AN INVESTIGATION OF SITE REQUIREMENTS FOR VERY-HIGH-FREQUENCY RADIO RANGES

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CAA INFORMATION AND STATISTICS

FOREWORD

The authors wish to express appreciation for the valuable assistance rendered by other members of the Radio Development Section and by the CAA Experimental Station

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AN INVESTIGATION OF SITE REQUIREMENTS FOR VERY-HIGH-FREQUENCY RADIO RANGES

SUMMARY

This note presents an analysis of the results of extensive flight tests on a two-course visual radio range operating on a frequency of 125.4 megacycles The objective of these tests was to determine the effect of buildings, trees and telephone or power lines on the range courses and to establish from these results the site requirements for future installations A portable radio range was used and tests were made at various distances from reflecting objects and with the courses aligned in several different directions. Both on-course and cross-course recordings were obtained. Due to inability to isolate a reflecting object for study, it was impossible to reach definite conclusions concerning the reflection coefficients of any one of these objects. However, considerable valuable information was obtained which indicated that reflecting objects of the dimensions tested could not be tolerated within a radius of 220 to 870 feet from a range station depending upon the course orientation and the type of reflecting object

INTRODUCTION

A previous report[1] by the Civil Aeronautics Administration has described the results of some preliminary work performed to determine site requirements for very-high-frequency radio ranges. This report dealt primarily with the effects of wave polarization, however, and the results relating to site requirements were incomplete Subsequent to the tests described in the previous report, several notable advancements were made in the very-high-frequency radio range art resulting in the development of a visual-aural very-high-frequency radio range with simultaneous voice [2] While the efforts of this extensive range program resulted in a navigational aid that provided the desired performance in flat and open country where nearly ideal site conditions prevailed, very little was accomplished toward the determination of minimum site requirements for ranges under the conditions normally found in transcontinental installations During the development of ranges and localizers[3,4] it was found that the proximity of buildings, trees and wires had a marked effect on the smoothness of the courses produced by these facilities. Tests were also conducted on the thickly-wooded range site at Black Moshannon, Pennsylvania, using an aural type range[5] At this location trees were cut outward from the antenna location until satisfactory courses were obtained. It was found essential that a cleared area having a radius of 500 feet around the station had to be provided before flyable courses were obtained However, this site

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[1]J M. Lee and C. H Jackson, "Preliminary Investigation of the Effects of Wave Polarization and Site Determination with the Portable Ultra-High-Frequency Visual Radio Range", Technical Development Report No 24, February, 1940

[2]Radio Development Section, "A Visual-Aural Ultra-High Frequency Radio Range with Simultaneous Voice", Technical Development Report No. 49, April, 1945

[3]H. I Metz, "The CAA-RTCA Instrument Landing System, Part I, Development and Installation", Technical Development Report No 35, October, 1943.

[4]H. I. Metz, "The CAA-RTCA Instrument Landing System, Part II, Tests and Modifications", Technical Development Report No 36, October, 1943.

[5]J. C Hromada and P B King, "Development of the Ultra-High-Frequency Radio Range, Part I, The Ultra-High-Frequency Aural Radio Range", Technical Development Report No 42, June, 1944

requirement applied only where there were trees approximately 40 feet high The results of the Black Moshannon aural range tests were later confirmed at the same site using a visual range system with simultaneous voice.

Although previous tests had indicated some general information relating to site requirements, little effort had been made to correlate any of this information or to determine other essential data such as the effect of the height and size of reflecting objects, the effect of course orientation from these objects and exactly what degree of course scalloping due to reflections could be tolerated It was decided, therefore, to conduct a further investigation on this subject with a view toward collecting sufficient data to determine the trend of the reflection phenomenon and its effect on radio range courses Since the tests were to be conducted in the vicinity of the Administration's Experimental Station at Indianapolis, it was realized that it would be impossible to completely isolate any one condition because of the multiplicity of reflecting objects anywhere in that area. It was possible to find several locations in the vicinity of Indianapolis where very good radio range performance could be expected but these areas were not sufficiently clear of obstructions to allow the portable range equipment to be moved any appreciable distance without encountering serious reflections from a combination of buildings, wires and particularly trees Likewise, if it was desired to determine effect of distance from a certain object upon the amount of course scalloping due to reflections, it would be impossible to move the equipment any appreciable distance from this object without encountering reflections from other objects It was decided, however, that very valuable information could be obtained under these conditions and that the trend of the results would indicate the final tests that should be made at a location where each reflecting object could be isolated.

EQUIPMENT

The trailer described in the previous report[1] was used to house a complete two-course visual radio range system. The same towing vehicle was also used The original antenna system, transmitter and transmission line modulator were replaced by equipment of more modern design The power supply, voltage regulating equipment and frequency regulating equipment remained the same as in the previous tests

Horizontal loop-type antennas were used because it was desired to duplicate the equipment used in fixed installations where it is necessary to provide essentially pure horizontal polarization. The theory of operation and general description of the antenna system and modulator are completely covered in the report on the visual-aural system with simultaneous voice.[2] The aural and simultaneous voice features were not provided in this equipment since any data applying to the visual system would also apply to the aural system and since reflections have not been found to cause any serious interference to the voice channel A block diagram of the complete transmitting equipment is shown in figure 1 Since only visual signals were transmitted, the antenna system consisted of three loops. The spacing between adjacent antennas was 120 degrees and a current ratio of 1.73 to 1 existed between the center and outside loops The resulting field pattern as measured on the ground is shown in figure 2. A metal counterpoise having the dimensions shown in figure 3 was installed on the roof of the trailer one-half wavelength below the loop antennas. The counterpoise was covered with one-half inch mesh wire screen and was so designed that those sections extending beyond the limits of the trailer could be folded onto the roof during transit. This counterpoise effectively reduced the radiation of lobes at high angles thereby eliminating the possibility of course discontinuity due to the lobes Figure 4 is a photograph of the complete trailer equipment located for tests to determine the effect of trees

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[1]Loc Cit.

[2]Loc. Cit.

The transmitter used was a type TUD operating at 125.4 megacycles. A type 807 tube was used as a fundamental crystal oscillator and frequency quadrupler A crystal frequency of 5225 0 kilocycles was used The crystal stage was followed by an 807 doubler and a neutralizer fundamental amplifier which used a type HK 54 tube. This stage was link coupled to a pair of HK 54 tubes which were used as a push-pull tripler. The tripler stage was inductively coupled to the neutralized power-amplifier which also used a pair of HK 54 tubes An untuned output circuit coupled the output to the mechanical modulator The average carrier power output of the transmitter was 150 watts The transmitter was originally designed for transmission of airport traffic control voice signals at 132 megacycles and the modulator was used in these tests for occasional voice communication from ground to plane Voice communication was found to be essential for efficient coordination of work between the ground and flight personnel Such extensive flight tests were planned that it would have been very inefficient for the plane to land each time it was desired to move the trailer to a new location A 140-megacycle transmitter was installed in the plane for communication with ground personnel and a Hallicrafter very-high-frequency reciever was provided in the trailer towing truck for reception of these signals. With this arrangement instructions for placement of the trailer could be given from the plane, the instructions acknowledged from the ground and the trailer moved while the plane was proceeding to the location where cross-course tests would be made with the new course orientation Although it was anticipated that badly distorted voice signals would be received from the ground equipment, the received speech was found to be exceptionally good considering the method of modulation used

A Western Electric type RUM receiver was used in the airplane for reception of the trailer signals This receiver is similar to the type RUK localizer receiver[3] except that it was modified to include a radio frequency amplifier and several other improvements A Western Electric type 385-A tube was used as a radio-frequency amplifier and its grid circuit was capacitively coupled to the antenna input circuit The plate circuit was inductively coupled to a type 6J7 mixer tube The heterodyne voltage was applied to the screen grid of the mixer A crystal-controlled oscillator operating at a frequency of 9 617 megacycles and three harmonic multipliers were used to produce heterodyne voltage Two twin-triode type 6N7 tubes served as the crystal oscillator and harmonic multiplier

The mixer stage was coupled into a three-stage, 10-megacycle, intermediate-frequency amplifier which used three 6SK7 tubes The intermediate-frequency response was such as to provide a band width of approximately 70 kilocycles at six decibels attenuation and 275 kilocycles at 60 decibels The diode portions of a type 6SQ7 tube constituted the detector and delayed automatic volume control rectifier The triode portion of the 6SQ7 tube acted as the first audio amplifier The output of this tube was fed to the grid circuits of a twin-triode type 12SN7GT tube where the speech and visual signals were separated by means of resistance-capacity high-pass and low-pass filters The audio frequency response of the aural channel was attenuated 19 decibels at 100 cycles, 3 decibels at 400 cycles and 7 5 decibels at 4000 cycles from the response obtained at 1000 cycles The visual output of the 12SN7GT was coupled to 90-cycle and 150-cycle band-pass filters connected in parallel The outputs of the two filters were applied to copper-oxide rectifier units whose load circuits were connected to a balanced bridge circuit The vertical needle of a crossed-pointer direct current instrument was operated by the rectified difference of the two voltages Figure 5 is a photograph of this receiver

The aircraft receiving antenna was a V-type as shown in figure 6. The theory connected with this antenna has been covered in the simultaneous range report [2] Its aerodynamic drag is negligible and its gain is somewhat higher than that of other antennas used previously The horizontal field pattern of the antenna as measured during level flight is shown in figure 7

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[3] Loc. Cit

[2] Loc. Cit.

The flight tests were conducted in the Administration's airplane NC-11, a Boeing Model 247D Figure 8 is a photograph of the aircraft instrument panel showing the crossed-pointer instrument installation. The instrument actually used in these tests is shown at the extreme left.

The direct current flowing in the crossed-pointer instrument circuit was applied to a General Radio type 715AE direct-current amplifier in order to obtain sufficient potential for full scale deflections of an Easterline-Angus Model AW, 0-5 milliampere graphic recorder

The recorder was adjusted so that the on-course or zero signal would indicate on the center of the recorder chart while full scale pointer deflections to the right or left would cause full scale deflection of the recorder in the same direction All recordings were calibrated to show the magnitude of amplification. This calibration was accomplished by marking the record when the vertical needle of the crossed-pointer instrument was deflected to the wingtip of the miniature airplane, three dots and four dots. Since the distance from center to the wingtip of the minature airplane is approximately one and one-half dots for the old style instruments and two dots for the newer style instruments, the next two dots beyond the wingtip are considered three dots and four dots, respectively The instrument used in these tests was an old type instrument having wingtip to wingtip dimensions of 3 dots and having serial number 193 The visual course width was measured in terms of a pointer deflection of four dots right to four dots left or vice versa.

TESTS

It was originally anticipated that tests made at Indianapolis would provide definite data which would indicate the effect on the course of the distance of the range from reflecting objects such as the Experimental Station building, telephone wires and trees It was also anticipated that definite reflection coefficients for these objects could be obtained. As previously explained, however, it was impossible to locate suitable sites where each condition could be isolated Inasmuch as other arrangements could not be made at the time, the tests proceeded as planned

Preliminary tests were made to determine that all of the equipment was in proper operating condition and to adjust the input potential to the 90- and 150-cycle filters in the receiver to provide a 4-dot to 4-dot deflection for a total course width of 20 degrees This course width had been found to be optimum during previous range work Within usable limits, the resulting course width varies inversely as the filter input potential since the greater the input potential, the greater will be the rectified differential voltage between the 90- and 150-cycle patterns resulting in greater indicator deflection thus producing a sharper course For this radio range the filter input potential for a 20-degree course width was found to be 20 volts This potential was maintained during all of the tests so that all recordings would be analyzed under identical conditions of course width. The filter potential for a given course width will change with different types of receivers where the filter circuits are not identical and where the crossed-pointer instrument calibration varies

Figure 9 shows the location of the various test points The letter references at each test point indicate the corresponding recording shown in subsequent figures. Test locations along the line normal to the face of the hangar are indicated by the symbol ⊥ while those along an angle of 45 degrees to the hangar are indicated by the symbol ∠ The first group of flight tests was made to determine the effect of the Experimental Station building on the range courses when the trailer was located at various distances on a line perpendicular to the face of the building Figure 10 is a photograph of the side of the building used in the tests The building is 120 feet long and 30 feet high The results of the flight tests are shown in figures 11 to 16, inclusive. Cross-course recordings with the courses aligned parallel to, perpendicular to and at 45 degrees to the face of the hangar are shown in figures 11, 13 and 15, respectively The corresponding on-course recordings are shown in figures 12, 14 and 16, respectively The charts are placed in the same order for cross-course and on-course recordings so an easy comparison may be made. Two graphs showing the effect of distance on the amplitude of scalloping for each course are included in the figures containing the cross-course records On each graph the amplitude of scalloping is also shown along the Y-axis of the graph as scalloping in percent of the 4-dot to 4-dot deflection This is the only means by which the recordings can be properly analyzed and compared with past or future records The amplitude of the 4-dot deflection may vary from time to time due to a change in gain of the direct-current amplifier Therefore, a quarter inch of measured amplitude may be perfectly satisfactory when the 4-dot to 4-dot calibration is in the order of 4 inches A course would not be flyable, however, if the same quarter inch of scalloping is present when the 4-dot to 4-dot calibration is less than one inch Therefore, all scalloping encountered during these tests is ultimately referred to in terms of scalloping in percent of 4-dot to 4-dot deflection A sketch is included at the lower center of each figure to show the test points for the respective recordings Each course was cross-checked at distances ranging from 10 to 23 miles from the trailer depending upon convenient check points Cross-course checks were also made at a distance of one mile from the station The on-course records show the distance from the station where the recording started, the ease with which the course was flown and the signal encountered over the station

An analysis of the first group of recordings reveals the information contained in Table I The terminology used in the "ease of flight" column of the table are those adopted at the time the flight tests were made The term "easy to fly" should be interpreted as meaning any course that is flyable Under this condition a course might be excellent or barely flyable In almost all other cases some sort of difficulty was encountered which would make the course not acceptable for ordinary flight procedures. As indicated in the table, the maximum amount of scalloping that can be tolerated under the test conditions for "easy to fly" or flyable courses is 25 percent With the exception of the southeast course satisfactory operation was obtained when the trailer was located 500 feet or more from the building.

During the tests with the trailer located 500 feet from the front of the building some additional flight checks were made with the courses oriented at other angles to the face of the hangar All of the flight data obtained at this location are shown in figures 17 and 18 Figure 17 which contains the cross-course data has a polar graph showing the effect of course orientation on scalloping under the test condition The terminology used in grading the courses will be described later. The results of these tests are also shown in Table II The maximum amount of scalloping for "easy to fly" courses was found to be 22 2 percent Unsatisfactory courses were found toward the southeast at angles of 45 degrees and 60 degrees from the face of the building. Occasionally a course that is labeled as "fairly easy to fly" is considered satisfactory while in other cases it is considered as unsatisfactory These courses are only considered as unsatisfactory, however, when the percent scalloping exceeds the maximum "easy to fly" value The terminology "fairly easy to fly" was generally used in borderline cases and experience has shown that when excessive scalloping exists, it may be possible to find an unsatisfactory course easy to fly when the course is intercepted at just the right point where a favorable multiple course condition exists In these cases, however, it is usually found that this point is not easily located and further flight tests will find the course generally unsatisfactory. When a low degree of scalloping exists, it is generally found that "fairly easy to fly courses" are satisfactory.

When the trailer was located at a distance of 3150 feet from the front of the hangar, flight tests were conducted to determine if the scalloping changed with altitude and distance Tests were made at 20 miles and 3200 feet, 17 miles and 2000 feet, and 15 miles and 1200 feet. The results are shown in figure 19 In this particular case there was no observable difference between any of the recordings The southwest side of the course contained the most scalloping and remained practically identical in all three records. It is believed that this might not be the case, however, where the reflection pattern was very sharp or confined to an extremely small angle This condition is believed to be quite rare since, in most cases, the interference pattern was found to be quite broad.

Figure 20 is a group of four panoramic photographs showing the obstruction conditions that existed at the four test locations where the tests previously described were made.

A second group of tests were made on a line approximately 45 degrees to the face of the hangar toward the southwest. Figure 21 is a view of the building from the angle used in these tests The building has dimensions of 120 feet along the front, 150 feet along the side and approximately 30 feet of height The trailer was located at distances of 130 feet, 530 feet, 900 feet and 2100 feet from the hangar with three different values of course orientation at each location The results are shown in figures 22 to 27, inclusive Cross-course recordings are shown in figures 22, 24 and 26 while on-course recordings are shown in figures 23, 25 and 27 The same order of presentation has been used as for the previous group of tests.

An analysis of this group of tests is shown in Table III. The maximum amount of scalloping for "easy to fly" courses was 26.6 percent With the exception of the southeast and northwest courses, satisfactory operation was obtained when the trailer was located 530 feet or more from the building Figure 28 shows panoramic photographs of the four sites involved in this group of tests

The building tests just described are the only tests made where the recorded scalloping had any degree of regularity From the period of regularly occurring maxima or minima it is possible to determine the distance of the reflecting object from the course line With this information it is then possible to determine the exact location by inspection of the surrounding terrain An attempt was made during the building tests to check the computed distance of the reflecting object from the course line as determined by the period against the actual measured distance. A fair agreement was obtained at distances up to 500 feet Beyond that point reflections from other buildings began to cause more scalloping of the course than the building under test particularly at some angles Occasionally large errors were encountered at distances under 500 feet when the pattern maximum was oriented toward another building

A third group of tests were made to determine the scalloping effect from telephone or power lines. As has already been stated it was impossible to find a location where a wire line existed without trees or buildings being present to prevent isolation of the wire line effect. However, the sites selected were the best that could be found within a reasonable distance from Indianapolis The results of the wire line tests are shown in figures 29 to 32, inclusive. Two different course orientations were used at each site Table IV itemizes the results of each test The maximum scalloping for "easy to fly" courses was 23.2 percent Satisfactory courses were obtained at the second test point located 980 feet from the wire lines. However, the wire line effect at this point and beyond is almost completely obscured by reflections from neighboring trees Other course orientations and other locations between 50 and 980 feet were impossible to obtain because the trailer could not be maneuvered in the congested area Figure 33 is a group of panoramic photographs showing the three site locations involved in this group of tests.

The final group of tests was made to determine the effect of trees upon course scalloping Since it was not possible to find one isolated group of trees, these tests will only show the effect of different tree combinations The results are shown in figures 34 and 35 Only one direction of course orientation was possible due to inability to maneuver the trailer at all locations The results are also shown in Table V. As indicated, the maximum value of scalloping for "easy to fly" courses is 25 5 percent Figure 36 is a group of panoramic photographs of the sites involved

During all of the flight tests, an opportunity was presented for the accumulation of other engineering data of interest although not directly associated with the site determination project. Figure 37 contains two range signal recordings taken while the aircraft was circling the station at one mile The top recording was made with the recorder amplifier sensitivity reduced so that any irregularities in the patterns at off-course points could be observed. The bottom recording was taken with normal gain and shows that the instrument pointer is always off-scale except when at or near course. The miniature airplane and dot calibration are included on both records to show the degree of amplification.

It has always been of interest to obtain vertical field patterns of the range systems to determine the effect of the counterpoise in reducing vertical radiation and to show the general shape of the vertical patterns This is done by recording automatic volume control current and by means of a calibration curve obtained with a standard signal generator converting this current to relative field intensity in microvolts. The results of two such recordings are shown in figure 38 where recorder chart deflections have been plotted for various distances from the station Figure 39 is an automatic volume control current calibration curve for the receiver used in the tests In figure 40 the two graphs shown in figure 38 have been replotted in terms of relative field intensity at various distances.

An analysis of all the tests conducted indicates that the maximum value of scalloping that can be tolerated for flyable courses is approximately 25 percent when the course width is set for 20 degrees using an old type crossed-pointer indicator Since the time these data were taken, a new type meter has been adopted as standard by the Civil Aeronautics Administration As previously explained, the new type meter has wing tip to wing tip dimensions of the miniature airplane equivalent to the spacing of 4 dots while the old instrument has a 3 dot spacing for the miniature airplane. Therefore, the total dot width from 4 dots to 4 dots on the new meter is 8 dots and on the old meter is 7 dots The angular increase for 4 dots to 4 dots from the old to the new meter is approximately 11 2 percent Since the 4-dot spacing has increased by this amount, the maximum allowable scalloping must be decreased by the same amount without any other change Therefore, the maximum allowable scalloping value of 25 percent obtained in these tests must be reduced to 22 percent when the new meter is used

It is sometimes desirable to grade the condition of a radio range system in terms of the amount of scalloping present Therefore, the values up to 22 percent were divided into four groups denoted as "Excellent", "Very Good", "Good", and "Flyable" The values of scalloping above 22 percent were termed as "Unusable" The following table shows a tentative division based on the new meter

Excellent - - - - - - - - - - - - - -	up to 5 5 percent
Very Good - - - - - - - - - - - - - -	5.5 to 11 percent
Good - - - - - - - - - - - - - - - -	11 to 16.5 percent
Flyable - - - - - - - - - - - - - - -	16 5 to 22 percent
Unusable - - - - - - - - - - - - - -	Over 22 percent

These are the values that appear on the polar diagram of figure 17 and may easily be changed to conform with other types of instruments provided the difference in angular degrees between the reference points is known. The 22 percent value for maximum allowable scalloping agrees very well with subsequent tests where trees had to be removed considerably beyond a 500 foot radius before flyable courses resulted When the percent scalloping was reduced to 22 percent, the courses became flyable, while values above 22 percent were found to be unusable. The trees were particularly high in the case mentioned thereby accounting for the increased scalloping at a given distance over that indicated by previous tests where the trees were not as high

The data obtained in the building and wire tests have been examined to see how far away from the subject reflecting objects the range would have to be placed in order to get satisfactory operation from both courses The tree tests were not considered in this analysis because of the extreme multiple conditions that existed Table VI shows the results of this analysis.

TABLE VI

Test	Course Alignment	Minimum Distance
Building (right angles)	East-West	220 Feet
	North-South	410 "
	Northwest-Southeast	500 "
Building (45 degrees)	East-West	235 "
	North-South	450 "
	Northwest-Southeast	870 "
Wire	East-West	475 "
	North-South	355 "

It should be emphasized that the tests contributing to the results contained in Table VI were made with reflecting objects having elevations of approximately 30 feet above ground These results would change considerably with obstructions whose height differed from this figure The figures in the table are also subject to some degree of error due to the presence of other reflecting objects.

CONCLUSIONS

As a result of the tests conducted and described herein, the following conclusions may be reached. In interpreting the results it should be borne in mind that the range equipment used had antennas located 13 feet above ground while actual fixed installations have the antennas located 34 feet above ground.

1 The maximum scalloping that can be tolerated for flyable courses when an old type crossed-pointer instrument is used as an indicator is 25 percent of the 4-dot to 4-dot deflection

2 When a new type meter is used the maximum value of scalloping decreases to 22 percent.

3 The degree of scalloping varies inversely as D^X where X is some value between the limits of one and two The exact value of X cannot be determined from the data obtained in these tests D is the distance from the transmitter to the reflecting object

4 When range equipment of the type employed in these tests is used the maximum amount of scalloping will occur when the courses are aligned approximately 30 degrees from a line perpendicular to the face of the reflecting object.

5 With range equipment of the type used in these tests, the necessary separation from reflecting objects having an average height of 30 feet will vary from 220 to 870 feet depending on the course orientation and the type of reflecting objects

6 Further tests are necessary to determine accurately the following information with respect to the effect of scalloping on the range courses.

(a) The effect of distance from reflecting objects (building, wires, trees)

(b) The effect of the size of the reflecting object (building, wires, trees)

(c) The effect of height of the reflecting object (building, wires, trees)

(d) The effect of the number of conductors on a wire line

(e) The effect of an airway light beacon tower

(f) The effect of different types of building surfaces

(g) The effect of raising the trailer equipment so that the antenna height is 34 feet above ground so that results may be interpreted in terms of fixed installations

APPENDIX

As a result of the data accumulated in the tests described in this note, it is apparent that further tests will be necessary before certain laws of behaviour can be established for various reflecting objects Consequently, plans for future tests have been made and outlined as follows

1 The tests must be conducted in a locality where no other obstructions exist within a radius of two miles or more

2 The laws of distance from buildings, height of buildings and size of buildings should be determined using wire screen to simulate the building surfaces The laws can then be applied to buildings of known reflection coefficients and the amount of scalloping from real buildings determined

3 Laws for the effect of distance from wire lines as well as for the effect of the number and height of conductors in a line should be similarly determined using specially constructed lines

4. The effect of various conditions of trees should be studied particularly with respect to the height of trees and the distance from a single group of a given height.

The only known terrain suitable for the final building and wire line tests is desert country where no buildings, wires or trees exist In such terrain it would be easy to find a location where no obstructions existed within at least two miles It would also be desirable that no high mountain ranges existed within 20 miles that would shield the signal at low altitudes Although there are probably several such desirable locations in the country, one is known to exist near Winslow, Arizona A particularly desirable site is located several miles east of Winslow near Holbrook The ground at this location is relatively flat and there is only 700 feet difference in elevation at distances up to 20 miles A map of this section of the country is shown in figure 41

A wire screen arrangement such as that shown in figure 42 should be constructed so that 50-foot sections may be easily elevated by means of pulleys on poles After construction of the screen, the tests outlined in figure 43 should be conducted to determine the laws of scalloping with respect to distance from the reflector and with respect to course orientation. The course orientation tests should be made at a distance of about 400 feet where scalloping exists but is not too violent to prevent easy analysis. These tests should be conducted every 15 degrees from a line perpendicular to one face of the reflector to a line 45 degrees removed. Tests should be made up to distances of 1600 feet along the perpendicular and 45-degree line.

Upon completion of the above work, tests should be made to determine the effect of height and size of a reflecting object as outlined in figure 44. The same wire screen assembly should be used and the screen sections varied as outlined Tests should be made using widths of 50, 100 and 150 feet and with heights of 0, 10, 20, 30 and 40 feet The tests should be made with the courses aligned for maximum scalloping. With these two groups of tests the laws of scalloping due to distance, height, width of reflecting objects as well as the effect of course orientation may be obtained and applied to scalloping known to exist from various hangar surfaces.

