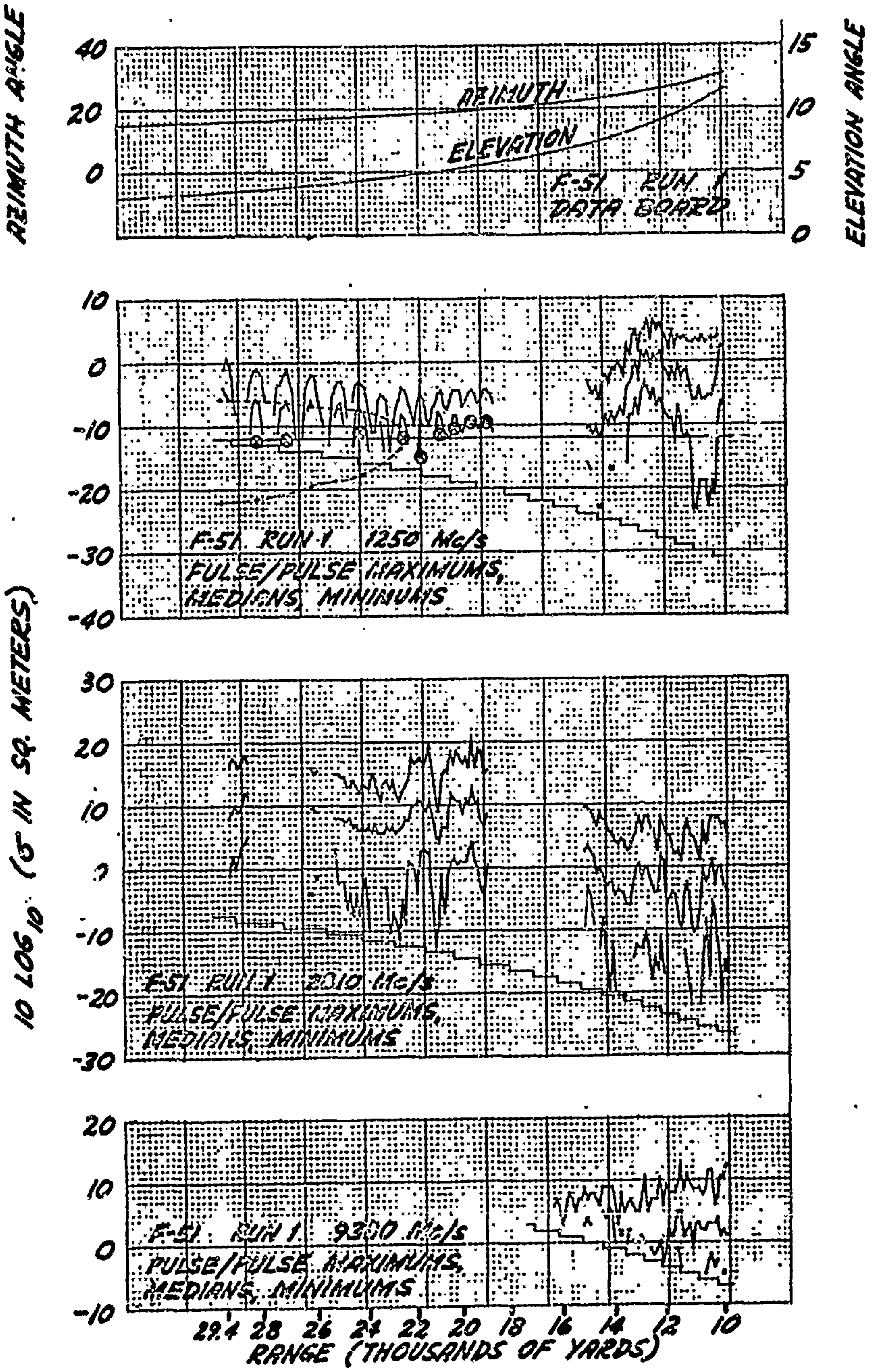


Figure 7



AZIMUTH ANGLE
40
20
0
AZIMUTH
ELEVATION
F-51 RUN 1
DATA BOARD
15
10
5
0
ELEVATION ANGLE
10 LOG10 (σ IN SQ. METERS)
F-51 RUN 1 1250 Mc/s
PULSE/PULSE MAXIMUMS, MEDIANS, MINIMUMS
F-51 RUN 1 2010 Mc/s
PULSE/PULSE MAXIMUMS, MEDIANS, MINIMUMS
F-51 RUN 1 9300 Mc/s
PULSE/PULSE MAXIMUMS, MEDIANS, MINIMUMS
29.4 28 26 24 22 20 18 16 14 12 10
RANGE (THOUSANDS OF YARDS)

