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TECHNICAL NOTE 4337

AN INVESTIGATION OF SOME PHENOMENA RELATING TO AURAL DETECTION OF AIRPLANES

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SUMMARY

An investigation was conducted to determine the effect of modifications made in the propulsion system of a single-engine airplane to substantially reduce its external noise and, thereby, to evaluate the significance of the external noise level of an airplane with regard to the problem of its detection by ground observers. Conventional noise-level measurements consisting of broad- and narrow-band frequency analyses were made for static tests on the ground. Also, listening data with the aid of ground observers were obtained for cruise flights as well as for take-offs, landings, and power-off glides.

Modifications to the propeller and exhaust system of the airplane resulted in overall noise-level reductions of approximately 15 decibels at cruise power and 20 decibels at take-off power. Engine exhaust noise seemed to be the main component at cruise power, whereas the propeller noise was the main component at take-off power. The modified airplane was not so easily audible to ground observers as was the unmodified airplane. For the particular environment of the present tests in which the background noise level was about 40 decibels, the unmodified airplane was detected at distances on the average about twice as great as those for the modified airplane. These differences are less than would be predicted on the basis of the assumption that there were no losses of energy caused by the effects of the atmosphere and of the intervening terrain.

The test results indicate that the external noise-level characteristics of the airplane, the propagation phenomena peculiar to the terrain over which the noise travels, and the ambient or background noise conditions near the observer are all significant factors in aural detection by ground observers.

INTRODUCTION

The object of the present study is to evaluate the significance of the external noise level of an airplane with regard to the problem of its detection by ground observers. A need was stated for a single-engine airplane which would have a very low external noise level and which would still have a useful payload for special missions. These requirements led to the modification of an airplane to reduce its noise substantially (ref. 1). Although this airplane is larger and more powerful than those for which the work of references 2 and 3 was accomplished, the resulting modifications, which included increasing the number of propeller blades, reducing the tip speed, and adding exhaust mufflers, were similar in nature.

In order to evaluate the modifications to this airplane, tests were made to measure external noise levels, as in the work of references 2 and 3, and also some listening tests by ground observers were performed.

A brief description is given of the airplane, the modifications made to it in the interest of noise reduction, and the results of noise measurements and listening tests conducted with the unmodified and the modified airplanes to evaluate the effectiveness of these modifications. Of particular interest are the results of the listening tests made by ground observers to determine the distances at which aural detection was possible in the presence of a very low background noise. Although the data presented apply directly to these specific test conditions, an attempt is made to interpret the results in a general way to define some of the significant factors in the aural detection problem.

SYMBOLS

B	number of blades
b	propeller blade chord, ft
D	propeller diameter, ft
f	fundamental cylinder firing frequency $\left(f = \frac{N}{120}\right)$
h	propeller blade section maximum thickness, ft
k	propagation loss coefficient, db/1,000 ft
L	noise level, db
l	distance, ft
L_o	overall noise level, db

m order of harmonic

N engine speed, rpm

P power to propeller, hp

R propeller tip radius, ft

r radial distance to blade element, ft

x maximum distance of detection measured from center line of runway, ft

y distance of aircraft from observer along center line of runway, ft

β propeller blade angle, deg

$\beta_{0.75R}$ propeller blade angle at the 0.75 radius station, deg

γ elevation angle of aircraft from ground observer, deg

ψ azimuth angle measured in clockwise direction with 0° at front of aircraft, deg

Subscript:

1 at a given station

APPARATUS AND METHODS

Description of Aircraft

Data were recorded for both an unmodified airplane and for one which was modified as shown in figure 1. Some of the significant characteristics of the two airplanes are given in table I. The unmodified airplane is a single-engine high-wing monoplane having a gross weight of 8,000 pounds, a useful load of 3,906 pounds, and a cruise speed of 106 knots. It is powered by a nine-cylinder four-cycle engine rated at 600 horsepower. The airplane is fitted with a three-blade variable-pitch metal propeller 11 feet in diameter. The blade-form curves for this propeller are given in figure 2(a). The propeller is geared to rotate at two-thirds of the engine speed. There are four ejector-type exhaust ports. Three of these each carry the exhaust gases from two cylinders, and the fourth exhausts the remaining three cylinders.

The modified airplane incorporated changes in the propeller, the gearbox, the engine exhaust system, and the engine cooling system. The fixed-pitch propeller incorporated five 12-foot-diameter wooden blades, and rotated at one-third of the engine speed. The blade-form curves for this propeller are given in figure 2(b). The ejector exhaust system of the unmodified airplane was changed to include a collector ring and twin exhaust mufflers such as shown in figure 3 and in reference 1. These changes in the propeller and in the exhaust system also necessitated internal changes in the standard gearbox and the incorporation of cooling flaps in the engine cowling. The resultant back pressure on the engine was less with the mufflers than with the standard ejector tubes.

It was noted in reference 1 that the total weight penalty for the modified airplane was approximately 250 pounds, 75 pounds of which is assigned to the mufflers. It was estimated in reference 1 that the total weight penalty could be reduced to about 125 pounds by careful design.

The fully modified airplane cruised at 96 knots in comparison with 106 knots for the unmodified airplane. A loss in speed of about 4 knots is thought to result from muffler drag and loss of ejector thrust. The remaining speed loss is believed to be caused by the fact that the fixed-pitch propeller was not set at the optimum pitch setting for the cruise condition. There need not necessarily be any appreciable cruise penalty associated with the operation of a multiblade propeller such as this; in fact, the experience cited in reference 2 for a five-blade propeller configuration and an internally mounted muffler indicated that an increase in cruise speed was obtained.

Noise Measurements

Noise measurements were made during both the static tests on the ground and the flight tests. During static tests on the ground, measurements were made at ground level at a distance of 50 feet for cruise and take-off power conditions and at various azimuth angles on both sides of the airplane. Broad-band data were measured with the aid of a sound level meter and octave band analyzer. Simultaneous FM and AM magnetic tape recordings of the outputs of two condenser-type microphone systems were also made for obtaining subsequent narrow-band frequency analyses. The FM system covered the range from 5 cycles per second to 1,500 cycles per second and the AM system covered the range of 100 cycles per second to 10,000 cycles per second. Of particular interest are the narrow-band analyses (5 cycles per second band width) of the FM tape records, a sample of which is shown in figure 4. Most of the significant engine and propeller noise components occur in the range below about 350 cycles per second. Consequently, only the FM records were analyzed as in figure 4.

In the flight tests some magnetic tape recordings were made of the airplane flying directly over the observation point. In addition, several broad-band spectra were measured with the sound level meter and octave band analyzer as the airplane passed by in cruise at altitudes of 300 and 1,000 feet and also in take-off and landing.

Listening-Test Methods

In the listening tests a listener and a recorder were stationed together at an observation point on the ground. The listeners were not permitted to see the airplane, but were alert at all times to the fact that an airplane was in the vicinity and thus made a deliberate effort to listen for it. During the time that the airplane flew a predetermined flight path, the listener would indicate to the recorder whether or not he could hear the airplane. The recorder made appropriate notes and recorded times measured with a stop watch in order that the data could be interpreted subsequently in terms of airplane distance and orientation from the observer. At least two observer teams were used in all listening tests, and in some of the tests three teams were used.

The audiograms for all six observers (designated hereafter by two initials) are given in figure 5. Hearing losses in decibels are shown for various test frequencies. All the observers except AS were judged to have normal hearing. The consistent hearing deficiencies at the lower frequencies, as indicated in figure 5, are not believed to be significant and are thought to result from adverse background noise conditions existing during the audiometric tests.

Test Conditions

Weather.- The static ground tests were conducted with the airplane headed into the wind, the wind velocity averaging 7 to 10 knots for these tests. Wind velocities during all other tests varied between 3 and 9 knots. Ambient temperatures in the range of 80° to 90° F existed during the ground and flight tests. Relative humidity was approximately 55 percent.

Ambient noise.- Two different background noise conditions existed as noted in figures 6 and 7. For the tests conducted at Langley Field, Va., the average background noise spectrum given in figure 6 applied. For purposes of comparison, some noise spectra measured in a quiet residential area of the city of Chicago (ref. 4) are included. It can be seen that the Langley Field background noise, which is exclusive of air traffic noise, is generally higher than the residential area noise at night, but is comparable to the residential area noise in the daytime with the exception of the lowest octave bands. These higher levels at Langley Field in the low frequencies are believed to be caused by the operation of large rotating machines which normally are not present in residential areas.

For the tests conducted at the West Point (Va.) Municipal Airport the background noise was relatively low. The average background noise spectrum in the area is given in figure 7 along with available measurements in other environments where the noise arises from natural phenomena. The measured data fall well within the hatched area which represents data from reference 5 and shows the normal range of noise levels in nature detectable by man. These noises are mostly caused by wind and air turbulence, especially as the air flows through trees and other vegetation. Noises due to light surf, such as are illustrated by the top curve, may be of higher level but are similar in spectrum shape.

Terrain features.- The location of the West Point Municipal airport relative to prominent terrain features in the area, the elevations of surrounding land, and the type of vegetation present are indicated in figures 8 and 9. Figure 8 is a composite photograph of four adjoining coast and geodetic survey maps of the area over which the flights were made. The region is generally flat, the extreme variations in elevation being about 100 feet.

The airport area in which the observers were located is about two miles from the center of town and is surrounded by wooded and marshy areas which are sparsely populated. A better appreciation of the types of vegetation and foliage in the area near the observer stations can be gathered from figure 9, an oblique aerial photograph taken from an altitude of 10,000 feet. In this figure are indicated runways 1, 2, and 3 used during the tests and also the observer stations designated A, B, and C. The terrain varies from heavily wooded to open as azimuth angle from an observer station changes, and this variation is a significant factor in the listening tests.

RESULTS AND DISCUSSION

Measurements of Airplane External Noise

The results of static ground tests are presented in tables II to V. Omissions in these tables indicate that either no measurements were made or reliable data were not obtained.

Static ground tests.- The overall levels and octave-band frequency analyses of the noise for the take-off-power condition $\left(\beta_{0.75R} = 25.5^{\circ}\right)$ are presented in table II for a distance of 50 feet and are illustrated by the curves of figures 10 and 11. Figure 10 shows a comparison of the polar distributions of the overall noise from the two airplanes. The overall levels for the unmodified airplane vary from 115 to 121 decibels, the higher levels occurring behind the propeller plane of rotation. The overall noise levels of the modified airplane vary from 93 to 97 decibels, and the radiation pattern is somewhat more nearly symmetrical. The overall noise reduction at take-off power is seen to be of the order of 20 decibels. The maximum reductions as seen in figure 11 for field points in the plane of the propeller occur in the octave bands below about 1,200 cycles per second in the range where the significant propeller and engine frequencies are known to occur.

For the cruise-power condition $\left(\beta_{0.75R} = 31^{\circ}\right)$ data were recorded for two additional modifications of the airplane. (See figs. 12 and 13.) The noise was measured from the airplane with the three-blade propeller and gearbox but with the mufflers and collector ring installed. Then the mufflers were disconnected, and the measurements were made with the collector ring and two stub exhaust ports. During this particular series of tests, it was noted that internal damage had been sustained in the first baffle of the muffler. Despite this damage, the muffler seemed to be fairly effective, as indicated by the data of figures 12 and 13 and table III.

The overall noise levels at various azimuth angles for the airplane without modifications and with all three modifications are given in figure 12. The corresponding spectra at field points in the plane of the propeller are shown in figure 13. By changing the exhaust system to a collector ring and twin exhaust ports, there was a small overall noise reduction. This reduction occurred mainly at the lower frequencies, probably because of cancellation of some of the low-order engine-exhaust harmonics. The addition of mufflers produced substantial overall noise reductions at all azimuth angles. These reductions occurred in all octave bands except the lowest, in which the propeller noise components were most significant. The addition of the five-blade propeller (modified airplane) resulted in a further decrease in the noise, particularly in or near the plane of the propeller. Since these reductions occurred in the first two octaves, it is indicated that the propeller had been the main contributor in that frequency range.