A group of wire line tests is outlined in figure 45 The same poles used for the wire screens may be used for these tests with two additional poles added to extend the line to 450 feet in length. Tests should be made with a single conductor elevated 10, 20, 30 and 40 feet and with two or more conductors at different elevations Another wire line test could be easily made in desert country by locating a highway containing a real power and telephone line and conducting tests as outlined in figure 46.

It is highly probable that when radio range sites are selected for general installation of these facilities, there will be several occasions where it will be desirable to use space adjoining existing airway beacon light towers. It seems very desirable, therefore, to investigate the effect of such a tower on course scalloping This test is outlined in figure 47

Figure 48 outlines a group of tests to determine the effect of one group of trees. This group will determine only the effect of distance from the trees and the result of different orientations of the courses It will then become necessary to select other sites where trees of different height exist This can be accomplished by selecting sites on different airports at various elevations since, in general, the height of the trees varies with the elevation Such sites can be found on the map shown in figure 49 Suitable sites can probably be found at the Valle, South Rim and North Rim airports It would also be very desirable to know what effect the elevation of the trailer to provide an antenna height of 34 feet instead of 13 feet would have on the condition of course scalloping at a given location This test should be made wherever found convenient during the course of the other tests

Upon completion of the outlined tests, it is believed that the data can be presented so that it will be possible to determine quickly and conveniently what the effect of various objects near prospective sites will be and whether a radio range having flyable courses will result from an installation at the site

TABLE I

MAXIMUM VALUE OF SCALLOPING FOR "EASY TO FLY" COURSES - 25 PERCENT

Distance Between Trailer and Building	Course Information	Scalloping in Percent of 4-Dot to 4-Dot Deflection	Ease of Flight
130 Feet	E course - parallel to building	40.3 Percent	Somewhat difficult to fly
	W course - parallel to building	25.0 Percent	Easy to fly
	N course - through building	111.0 Percent	Not flyable
	S course - opposite building	101.0 Percent	Fairly easy to fly - severe bend near station
	NW course - 45° to building	20.2 Percent	Very difficult to fly
	SE course - 45° to building	124.0 Percent	Not noted due weather
500 Feet	E course - parallel to building	16.4 Percent	Fairly easy to fly
	W course - parallel to building	10.0 Percent	Easy to fly
	N course - through building	22 2 Percent	Easy to fly
	S course - opposite building	16.0 Percent	Easy to fly
	NW course - 45° to building	15.0 Percent	Easy to fly
	SE course - 45° to building	28.5 Percent	Somewhat difficult to fly
1500 Feet	E course - parallel to building	7.9 Percent	Easy to fly
	W course - parallel to building	5.2 Percent	Easy to fly
	N course - through building	7.3 Percent	Easy to fly
	S course - opposite building	7.3 Percent	Easy to fly
	NW course - 45° to building	5.1 Percent	Easy to fly
	SE course - 45° to building	8.9 Percent	Easy to fly
3150 Feet	E course - parallel to building	5.9 Percent	Easy to fly
	W course - parallel to building	4.2 Percent	Easy to fly
	N course - through building	5.2 Percent	Easy to fly
	S course - opposite building	5.2 Percent	Easy to fly
	NW course - 45° to building	6.9 Percent	Easy to fly
	SE course - 45° to building	10.4 Percent	Easy to fly

TABLE II

MAXIMUM VALUE OF SCALLOPING FOR "EASY TO FLY" COURSES - 22.2 PERCENT

DISTANCE FROM TRAILER TO BUILDING - 500 FEET

Course Information	Scalloping in Percent of 4-Dot to 4-Dot Deflection	Ease of Flight
E course - parallel to building	16.4	Fairly easy to fly
W course - parallel to building	10.0	Easy to fly
SE course - 30° from building face	19.5	Somewhat difficult to fly
NW course - 30° from building face	9.0	Easy to fly
SE course - 45° from building face	28.5	Somewhat difficult to fly
NW course - 45° from building face	15.0	Easy to fly
SE course - 60° from building face	43.0	Fairly easy to fly
NW course - 60° from building face	14.5	Easy to fly
S course - opposite building	16.0	Easy to fly
N course - through building	22.2	Easy to fly

TABLE III

MAXIMUM VALUE OF SCALLOPING FOR "EASY TO FLY" COURSES - 26.6 PERCENT

Distance Between Trailer and Building	Course Information	Scalloping in Percent of 4-Dot To 4-Dot Deflection	Ease of Flight
130 Feet	E course - parallel to building	40.3	Somewhat difficult to fly
	W course - parallel to building	25.0	Easy to fly
	N course - through building	111.0	Not flyable
	S course - opposite building	101.0	Fairly easy to fly- severe bend near station
	NW course - 45° to building	20.2	Very difficult to fly
	SE course - 45° to building	124.0	Not noted due weather
530 Feet	E course - parallel to building front	16.0	Fairly easy to fly
	W course - parallel to building front	21.6	Fairly easy to fly
	N course - parallel to building side	26.6	Easy to fly
	S course - parallel to building side	20.4	Easy to fly
	NW course - 45° to building	35.5	Fairly easy to fly
	SE course - 45° to building	69.0	Very difficult to fly
900 Feet	E course - parallel to building front	7.3	Easy to fly
	W course - parallel to building front	7.1	Easy to fly
	N course - parallel to building side	12.4	Easy to fly
	S course - parallel to building side	10.5	Easy to fly
	NW course - 45° to building	7.8	Easy to fly
	SE course - 45° to building	25.0	Easy to fly
2100 Feet	E course - parallel to building front	3.7	Easy to fly
	W course - parallel to building front	10.6	Easy to fly
	N course - parallel to building side	3.7	Easy to fly
	S course - parallel to building side	12.1	Easy to fly
	NW course - 45° to building	4.9	Easy to fly
	SE course - 45° to building	7.2	Easy to fly

TABLE IV

MAXIMUM VALUE OF SCALLOPING FOR "EASY TO FLY" COURSES - 23 2 PERCENT

Distance Between Trailer and Wires	Course Information	Scalloping in Percent of 4-Dot to 4-Dot Deflection	Ease of Flight
50 Feet	E course - parallel to wires	258 0	Not flyable
	W course - parallel to wires	48 8	Not flyable
	N course - through wires	86 0	Not flyable
	S course - opposite wires	59 2	Not flyable
980 Feet	E course - parallel to wires	14 2	Fairly flyable
	W course - parallel to wires	6 45	Fairly flyable
	N course - through wires	12 5	Easy to fly
	S course - opposite wires	19 4	Easy to fly
2200 Feet	E course - parallel to wires	20 0	Easy to fly
	W course - parallel to wires	21 4	Easy to fly
	N course - through wires	14 2	Easy to fly
	S course - opposite wires	23 2	Easy to fly

TABLE V

MAXIMUM VALUE OF SCALLOPING FOR "EASY TO FLY" COURSES - 25 5 PERCENT

Distance Between Trailer and Trees	Course Information	Scalloping in Percent of 4-Dot to 4-Dot Deflection	Ease of Flight
10 Feet	E course	138 0	Not flyable
	W course	119 0	Very difficult to fly
2 local trees - 110 & 270 Ft	E course	62 0	Difficult to fly
Thick trees - 300 & 400 Ft	W course	25 5	Easy to fly
Local trees - 70 Ft	E course	53 1	Somewhat difficult to fly
Thick trees - 500 to 1300 Ft	W course	61 9	Somewhat difficult to fly
Local trees - 50 Ft	E course	23 1	Easy to fly
Thick trees - 800 to 3500 Ft	W course	25.0	Easy to fly

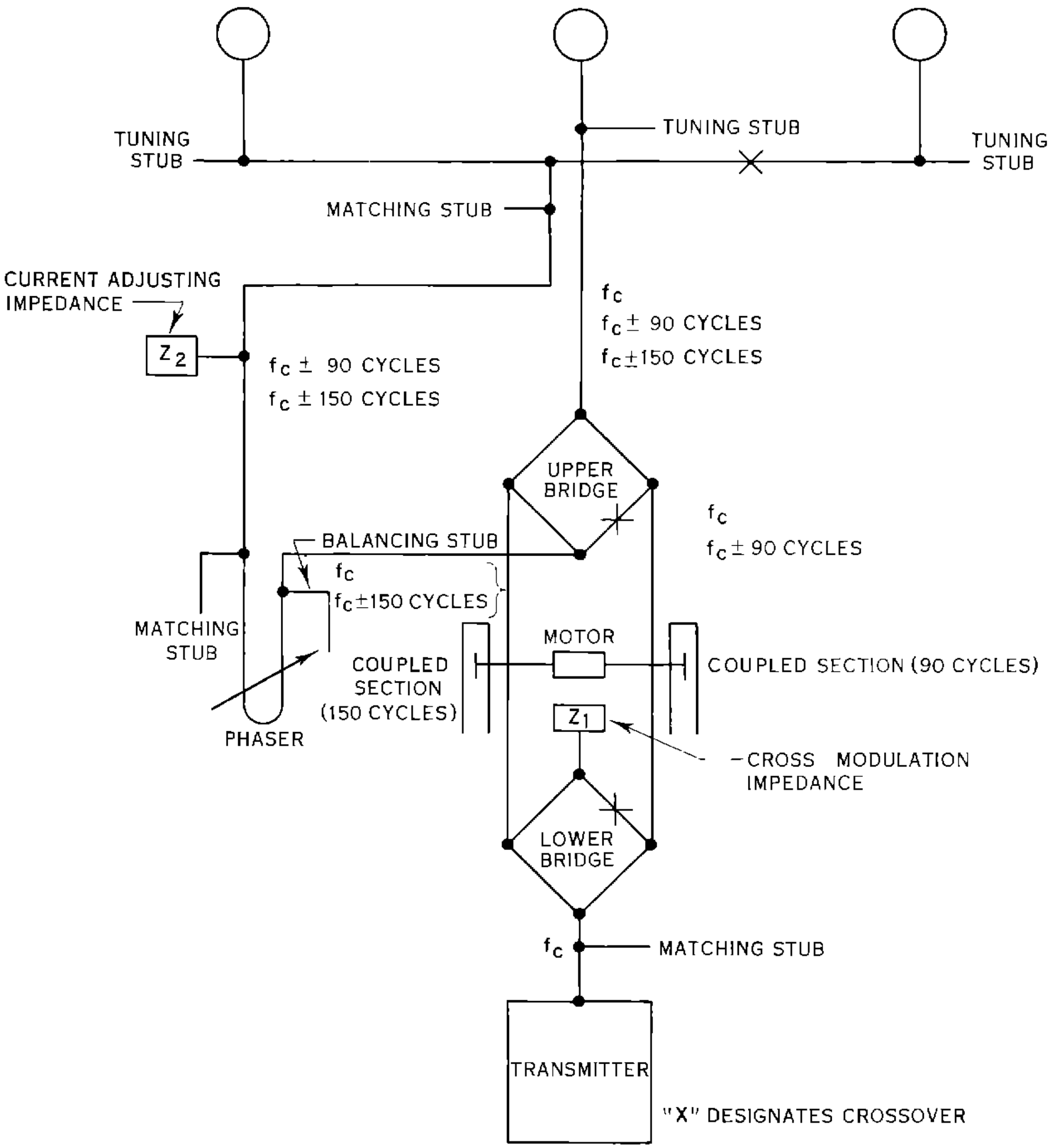
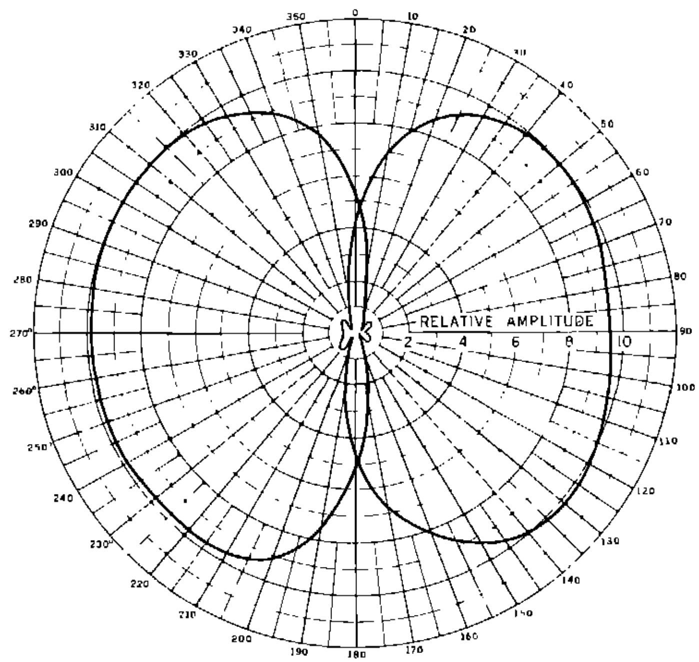
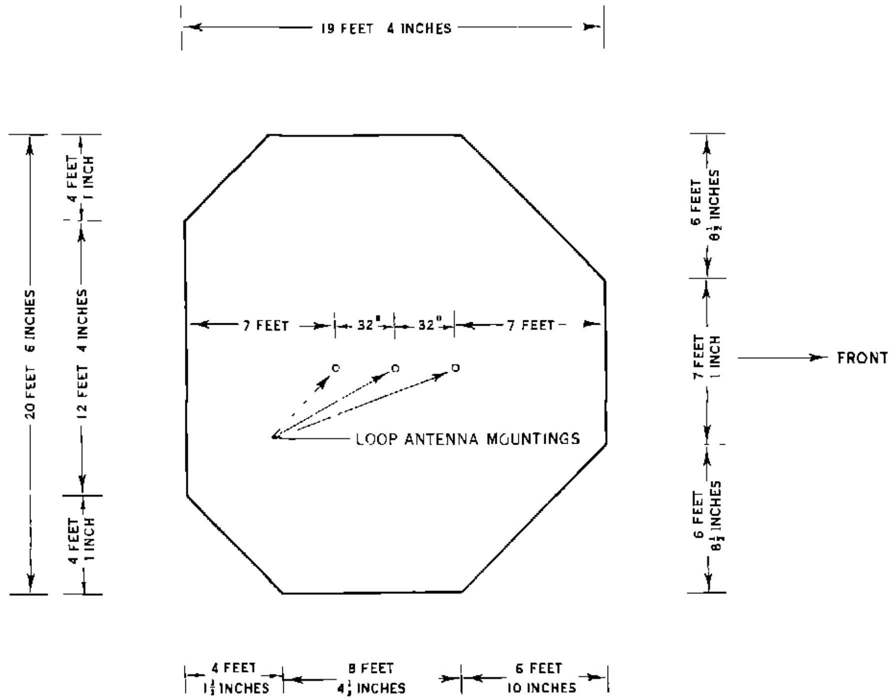


Figure 1 Block Diagram of Transmitting Equipment



CURRENT RATIO 1-1 73-1
SPACING 120

Figure 2 Antenna Radiation Pattern



HEIGHT OF COUNTERPOISE ABOVE GROUND 8 FEET 10 INCHES
HEIGHT OF LOOPS ABOVE COUNTERPOISE 3 FEET $11\frac{1}{2}$ INCHES
FREQUENCY 125 4 MEGACYCLES

Figure 3 Trailer Counterpoise

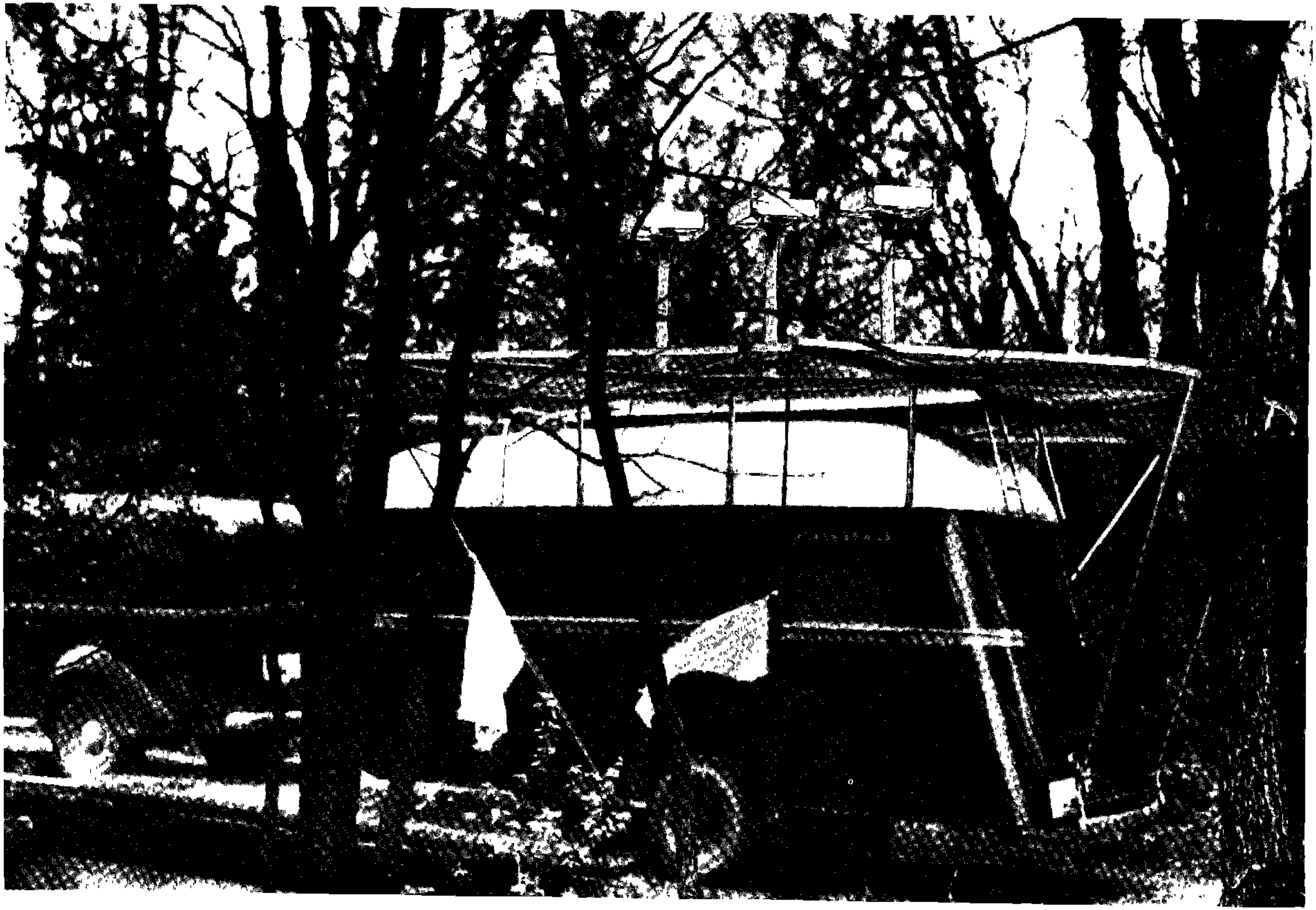


Figure 4 External View of the Complete Portable Ground Equipment Located for the Tree Tests.

Figure 5 The Aircraft Receiver

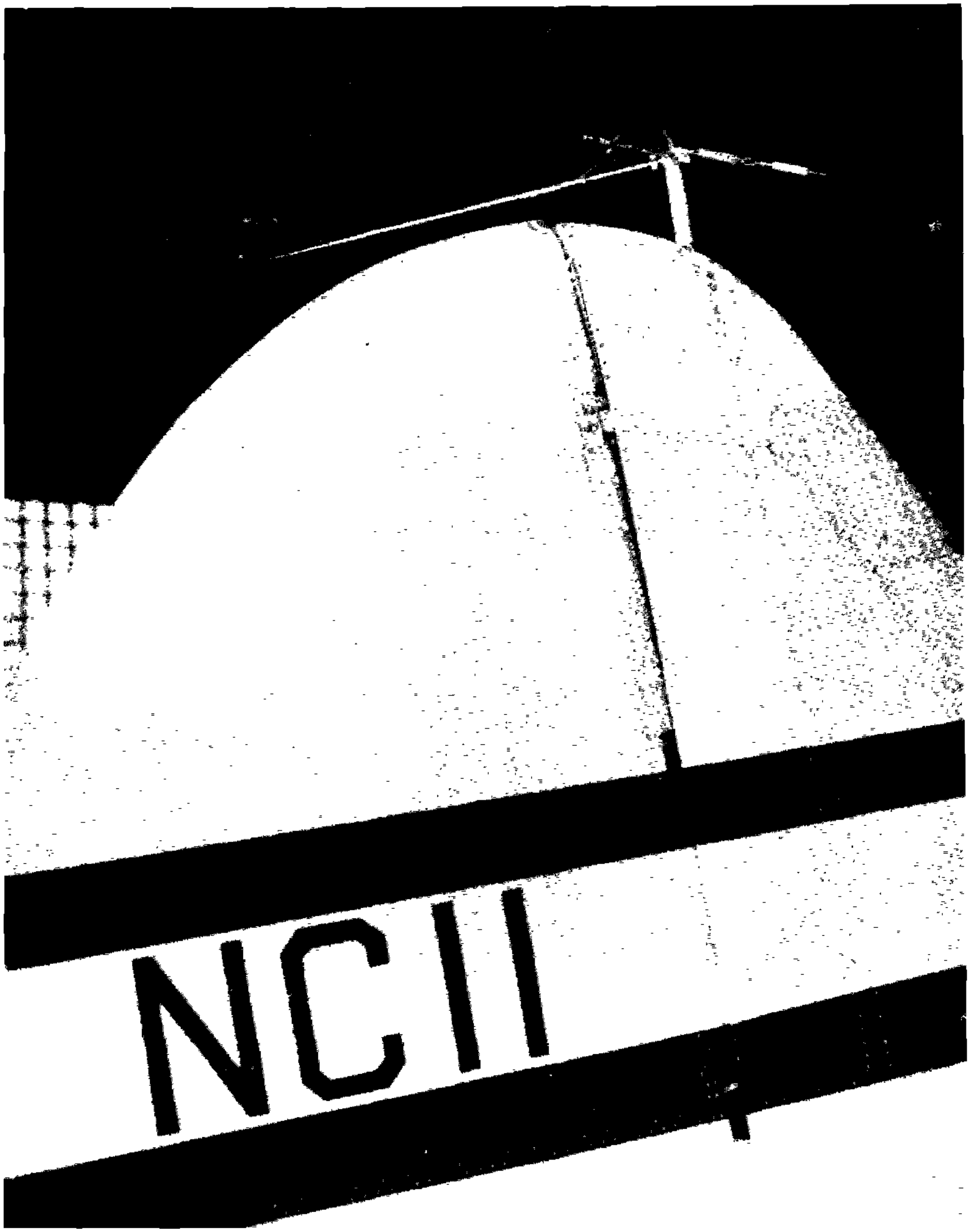
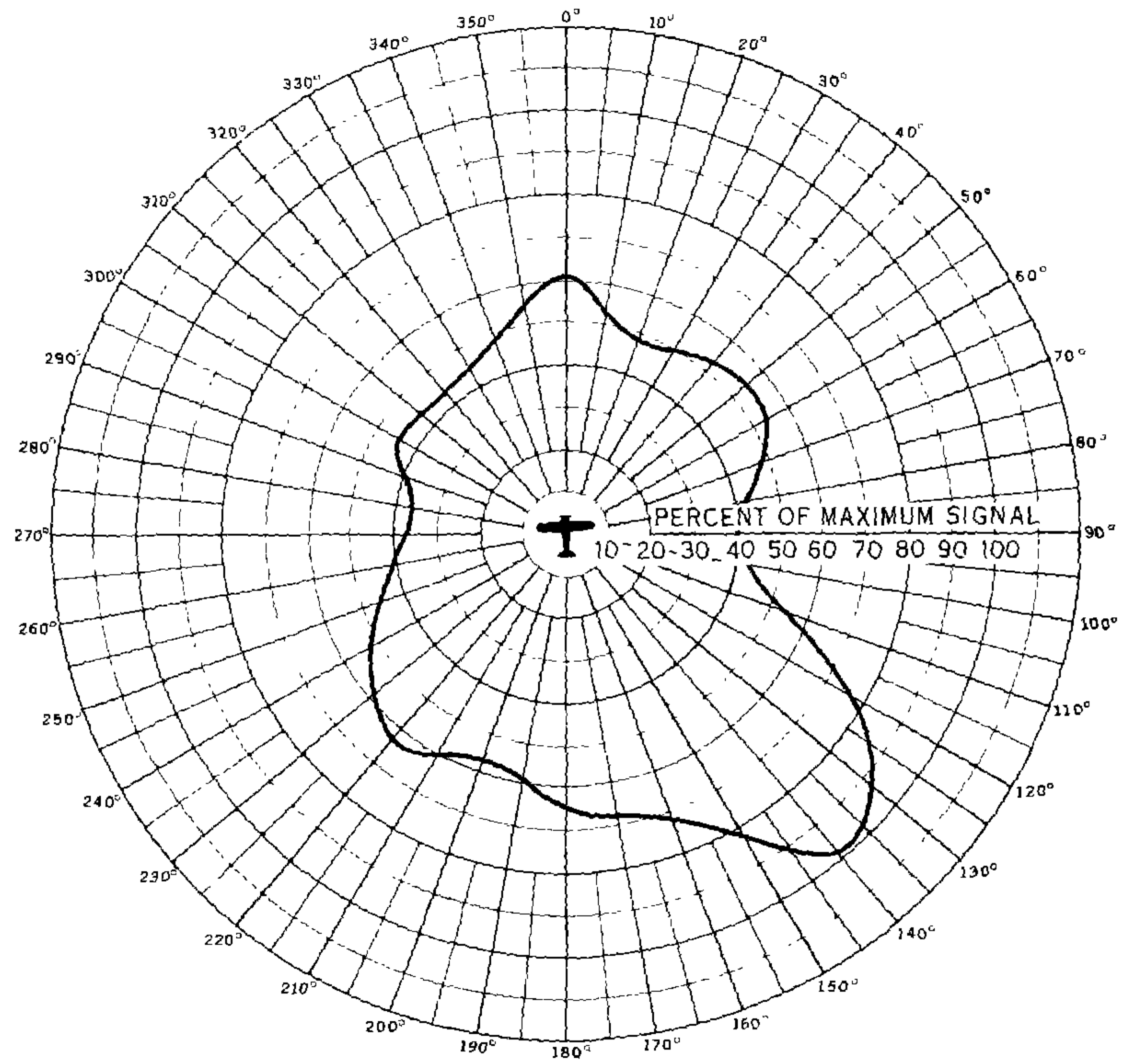