Figure 8

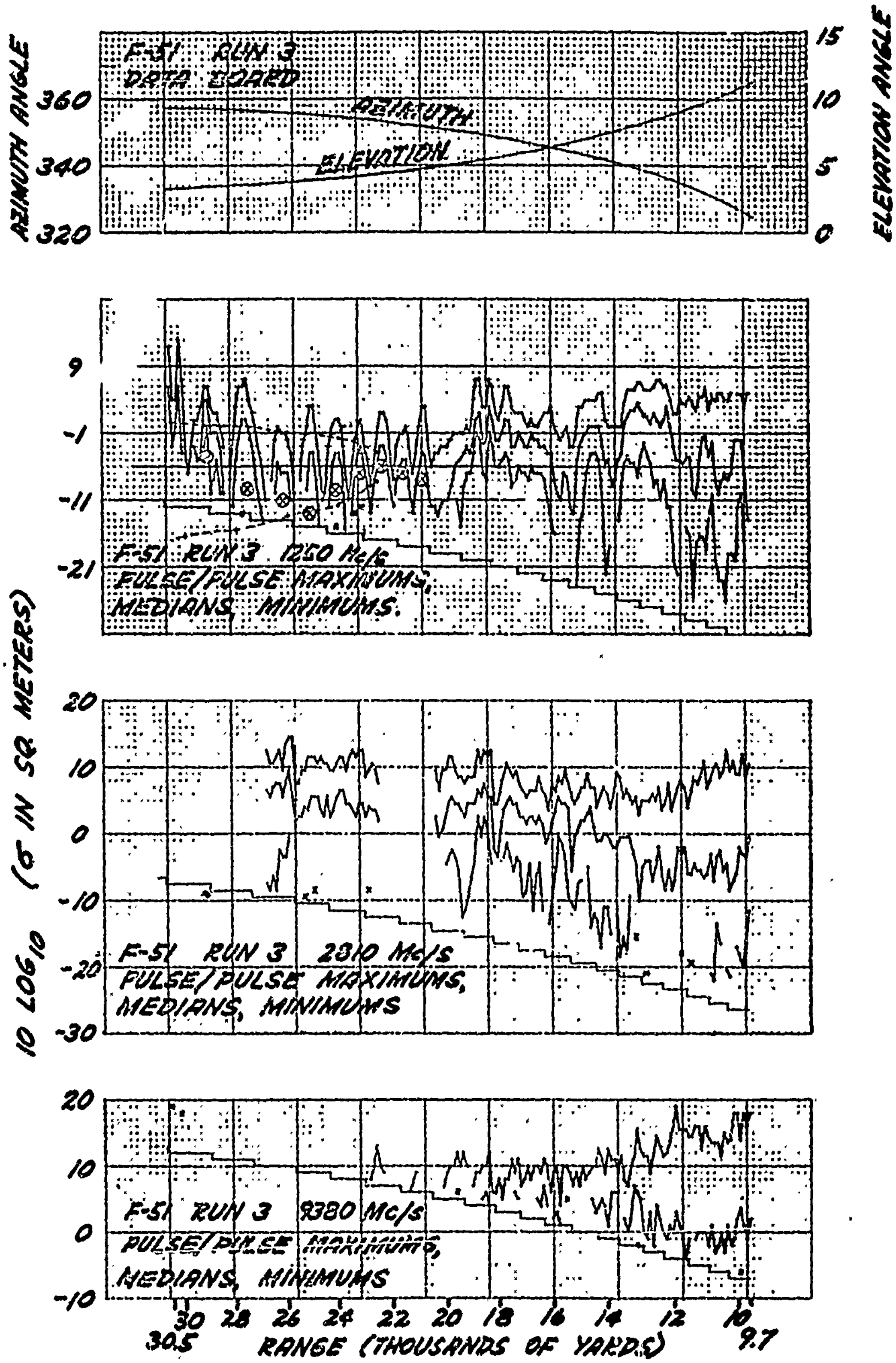

F-51 RUN 3
DATA BOARD
AZIMUTH
ELEVATION
AZIMUTH ANGLE
ELEVATION ANGLE
360
340
320
15
10
5
0
9
-1
-11
-21
F-51 RUN 3 1250 Mc/s
PULSE/PULSE MAXIMUMS,
MEDIANS, MINIMUMS.
10 LOG10 (σ IN SQ METERS)
20
10
0
-10
-20
-30
F-51 RUN 3 2810 Mc/s
PULSE/PULSE MAXIMUMS,
MEDIANS, MINIMUMS
F-51 RUN 3 9380 Mc/s
PULSE/PULSE MAXIMUMS,
MEDIANS, MINIMUMS
30 28 26 24 22 20 18 16 14 12 10
30.5
9.7
RANGE (THOUSANDS OF YARDS)

Figure 9

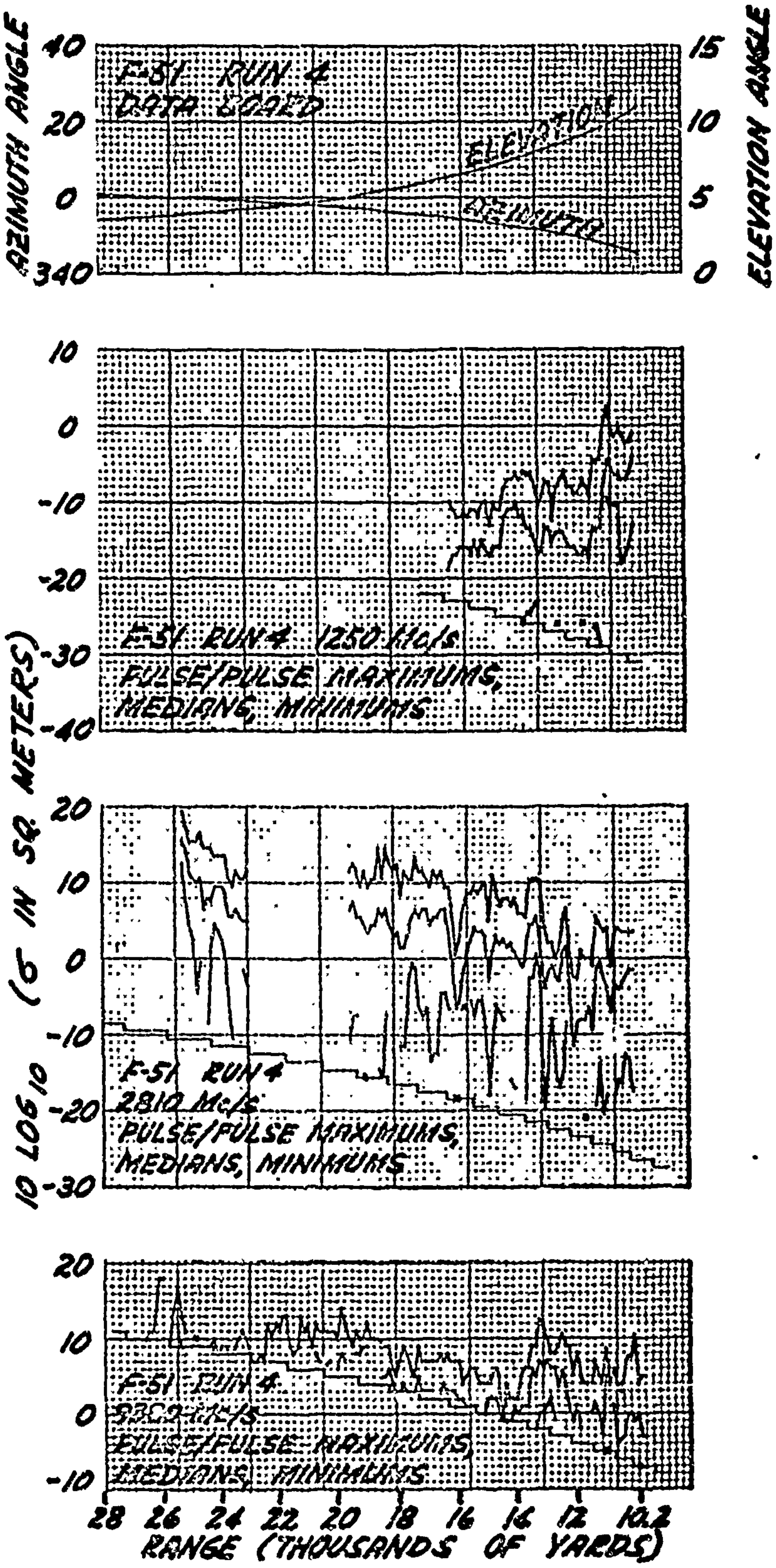

AZIMUTH ANGLE
ELEVATION ANGLE
F-51 RUN 4
DATA LOBED
ELEVATION
AZIMUTH
40
20
0
340
15
10
5
0
10 LOG10 (σ IN SQ. METERS)
F-51 RUN 4 1250 Mc/s
PULSE/PULSE MAXIMUMS,
MEDIANS, MINIMUMS
F-51 RUN 4
2810 Mc/s
PULSE/PULSE MAXIMUMS,
MEDIANS, MINIMUMS
F-51 RUN 4
PULSE/PULSE MAXIMUMS,
MEDIANS, MINIMUMS
28 26 24 22 20 18 16 14 12 10.2
RANGE (THOUSANDS OF YARDS)