Tables IV and V show that before modification the engine noise was the main contributor. After modification, in which the engine and propeller noises were both reduced, the engine exhaust noise apparently dominated at cruise and the propeller dominated at take-off. Included in tables IV and V are analyses of the noise measured under the engine cowling. These data were obtained only on the unmodified airplane during both take-off and cruise power. An analysis of the data showed that no frequencies were noted in addition to those associated with the exhaust of the engine.

Flight tests.- The overall noise levels and octave-band frequency analyses of the noise for various flight conditions of the modified and unmodified airplanes are given in figures 14 to 16. Figure 14 presents the overall levels as measured at a point on the ground at Langley Field for both airplanes during "fly-over" at a 300-foot altitude. The overall levels are plotted as a function of horizontal distance in feet from the observation point. The noise of the modified airplane exceeded the background noise of 67 decibels for a total distance of about 4,400 feet.

The spectra for the modified airplane corresponding to the condition of maximum noise of figure 14 are given in figure 15. Noise levels in various octave bands are shown for altitudes of 300 and 1,000 feet. Also shown in the figure is a curve for the unmodified airplane. This curve has been estimated on the basis of incomplete measured data. The levels plotted are the maximum recorded as the airplane passed overhead. These data were recorded at the West Point Municipal Airport, for which the average background noise is shown by the lower curve replotted from figure 7.

Data were also recorded for both the modified and the unmodified airplanes during low-level glides in an attempt to measure the airframe noise. These frequency spectra are shown in figure 16 for the unmodified airplane at airspeeds of 56 and 104 knots, together with those for the modified airplane at 56 knots for comparison. Data were obtained at 56 knots for the modified airplane with the engine both on and off, and the results were essentially the same. It was not possible during any of these tests to stop the propeller from turning and, hence, the data include not only airframe noise but also propeller and engine noise. During comparable tests lower noise levels were obtained with the modified airplane, even though the airspeed was the same. One possible explanation is that the mufflers substantially reduced the engine noise of the modified airplane. The data of figure 16 for a speed of 56 knots thus apply directly to a normal landing of the modified airplane and to a power-off landing of the unmodified airplane. Data are also included for a two-place liaison airplane in a power-off glide during which the engine and propeller were not rotating. This is an estimated curve for an airspeed of 56 knots based on measurements at other airspeeds, and the data are presented as a matter of interest to indicate the order of magnitude of the airframe noise of an airplane having a gross weight of about 1,500 pounds and about 25 percent of the surface area of the unmodified airplane. It seems reasonable to suggest that the airframe noise of the unmodified and the modified airplanes would be less than the spectrum for the power-off glide of the modified airplane and above that for a two-place liaison airplane.

Listening-Test Data

In addition to making physical measurements of the noise, some attempts were made to evaluate the airplane modifications in terms of the distance at which aural detection was possible by observers on the ground.

Take-offs.- Most listening data during take-offs were obtained with the aid of two observer teams located at the West Point Municipal Airport at various distances along runway 1 with the airplane operating from runway 2. (See fig. 9.) Ground roll started at the east end of runway 2, and in all cases the airplane was about 10 feet in the air at the intersection of runways 1 and 2. For the modified airplane it was found that up to a distance of 3,500 feet, the observers were able to hear the airplane from the ground roll until a considerable part of the climbout had been accomplished. At a distance of 4,000 feet, however, the ground roll was not detected nor was any aural detection made until the airplane had gained an altitude of about 50 feet and was then above the foliage. Thus, it can be noted here that the transmission losses are larger when the airplane is near the ground level. As a matter of interest, for this case in which the elevation angle γ was essentially zero the intervening terrain was open, whereas for the case in which the elevation angle was 0.7° the intervening terrain was thinly wooded.

Some data were also taken for take-offs on runway 3 with observers at station C. As can be noted in figure 9, observer station C is located in a small heavily wooded area. In this location, detection was not possible for a distance of 2,300 feet until an altitude of about 50 to 100 feet was obtained. The noise attenuation seemed to be greater than for open terrain, even for somewhat larger elevation angles.

Landings.- For the same deployment of observers and similar test conditions, data were also obtained for landings of the modified airplane. The distance to initial detection varied somewhat but, in general, it decreased as the observers were moved along runway 1 away from runway 2. (See fig. 9.) It is interesting to note that the most distinctive feature of the landing was the tire screech. The observers, after initially detecting the airplane on its approach, sometimes lost contact as it flared out at low level, but in most cases they noted the tire screech. For tests conducted with observers in the wooded region at C a landing at a distance of 2,300 feet from the observer was barely detectable.

Cruise flight.- The listening data obtained for the cruise flight conditions are given in tables VI and VII. Table VI pertains only to the modified airplane and gives the observations of the first set of observers (VH, AS, and BM) for flights at 300- and 1,000-foot altitudes. Data were obtained at both observer locations A and B for flights perpendicular to runway 1. The distances x and y of table VI which are defined in the sketch shown with the table are noted to be preceded by either a plus or minus sign, depending on the quadrant in which they are measured, in conformity with standard coordinate notation. The data of table VII are presented by means of the same notation. These data were obtained with the aid of the second set of observers (JM, WM, and GK) and apply to both the modified and the unmodified airplanes. For purposes of illustration, the data of table VII have been plotted in figures 17 and 18.

Figure 17(a) shows the results of listening tests of the unmodified airplane at an altitude of 300 feet along with its approximate flight path during the tests. The data for the three observers are plotted at the appropriate x- and y-coordinates. The solid symbols in all cases relate to points of initial detection, whereas the open symbols are for terminal points. The amount of scatter can be seen directly from the figure and is noted in extreme cases to be as much as 100 percent of the average value. The heavy line is drawn through these average observed distances as an aid in interpreting the results. It follows by definition that if the airplane was at a coordinate station within the curve, it would be detected, whereas the reverse is true at a coordinate station outside the curve. From the figure it can be seen that the average detection distance in the x-direction varied from near zero to about 25,000 feet, depending on the distance y of the airplane flight path. In the y-direction detection was possible up to 22,500 feet, but it should be noted that the tests were not extended to a sufficient distance to determine the maximum value in the y-direction.

Results of similar tests for the unmodified airplane at an altitude of 1,000 feet are given in figure 17(b). For these conditions, which except for altitude were comparable to those of figure 17(a), the same observers were able to detect the airplane at generally greater distances in all directions. Thus, it can be concluded that the altitude of flight is significant, the lower altitude being more desirable if detection by ground observers is to be minimized. This result suggests that the terrain over which the noise propagates affects its propagation and introduces some significant losses.

Listening data obtained by the same observers for the modified airplane are given in figure 18. By comparing the data of figure 18 at two altitudes, it can be seen in general that the modified airplane can also be detected at greater distances at the higher altitude.

In comparing the data of figure 18 with those of figure 17, it can be seen that the detection distances associated with the unmodified airplane are approximately twice those of the modified airplane for comparable conditions. This result would be expected; however, the differences are less than would be predicted on the basis of the assumption that there were no losses of noise energy caused by the effects of the atmosphere and intervening terrain.

Several other significant results of the tests may be observed from figures 17 and 18. It was judged that the modified airplane could be detected better when it was upwind than when it was downwind, although surface winds of only low velocity were encountered. In general, the terminal detection distance was greater than the initial detection distance, probably partly because of the fact that the noise characteristics of the airplane differ somewhat as a function of azimuth angle. It can be seen that the regions of detection in the figure are not symmetrical about the observer station. This dissymmetry is probably caused, in part, by the characteristics of the atmosphere and the airplanes and perhaps more significantly by the effects of variation in the terrain on the noise propagation. For instance, propagation in a generally north-south direction from the observer stations A and B is essentially over open terrain, as can be noted in figures 8 and 9. In other directions, where the losses were apparently higher, the intervening terrain was partly wooded.

In summary of the listening tests, there are strong indications that the terrain intervening between the source and the observer exerts a significant influence on the noise propagation. Because of the apparent importance of these phenomena with regard to the problems of noise propagation in general and of aural detection in particular, they are analyzed and given in more detail in the succeeding sections.

Noise Propagation Over Long Distances

The available information relating to propagation over long distances and in particular for transmission paths close to the surface of the earth has been used as an aid in interpreting results of the present tests. A brief discussion of the concepts involved are included herein.

If the noise level L_1 in decibels is known at a given distance l_1, then the noise level L at any other distance l may be expressed by the following relation from reference 6:

$$L = L_1 - 20 \log_{10}\left(\frac{l}{l_1}\right) - \left[k\left(l - l_1\right)\right] \tag{1}$$

where the first term involving distance is the expression for the classical spreading of a spherical wave, and the term in the brackets accounts for losses incurred because of atmospheric and terrain effects. The coefficient k is conventionally expressed in terms of decibels per thousand feet of distance. For short distances the term in brackets is negligible and the reduction is caused only by normal spreading. For long distances it is known that atmospheric losses can be appreciable, especially for the high frequencies, as shown by the curve of figure 19.

Noise attenuation in decibels per thousand feet of distance is plotted for the various octave bands based on measured data of reference 7. These results apply directly to an airplane passing overhead, in which case propagation is nearly vertical to a ground observer. The losses shown in figure 19 are considered to be caused by atmospheric effects such as turbulence, refraction, conduction, humidity, absorption, and so forth (ref. 8), and are measured in addition to normal spreading. It can be seen from the figure that rather large attenuations are caused by these atmospheric phenomena at the higher audible frequencies, whereas these effects are negligible at frequencies below 600 cycles per second.

The information just cited has been used as an aid in interpreting results of the present tests as, for example, in figure 20. These data are spectra of the noise from the modified airplane at the observer station for various distances from the airplane during take-off. The data for the solid curve was measured during the tests at a distance of 220 feet, whereas the data for the dashed curves were calculated by using the atmospheric loss coefficients of figure 19. It can be seen that the atmospheric losses attenuate the high frequency part of the spectrum at a rapid rate and at the same time have little or no effect on the lower frequency bands.

For the purposes of the present tests it has been assumed that detection is possible at least to the distance where the airplane noise spectrum becomes equal to the background noise in the vicinity of the observer. For the conditions of figure 20 this detection distance is between the limits of 16,000 to 64,000 feet, and it appears that the frequency band of 150 to 300 cycles per second is most significant in detection.

In order to permit examination of the propagation phenomena for this frequency band in more detail, figure 21 has been prepared. Noise levels, in the 150 to 300 cycles per second band are shown as a function of distance l in feet. The solid line is calculated by use of equation (1) and accounts for normal spreading and for the case where atmospheric losses are zero for this frequency band but does not account for losses induced by the terrain. By these latter assumptions the noise from the airplane becomes equal to the background noise at a distance l of about 37,000 feet, and detection should be possible to that distance. For the test condition where the noise propagated over partly wooded terrain the actual observed detection distance was 4,000 feet for an elevation angle γ of 0.7°. If it is assumed that the losses are incurred uniformly over the distance, then the dashed curve as shown would apply, and the deviation from the solid curve is the terrain loss at any given distance. At lower elevation angles and for similar terrain conditions the airplane was not detectable. It is apparent that the losses due to the terrain over which the noise propagates has an important effect on the distance of detection for low flying airplanes. At elevation angles higher than 0.7°, however, detection was possible at distances up to about 10,000 feet. This result is in qualitative agreement with the findings of reference 9, wherein it was noted that a noise source at a higher elevation could be detected at a greater distance.

Since it was noted that these losses were a function of the type of terrain over which the noise propagated as well as the elevation angle, an attempt was made by the method just outlined to establish approximate values of k for a range of these two variables. The results are given in figure 22 for elevation angles γ ranging from near 0° to about 5°. Only a few data points are available for conditions where the terrain intervening between the source and the receiver was either open or heavily wooded. These data points were used to define the small hatched and cross-hatched areas. The large hatched region encompasses data points from test conditions intermediate between these two where the terrain was noted to be partly wooded and partly open. As an estimate, the partly wooded terrain had about 10 to 25 percent of the density of vegetation existing on the heavily wooded terrain. Also shown for comparison is a small heavily shaded region which is estimated from measurements made in reference 10 for propagation at low elevation angles over grassy terrain. The k-values of figure 22 should be used only as an indication of the order of magnitude. They are, however, consistent with the measurements of references 6 and 11 for a wide range of terrain conditions, including some which are similar to those of the present tests. As a matter of interest, at low elevation angles the propagation losses could vary from approximately 0 to 10 decibels per thousand feet for terrain which varies from open to heavily wooded.