Figure 6 The Aircraft Receiving Antenna



AVC CURRENT RECORDED FOR VARIOUS GYRO HEADINGS IN LEVEL FLIGHT
DISTANCE - 34 MILES ALTITUDE - 3000 FEET

Figure 7 The Aircraft Receiving Antenna Pattern

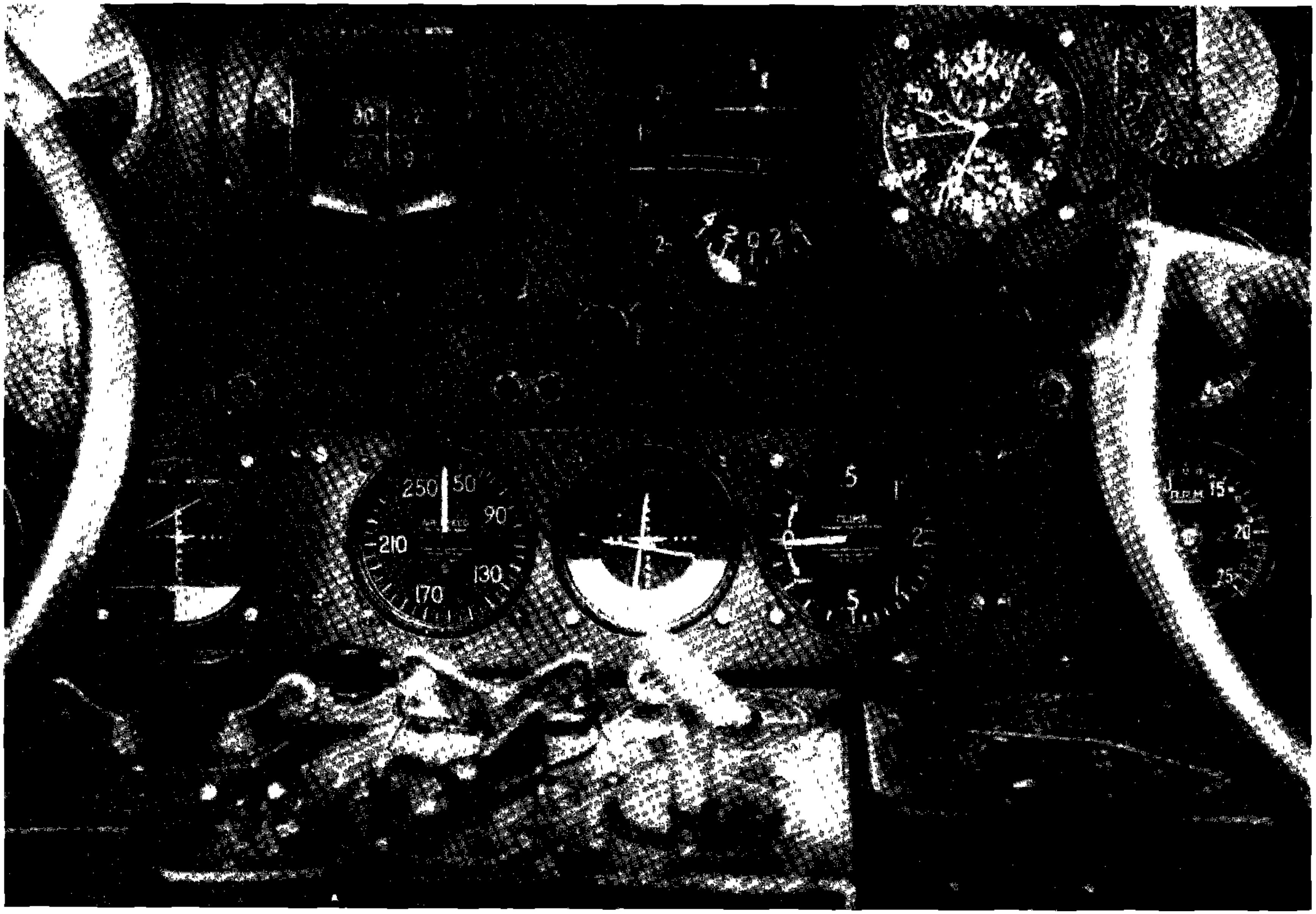


Figure 8   Aircraft Instrument Panel Showing Crossed Pointer Instrument Installation

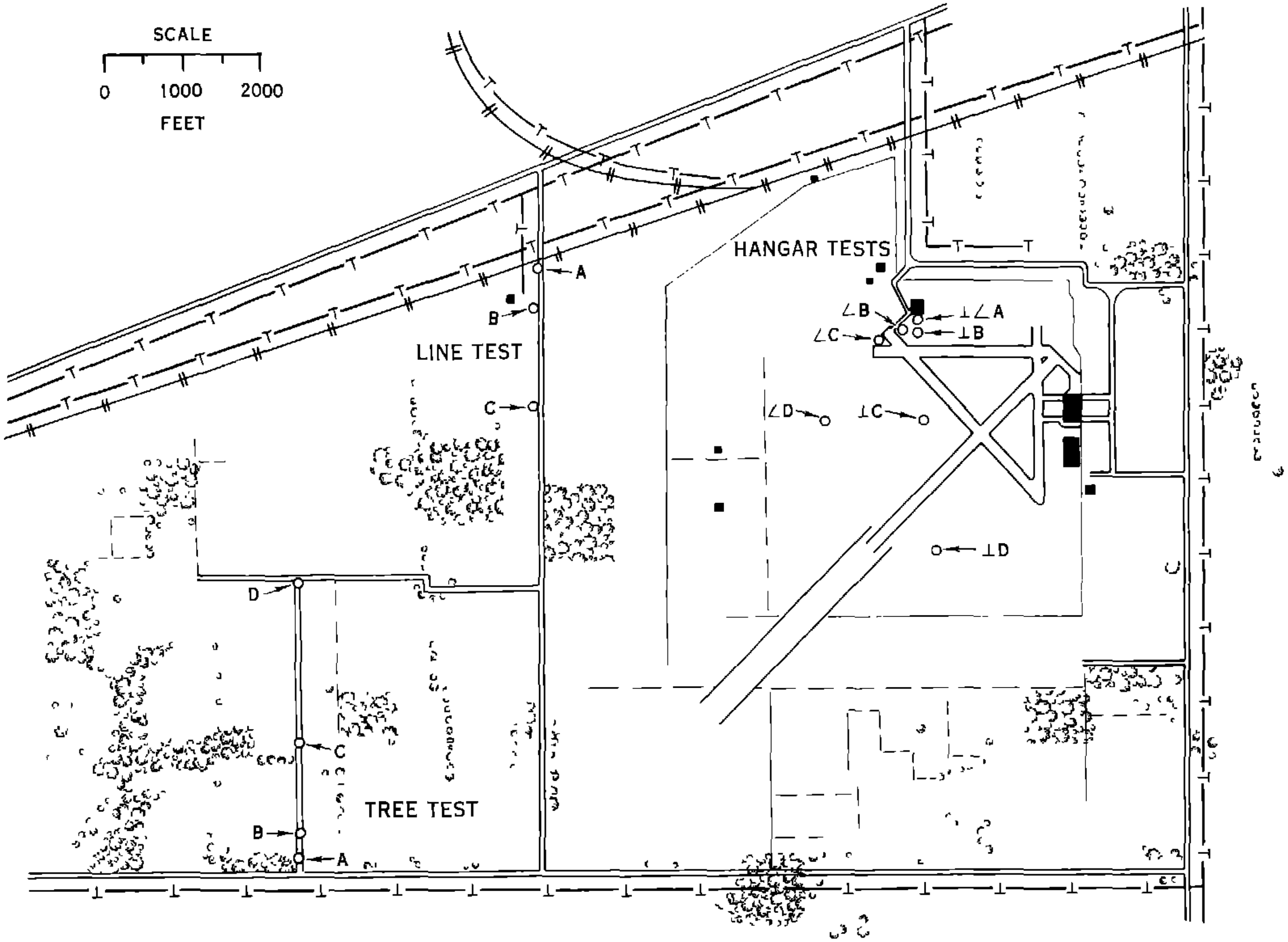


Figure 9 Test Locations

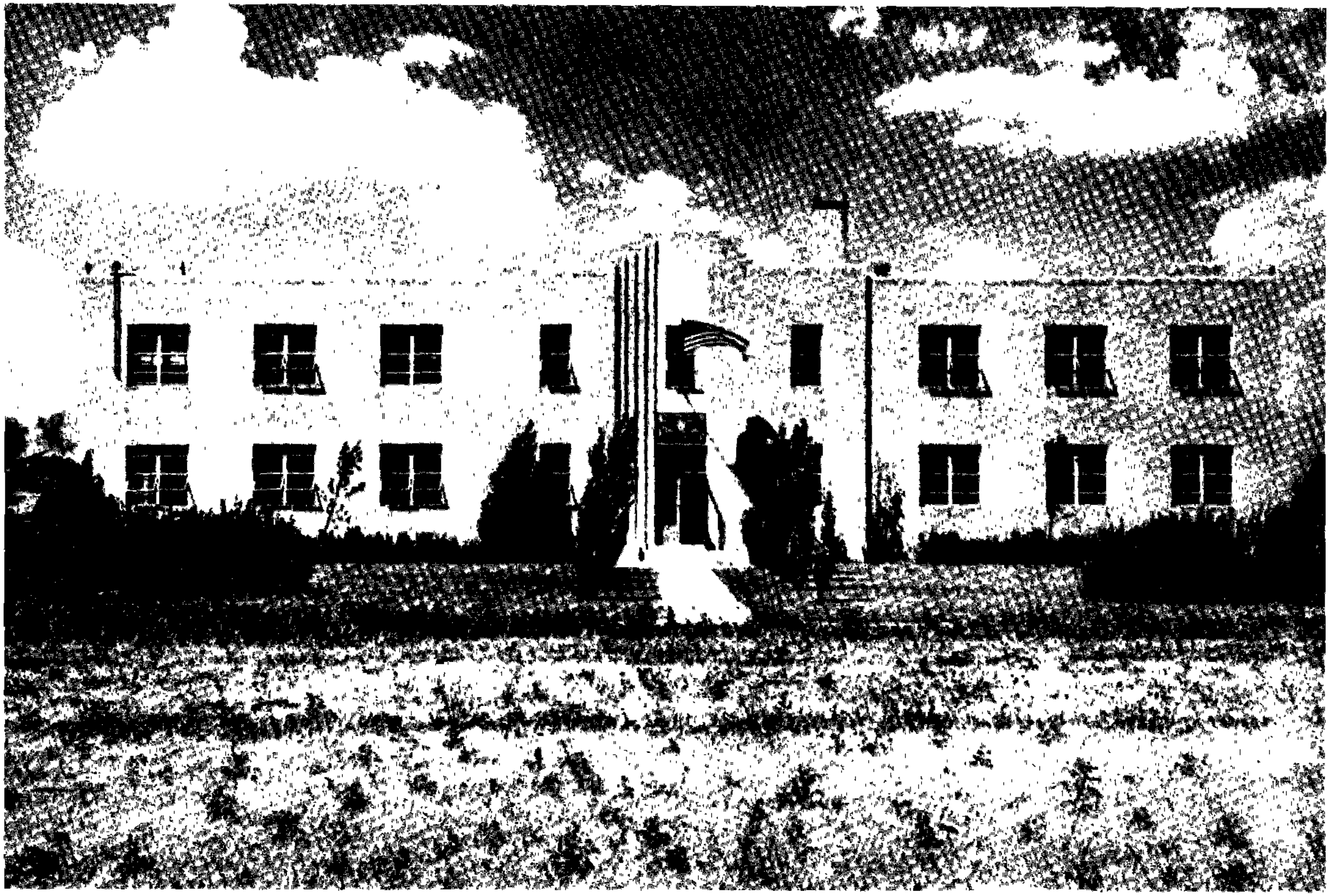


Figure 10 View of Experimental Station Building Used for Tests Perpendicular to a Building or Hangar

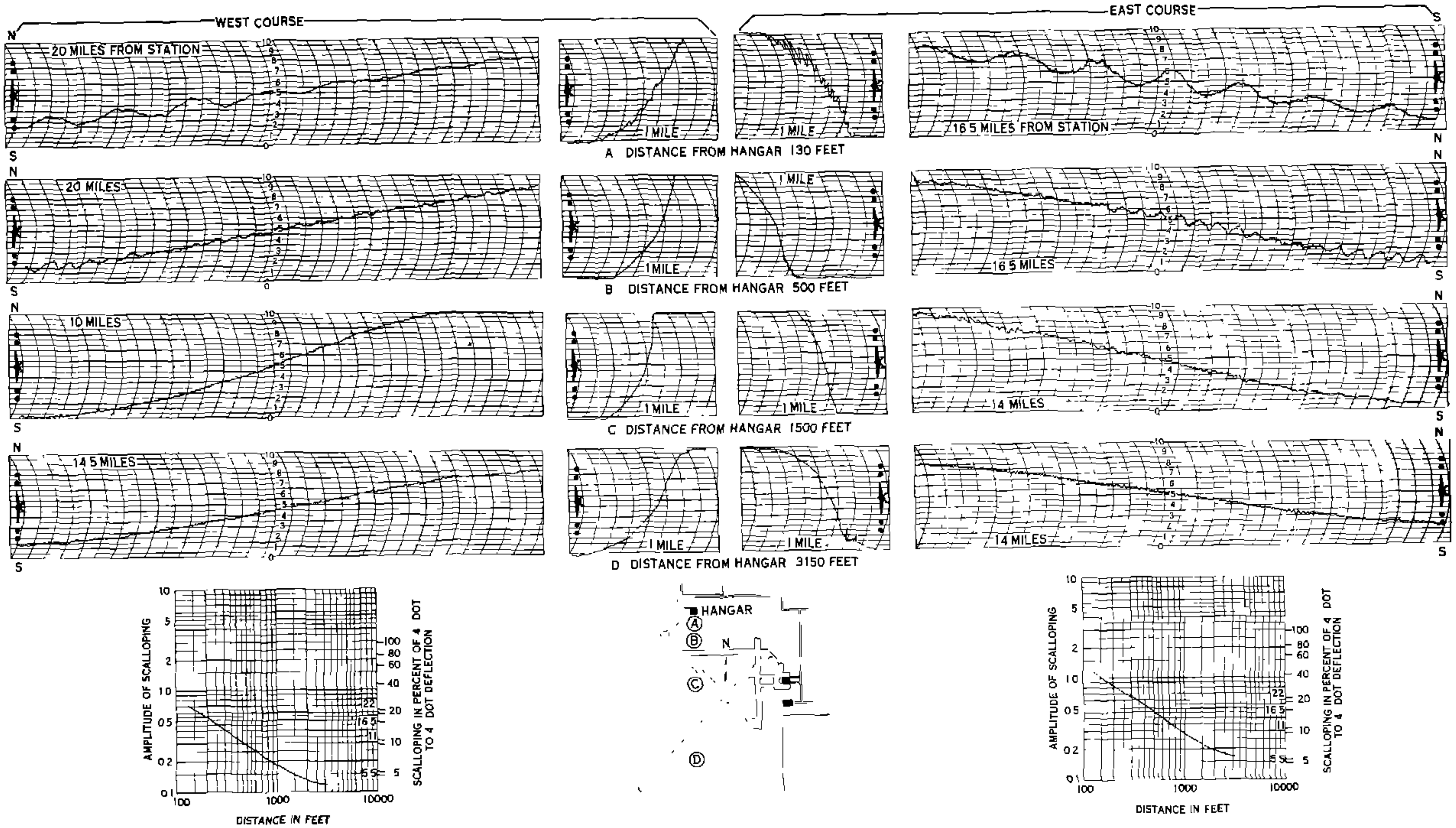


Figure 11 Cross Course Recordings of East and West Courses, and Graphs, Showing the Effect of Distance from a Hangar on the Courses with the Portable Range Located at Various Distances Measured Perpendicularly to the Experimental Station

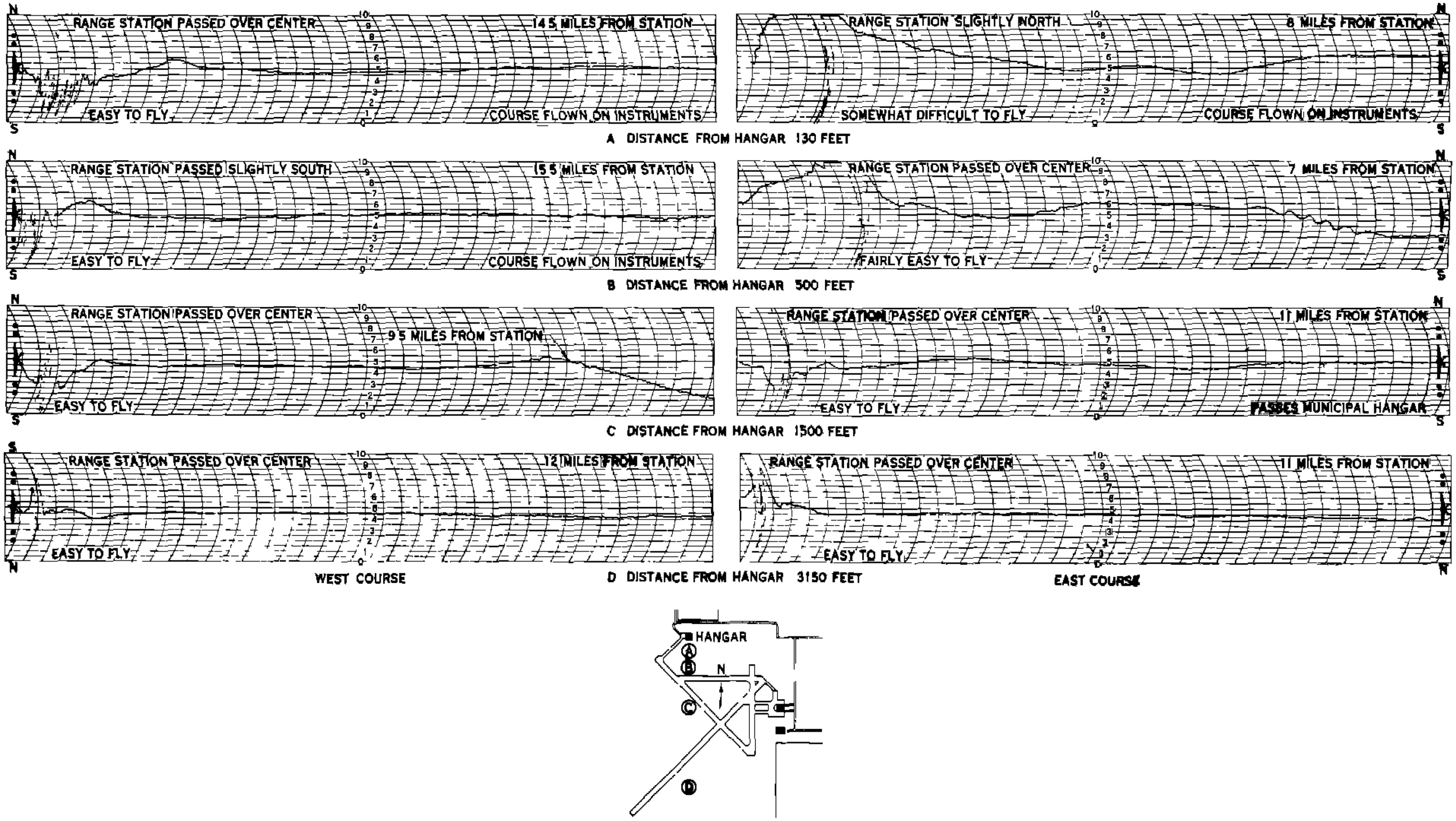


Figure 12 On Course Recordings Toward the Station of East and West Courses Showing the Effect of Distance from a Hangar on the Courses with the Portable Range Located at Various Distances Measured Perpendicularly to the Experimental Station

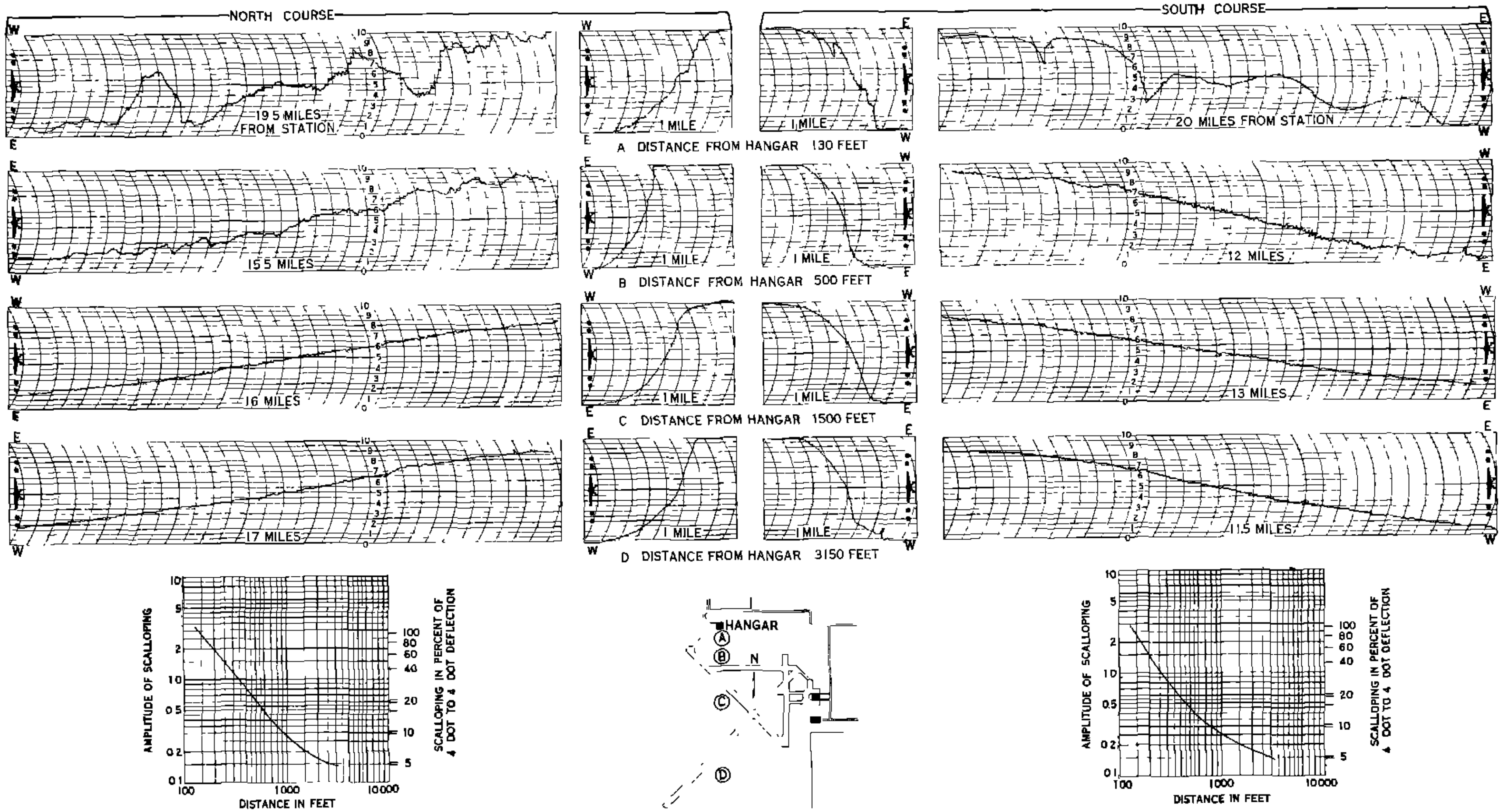


Figure 13 Cross-Course Recordings of North and South Courses, and Graphs, Showing the Effect of Distance from a Hangar on the Courses with the Portable Range Located at Various Distances Measured Perpendicularly to the Experimental Station