Figure 10

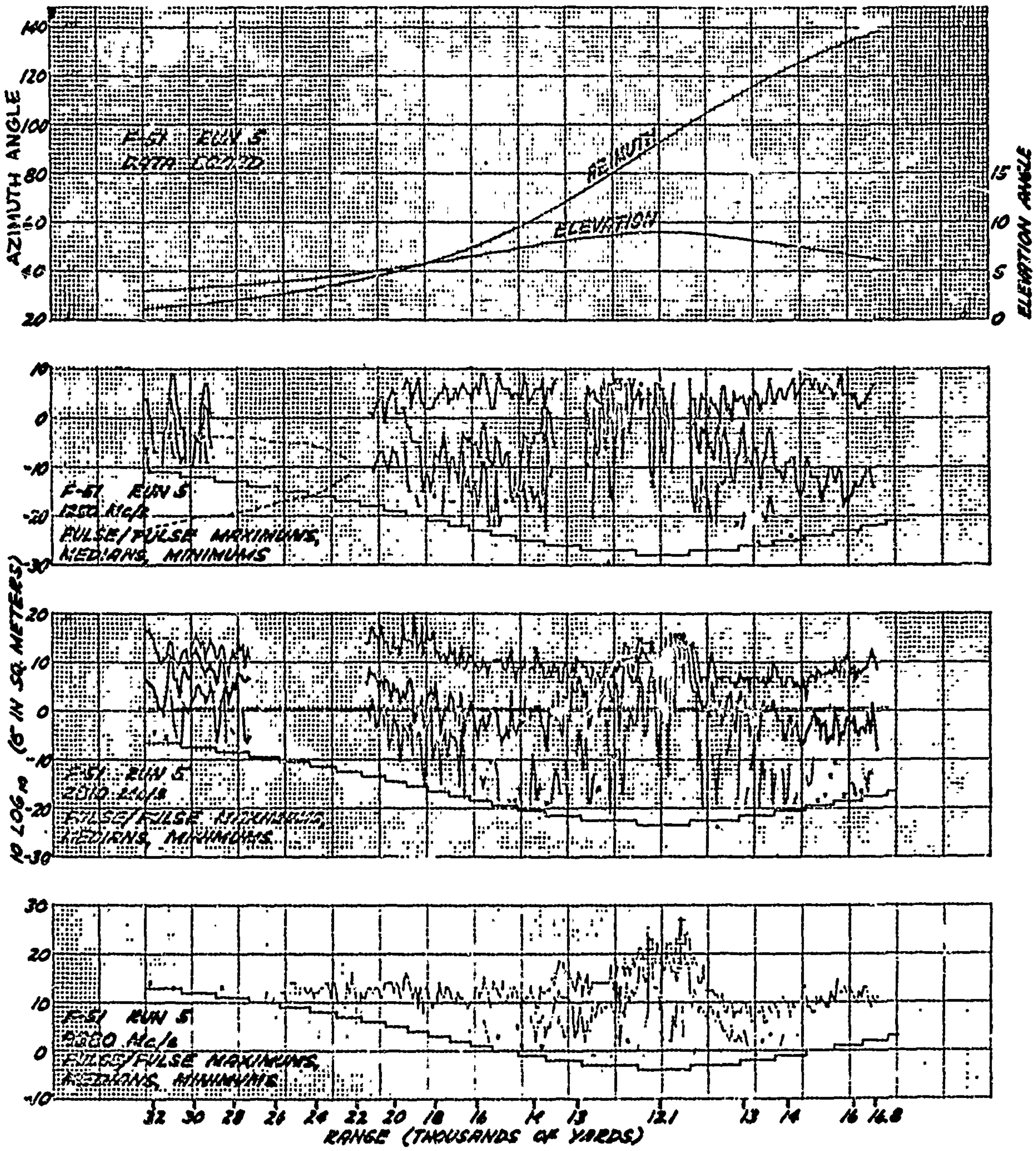

AZIMUTH ANGLE
ELEVATION ANGLE
F-51 RUN 5
DATA LOGGED
AZIMUTH
ELEVATION
F-51 RUN 5
1250 Mc/s
PULSE/PULSE MAXIMUMS,
MEDIANS, MINIMUMS
10 LOG10 (σ IN SQ. METERS)
F-51 RUN 5
PULSE/PULSE MAXIMUMS,
MEDIANS, MINIMUMS
F-51 RUN 5
PULSE/PULSE MAXIMUMS,
MEDIANS, MINIMUMS
RANGE (THOUSANDS OF YARDS)