It should be noted that there appeared to be no extreme temperature, wind, or turbulence variations during any of these tests. Consequently, the scatter observed here is probably less than that which would be observed under more extreme atmospheric conditions. Caution should also be exercised in extrapolation of these data for other conditions having different types of vegetation.

Factors Affecting Aural Detection

By making use of the findings of the present studies it is possible to relate the factors which are most significant in the aural detection of airplanes by ground observers. The nature of this problem is illustrated by figure 23, in which are related such parameters as airplane external noise level, ambient or background noise level at the observer station, and the phenomena involved in noise propagation from source to observer.

Noise levels in decibels are shown as a function of distance l for both an unmodified airplane and one which was modified to reduce its external noise by about 18 decibels. The levels measured at a distance of 1,000 feet were used in evaluating equation (1) for the distances l of the figure. These results for both the unmodified and modified airplanes are given by the solid curves for $k = 0$. The airplane noise levels are those in the 150 to 300 cycles per second band, and for this frequency range the so-called atmospheric losses are negligible, as indicated in figure 19. Thus, the solid curves apply directly to the case in which the elevation angle γ is sufficiently large that the terrain effects are negligible; for the partly wooded terrain conditions (fig. 22) the corresponding elevation angles γ are of the order of about 7° or larger. If $k = 0$, then the noise levels decrease 6 decibels with each doubling of distance, and an 18-decibel difference in the external noise levels of the two airplanes corresponds to a factor of about 8 in the distances at which the same noise level will be observed. It follows then that, if detection is possible up to the distance where the airplane noise is equal to the background noise level of 33 decibels, the detection distances are about 17,000 feet and 150,000 feet, respectively, for the modified and the unmodified airplanes. If the aircraft were flown at lower altitudes in order to minimize detection, then the propagation loss coefficient k would no longer be zero.

For instance, if it is assumed that $k = 0.5$ decibel per thousand feet, equation (1) would give the dashed curves in both cases. The shaded region between the solid and dashed lines is an indication of the losses incurred from the effects of terrain. It can be seen that these losses are equal for both airplanes at equal distances, but the resultant effects are larger for the unmodified airplane because of the greater distance over which the noise travels. As a result, the detection distances are, in this case, about 9,500 feet and 30,000 feet, respectively, for the modified and unmodified airplanes. These results are consistent with those observed in the present tests and thus would apply for an environment such as that encountered in these tests. Thus, it can be seen that although the detection distance is greater for the airplane having the highest external noise level, this difference is not as great as would be predicted on the basis of there being no propagation losses.

So far, only one example background noise level has been considered. If the background noise level were changed from 33 decibels as noted during the tests at West Point Municipal Airport to 54 decibels as noted at Langley Field, the detection distances would be about 1,500 feet and 8,500 feet, respectively, for the modified and the unmodified airplanes. In this comparison the difference in background noise level at the observer can be seen to be very significant in reducing the detection distance. In fact, a 21-decibel increase in the ambient noise level in the observation area is equivalent to a 21-decibel decrease in the external noise level of the airplane.

In the summary of figure 23 it should be noted that a reduction of the external noise level of the airplane or an increase of the background noise level at the observer station will make aural detection more difficult. It should also be noted that propagation losses are significant, particularly for long distances and small elevation angles, and should not be overlooked in an analysis of this type.

CONCLUSIONS

Noise measurements and ground-observer listening tests for an unmodified single-engine airplane and for one which was modified to reduce its external noise indicate the following conclusions:

1. Modifications to the propeller and exhaust system of the airplane resulted in overall noise-level reductions of approximately 15 decibels at cruise power and 20 decibels at take-off power. Engine exhaust noise seemed to be the main component at cruise power, whereas the propeller noise was the main component at take-off power.

2. The modified airplane was not so easily audible to ground observers as was the unmodified airplane. For the particular environment of the present tests, in which the background noise level was about 40 decibels, the unmodified airplane was detected at distances on the average about twice as great as those for the modified airplane. These differences are less than would be predicted on the basis of the assumption that there were no losses of energy caused by the effects of the atmosphere and intervening terrain.

3. Losses due to the terrain over which the noise propagated were noted to have important effects on the distance of detection for low-flying airplanes. At low elevation angles, propagation losses from near 0 to about 10 decibels per thousand feet were estimated for terrain which varied from open to heavily wooded.

4. Three significant related factors in the aural detection of aircraft were noted to be: the external noise level of the aircraft, the propagation phenomena peculiar to the terrain over which the noise travels to the observer, and the ambient noise level at the location of the observer.

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National Advisory Committee for Aeronautics,
Langley Field, Va., August 14, 1958.

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TABLE I

CHARACTERISTICS OF THE UNMODIFIED AND MODIFIED

AIRPLANES FOR STATIC GROUND TESTS

Airplane		Propeller					Engine			
Configuration	Operating condition	Number of blades, B	Diameter, D, ft	Ground clearance, ft	Speed, rpm	Tip rotational Mach no.	Power, P_o, hp	Speed, N, rpm	Gear ratio	Exhaust system
Unmodified	Cruise power	3	11	0.96	1,100	0.56	300	1,650	2/3	Four ejector exhaust ports (three exhaust two cylinders each and one exhausts three cylinders)
	Take-off power	3	11	.96	1,500	.77	600	2,250	2/3	
Modified	Cruise power	5	12.0	.42	550	.31	300	1,650	1/3	Collector ring plus twin exhaust mufflers
	Take-off power	5	12.0	.42	750	.42	600	2,250	1/3	

TABLE II

BROAD-BAND NOISE MEASURED ON A SINGLE-ENGINE AIRPLANE AT A

DISTANCE OF 50 FEET FOR TAKE-OFF-POWER CONDITIONS

Azimuth angle, ψ, deg	Noise levels, decibels								
	Overall	20 to 75 cps	75 to 150 cps	150 to 300 cps	300 to 600 cps	600 to 1,200 cps	1,200 to 2,400 cps	2,400 to 4,800 cps	4,800 to 10,000 cps
Unmodified airplane									
0	116	104	108	107	110	108	104	110	96
210	120	112	114	110	112	112	110	106	106
240	121	113	115	115	117	113	107	104	97
270	120	116	112	115	115	114	108	106	104
300	116	102	110	110	110	110	98	98	96
330	115	98	108	106	112	104	98	86	92
Modified airplane									
0	96	82	90	94	92	85	85	85	82
30	96	82	90	88	88	78	85	87	84
60	93	84	88	86	85	77	84	85	80
90	94	84	87	85	81	80	87	87	82
120	96	86	86	86	86	81	88	88	87
135	97	88	89	89	89	81	86	87	86
225	97								
240	97								
270	94								
300	95								
330	97								

TABLE III

BROAD-BAND NOISE MEASURED ON A SINGLE-ENGINE AIRPLANE AT A DISTANCE OF 50 FEET FOR CRUISE POWER CONDITIONS

Azimuth angle, ψ, deg	Noise levels, decibels								
	Overall	20 to 75 cps	75 to 150 cps	150 to 300 cps	300 to 600 cps	600 to 1,200 cps	1,200 to 2,400 cps	2,400 to 4,800 cps	4,800 to 10,000 cps
Standard (3-blade propeller, ejector exhaust ports)									
0	108	94	103	101	103	97	89	85	75
210	110	97	105	105	105	91	85	85	75
240	112	106	108	104	104	100	94	92	82
270	110	104	106	100	98	90	90	90	86
300	106	97	100	100	100	94	88	88	84
330	108	92	100	104	102	94	86	82	76
Partially modified (3-blade propeller, collector ring twin exhaust ports)									
0	104								
30	104	91	101	99	93	80	86	86	81
60	106	93	103	101	91	79	87	87	83
90	107	96	104	103	98	89	90	89	82
120	108	98	106	104	95	88	93	92	84
135	108	97	106	101	94	84	88	88	81
225	107								
240	109								
270	110								
300	107								
330	105								
Partially modified (3-blade propeller, collector ring and twin exhaust mufflers)									
0	96	87	89	90	88	81	84	86	77
30	96	86	88	90	84	81	87	87	79
60	96	90	88	86	83	78	84	86	80
90	98	96	91	87	86	86	84	84	78
120	103	102	90	89	81	80	88	83	76
135	98	97	91	88	84	80	74	82	74
225	99								
240	102								
270	100								
300	95								
330	96								
Modified (5-blade propeller, gear reduction collector ring and twin exhaust mufflers)									
0	94	90	91	86	84	76	85	84	78
30	94	90	88	86	86	76	84	84	77
60	94	89	87	87	85	75	84	84	77
90	96	91	86	89	88	86	86	84	77
120	95	88	89	88	86	78	86	85	79
135	96	90	91	86	84	76	85	84	78
225	96								
240	95	88	90	91	88	85	86	86	78
270	96	90	91	87	89	86	86	84	77
300	96								
330	95								

TABLE IV

NARROW-BAND ANALYSES OF NOISE MEASURED ON A SINGLE-ENGINE AIRPLANE

AT A DISTANCE OF 50 FEET FOR TAKE-OFF-POWER CONDITIONS

Noise component frequency, cps	Harmonic		Noise levels, decibels											
	Propeller	Engine cylinder	Azimuth angle, ψ											Under engine cowling
			0°	30°	60°	90°	120°	150°	210°	240°	270°	300°	330°	
Unmodified (3-blade propeller and ejector exhaust ports)														
18.7	0	1	---	---	---	---	---	---	94	---	---	---	---	117
37.5	0	2	90	92	98	99	99	99	101	99	98	94	83	130
56.2	0	3	82	---	89	94	95	96	---	90	92	90	84	121
75.0	1	4	99	100	103	108	112	105	106	111	109	103	102	121
93.7	0	5	81	---	78	---	86	91	---	89	---	---	84	111
112.5	0	6	89	---	91	95	96	97	---	94	98	93	86	125
131.2	0	7	92	99	105	104	106	107	107	105	108	107	102	133
150.0	2	8	99	103	104	104	108	97	107	98	106	105	105	116
168.7	0	9	103	104	101	95	104	105	106	107	101	97	102	117
187.5	0	10	88	---	90	90	91	92	---	95	92	86	90	111
206.2	0	11	101	97	93	83	99	101	97	100	98	101	98	125
225.0	3	12	97	105	100	100	101	100	105	97	100	104	108	117
243.7	0	13	85	96	85	89	84	93	95	99	---	95	94	125
262.5	0	14	91	88	89	---	91	95	97	---	95	89	93	115
281.2	0	15	88	89	93	98	96	92	95	87	97	90	90	116
300.0	4	16	101	105	100	104	94	99	107	101	107	103	105	127
318.7	0	17	90	89	98	96	93	99	94	95	96	94	90	123
337.5	0	18	95	103	100	103	93	105	95	100	101	96	93	117
356.2	0	19	93	94	92	95	99	96	97	91	89	87	90	117
375.0	5	20	107	105	99	102	98	105	102	108	106	104	104	125
393.7	0	21	86	94	96	89	93	97	97	96	97	97	86	116
412.5	0	22	93	---	95	---	96	102	101	98	98	91	95	118
431.2	0	23	92	---	92	88	93	97	105	100	94	97	88	114
450.0	6	24	103	98	96	93	95	88	102	106	101	102	105	113
468.7	0	25	93	98	85	100	96	92	101	100	100	97	96	113