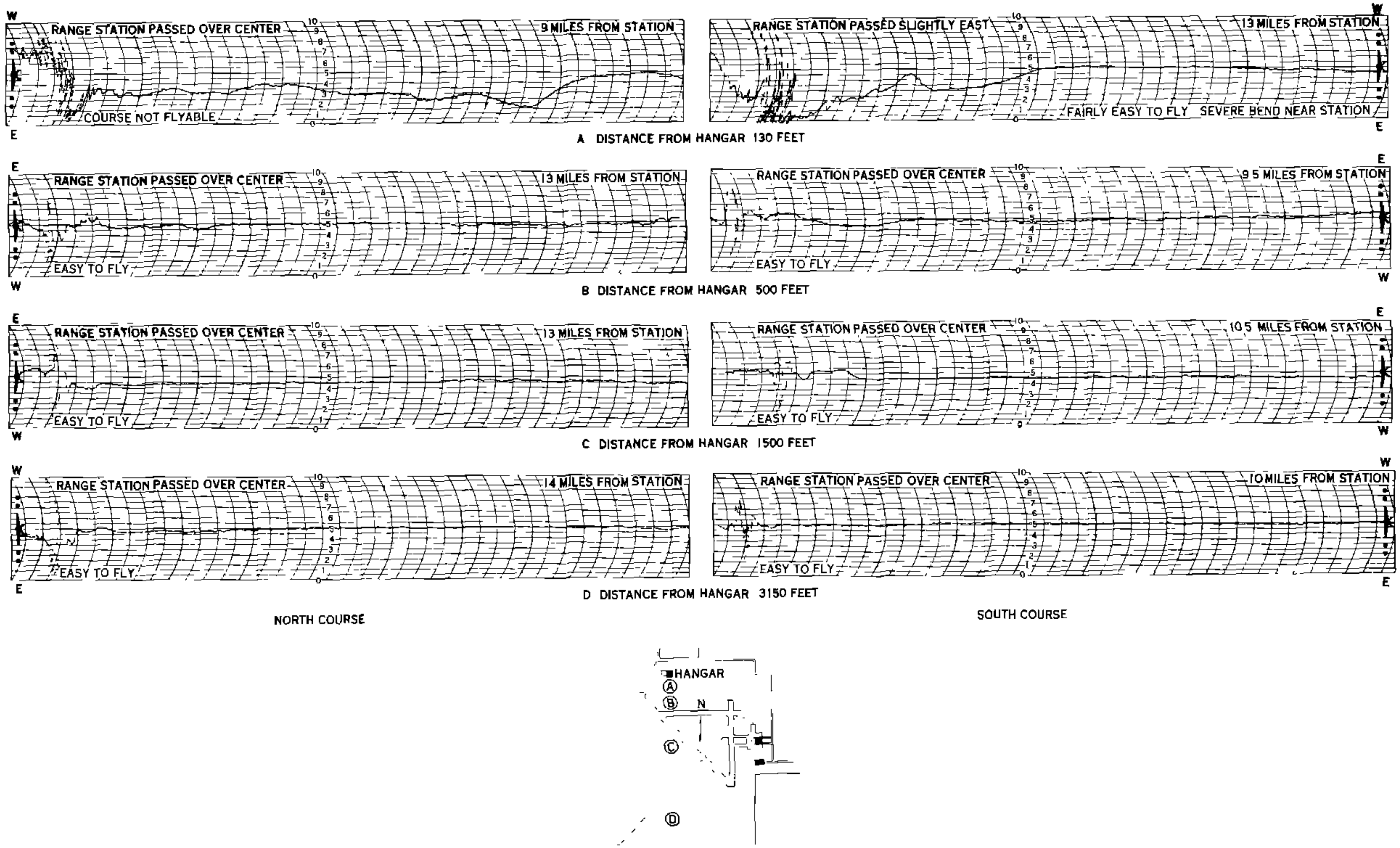


Figure 14 On-Course Recordings Toward the Station of North and South Courses Showing the Effect of Distance from a Hangar on the Courses with the Portable Range Located at Various Distances Measured Perpendicularly to the Experimental Station

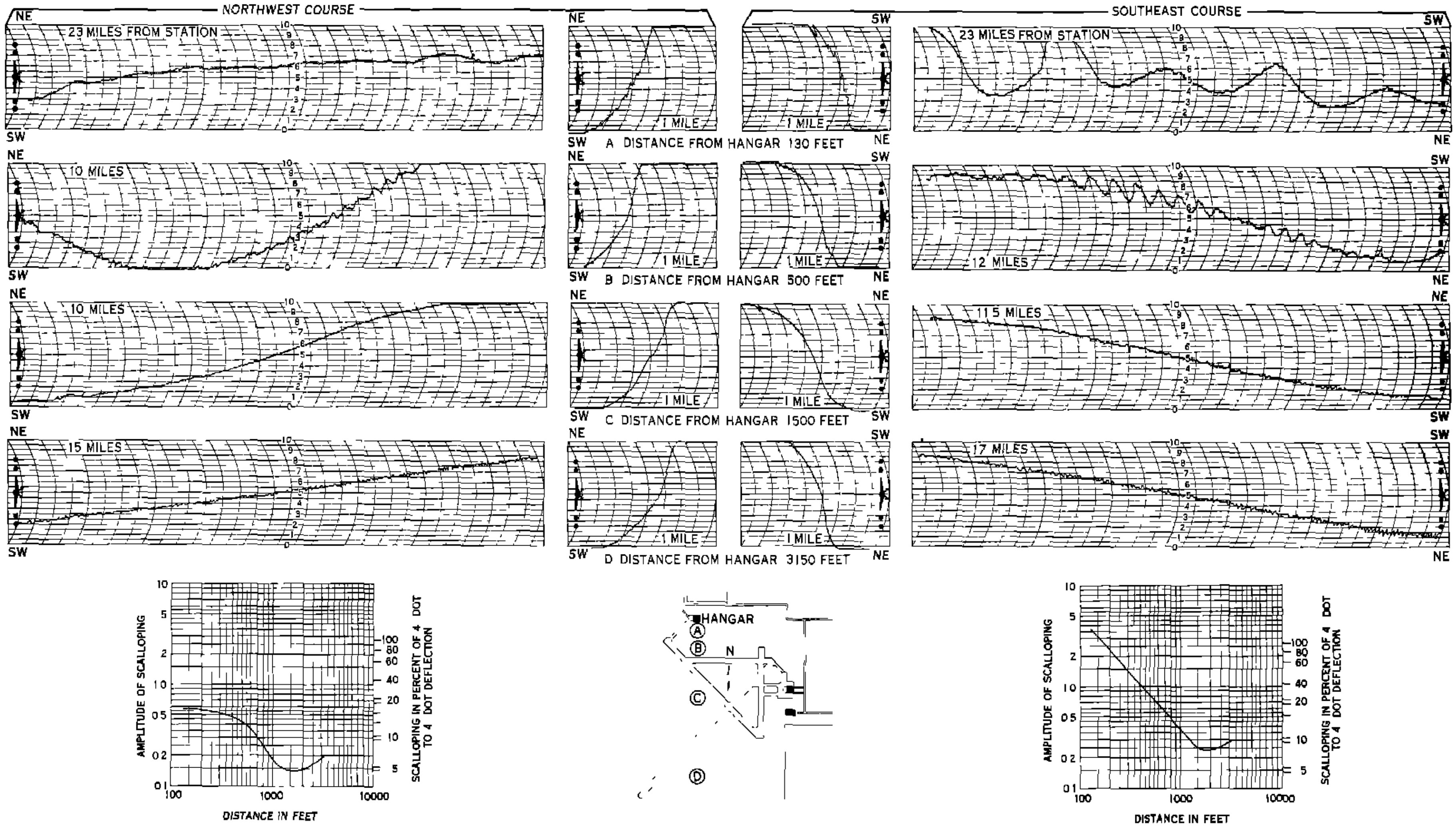


Figure 15 Cross-Course Recordings of Northwest and Southeast Courses, and Graphs, Showing the Effect of Distance from a Hangar on the Courses with the Portable Range Located at Various Distances Measured Perpendicularly to the Experimental Station

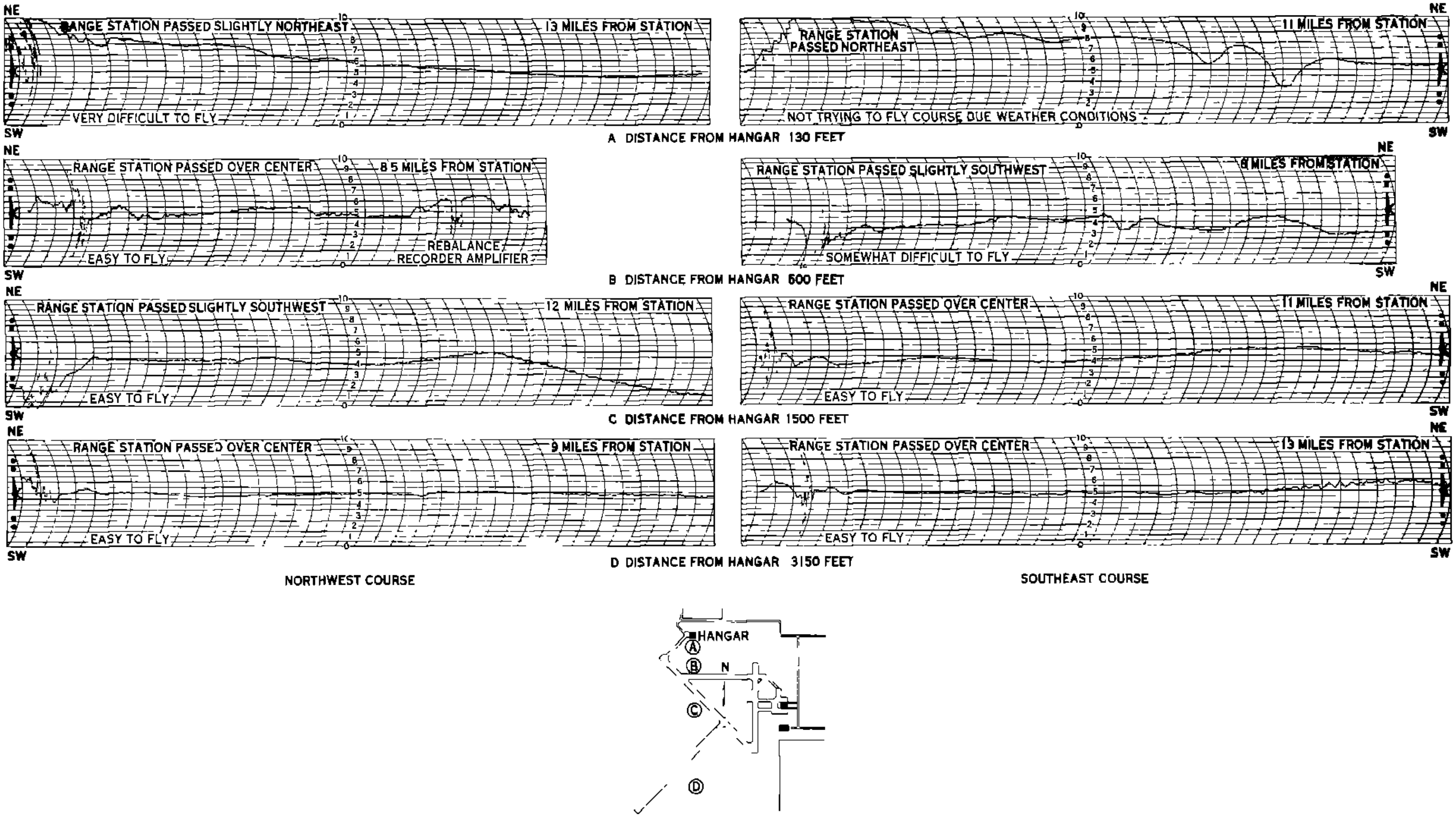
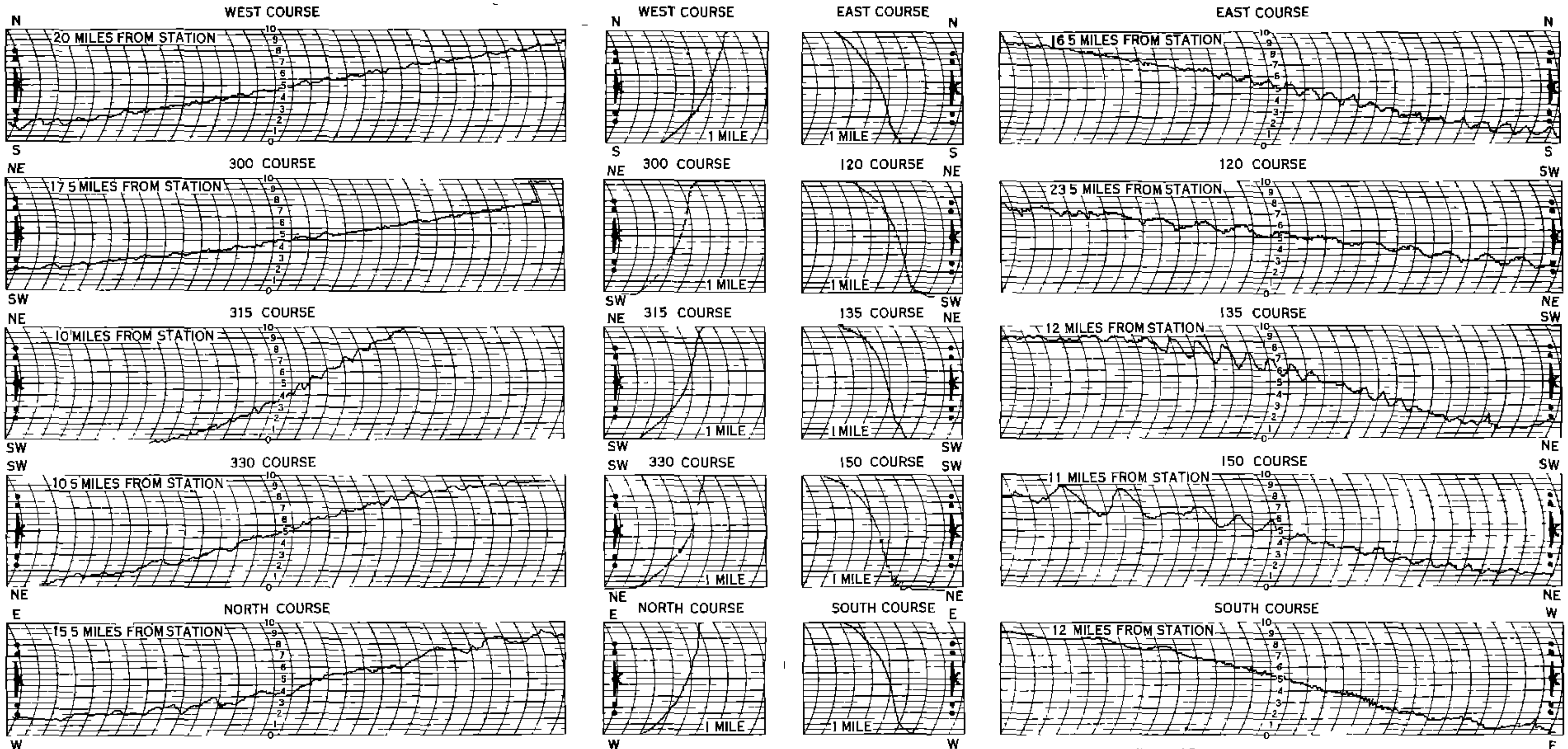
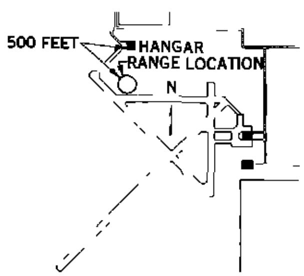
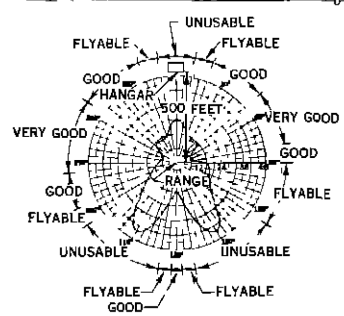


Figure 16 On Course Recordings Toward the Station of Northwest and Southeast Courses Showing the Effect of Distance from a Hangar on the Courses with the Portable Range Located at Various Distances Measured Perpendicularly to the Experimental Station







EXCELLENT - UP TO 5 5% SCALLOPING
VERY GOOD - 5 5% TO 11% SCALLOPING
GOOD - 11% TO 16 5% SCALLOPING
FLYABLE - 16 5% TO 22% SCALLOPING
UNUSABLE - OVER 22% SCALLOPING

Figure 17 Cross Course Recordings Showing Effect of Course Orientation upon Scalloping with the Portable Range Located 500 Feet Measured Perpendicularly to the Experimental Station Hangar

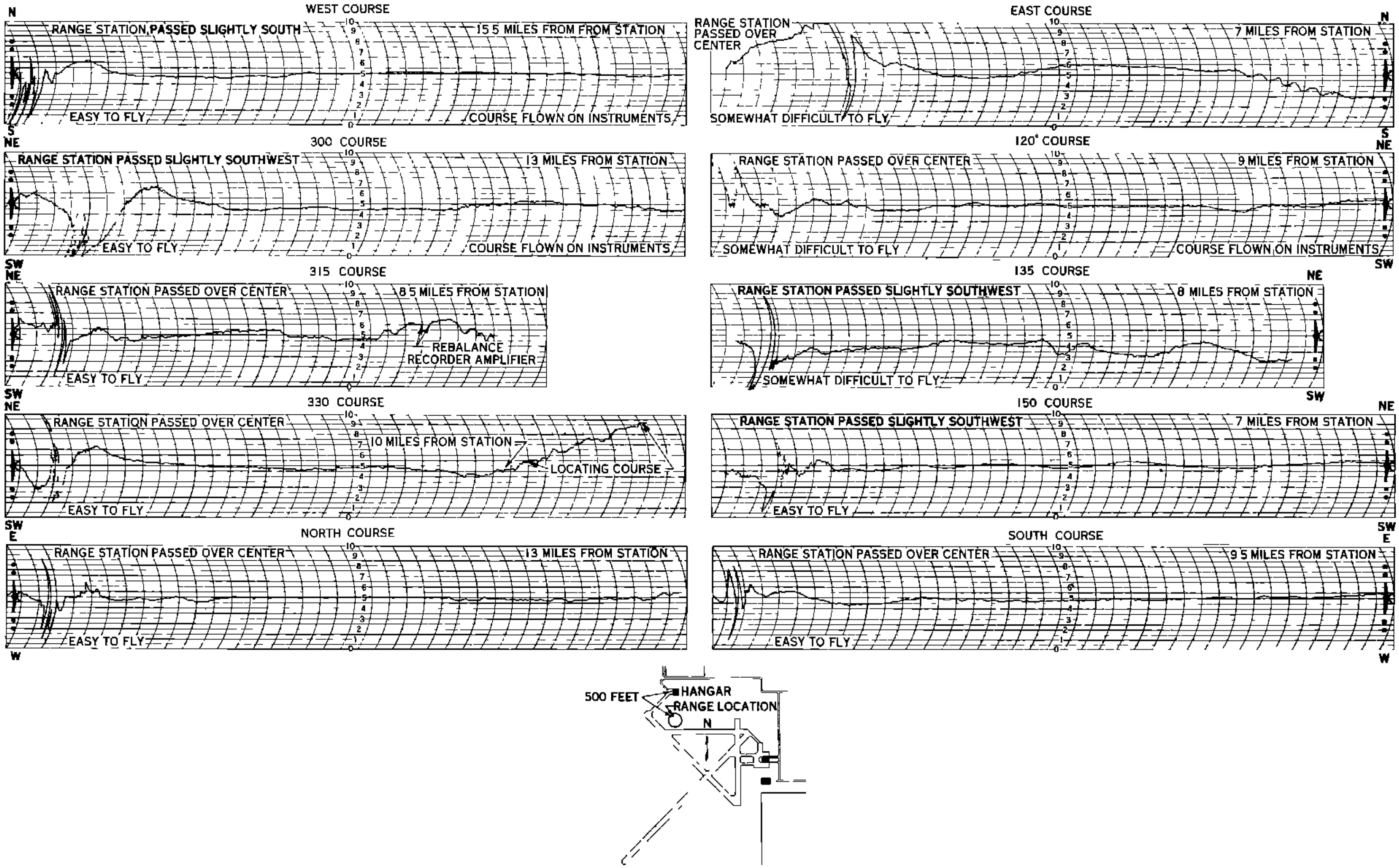
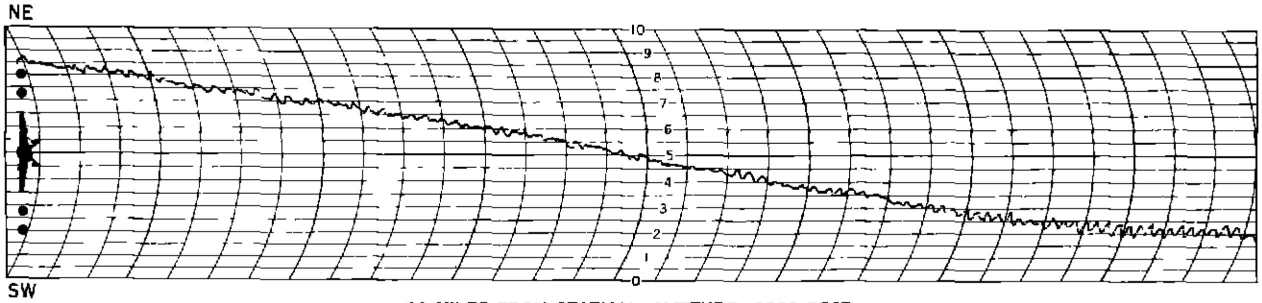
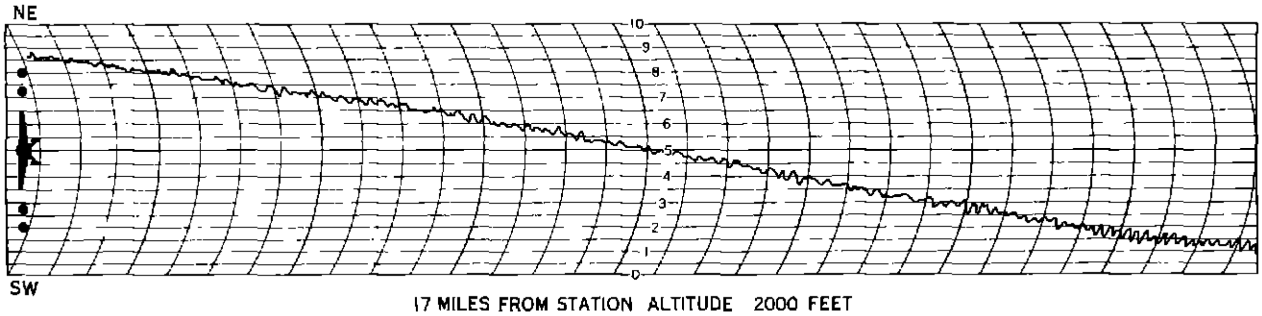


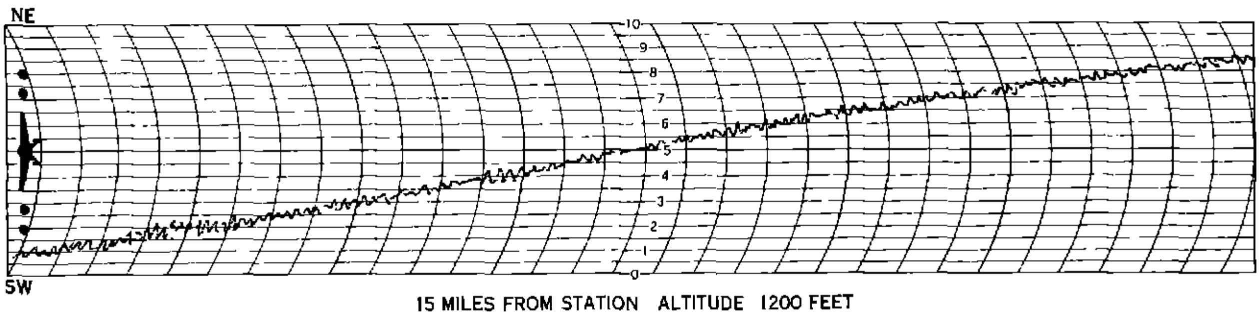
Figure 18 On-Course Recordings Toward the Station Showing the Effect of Course Orientation upon Scalloping with the Portable Range Located 500 Feet Measured Perpendicularly to the Experimental Station Hangar



20 MILES FROM STATION ALTITUDE - 3200 FEET



17 MILES FROM STATION ALTITUDE 2000 FEET



15 MILES FROM STATION ALTITUDE 1200 FEET

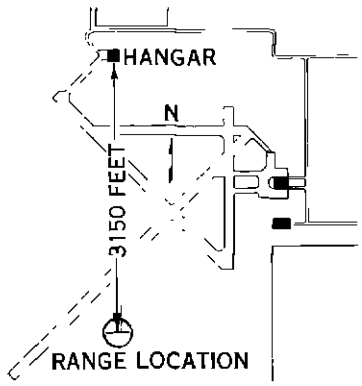


Figure 19 Cross-Course Recordings of Southeast Course Showing the Effect of Altitude and Distance from the Station upon Scalloping with the Portable Range Located 3150 Feet Measured Perpendicularly to the Experimental Station Hangar