Figure 11

CONFIDENTIAL

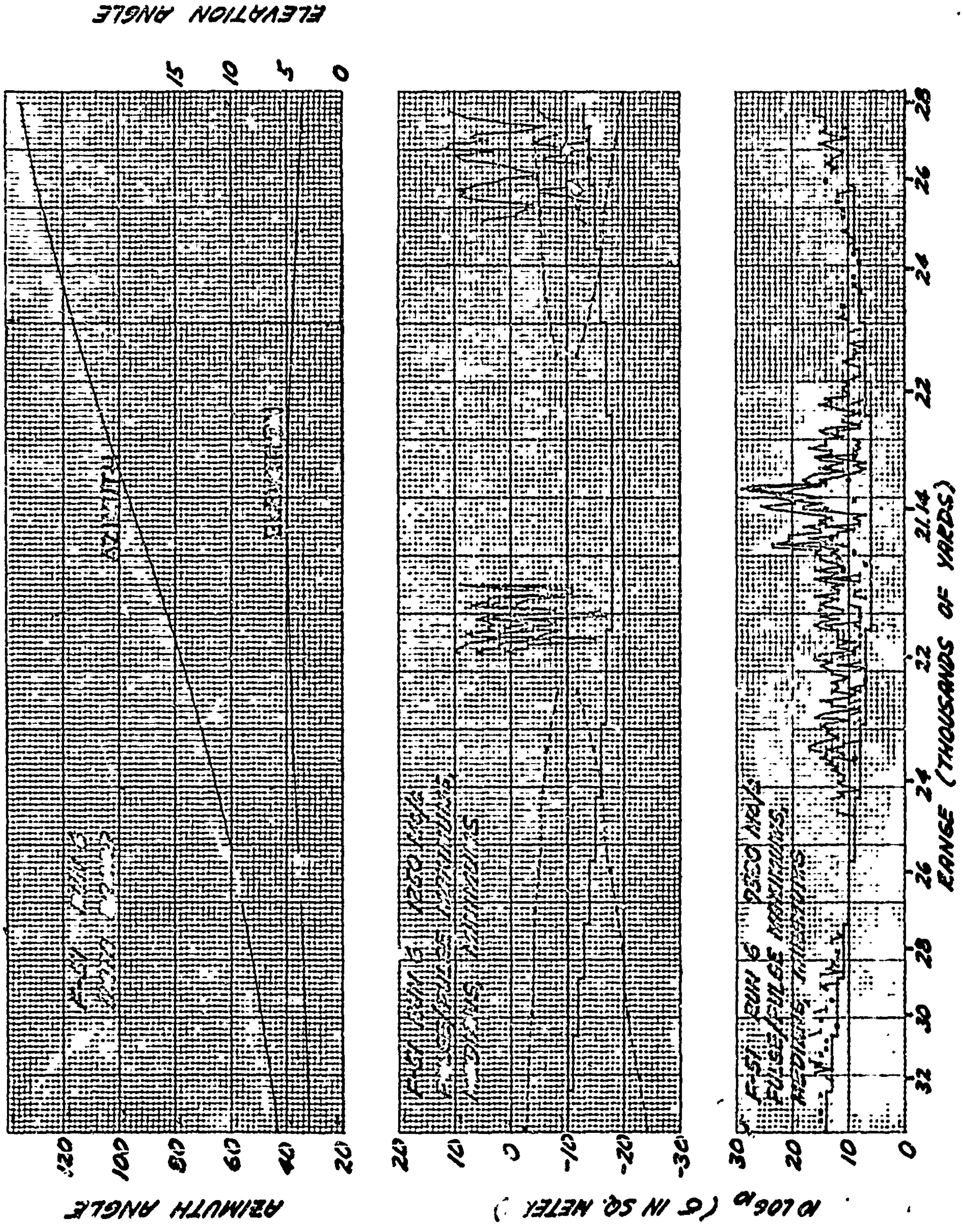


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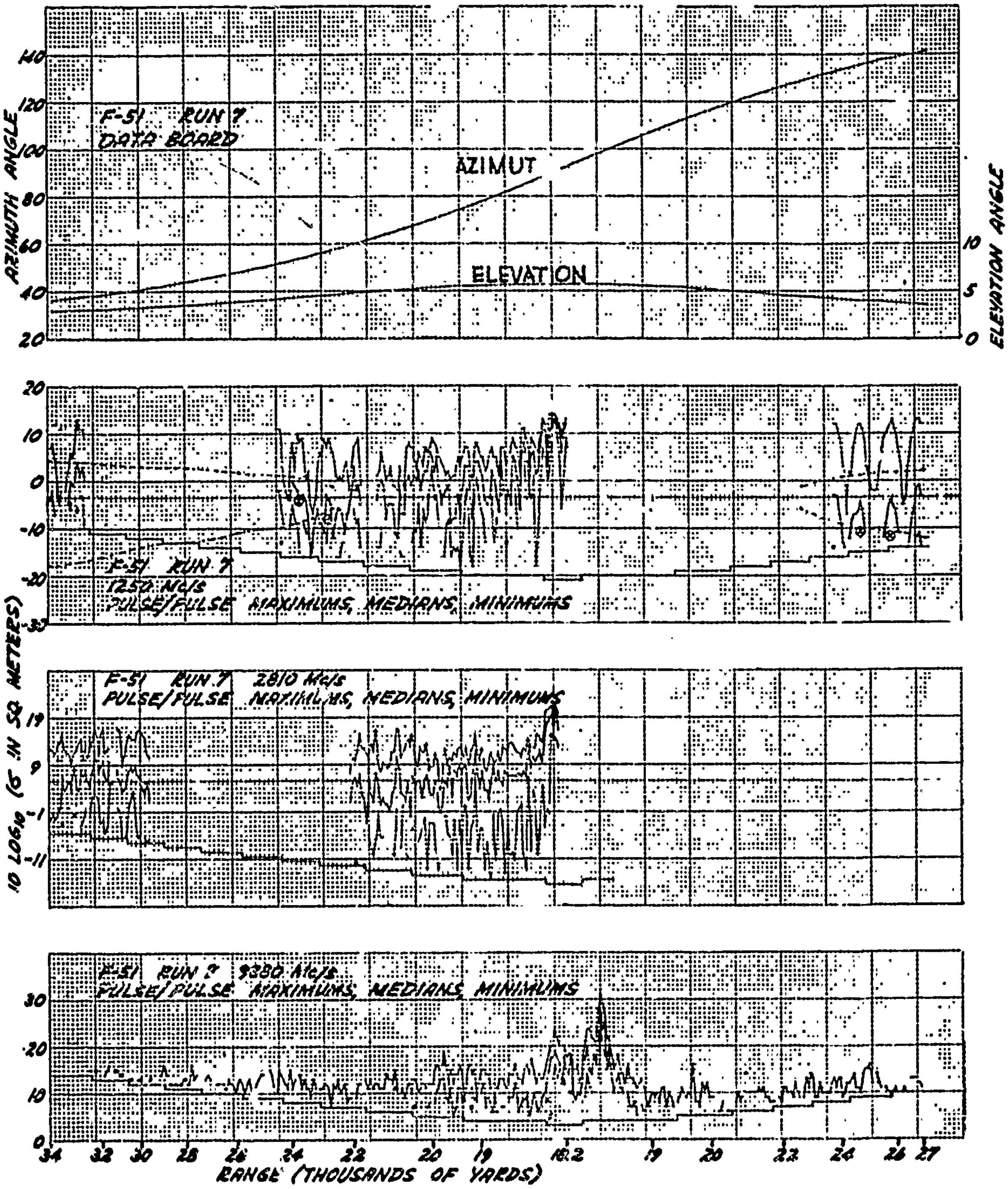
Figure-12



F-51 RUN 7
DATA BOARD
AZIMUT
ELEVATION
AZIMUTH ANGLE
ELEVATION ANGLE
F-51 RUN 7
1250 Mc/s
PULSE/PULSE MAXIMUMS, MEDIANS, MINIMUMS
F-51 RUN 7 2810 Mc/s
PULSE/PULSE MAXIMUMS, MEDIANS, MINIMUMS
10 LOG10 (σ IN SQ METERS)
F-51 RUN 7 9380 Mc/s
PULSE/PULSE MAXIMUMS, MEDIANS, MINIMUMS
RANGE (THOUSANDS OF YARDS)

Figure 13

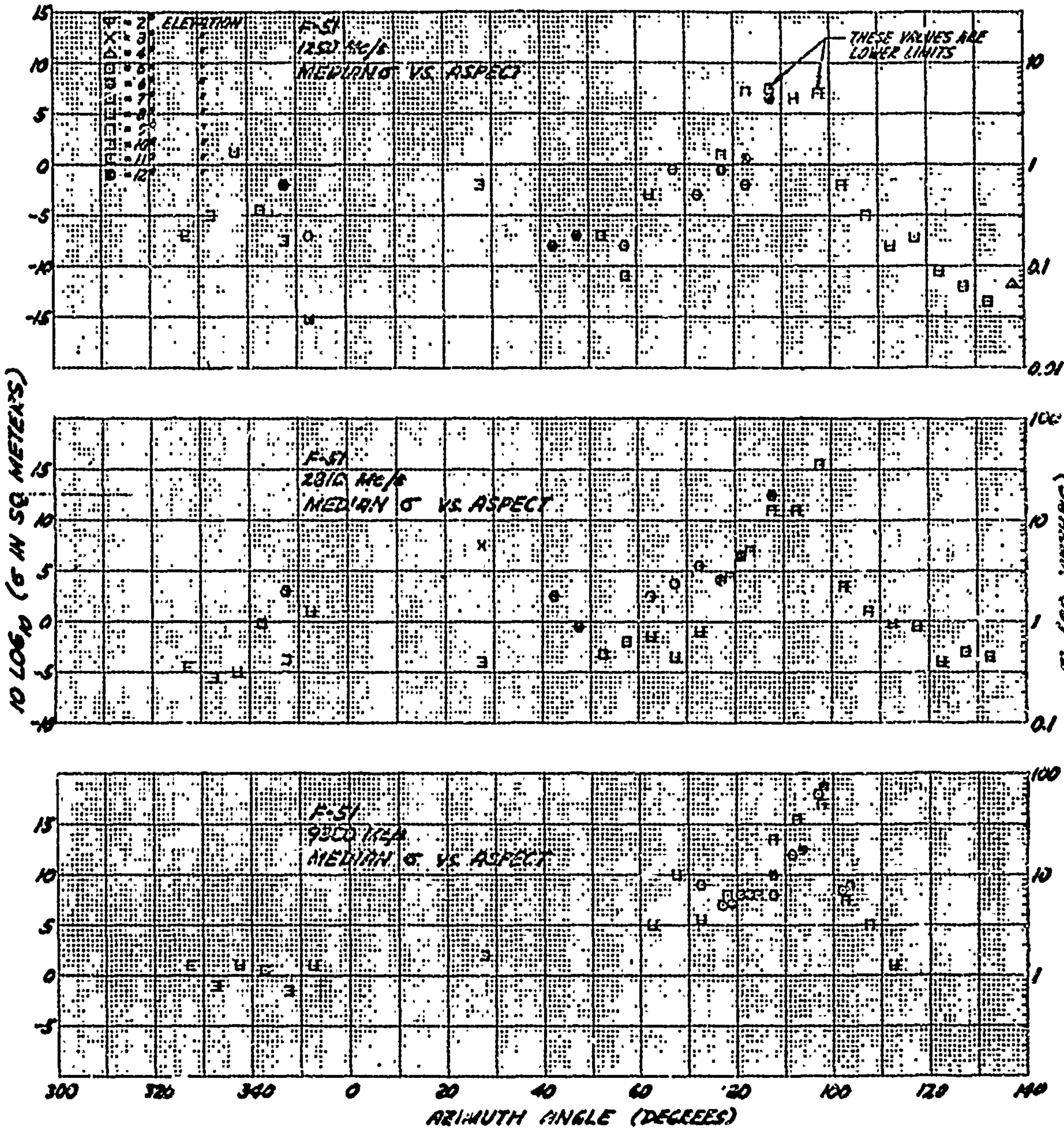

F-51
1250 Mc/s
MEDIAN σ VS. ASPECT
ELEVATION
THESE VALUES ARE LOWER LIMITS
F-51
2810 Mc/s
MEDIAN σ VS. ASPECT
F-51
9300 Mc/s
MEDIAN σ VS. ASPECT
10 LOG10 (σ IN SQ METERS)
σ (SQ METERS)
AZIMUTH ANGLE (DEGREES)
300
320
340
0
20
40
60
80
100
120
140