Noise component frequency, cps	Harmonic		Noise levels, decibels											
	Propeller	Engine cylinder	Azimuth angle, ψ											
			0°	30°	60°	90°	120°	135°	225°	240°	270°	300°	330°	
Modified (5-blade propeller, gear reduction, collector ring, and twin exhaust mufflers)														
18.7	0	1	---	---	---	---	---	---	---	---	---	---	---	
37.5	0	2	79	78	78	85	79	76	86	85	81	78	72	
56.2	0	3	---	74	75	79	80	82	---	80	79	77	---	
62.5	1		87	81	81	84	82	81	86	84	82	78	85	
75.0	0	4	---	71	72	77	82	85	83	78	78	69	---	
93.7	0	5	---	---	74	74	75	79	---	---	69	68	---	
112.5	0	6	78	---	---	71	---	---	---	---	---	70	---	
125.0	2		89	85	93	71	80	83	88	90	80	79	84	
131.2	0	7	---	94	79	80	80	---	---	---	77	---	---	
150.0	0	8	---	---	67	---	---	---	---	---	---	---	---	
168.7	0	9	---	---	73	73	---	---	---	75	68	70	---	
187.5	3	10	85	81	79	77	78	85	91	90	82	80	84	
206.2	0	11	76	74	---	71	71	---	---	---	73	67	---	
225.0	0	12	---	---	---	---	---	---	---	---	67	---	---	
243.7	0	13	---	---	---	---	---	---	---	---	---	---	---	
250.0	4		87	80	77	73	75	80	91	88	77	81	81	
262.5	0	14	---	---	---	---	---	---	---	---	69	---	---	
281.2	0	15	---	---	---	---	---	---	---	---	67	67	---	
300.0	0	16	---	73	---	69	---	---	---	---	---	---	---	
312.0	5		88	80	74	72	74	70	90	85	79	74	79	
318.7	0	17	---	---	---	---	---	---	---	---	---	---	---	
337.5	0	18	---	---	---	---	---	---	---	---	---	---	---	
356.2	0	19	---	---	---	---	---	---	---	---	---	---	---	
375.0	6	20	85	76	69	---	74	81	86	82	77	75	77	
393.7	0	21	---	---	---	---	---	---	---	---	---	---	---	
412.5	0	22	---	---	---	---	---	---	---	---	---	---	---	
431.2	0	23	---	---	---	---	---	---	---	---	---	---	---	
437.5	7		80	76	69	---	72	71	81	78	77	70	75	
450.0	0	24	---	---	---	---	---	---	---	---	---	---	---	
468.7	0	25	---	---	---	---	---	---	---	---	---	---	---	

TABLE V

NARROW-BAND ANALYSES OF NOISE MEASURED ON A SINGLE-ENGINE AIRPLANE

AT A DISTANCE OF 50 FEET FOR CRUISE-POWER CONDITIONS

Noise component frequency, cps	Harmonic		Noise levels, decibels											
	Propeller	Engine cylinder	Azimuth angle, ψ: 0°	30°	60°	90°	120°	150°	210°	240°	270°	300°	330°	Under engine cowling
Unmodified (3-blade propeller and ejector exhaust ports)														
13.8	0	1	--	----	---	---	---	--	--	---	--	--	---	112
27.5	0	2	79	80	86	87	87	86	80	81	79	79	---	121
41.3	0	3	75	----	83	84	83	83	--	---	--	--	---	118
55.0	1	4	88	91	90	94	94	93	96	98	90	95	93	108
68.8	0	5	76	----	80	84	83	78	82	81	--	80	80	116
82.5	0	6	80	76	84	85	84	86	81	85	83	80	82	119
96.3	0	7	82	80	94	100	101	98	96	100	98	93	86	128
110.0	2	8	82	98	94	86	92	97	98	87	91	91	97	116
123.8	0	9	96	94	96	95	97	97	98	97	96	96	93	119
137.5	0	10	--	76	80	86	84	85	82	84	83	86	83	117
151.3	0	11	90	96	97	95	97	98	92	93	96	93	92	123
165.0	3	12	96	96	95	86	89	94	97	99	91	96	100	109
178.8	0	13	79	86	86	86	86	89	88	91	88	87	87	106
192.5	0	14	77	86	84	82	---	89	88	85	82	86	88	105
206.3	0	15	82	----	76	---	---	--	84	---	79	--	83	93
220.0	4	16	74	94	93	86	94	94	99	99	87	96	97	105
233.8	0	17	80	82	---	76	---	80	84	85	76	82	81	110
247.5	0	18	86	88	88	84	88	88	84	88	87	89	87	118
261.3	0	19	82	81	76	80	---	81	81	---	77	--	---	109
275.0	5	20	94	92	91	89	90	87	95	98	88	94	94	108
288.8	0	21	80	82	---	84	---	87	86	---	84	82	84	108
302.5	0	22	77	84	---	80	---	85	90	84	83	81	85	110
316.3	0	23	--	81	86	---	85	81	87	84	81	86	83	---
330.0	6	24	93	94	87	86	86	87	94	97	92	92	95	108
343.8	0	25	87	83	80	84	---	87	92	87	83	85	85	107

Noise component frequency, cps	Harmonic		Noise levels, decibels											
	Propeller	Engine cylinder	Azimuth angle, ψ: 0°	30°	60°	90°	120°	135°	225°	240°	270°	300°	330°	
Partially modified (3-blade propeller, collector ring, and twin exhaust ports)														
13.8	0	1	--	----	---	---	---	--	--	---	--	--	---	
27.5	0	2	--	77	81	81	83	83	78	80	80	77	76	
41.3	0	3	--	73	---	78	79	77	80	81	78	77	75	
55.0	1	4	85	78	85	90	93	88	91	94	91	88	86	
68.8	0	5	81	81	83	82	85	85	82	81	82	82	82	
82.5	0	6	85	----	81	81	84	--	88	89	88	88	88	
96.3	0	7	94	94.5	98	95	99	99	97	98	99	99	96	
110.0	2	8	87	84	87	86	87	88	91	92	81	89	87	
123.8	0	9	90	92	91	90	88	86	91	90	91	92	94	
137.5	0	10	--	83	88	86	85	84	82	84	91	85	82	
151.3	0	11	90	93	100	98	97	96	86	85	95	94	92	
165.0	3	12	89	84	82	---	83	--	84	78	87	83	86	
178.8	0	13	80	85	85	87	89	85	84	86	87	88	79	
192.5	0	14	78	80	77	78	83	79	82	84	76	78	82	
206.3	0	15	82	77	---	79	82	79	80	80	--	77	78	
220.0	4	16	90	84	80	80	79	76	87	87	88	83	88	
233.8	0	17	79	80	79	---	78	83	81	82	82	77	---	
247.5	0	18	82	73	79	85	86	84	79	80	87	79	75	
261.3	0	19	80	82	85	87	88	85	84	85	82	78	76	
275.0	5	20	86	88	91	90	93	86	83	81	77	83	84	
288.8	0	21	--	----	---	---	81	--	75	82	76	--	---	
302.5	0	22	78	85	74	86	90	86	72	81	74	--	---	
316.3	0	23	80	77	---	---	---	--	78	81	81	77	---	
330.0	6	24	81	79	---	79	79	79	81	84	75	--	---	
343.8	0	25	74	79	---	80	78	--	85	--	73	79	---	

TABLE V.- Concluded

NARROW-BAND ANALYSES OF NOISE MEASURED ON A SINGLE-ENGINE AIRPLANE AT A DISTANCE OF 50 FEET FOR CRUISE-POWER CONDITIONS

Noise component frequency, cps	Harmonic		Noise levels, decibels										
			Azimuth angle, ψ										
	Propeller	Engine cylinder	0°	30°	60°	90°	120°	135°	225°	240°	270°	300°	330°
Partially modified (3-blade propeller, collector ring, and twin exhaust mufflers													
13.8	0	1	--	--	--	--	--	--	77	--	--	--	--
27.5	0	2	68	72	76	78	80	81	76	77	76	72	68
41.3	0	3	68	68	71	--	--	--	--	--	--	--	--
55.0	1	4	82	84	86	91	97	91	90	95	92	84	83
68.8	0	5	73	76	78	78	--	79	--	--	--	--	73
82.5	0	6	72	72	--	73	--	74	73	--	73	71	71
96.3	0	7	73	75	80	83	83	83	83	81	84	81	81
110.0	2	8	86	81	77	79	80	76	85	86	82	86	83
123.8	0	9	76	72	72	76	77	76	77	78	77	74	73
137.5	0	10	68	68	68	--	--	68	--	--	--	--	--
151.3	0	11	76	72	73	74	77	72	--	--	76	73	--
165.0	3	12	86	82	75	74	73	77	87	81	82	77	87
178.8	0	13	--	--	72	73	--	72	--	--	73	71	73
192.5	0	14	71	70	--	--	--	--	--	--	--	--	--
206.3	0	15	69	69	--	--	--	--	--	--	--	--	--
220.0	4	16	84	80	74	68	--	74	86	80	80	82	80
233.8	0	17	--	68	--	--	--	--	--	--	--	--	--
247.5	0	18	73	69	--	68	--	68	--	--	--	72	--
261.3	0	19	--	--	--	--	--	--	--	--	--	--	--
275.0	5	20	83	80	72	70	--	76	86	83	82	81	78
288.8	0	21	--	--	--	--	--	--	--	--	--	--	--
302.5	0	22	71	67	--	--	--	66	--	--	--	--	--
316.3	0	23	--	--	--	--	--	--	--	--	--	--	--
330.0	6	24	76	78	63	--	--	75	85	78	78	77	77
343.8	0	25	--	--	--	--	--	--	--	--	--	--	--
Modified (5-blade propeller, gear reduction, collector ring, and twin exhaust mufflers)													
13.8	0	1	--	--	--	--	--	--	--	--	--	--	--
27.5	0	2	65	68	75	78	82	81	79	78	76	74	76
41.3	0	3	--	--	--	--	--	--	--	--	--	--	--
45.8	1		73	71	76	74	71	--	79	85	75	76	77
55.0	0	4	--	69	68	77	76	83	79	79	75	73	76
68.8	0	5	--	71	76	75	76	77	78	75	72	75	75
82.5	0	6	--	--	71	72	71	74	75	--	73	--	73
91.6	2		77	77	--	--	--	--	--	88	--	--	75
96.3	0	7	--	81	81	85	80	84	84	--	81	83	80
110.0	0	8	69	--	72	--	71	74	74	--	69	75	73
123.8	0	9	70	71	71	75	75	77	77	76	71	69	77
137.5	3	10	76	73	76	72	68	74	76	87	74	72	73
151.3	0	11	69	73	74	73	72	69	74	76	76	76	73
165.0	0	12	--	67	67	63	63	68	71	71	--	68	--
178.8	0	13	--	75	--	--	--	--	--	--	76	75	--
183.3	4		79	69	76	69	70	73	76	81	76	73	75
192.5	0	14	72	--	73	--	--	71	72	75	73	74	73
206.3	0	15	71	66	67	--	--	67	73	--	66	69	--
220.0	0	16	71	71	72	--	71	71	--	71	69	73	--
229.2	5		75	72	71	67	69	70	76	77	--	67	--
233.8	0	17	--	68	--	--	--	--	--	--	76	70	--
247.5	0	18	69	71	69	74	71	74	--	73	64	74	76
261.3	0	19	--	--	--	68	--	--	73	--	--	--	--
275.0	6	20	74	75	72	75	74	71	75	77	71	74	--
288.8	0	21	--	69	--	--	--	--	--	--	69	68	--
302.5	0	22	66	74	67	--	--	--	--	71	67	72	--
316.3	0	23	--	--	--	--	--	--	--	75	--	--	--
320.8	7		68	71	67	--	--	--	--	--	--	72	--
330.0	0	24	--	--	--	--	--	--	--	--	69	69	--
343.8	0	25	--	--	--	--	--	--	--	--	--	68	--

TABLE VI

AIRPLANE DETECTION DISTANCES FOR THE CRUISE CONDITION AS DETERMINED BY

THE FIRST SET OF OBSERVERS (VH, AS, and BM)