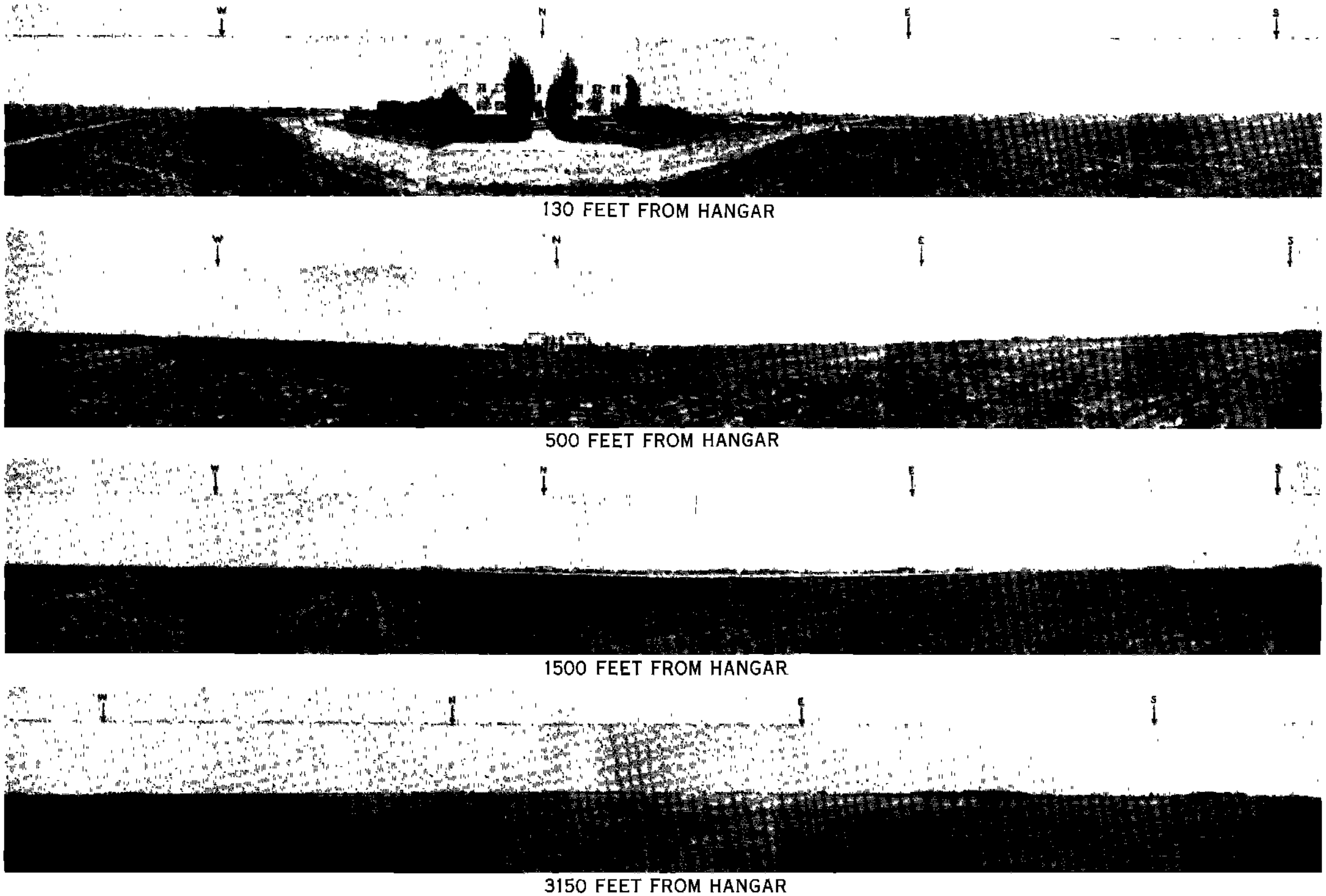


Figure 20 Panoramic Photographs Taken from the Four Sites Investigated on a Line Perpendicular to the Experimental Station Hangar

Figure 21 View of Experimental Station Building Used for Tests at an Angle of 45 Degrees from a Building or Hangar

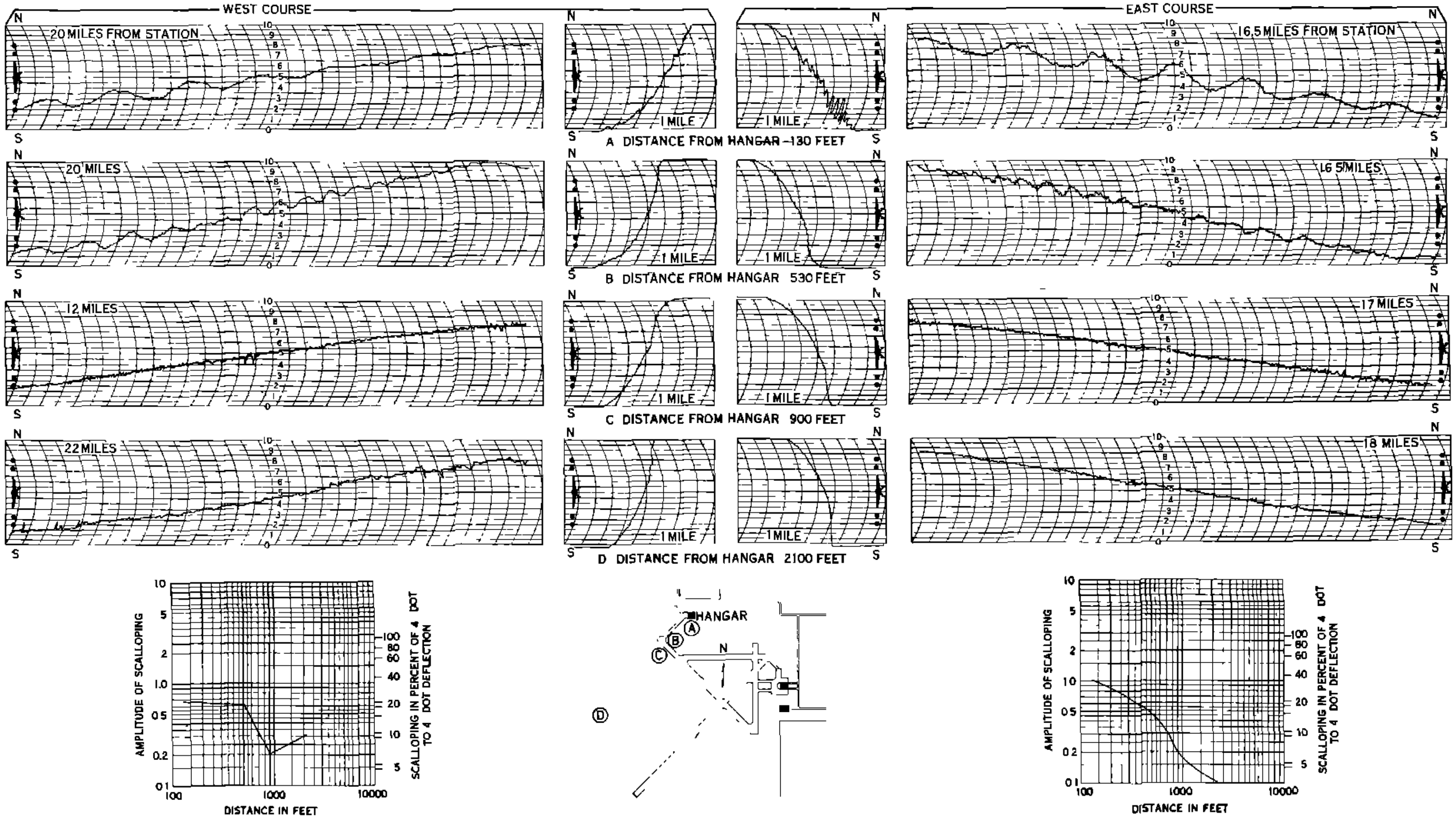


Figure 22 Cross-Course Recordings of East and West Courses, and Graphs, Showing the Effect of Distance from a Hangar on the Courses with the Portable Range Located at Various Distances Measured at an Angle of 45 Degrees from the Experimental Station

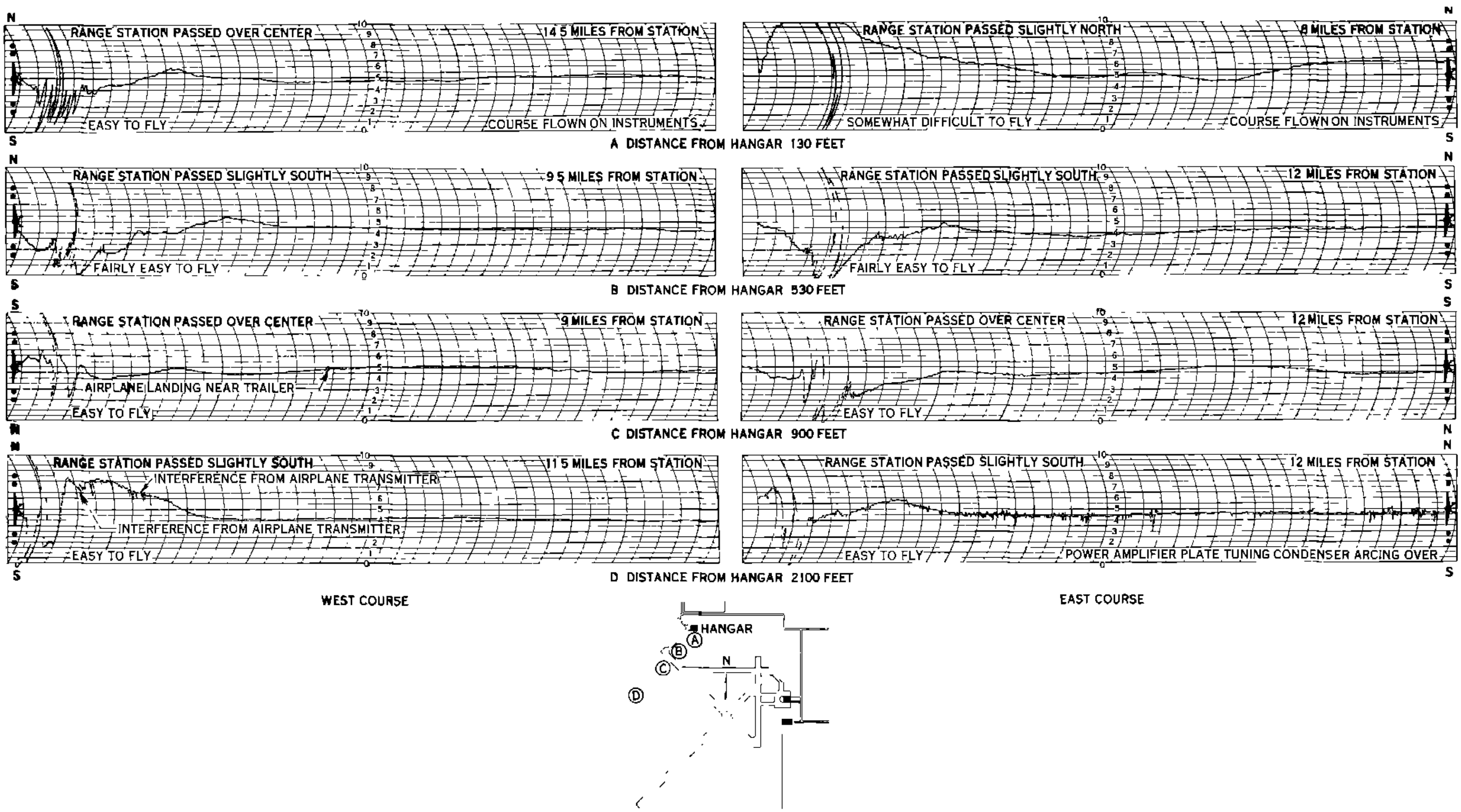


Figure 23 On Course Recordings Toward the Station of East and West Courses Showing the Effect of Distance at an Angle of 45 Degrees from a Hangar on the Courses with the Portable Range Located at Various Distances from the Experimental Station

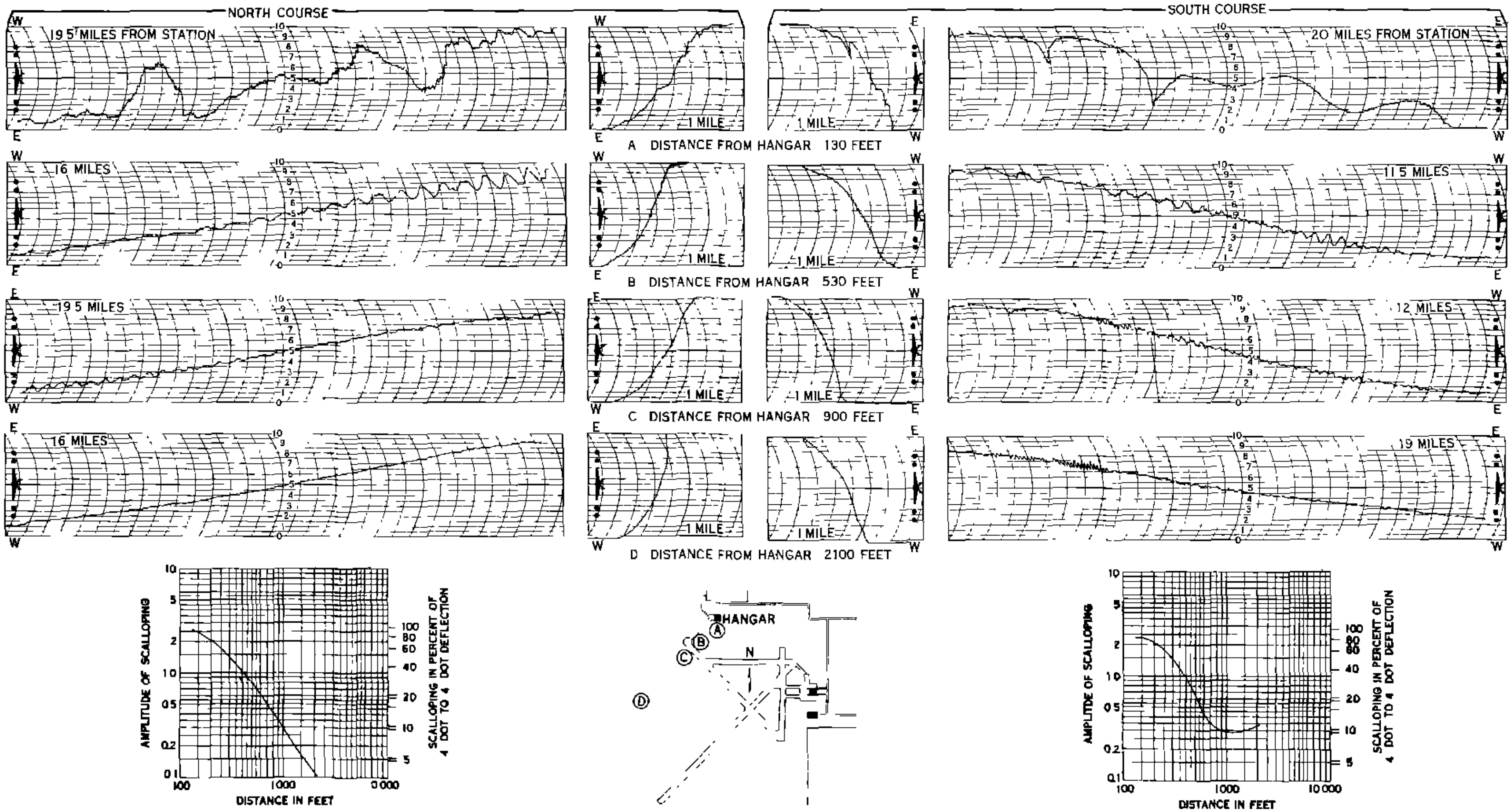


Figure 24 Cross Course Recordings of North and South Courses, and Graphs, Showing the Effect of Distance from a Hangar on the Courses with the Portable Range Located at Various Distances Measured at an Angle of 45 Degrees from the Experimental Station

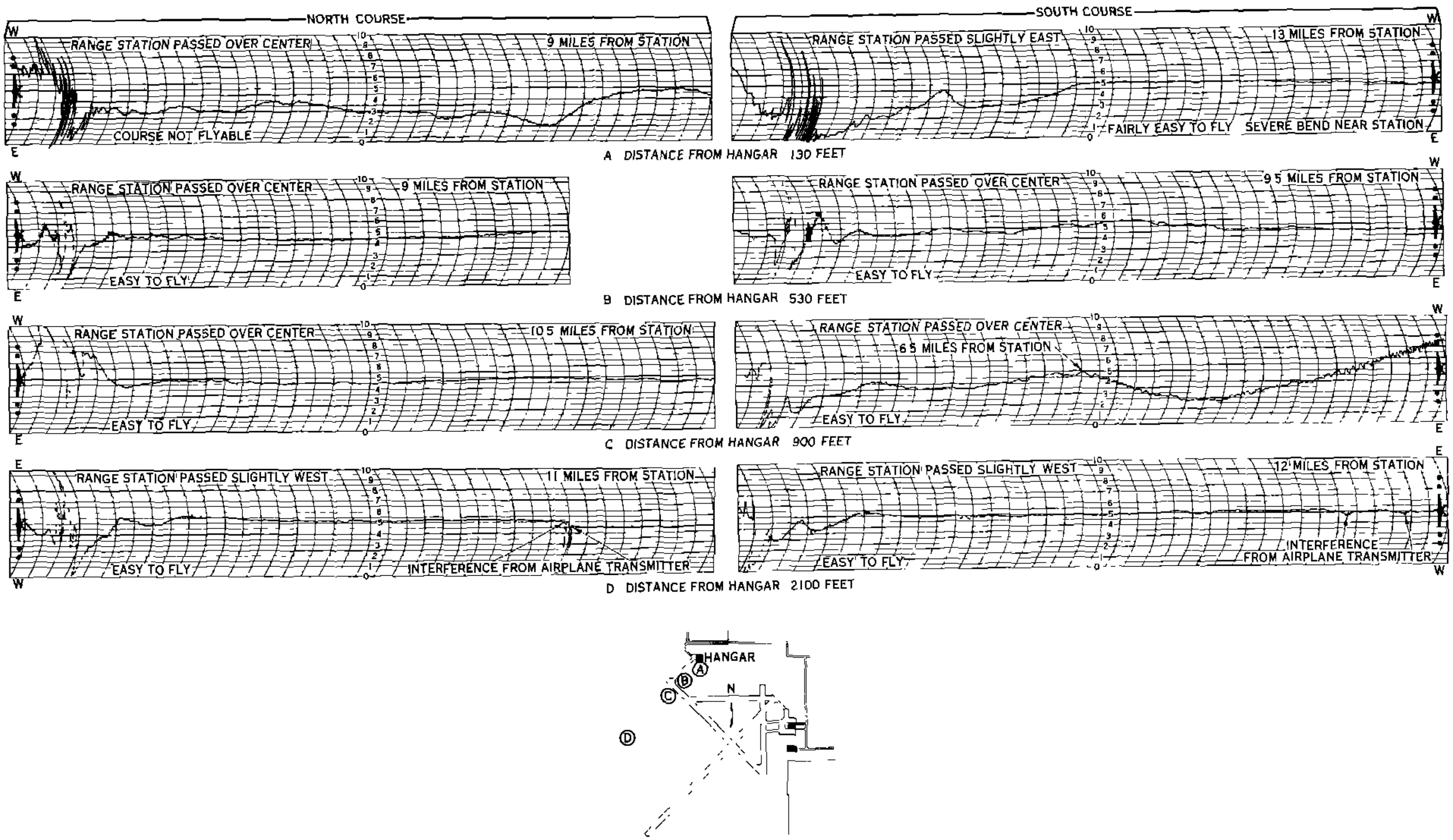


Figure 25 On-Course Recordings Toward the Station of North and South Courses Showing the Effect of Distance at an Angle of 45 Degrees from a Hangar on the Courses with the Portable Range Located at Various Distances from the Experimental Station

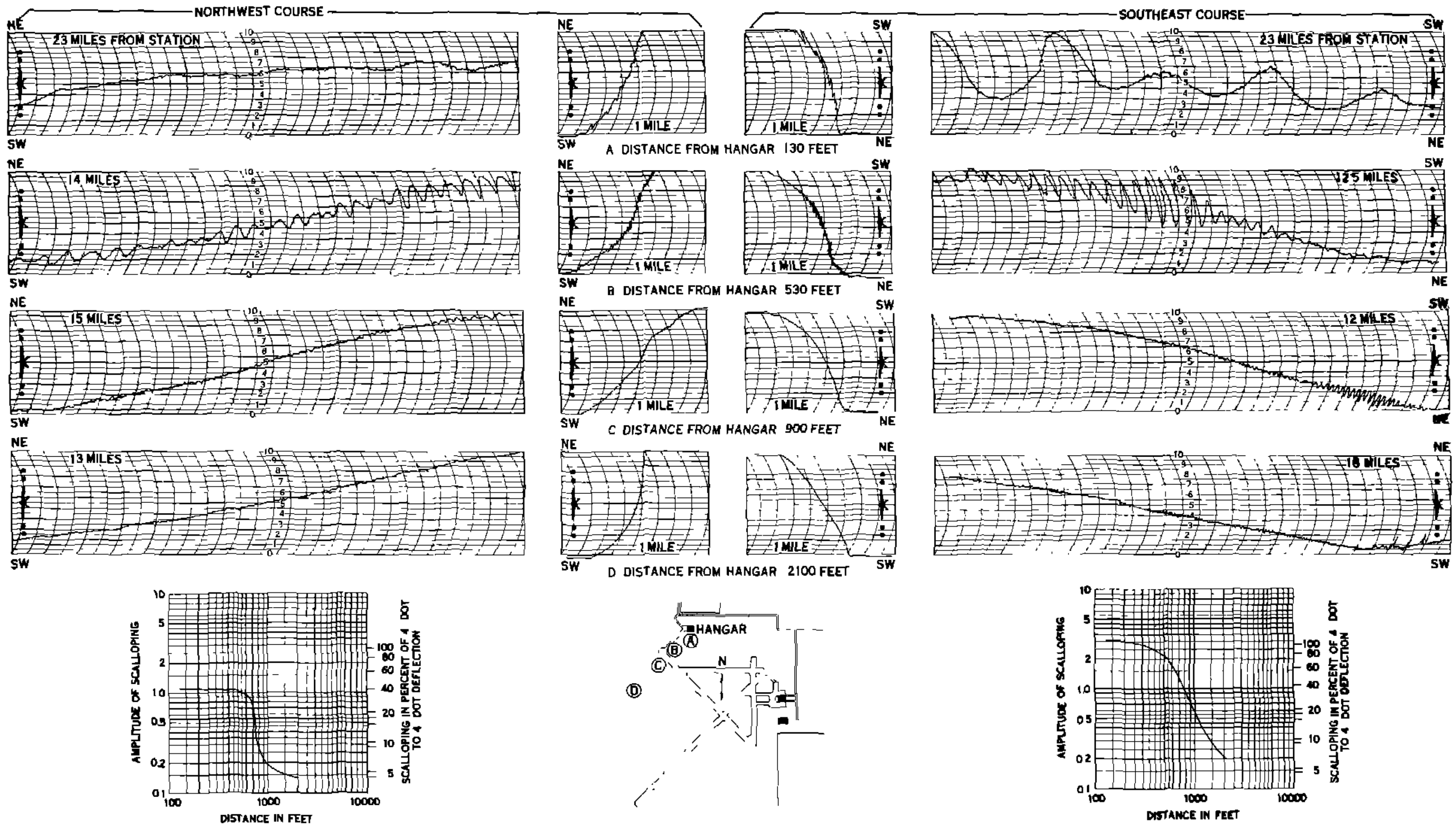


Figure 26 Cross-Course Recordings of Northwest and Southeast Courses, and Graphs, Showing the Effect of Distance from a Hangar on the Courses with the Portable Range Located at Various Distances Measured at an Angle of 45 Degrees from the Experimental Station

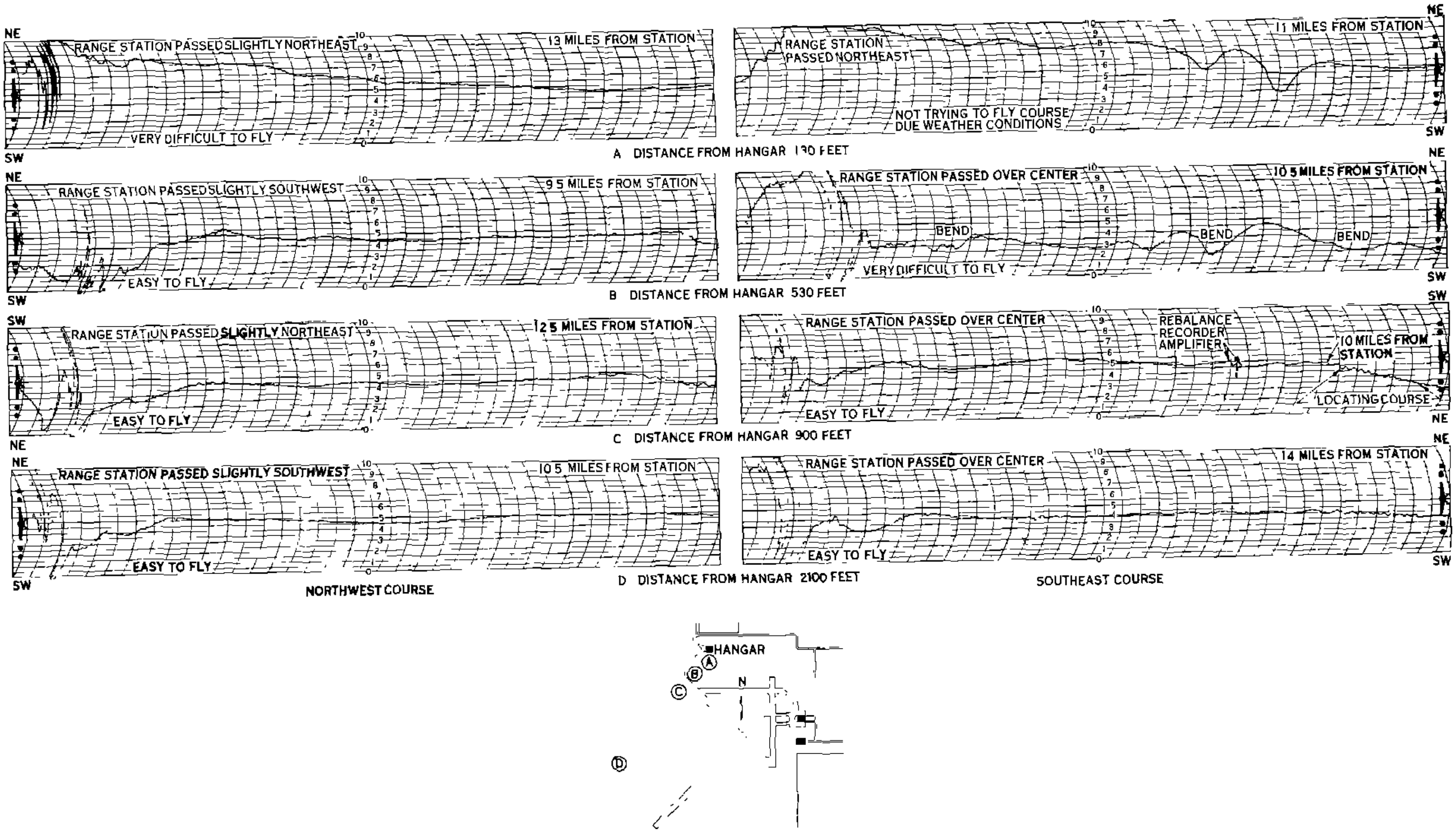


Figure 27 On-Course Recordings toward the Station of Northwest and Southeast Courses Showing the Effect of Distance at an Angle of 45 Degrees from a Hangar on the Courses with the Portable Range Located at Various Distances from the Experimental Station