Figure 14

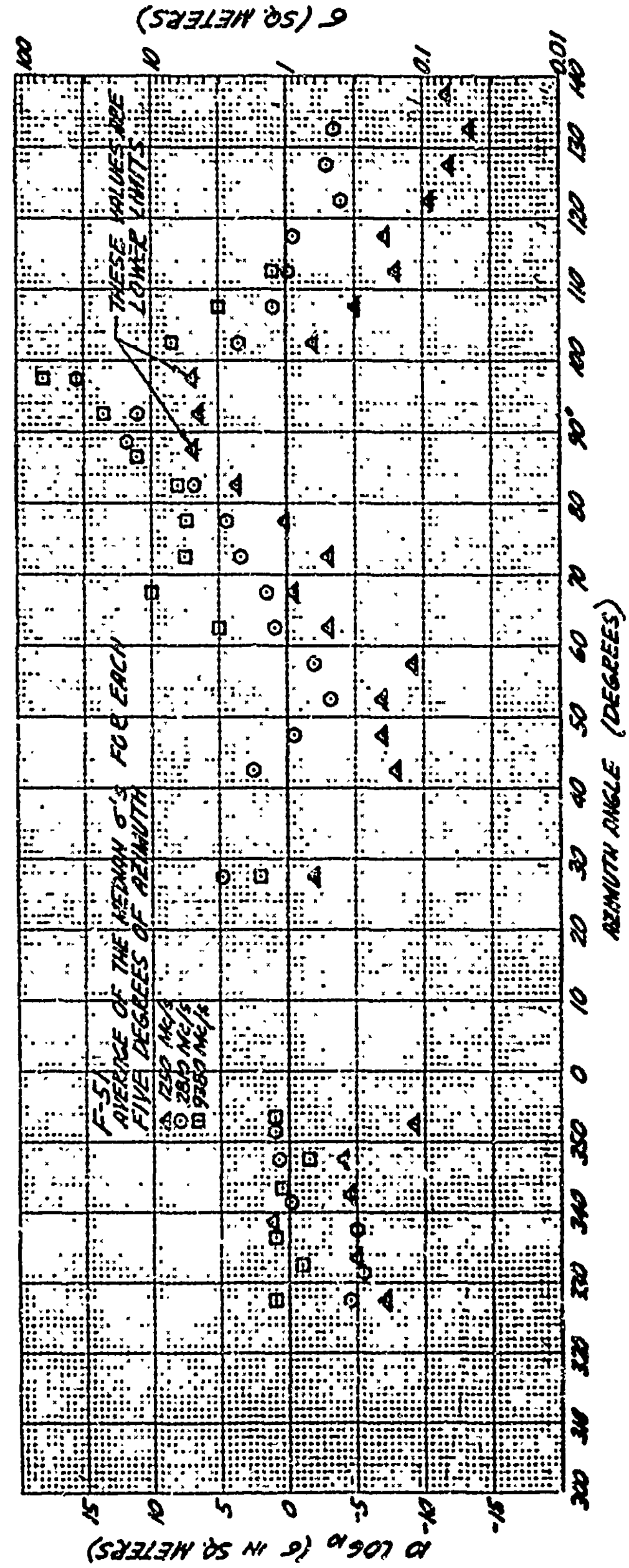

σ (SQ. METERS)
THESE VALUES ARE LOWER LIMITS
F-5A
AVERAGE OF THE MEDIAN σ's FOR EACH FIVE DEGREES OF AZIMUTH
1250 MC/S
2800 MC/S
AZIMUTH ANGLE (DEGREES)
10 LOG10 (σ IN SQ. METERS)

Figure 15

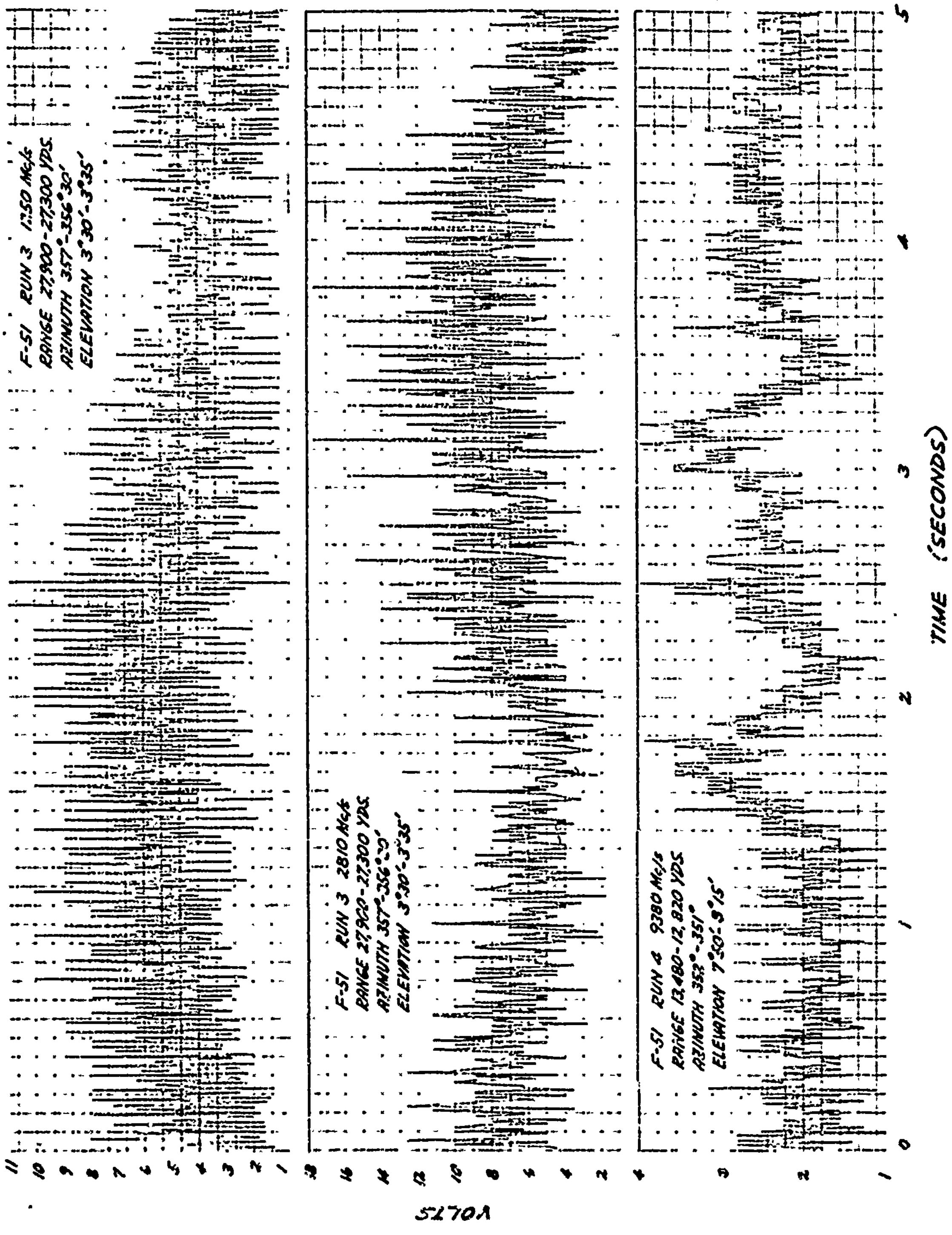

F-51 RUN 3 1250 Mc/s
RANGE 27,900-27,300 YDS.
AZIMUTH 357°-356°30'
ELEVATION 3°30'-3°35'
F-51 RUN 3 2810 Mc/s
RANGE 27,900-27,300 YDS.
AZIMUTH 357°-356°30'
ELEVATION 3°30'-3°35'
F-51 RUN 4 9380 Mc/s
RANGE 13,480-12,820 YDS
AZIMUTH 352°-351°
ELEVATION 7°50'-9°15'
TIME (SECONDS)
VOLTS