Airplane configuration	Airplane altitude, ft	Observer location	Distance from observer, y, ft	Flight heading	Maximum distance of detection, x, ft					
					Observer VH		Observer AS		Observer BM	
					Initial	Terminal	Initial	Terminal	Initial	Terminal
Modified	300	A	0	East	-4,730	+6,700	-4,900	+6,200	-5,720	+8,160
			-1,000	West	+4,570	-6,700	+4,900	-5,060	+4,890	-7,670
			-2,000	East	-4,240	+7,180	-4,080	+5,060	-3,100	+5,710
			-3,000	West	+6,360	-7,180	+5,550	-5,870	+4,900	-7,670
			-4,000	East	-7,020	+5,720	-4,410	+3,920	-4,900	+8,160
			-5,000	West	+7,180	-6,040	+7,350	-4,410	+8,480	-5,720
		B	0	East	-6,860	+6,530	-3,260	+6,200	-4,570	+8,970
			1,000	West	+7,840	-6,210	+2,600	-5,050	+9,780	-4,080
			2,000	East	-8,980	+6,700	-1,630	+6,700	-2,930	+7,180
			3,000	West	+7,350	-5,720	+3,430	-4,410	+9,300	-4,880
			4,000	East	-3,100	+7,180	-1,630	+5,060	------	------
	1,000		0	East	------	+8,980	-4,890	+8,820	-7,170	+10,120
			1,000	West	+8,650	------	+8,150	-6,680	+10,780	-7,510
			2,000	East	-9,630	+7,680	-7,020	+9,620	-9,800	+11,760
			3,000	West	+7,340	-9,620	+7,510	-8,000	+8,480	-8,650
			4,000	East	-5,710	+8,000	-5,550	+7,830	-5,710	+8,650
			5,000	West	------	-7,180	+5,060	-7,020	+3,260	-5,710
		A	0	West	------	------	+8,160	-10,780	-------	-------
			-500	East	-9,300	+9,470	-8,160	+5,870	-8,650	+9,470
			-1,000	West	+9,780	------	+6,690	-7,510	+10,620	-9,780
			-1,500	East	-7,830	+9,780	-9,140	+5,550	-8,980	+7,180
			-2,000	West	+11,760	-8,000	+9,300	-9,780	+13,070	-8,480
			-2,500	East	-9,800	+8,980	-9,300	+9,130	-11,920	+7,680
			-3,000	West	+12,400	-8,160	+7,020	-9,300	-------	-------
			-3,500	East	-8,330	+8,650	------	-------	-8,820	+9,950
			-4,000	West	+4,560	-14,540	+7,170	-5,870	+5,220	-10,460
			-4,500	East	-9,130	+7,830	------	-------	-8,980	+10,620

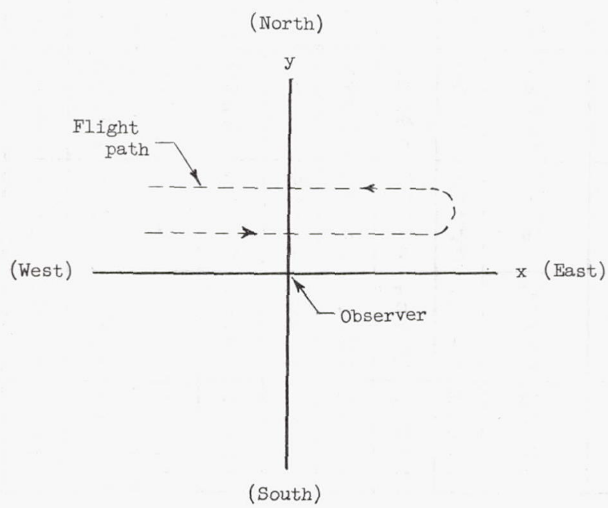


TABLE VII

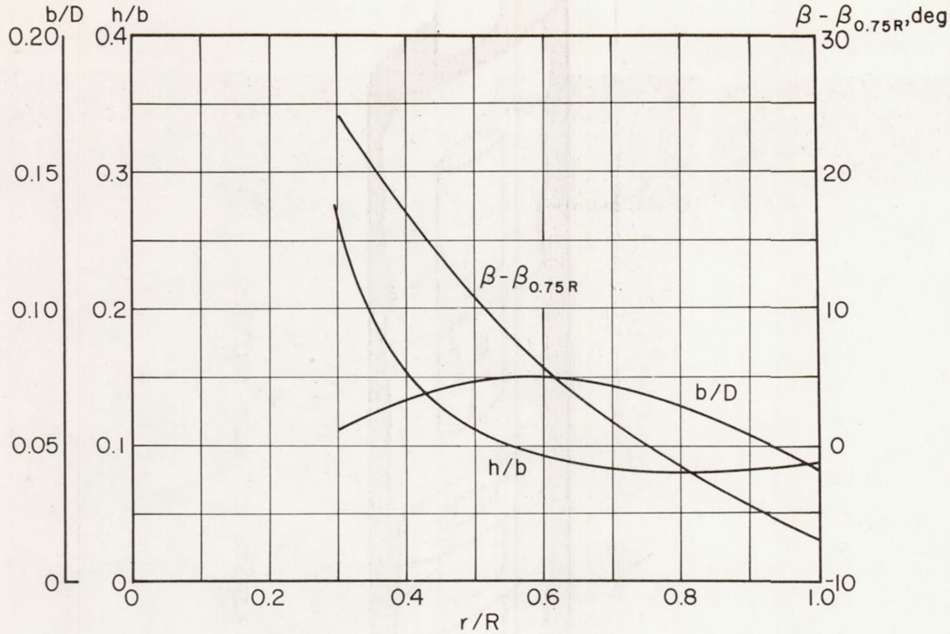
AIRPLANE DETECTION DISTANCES FOR THE CRUISE CONDITION AS DETERMINED BY

THE SECOND SET OF OBSERVERS (JM, WM, and GK)

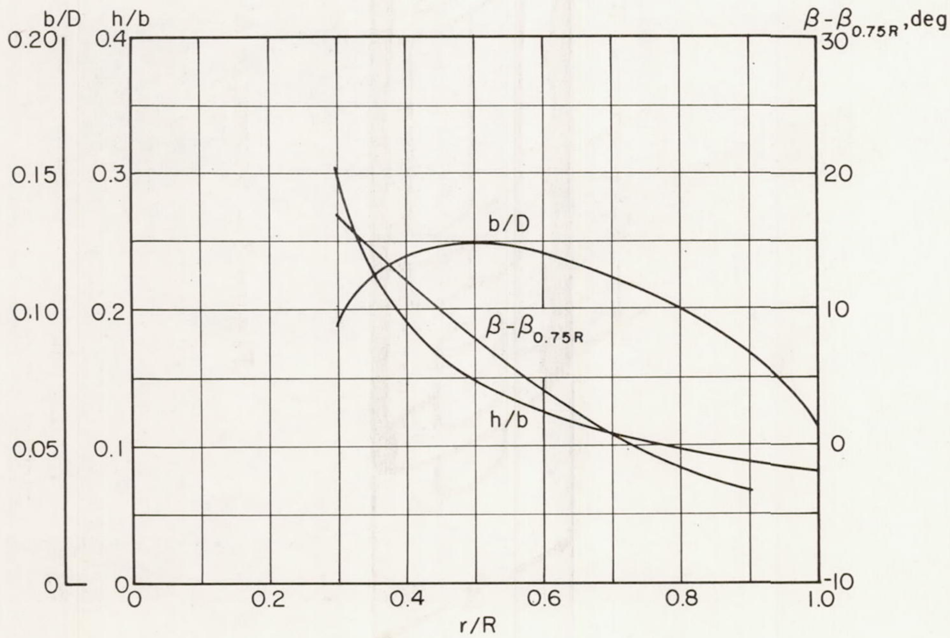
Airplane configuration	Airplane altitude, ft	Observer location	Distance from observer, y, ft	Flight heading	Maximum distance of detection, x, ft					
					Observer JM		Observer WM		Observer GK	
					Initial	Terminal	Initial	Terminal	Initial	Terminal
Unmodified	1,000	B	0	West	+15,200	-10,360	+13,600	-15,050	+15,740	-11,100
			2,500	East	-9,670	+25,200	-12,520	+30,390	-8,250	+9,000*
			5,000	West	+16,100	-13,770	+15,200	-19,680	+14,150	-13,250
			7,500	East	-13,090	+29,900*	-17,870	+26,800	-14,480	+11,270*
			13,000	East	-4,480	+18,770	-14,310	+20,500	-7,350	+32,000*
			22,000	West	+6,260	-12,000	+21,500	-15,220	+36,200	-13,370*
			28,000	East	-4,480	+3,220	-19,660	+12,520*	-------	--------
	300		0	East	-7,700	+22,700	-18,400	+22,900*	-7,700	+32,200*
			5,000	West	+13,090	-12,880	+15,200	-17,000	+22,500	-11,630*
			12,500	East	-7,140	+13,420	-14,300	--------	-5,000	+18,770
			22,000	West	-1,252	-5,740	0	0	-------	--------
Modified	300	A	0	East	-5,870	+8,000	-4,890	+7,340	-5,480	+8,650
			0	West	+9,780	-8,160	+8,980	-8,160	+12,900	-7,840
			-2,500	East	-7,520	+12,410	-7,340	+9,780	-6,040	+10,290
			-5,000	West	+9,780	-9,780	+10,620	-11,430	+6,860	-10,620
			-7,500	East	-8,660	+9,630	-6,530	+7,840	-7,670	+8,160
			-10,000	West	+5,720	-8,160	+6,530	-7,180	+7,340	-8,980
			-12,500	East	-2,450	+4,890	-9,800	+9,800	-5,870	+5,060
			-15,000	West	-2,610	-5,220	-2,280	-12,240	+6,030	-7,520
		B	0	West	-6,030	-6,210	+8,480	-7,670	-8,980	-8,650
			2,500	East	-4,080	+8,160	-3,920	+7,020	-14,700	+7,670
			5,000	East	-2,610	+11,260	-5,720	+5,720	-4,240	+11,260
			7,500	West	+5,720	-4,410	+2,770	-5,720	+5,380	-7,180
			10,000	East	-978	+5,380	0	0	-1,960	+8,330
			12,500	West	0	0	0	0	+3,260	-3,590
			15,000	East	0	0	0	0	-978	+2,280
	1,000		0	East	-8,820	+11,600	-8,660	+12,570	-9,630	+12,900
			2,500	West	+17,450	-10,290	+13,390	-10,780	+15,350	-7,830
			5,000	East	-6,040	+12,730	-6,370	+16,000	-13,390	+6,210
			7,500	West	+15,350	-7,520	+15,500	-10,780	+12,250	-11,590
			10,000	East	-2,940	+6,370	-2,610	+4,240	-5,060	+16,800
		A	0	East	-6,030	+11,100	-7,340	+12,410	-------	--------
			0	West	+8,980	-13,060	+10,450	-10,780	+9,960	-10,290
			-2,500	East	-9,800	+11,920	-9,320	+11,920	-11,750	+12,250
			-5,000	West	+8,490	-13,560	+6,370	-12,900	+12,080	-11,600
			-7,500	East	-7,020	+12,900	-7,340	+10,940	-12,570	+10,930
			-10,000	West	+9,800	-------	+8,980	-7,340	+11,430	-10,610

*Aircraft made turn for next pass before observer could obtain terminal distance.

Figure 1.- Modified airplane. L-57-2890.1



(a) 11-foot diameter, three-blade propeller of unmodified airplane.



(b) 12-foot diameter, five-blade propeller of modified airplane.

Figure 2.- Blade-form curves.

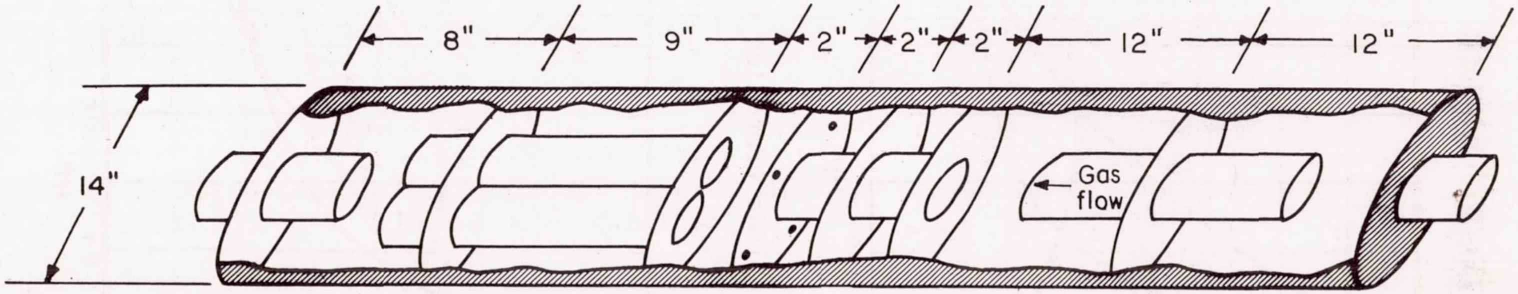


Figure 3.- Schematic diagram of engine exhaust muffler.