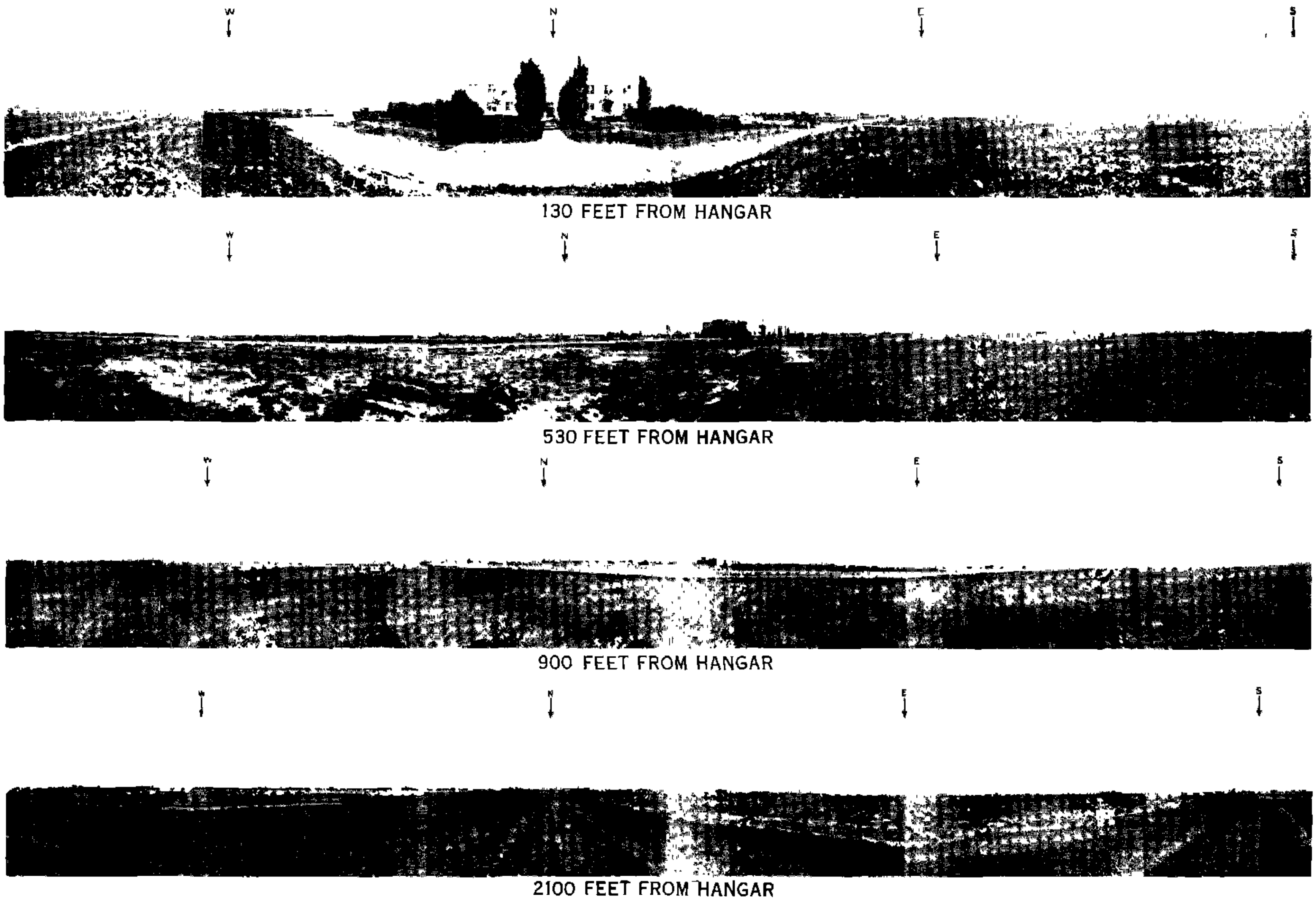


Figure 28 Panoramic Photographs Taken from the Four Sites Investigated on a Line 45 Degrees to the Experimental Station Hangar

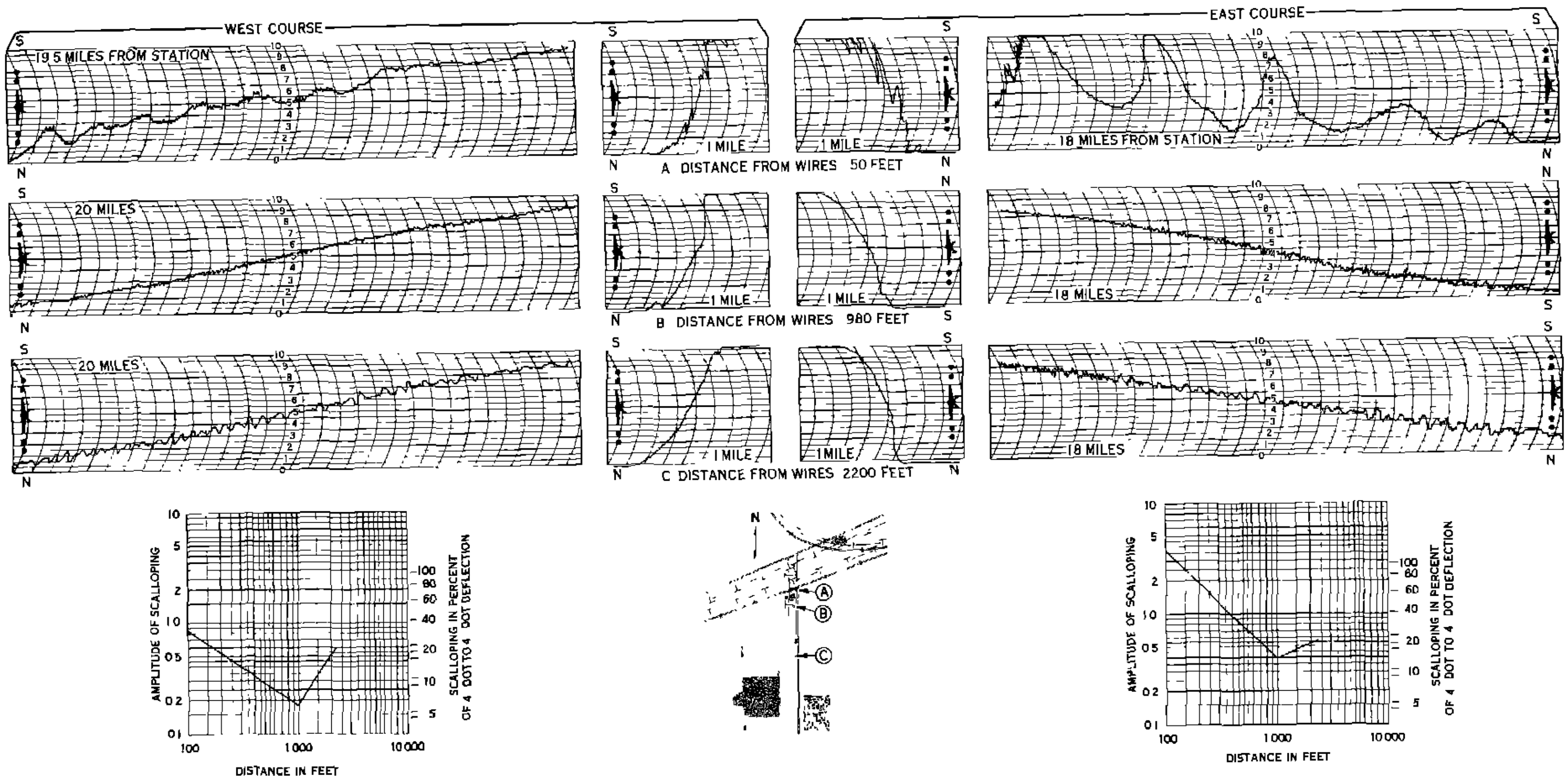


Figure 29 Cross-Course Recordings of East and West Courses, and Graphs, Showing the Effect of Distance from Telephone Wires

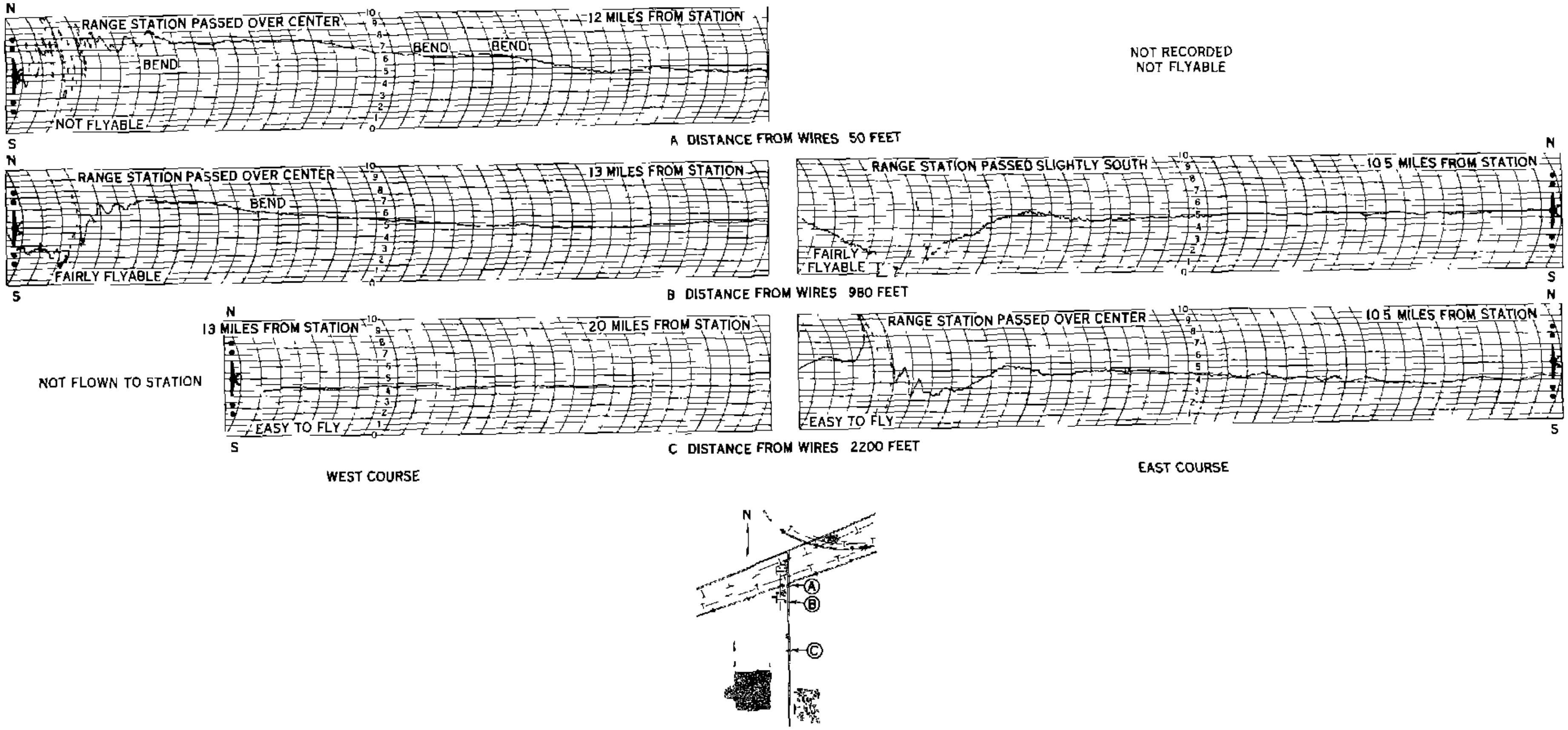


Figure 30 On-Course Recordings Toward the Station of East and West Courses Showing the Effect of Distance from Telephone Wires

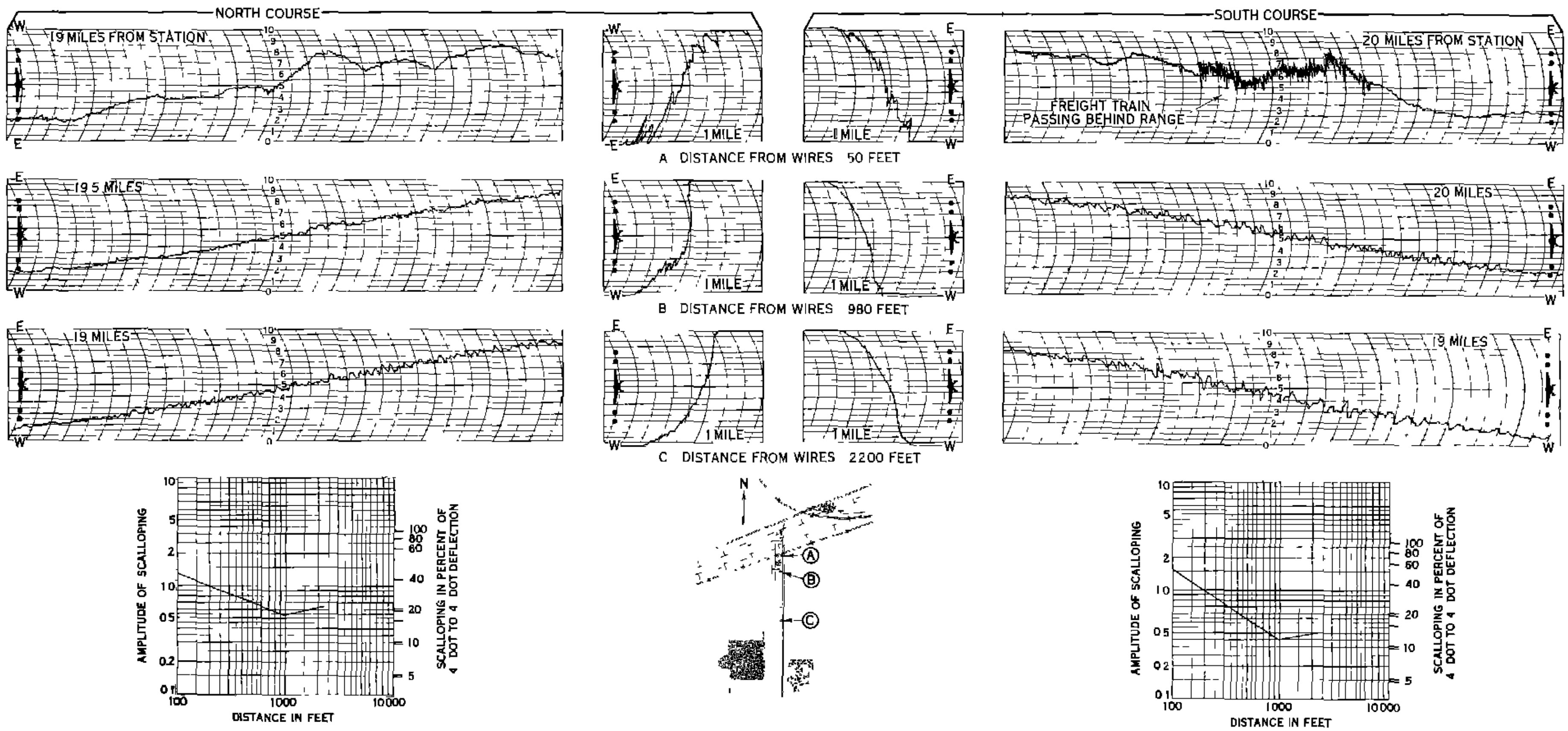


Figure 31 Cross-Course Recordings of North and South Courses, and Graphs, Showing the Effect of Distance from Telephone Wires

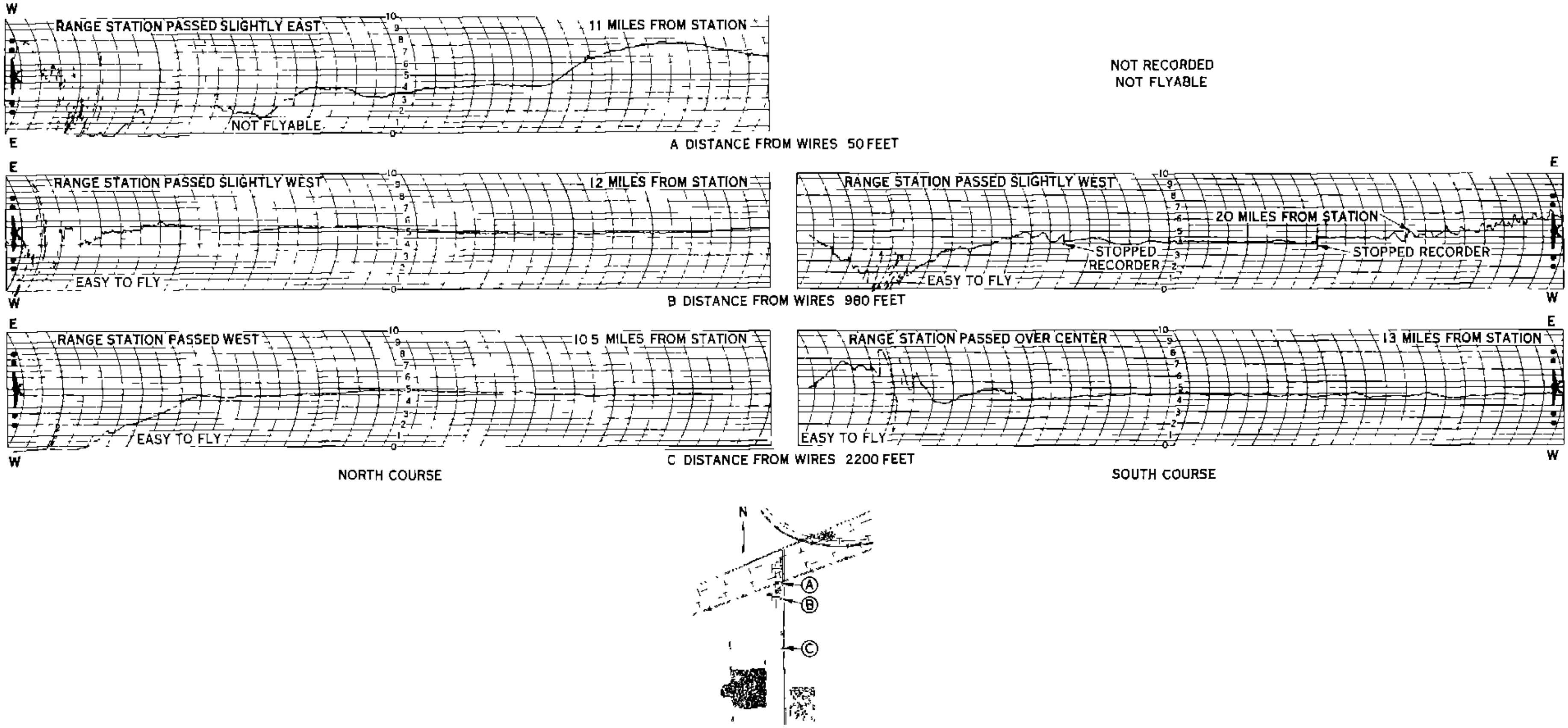


Figure 32 On Course Recordings toward the Station of North and South Courses Showing the Effect of Distance from Telephone Wires

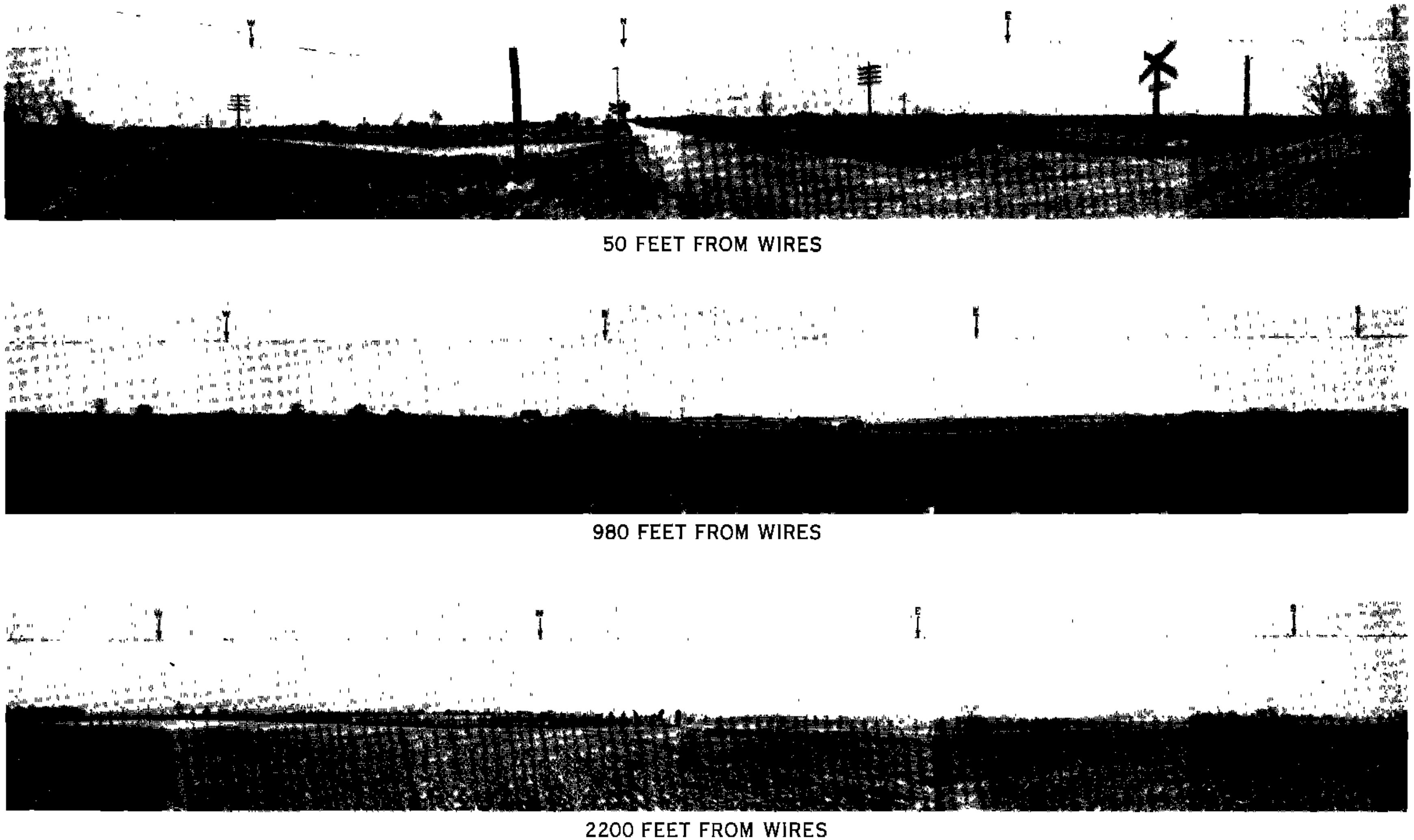


Figure 33 Panoramic Photographs Taken from the Three Sites Investigated on a Line Approximately Perpendicular to Telephone Wires

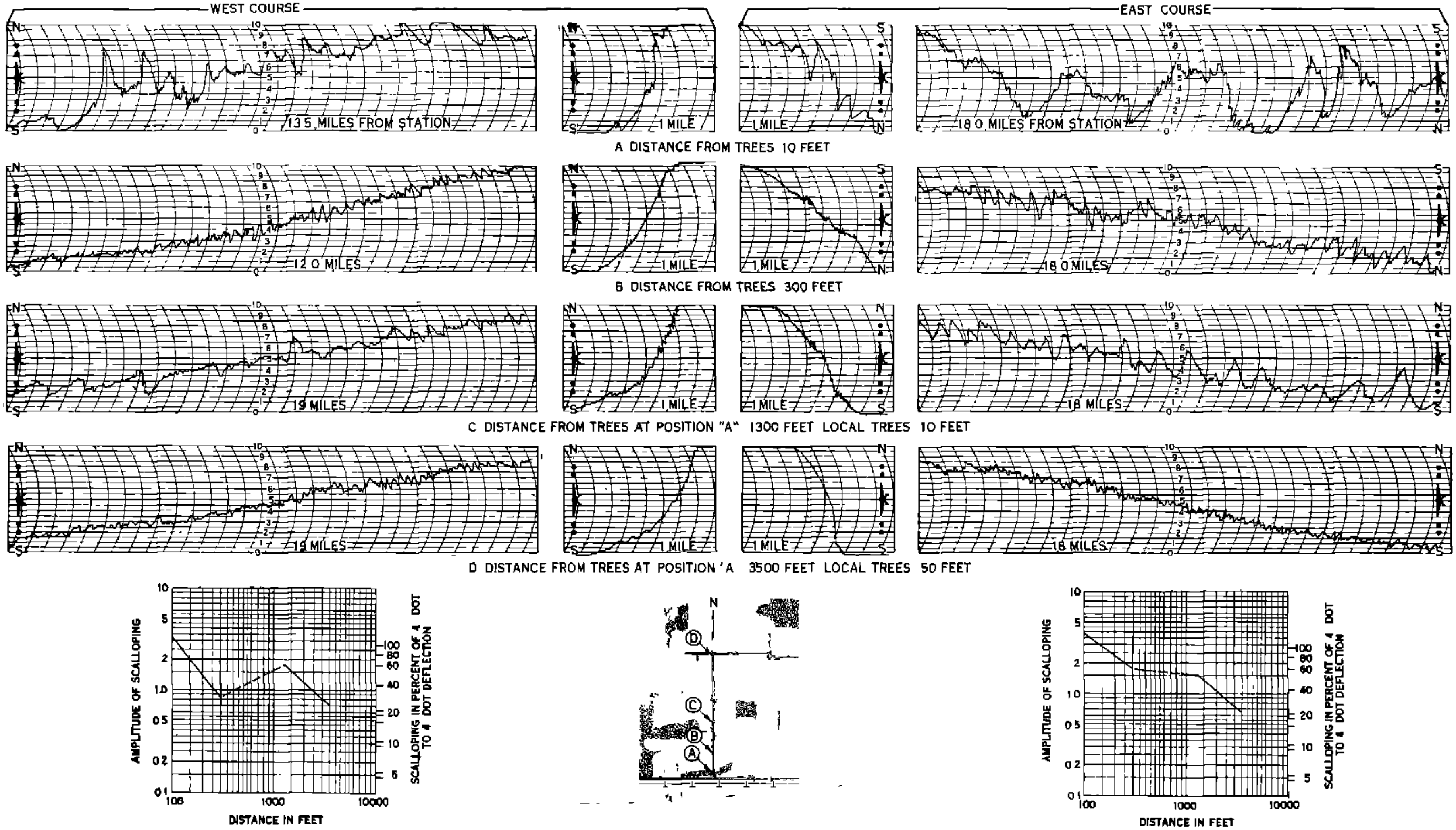


Figure 34 Cross-Course Recordings of West and East Courses, and Graphs, Showing the Effect of Distance from Trees