Figure 16

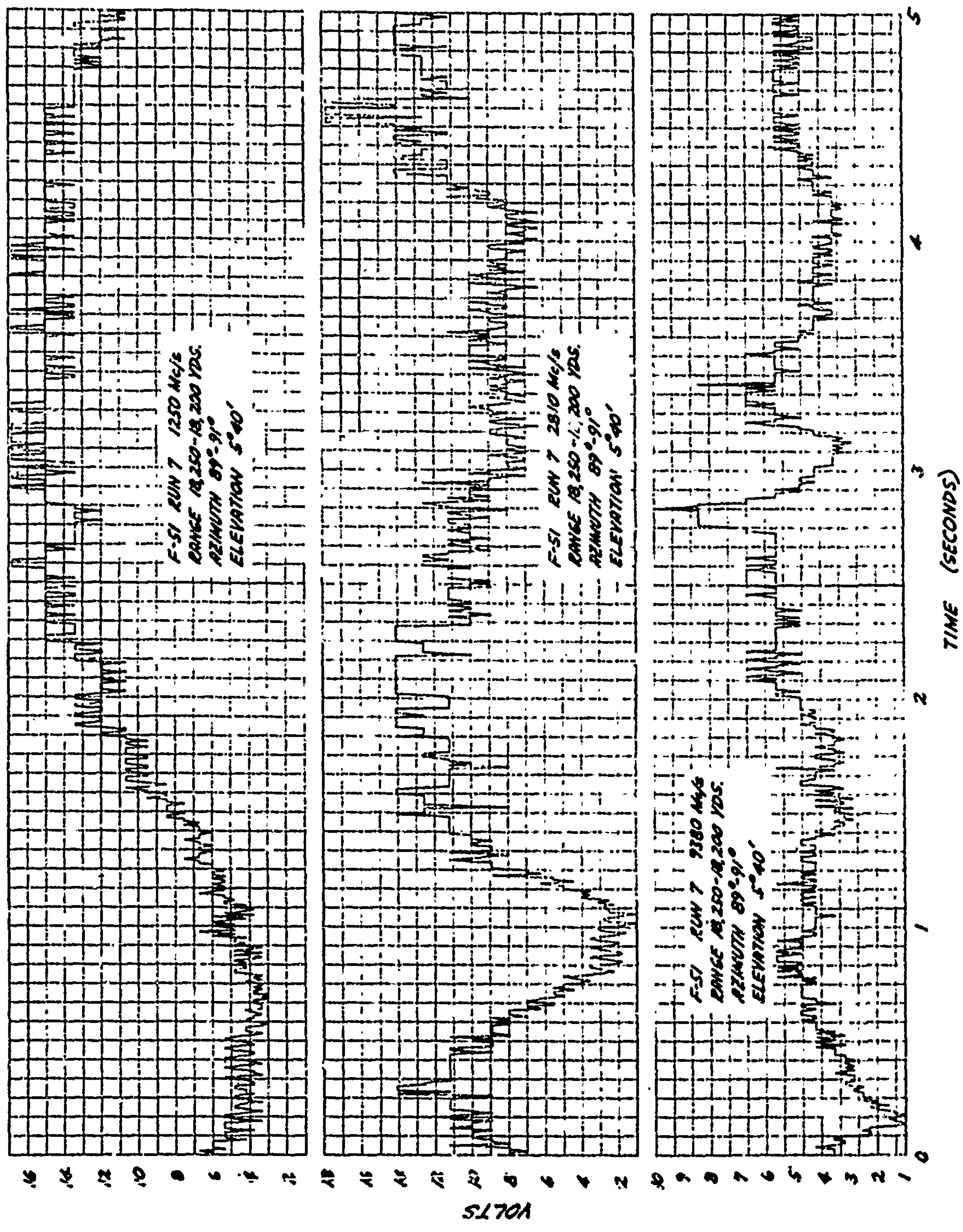

F-51 RUN 7 1250 Mc/s
F-51 RUN 7 2810 Mc/s
F-51 RUN 7 9380 Mc/s
VOLTS
TIME (SECONDS)

Figure 17

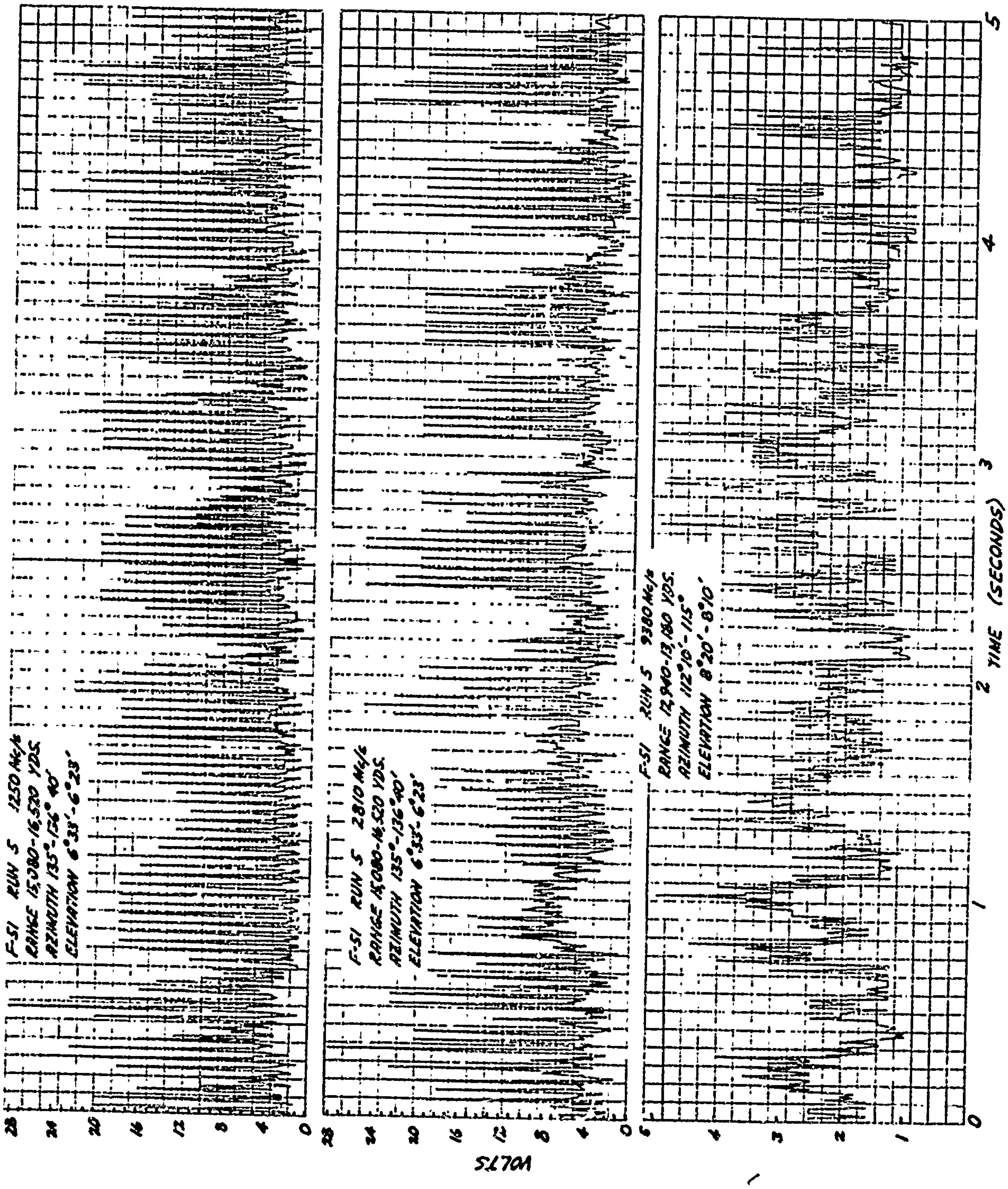
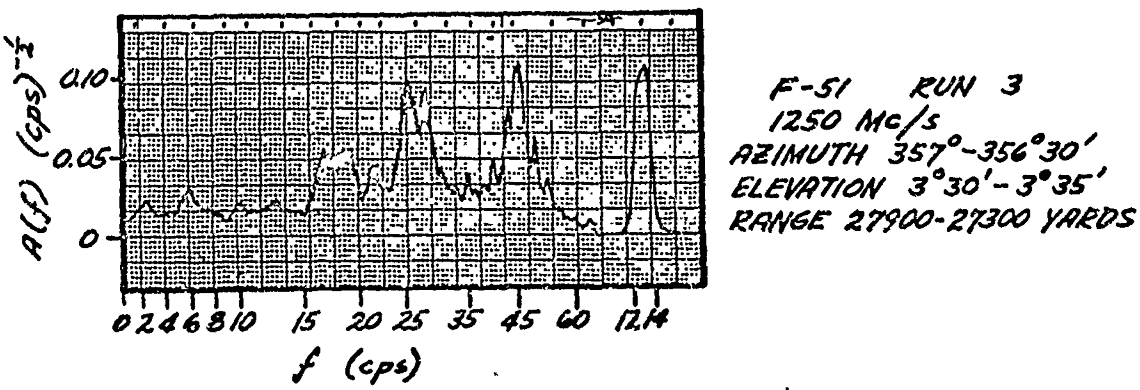