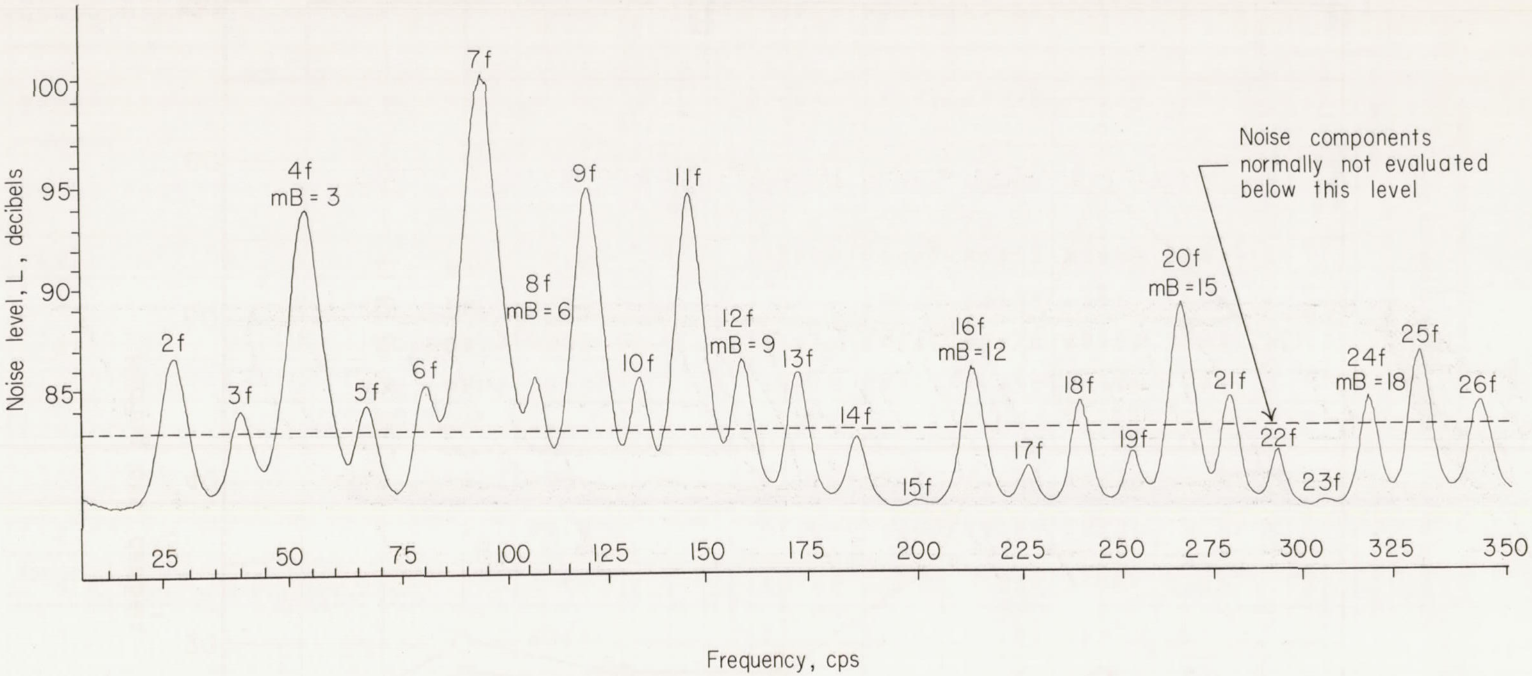


Figure 4.- Sample narrow-band analysis of airplane noise. Unmodified airplane; engine speed, $N = 1{,}650$ rpm; azimuth angle, $\psi = 90^{\circ}$; distance, $l = 50$ ft; filter-band width = 5 cps.

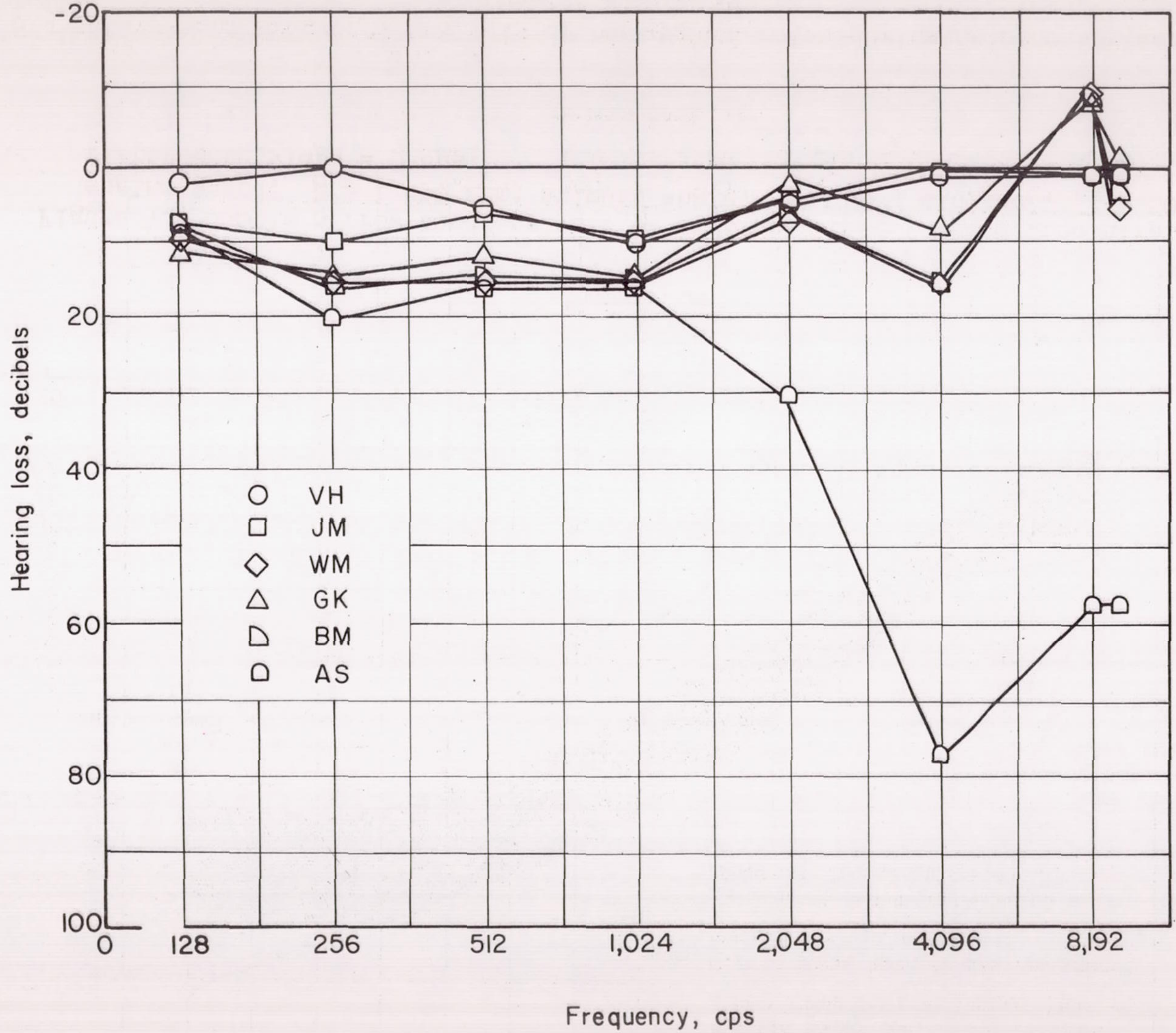


Figure 5.- Audiograms of observers used for listening tests.

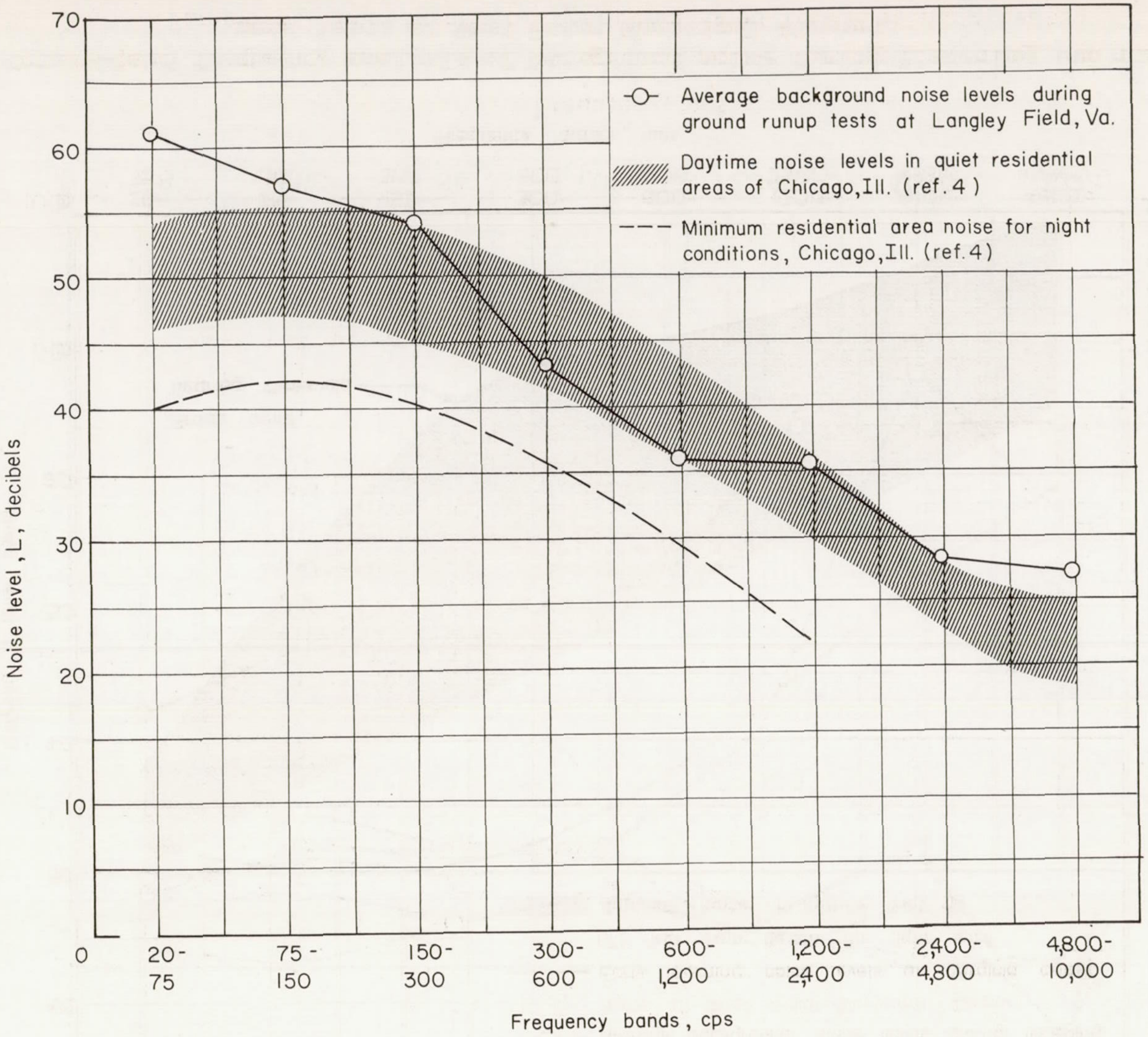


Figure 6.- Octave-band frequency analysis of background noise during noise measurement tests at Langley Field, Va.