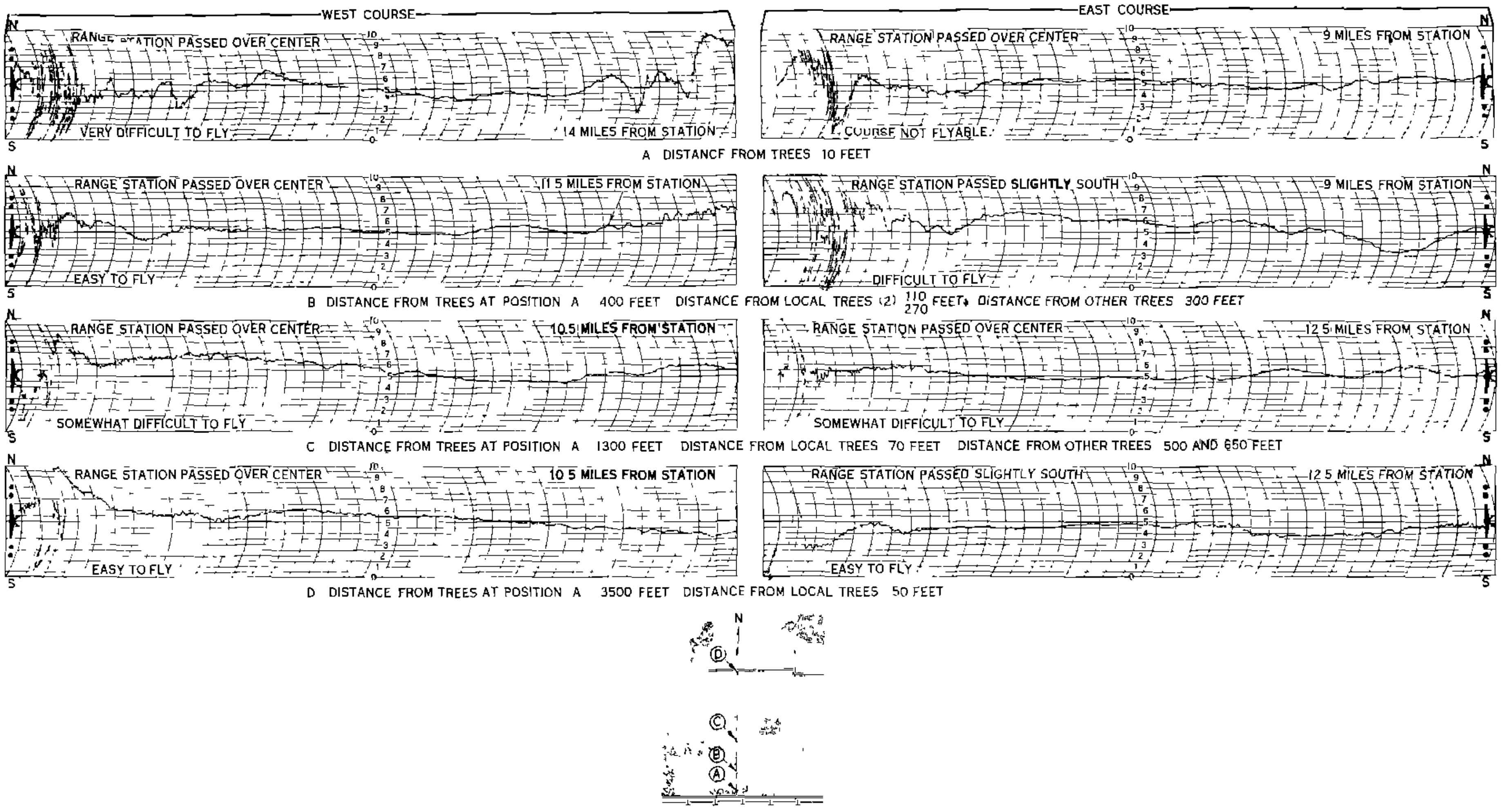


Figure 35 On Course Recordings Toward the Station West and East Courses Showing the Effect of Distance from Trees

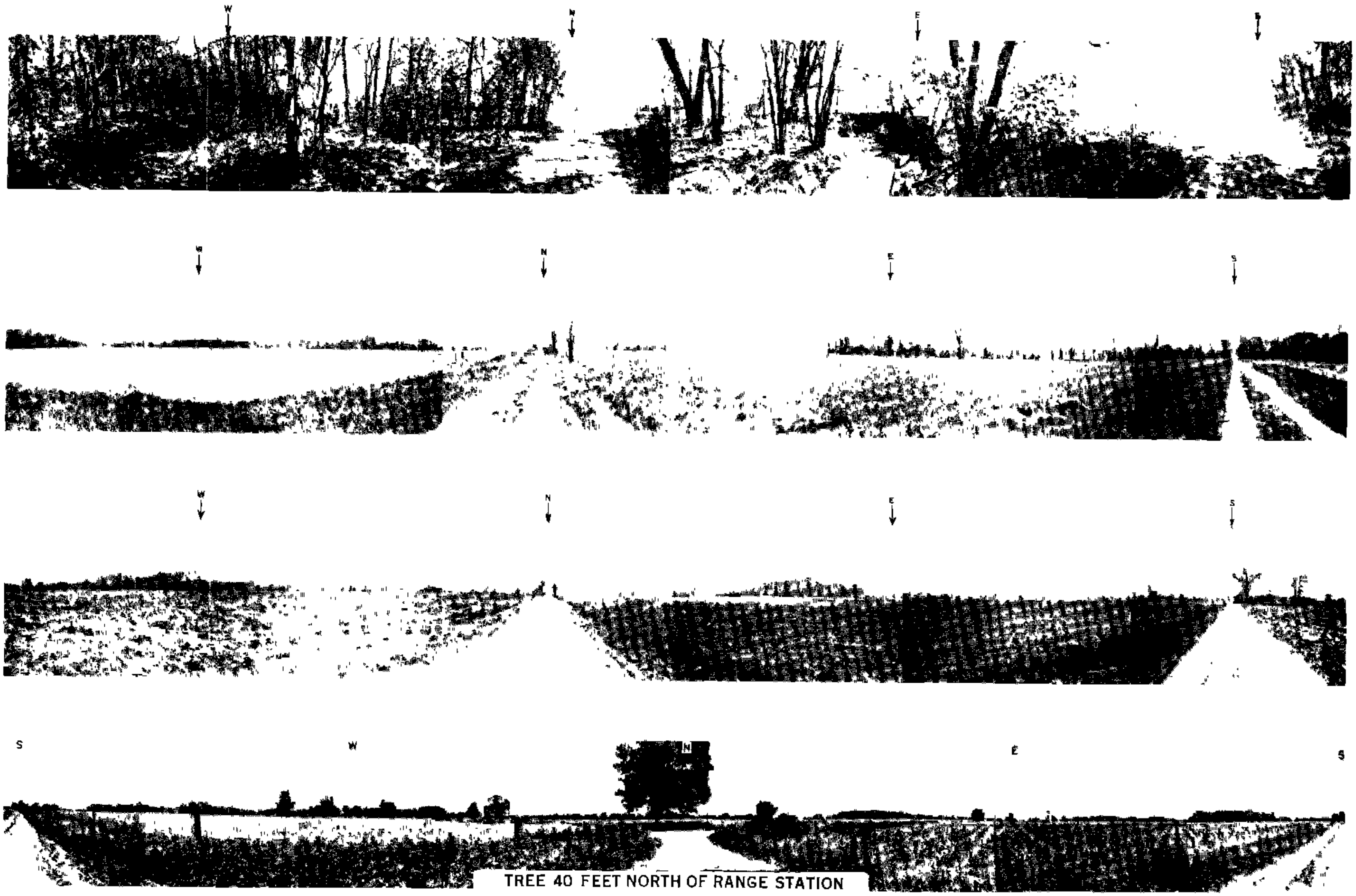


Figure 36 Panoramic Photographs of Sites Used for Tree Tests

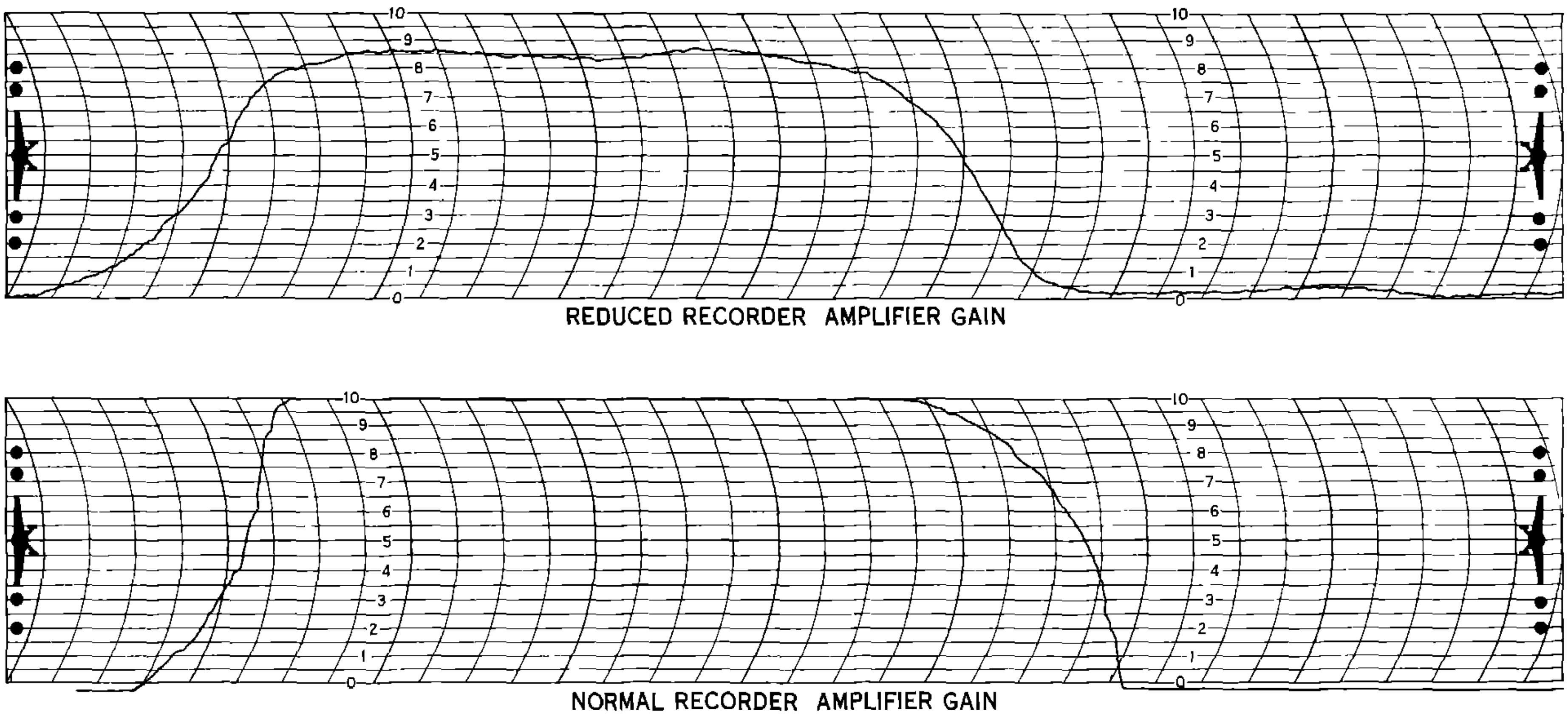


Figure 37 Recordings Taken During a Flight Around the Station at One *Mile Showing the Clearance Provided by the Range System*

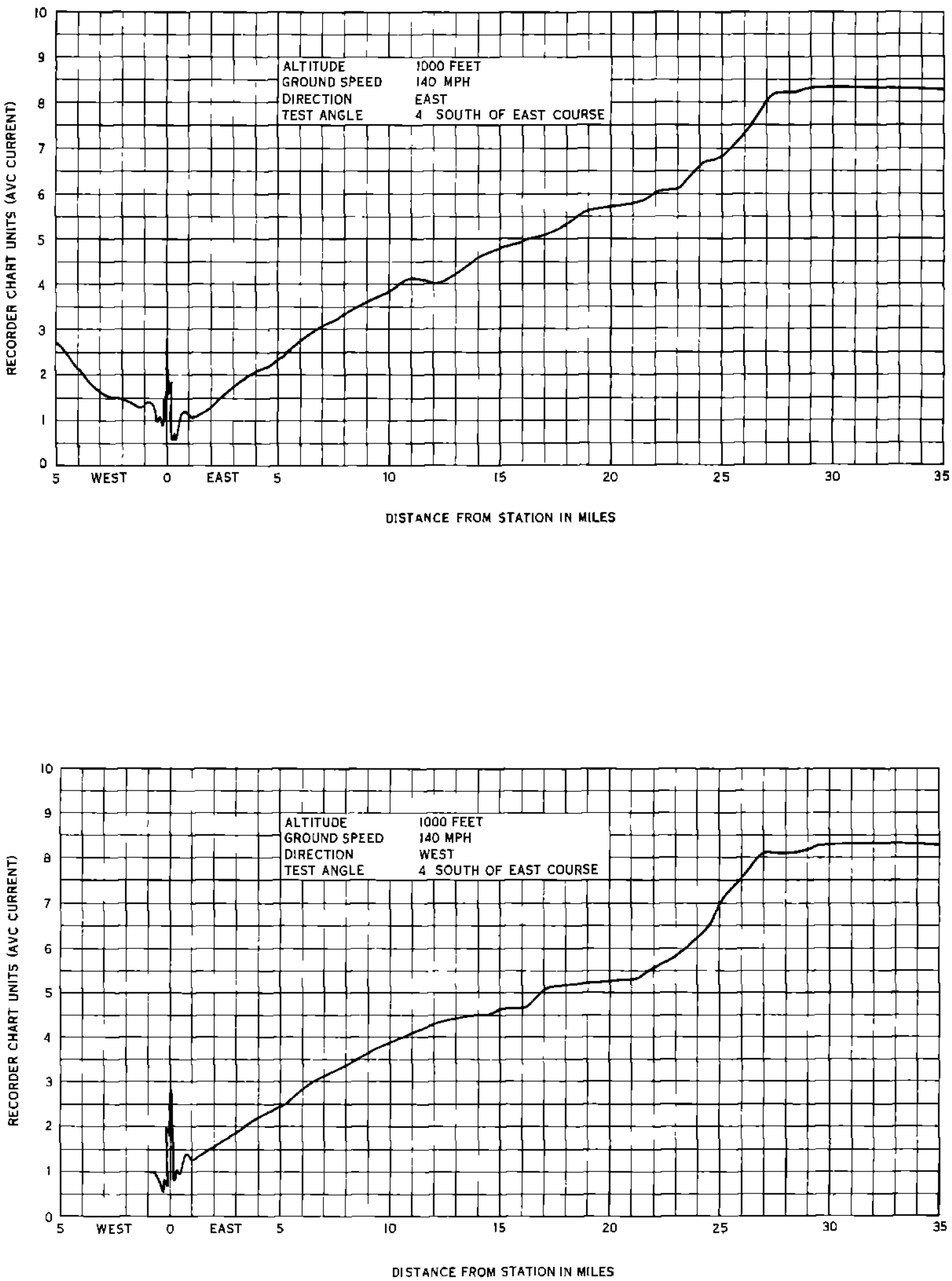


Figure 38 AVC Current Graphs Obtained for the Purpose of Plotting a Vertical Field Pattern of the Range Antenna System

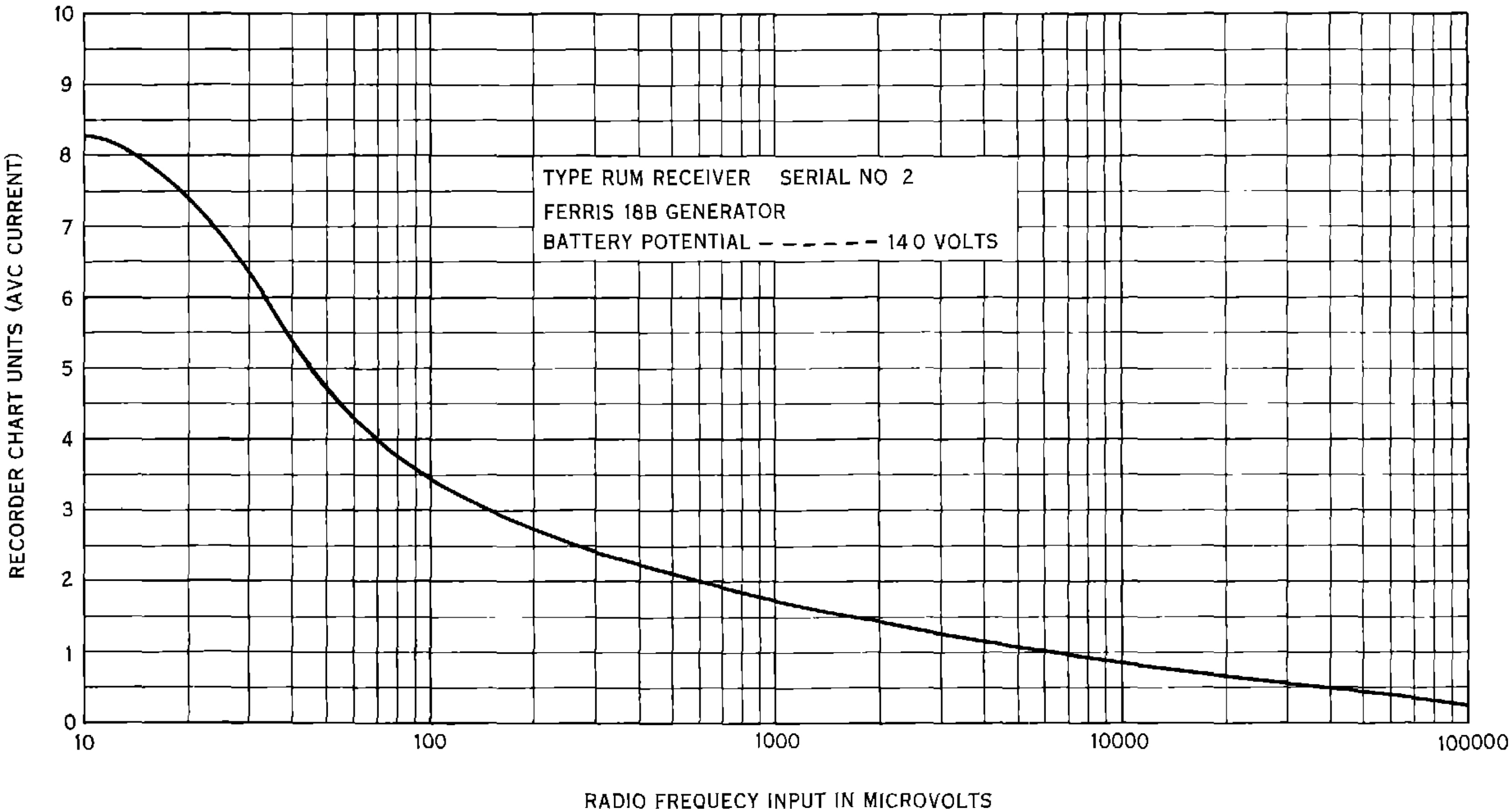


Figure 39 Calibration of Input vs AVC Current for the Receiver Used During the Tests

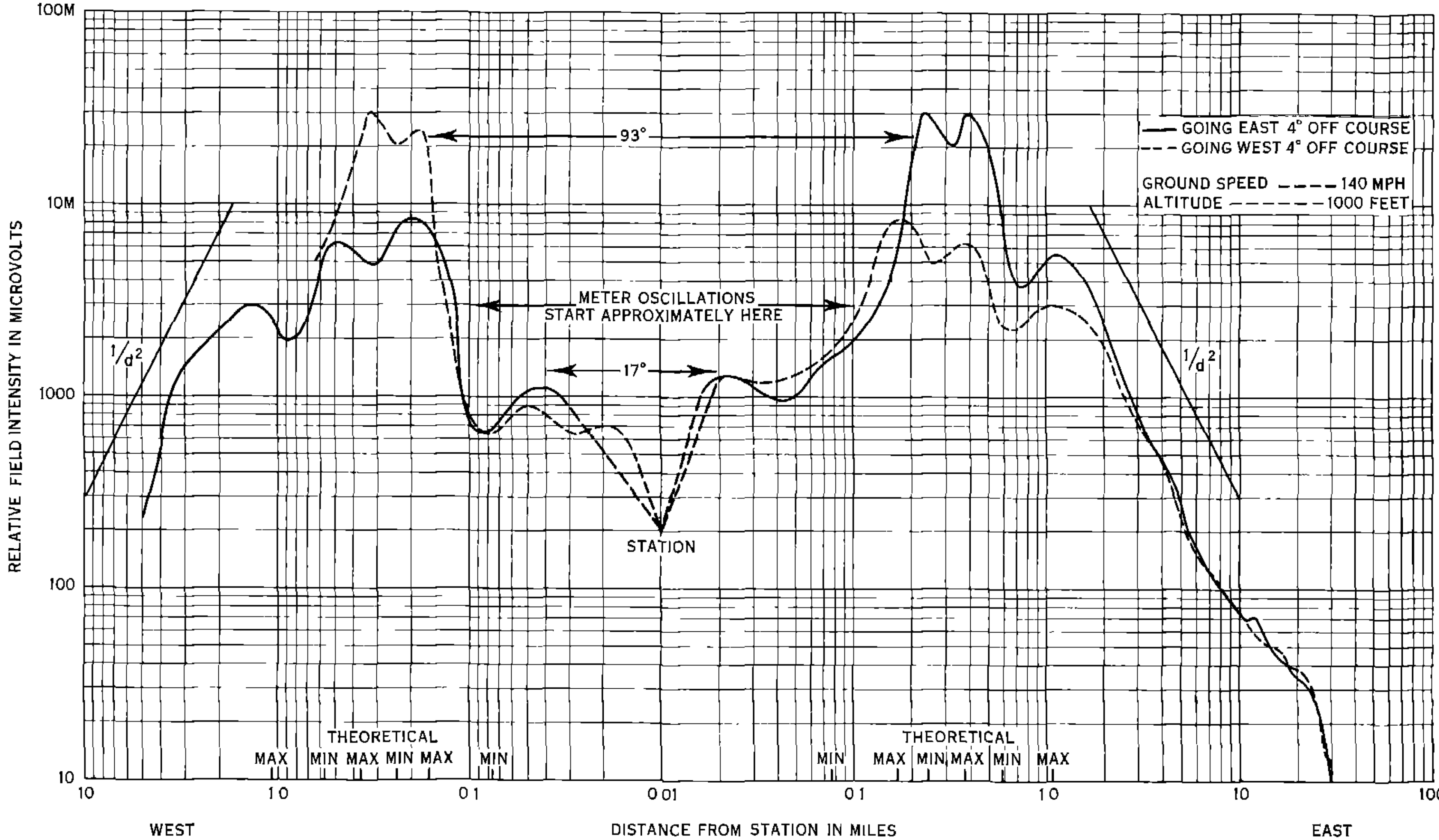


Figure 40 Relative Field Intensity Graphs Showing the Vertical Field Pattern of the Range Antenna System