F-51 RUN 5 1250 Mc/s
RANGE 15,080-16,520 YDS.
AZIMUTH 135°-136°40'
ELEVATION 6°33'-6°23'
F-51 RUN 5 2810 Mc/s
RANGE 15,080-16,520 YDS.
AZIMUTH 135°-136°40'
ELEVATION 6°33'-6°23'
F-51 RUN 5 9380 Mc/s
RANGE 12,940-13,180 YDS.
AZIMUTH 112°10'-115°
ELEVATION 8°20'-8°10'
VOLTS
TIME (SECONDS)

Figure 18


A(f) (cps)^-1/2
0.10
0.05
0
0 2 4 6 8 10 15 20 25 35 45 60 12 14
f (cps)
F-51 RUN 3
1250 Mc/s
AZIMUTH 357°-356°30'
ELEVATION 3°30'-3°35'
RANGE 27900-27300 YARDS

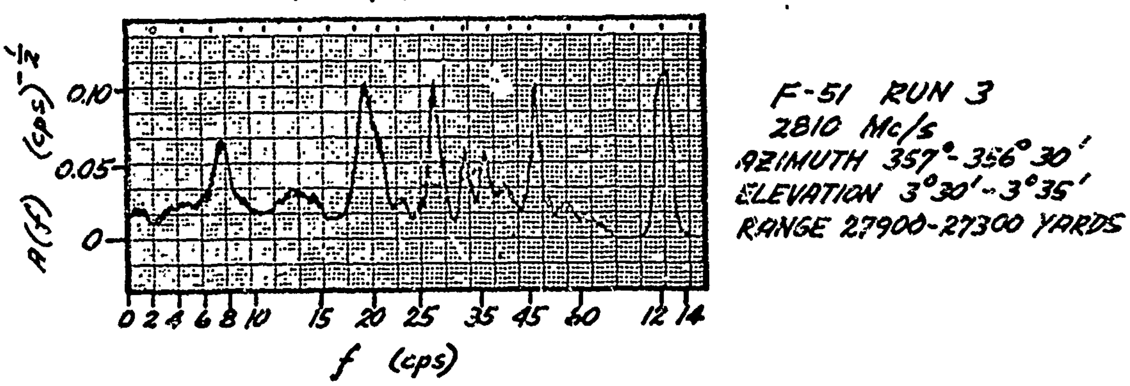
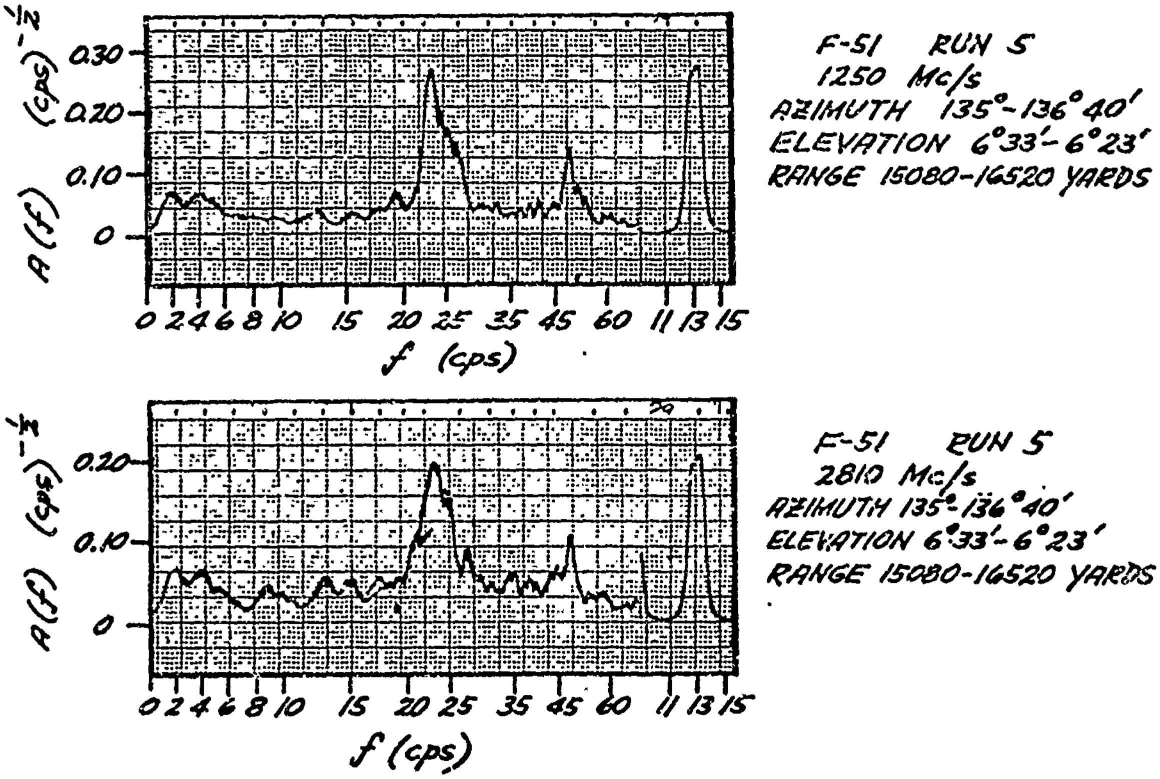
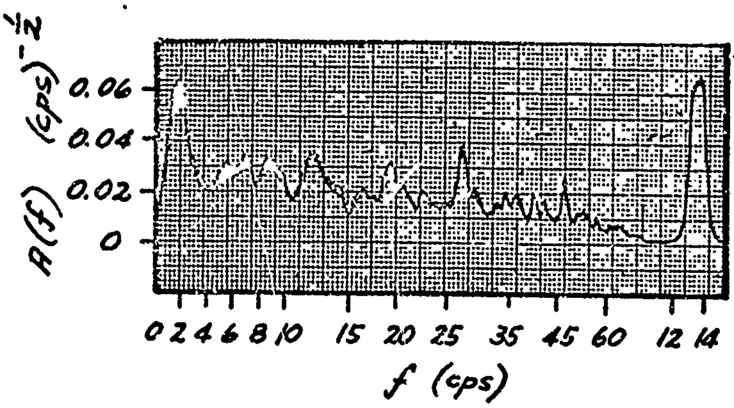

A(f) (cps)^-1/2
0.10
0.05
0
0 2 4 6 8 10 15 20 25 35 45 60 12 14
f (cps)
F-51 RUN 3
2810 Mc/s
AZIMUTH 357°-356°30'
ELEVATION 3°30'-3°35'
RANGE 27900-27300 YARDS

Figure 19

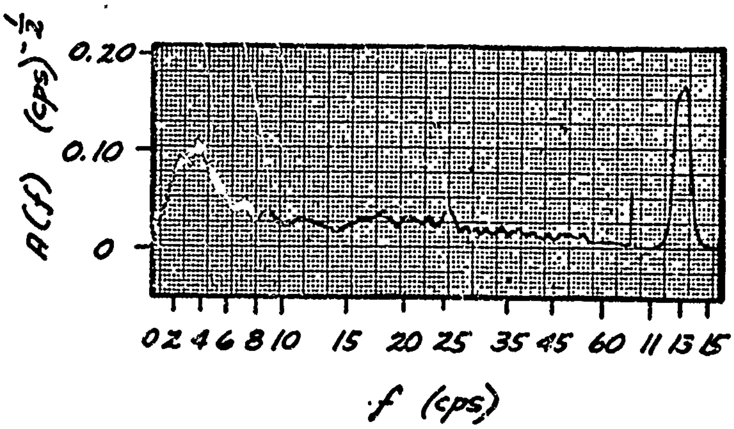
[redacted]



0.30
0.20
0.10
0
A(f) (cps)^-½
0 2 4 6 8 10 15 20 25 35 45 60 11 13 15
f (cps)
F-51 RUN 5
1250 Mc/s
AZIMUTH 135°-136° 40'
ELEVATION 6°33'-6°23'
RANGE 15080-16520 YARDS
0.20
0.10
0
A(f) (cps)^-½
0 2 4 6 8 10 15 20 25 35 45 60 11 13 15
f (cps)
F-51 RUN 5
2810 Mc/s
AZIMUTH 135°-136°40'
ELEVATION 6°33'-6°23'
RANGE 15080-16520 YARDS



F-51 RUN 4
9380 Mc/s
AZIMUTH 352°-351°
ELEVATION 7°50'-8°15'
RANGE 13480-12820 YARDS



F-51 RUN 5
9380 Mc/s
AZIMUTH 112°40'-115°
ELEVATION 8°20'-8°10'
RANGE 12940-13180 YARDS

Figure 21.