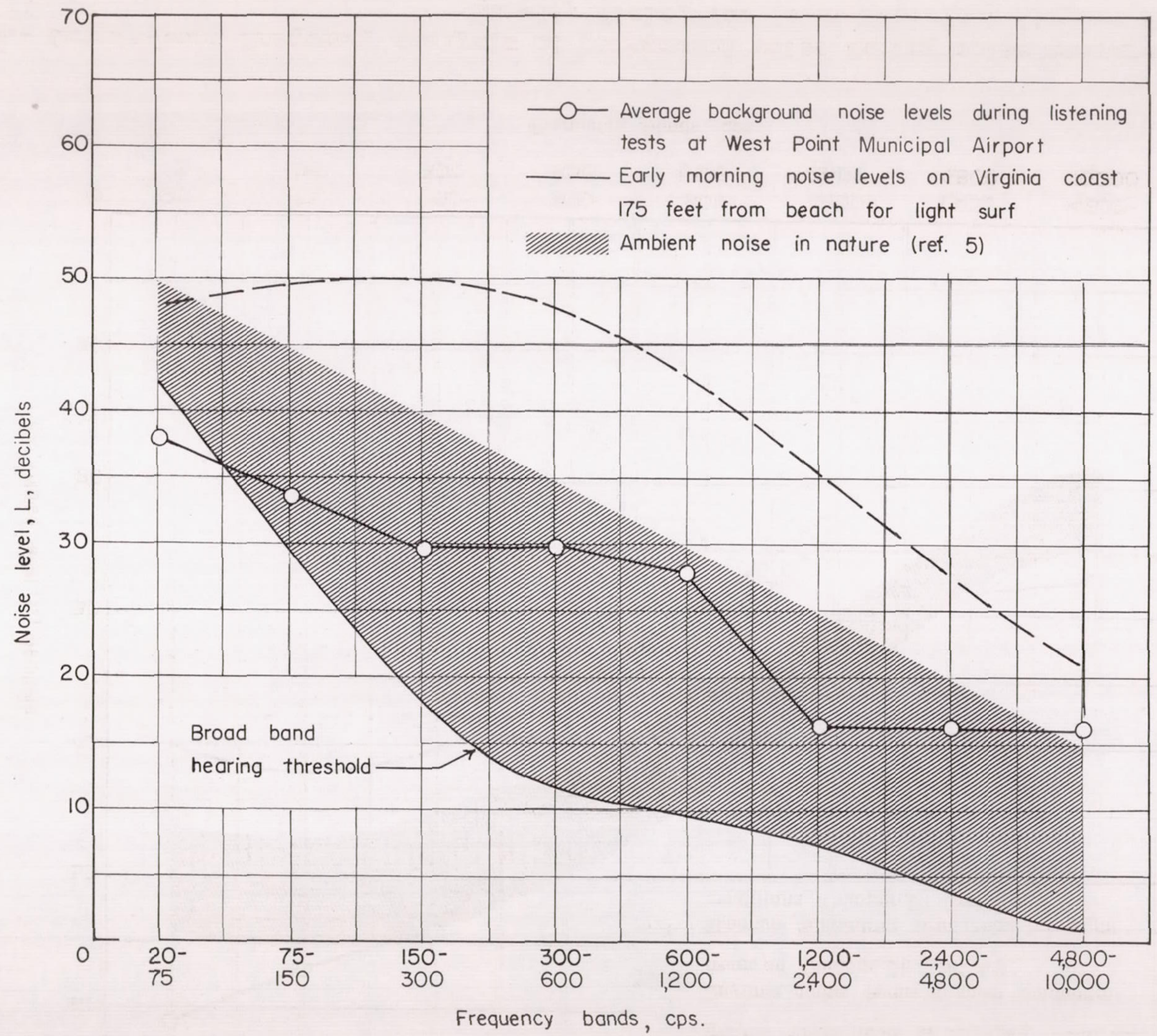


Figure 7.- Octave-band frequency analysis of background noise during listening and noise measurement tests at West Point Municipal Airport.

L-58-2552

Figure 8.- Photograph of coast and geodetic map of the West Point Municipal Airport area in which listening tests were conducted. (Contour interval is 20 feet.)

L-58-2529

Figure 9.- Aerial photograph of the terrain near the West Point Municipal Airport. Numbers designate runways and letters designate observer stations. (Picture taken from a 10,000-foot altitude looking east, northeast.)

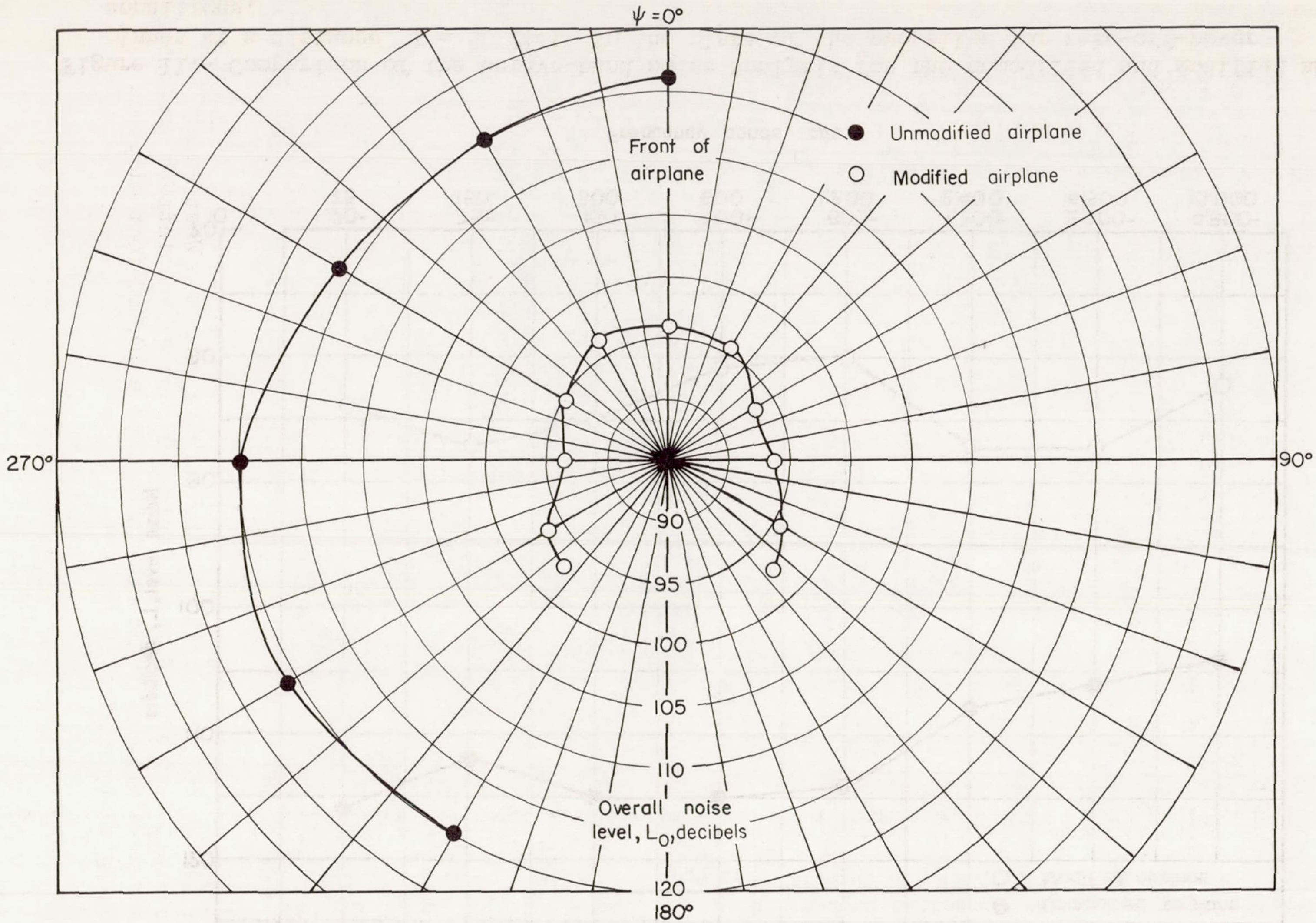


Figure 10.- Comparison of overall noise levels at various azimuth angles for the unmodified and modified airplanes at the take-off-power condition. P = 600; l = 50 feet.

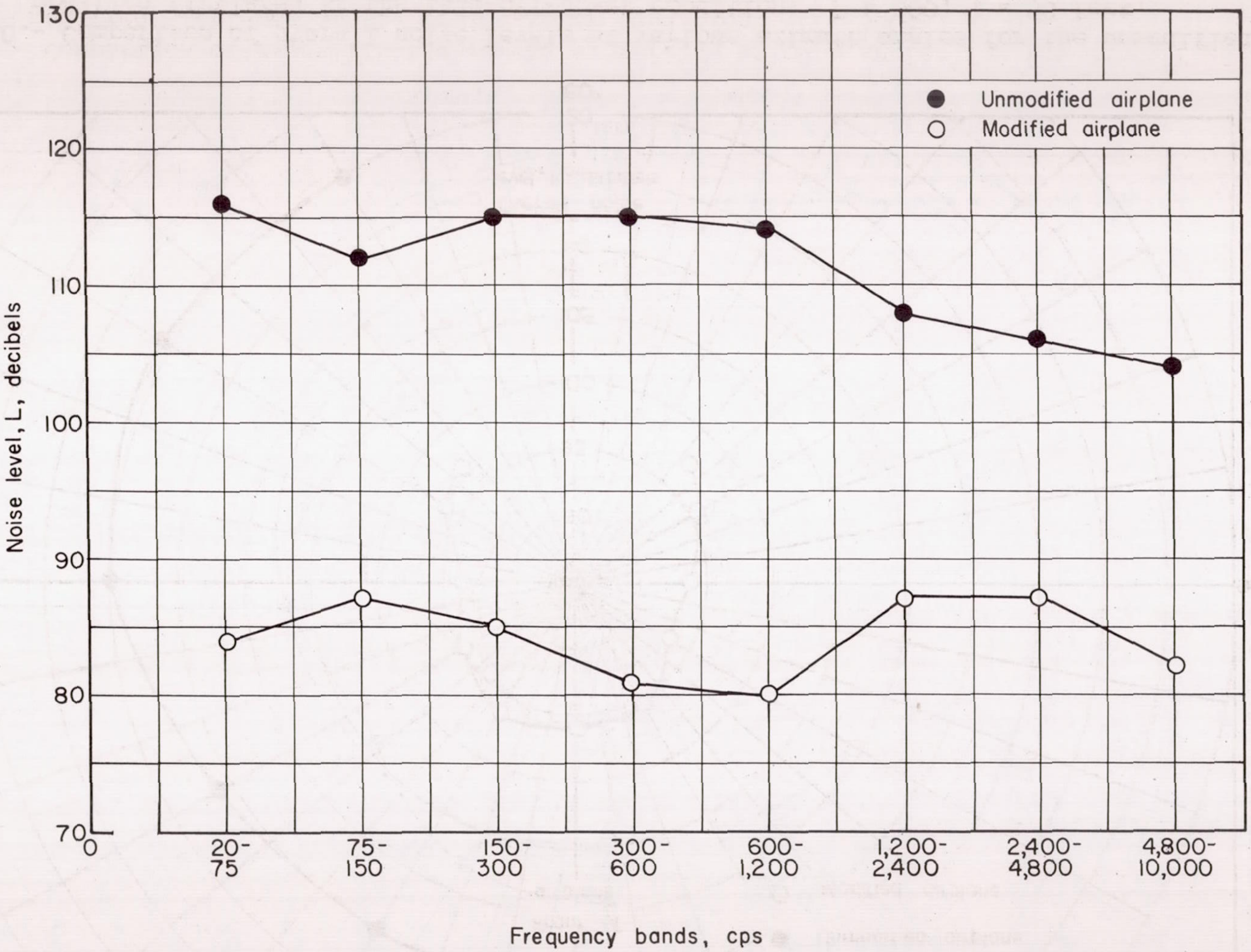


Figure 11.- Comparison of the octave-band noise analysis for the unmodified and modified airplanes at a distance $l = 50$ feet in the plane of the propeller for take-off-power conditions.