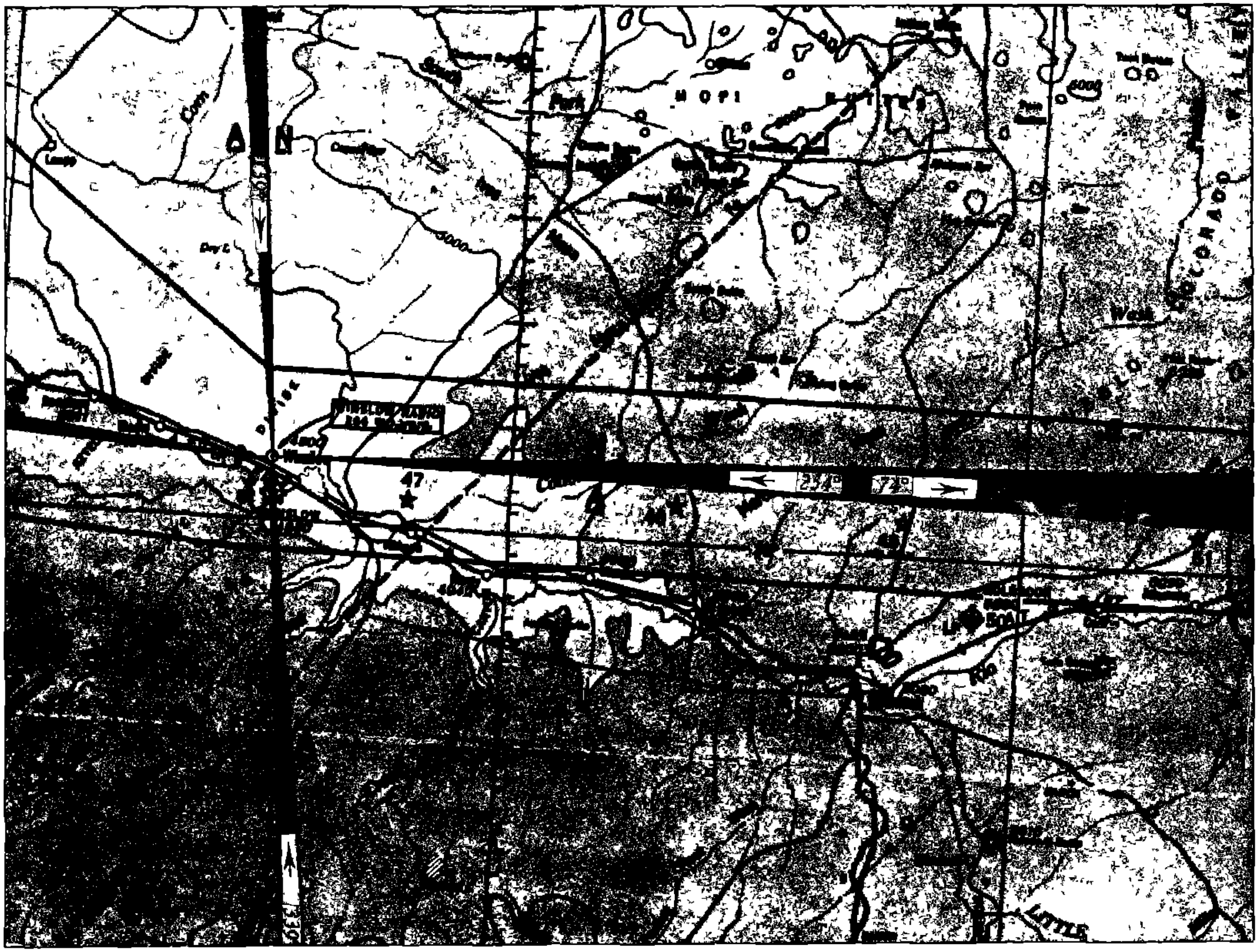


Figure 41 Map Showing a General Location Suitable for Future Tests

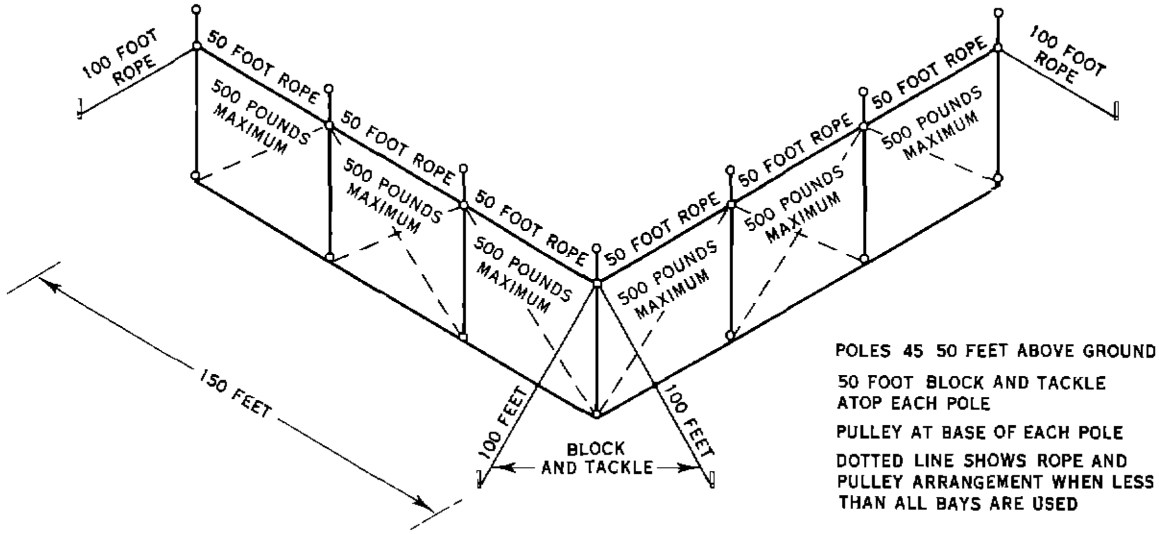


Figure 42 Proposed Arrangement of Wire Screens for Future Tests

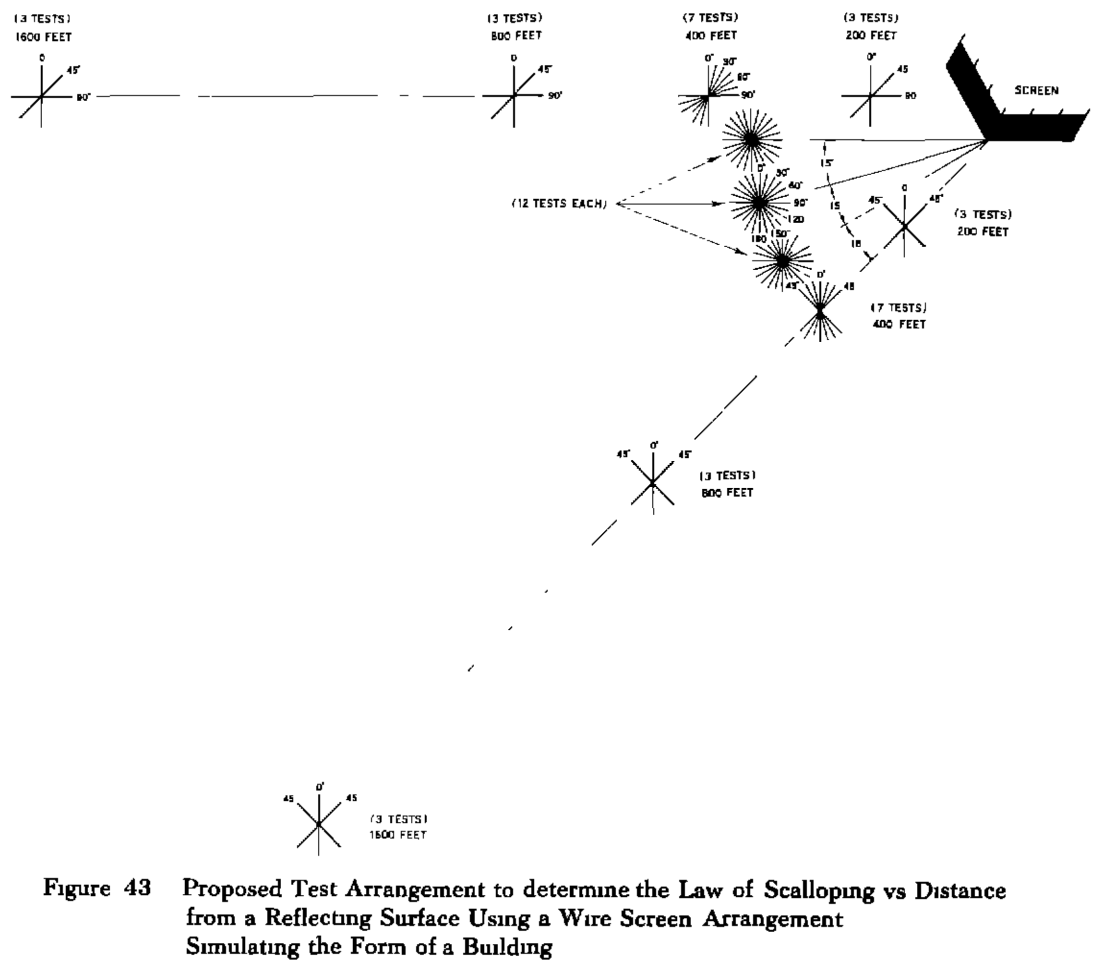


Figure 43 Proposed Test Arrangement to determine the Law of Scalloping vs Distance from a Reflecting Surface Using a Wire Screen Arrangement Simulating the Form of a Building

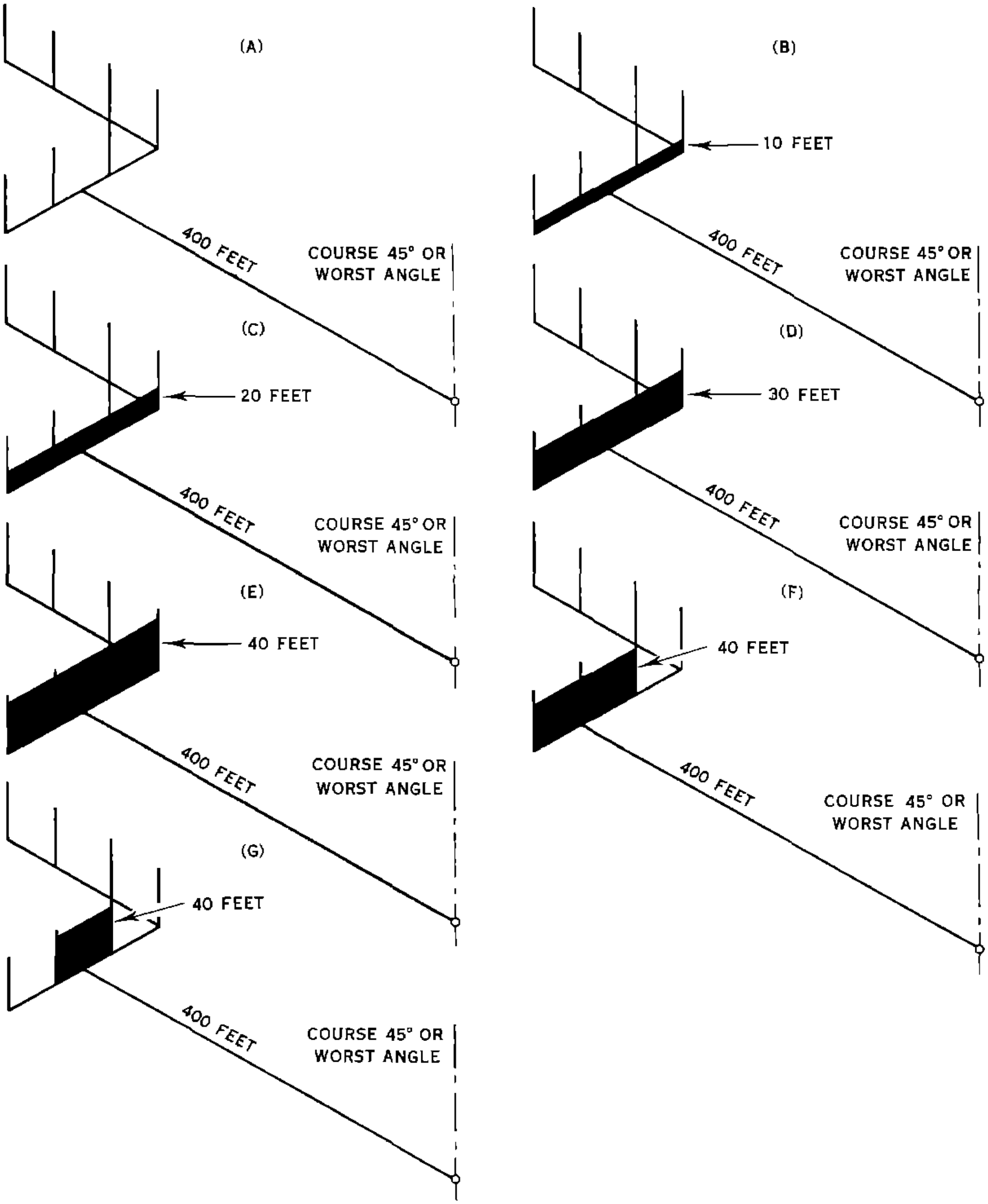


Figure 44 Proposed Tests to Determine the the Law of Scalloping vs Height and Area of a Reflecting Object

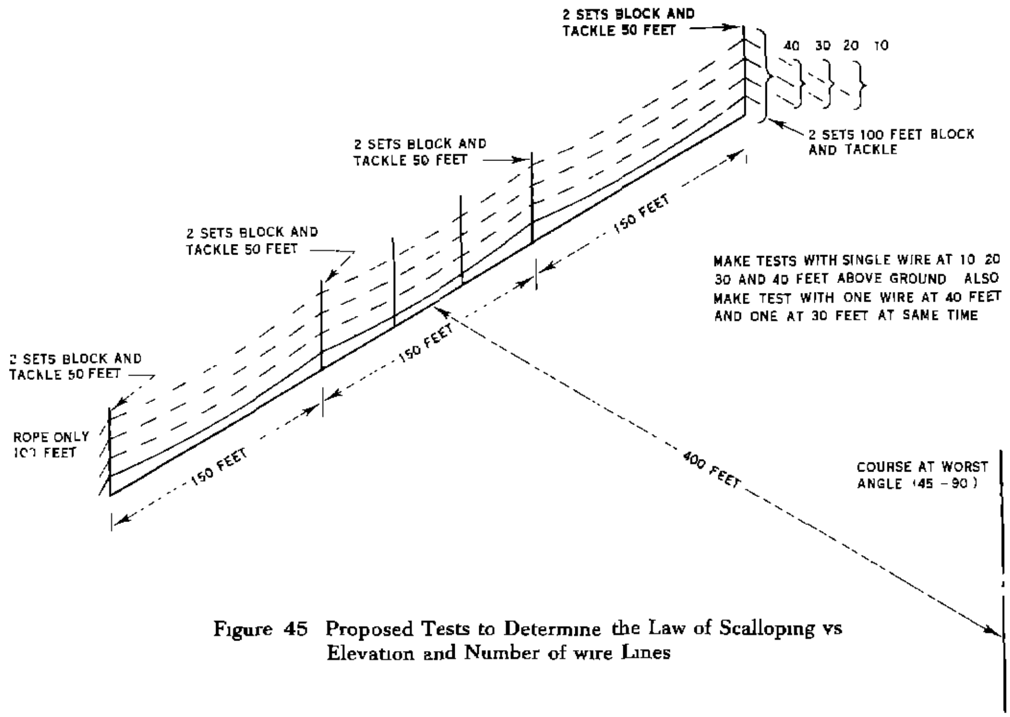


Figure 45 Proposed Tests to Determine the Law of Scalloping vs Elevation and Number of wire Lines

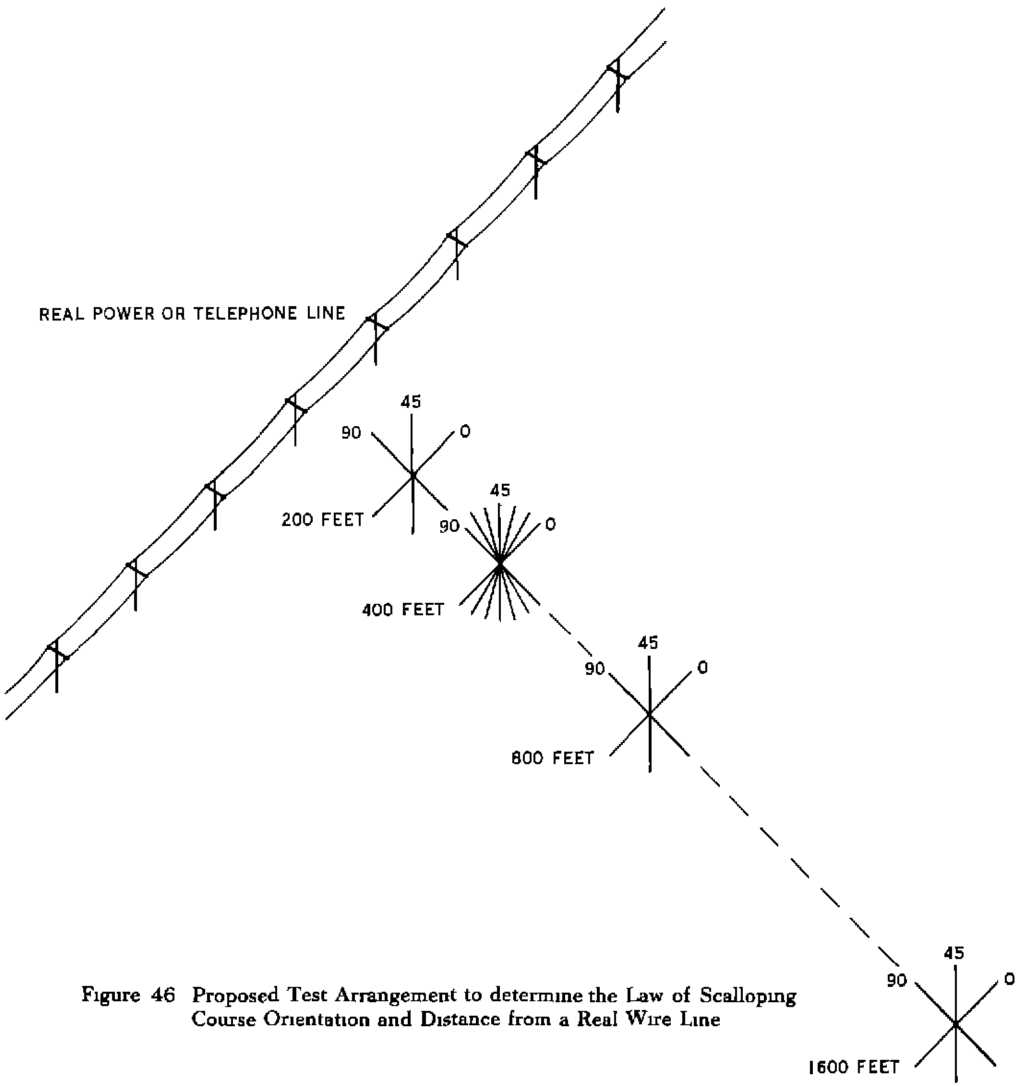


Figure 46 Proposed Test Arrangement to determine the Law of Scalloping Course Orientation and Distance from a Real Wire Line

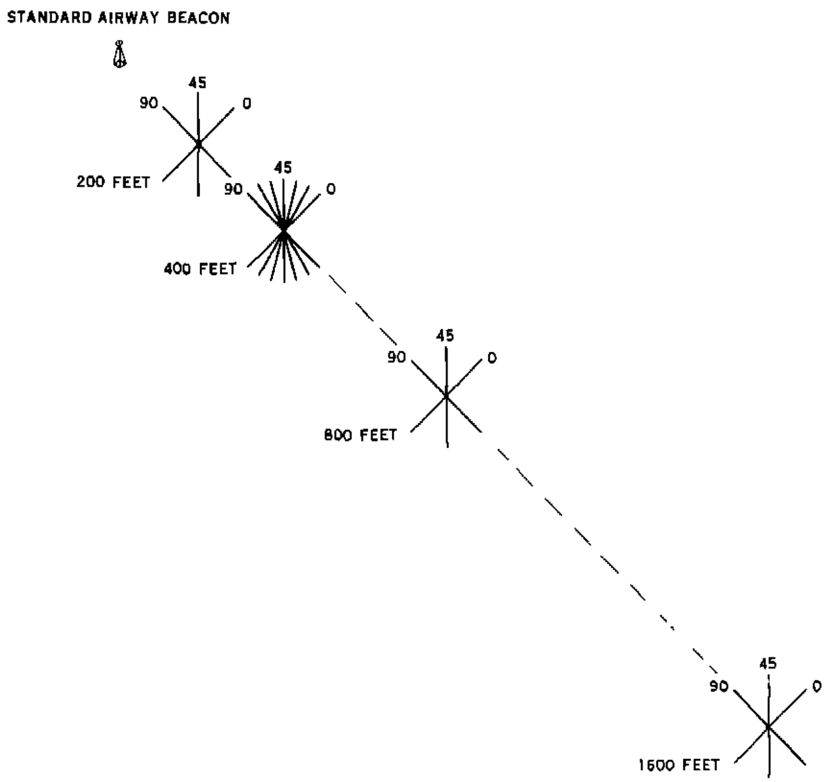


Figure 47 Proposed Tests to Determine the Law of Scalloping vs Course Orientation and Distance from a Standard Airway Beacon Tower

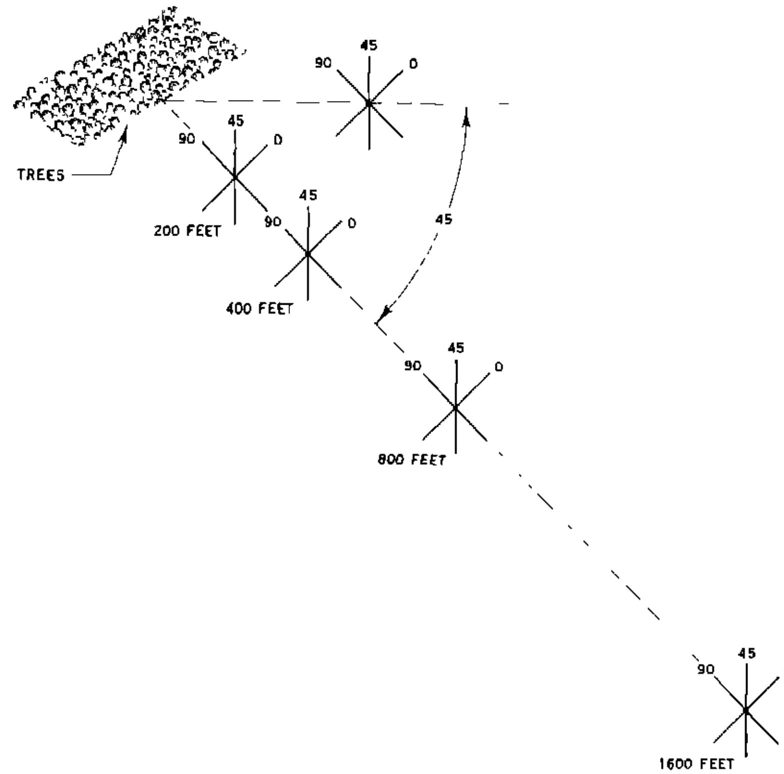


Figure 48 Proposed Tests to Determine the Law of Scalloping vs Course Orientatation and Distance from Trees

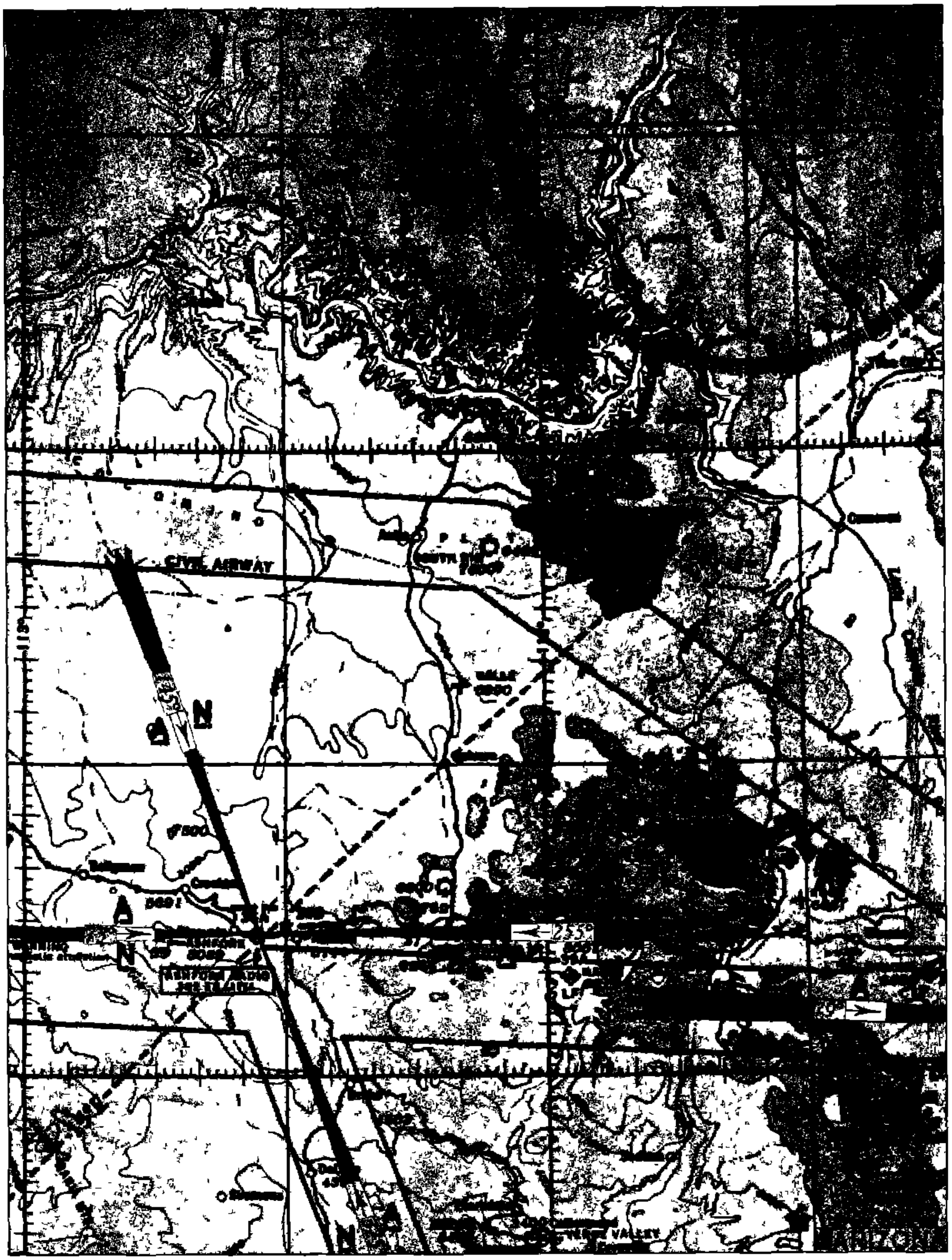


Figure 49 Map Showing Suitable Locations for Tests to Determine the Law of Scalloping vs the Height of Trees