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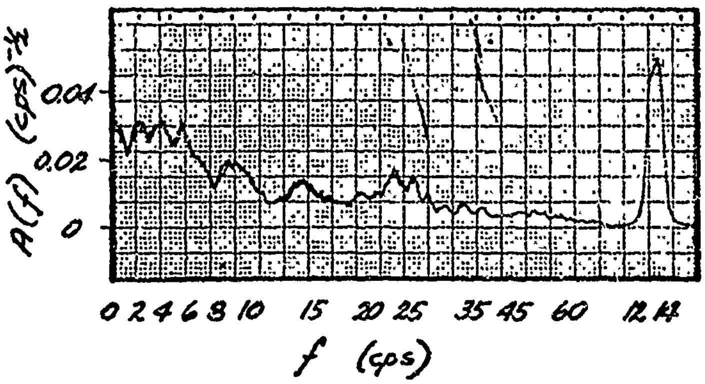
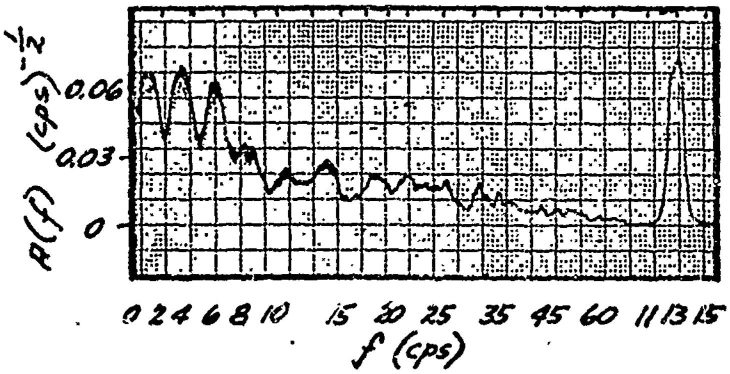
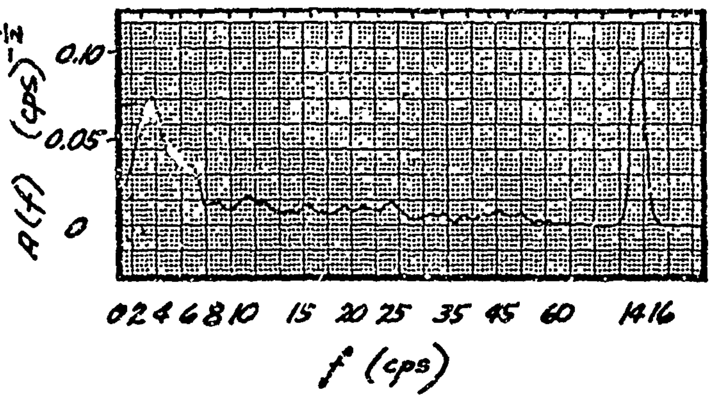


F-51 RUN 7
1250 Mc/s
AZIMUTH 89°- 91°
ELEVATION 5°40'
RANGE 18250-18200 YARDS



F-51 RUN 7
2810 Mc/s
AZIMUTH 89°-91°
ELEVATION 5°40'
RANGE 18250-18200 YARDS



F-51 RUN 7
9380 Mc/s
AZIMUTH 89°-91°
ELEVATION 5°40'
RANGE 18250-18200 YARDS

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C[redacted]
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Figure 22

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[redacted]

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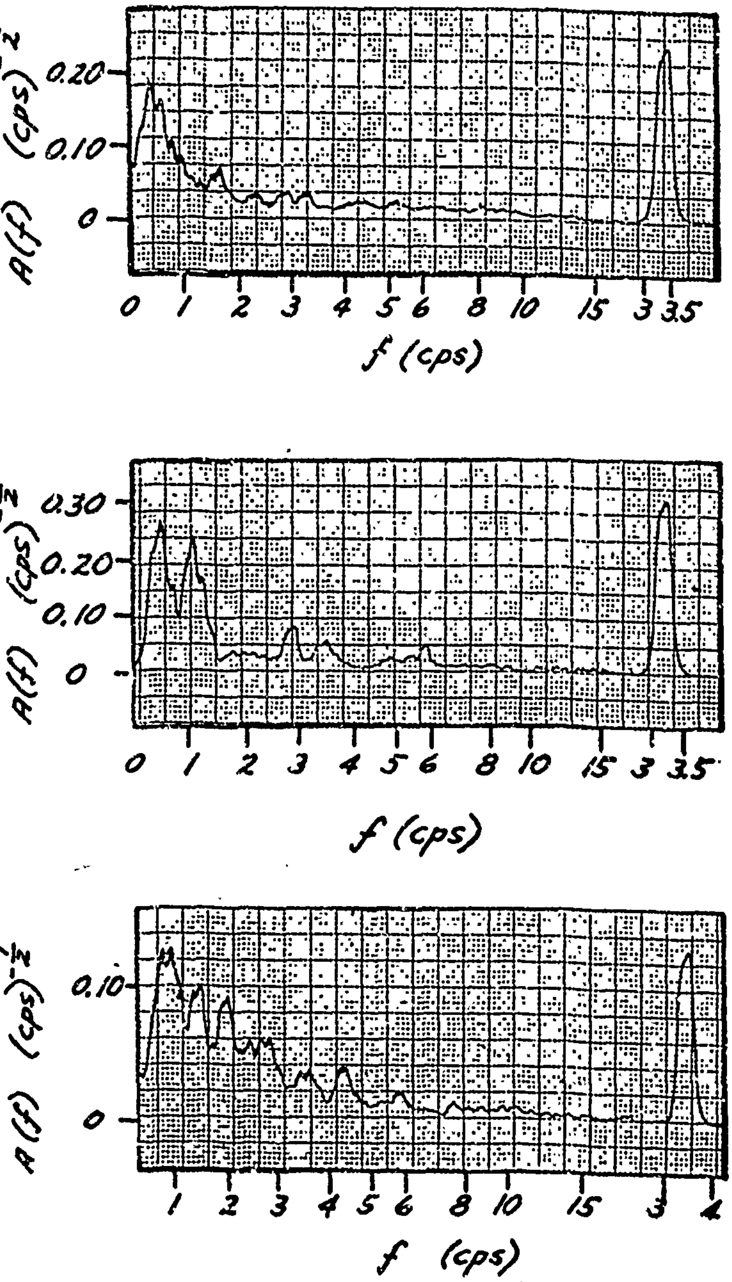

F-51 RUN 7
1250 Mc/s
AZIMUTH 89°-91°
ELEVATION 5° 40'
RANGE 18250-18200 YARDS

F-51 RUN 7
2810 Mc/s
AZIMUTH 89°-91°
ELEVATION 5° 40'
RANGE 18250-18200 YARDS

F-51 RUN 7
9380 Mc/s
AZIMUTH 89°-91°
ELEVATION 5° 40'
RANGE 18250-18200 YARDS

UNCLASSIFIED

[redacted]
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Figure 23