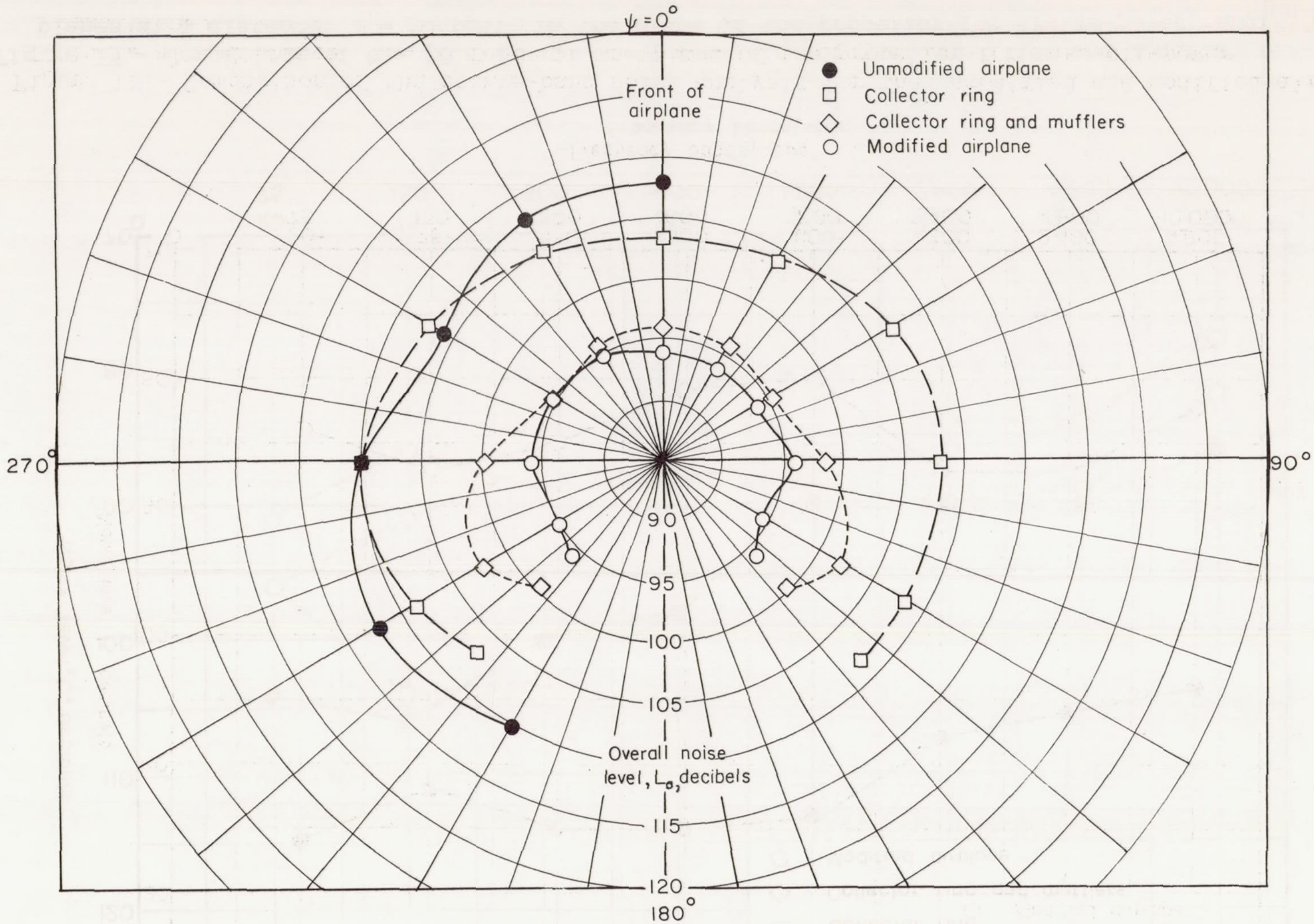


Figure 12.- Comparison of overall noise levels at various azimuth angles for the unmodified and modified airplanes at the cruise-power condition. P = 300; l = 50 feet.

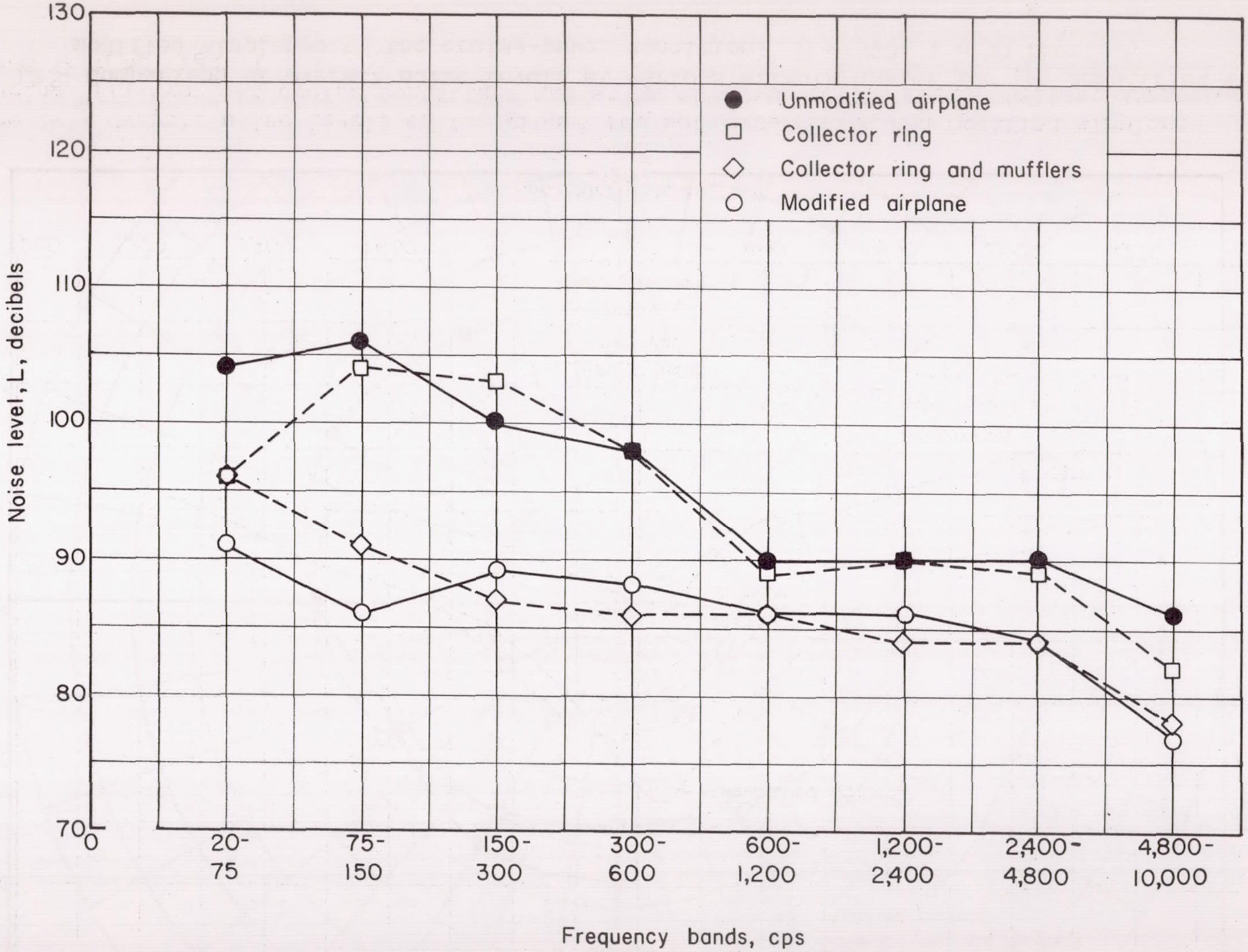


Figure 13.- Comparison of the octave-band noise analysis for the unmodified and modified airplanes at a distance l = 50 feet in the plane of the propeller for cruise-power conditions.

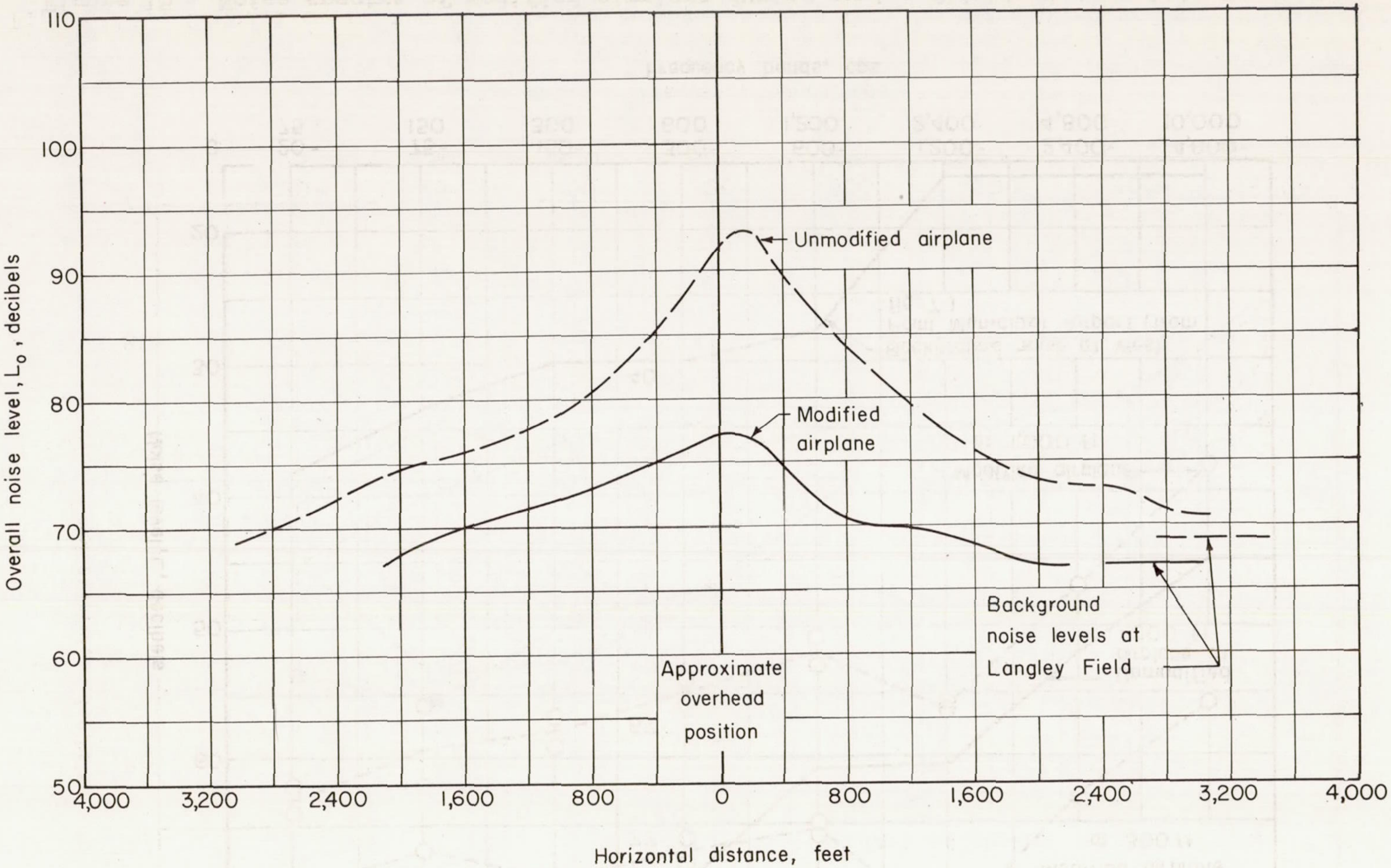


Figure 14.- Overall noise levels on the ground for both unmodified and modified airplanes during "fly-over" at cruise conditions and at an altitude of 300 feet. (Flight direction is from left to right.)

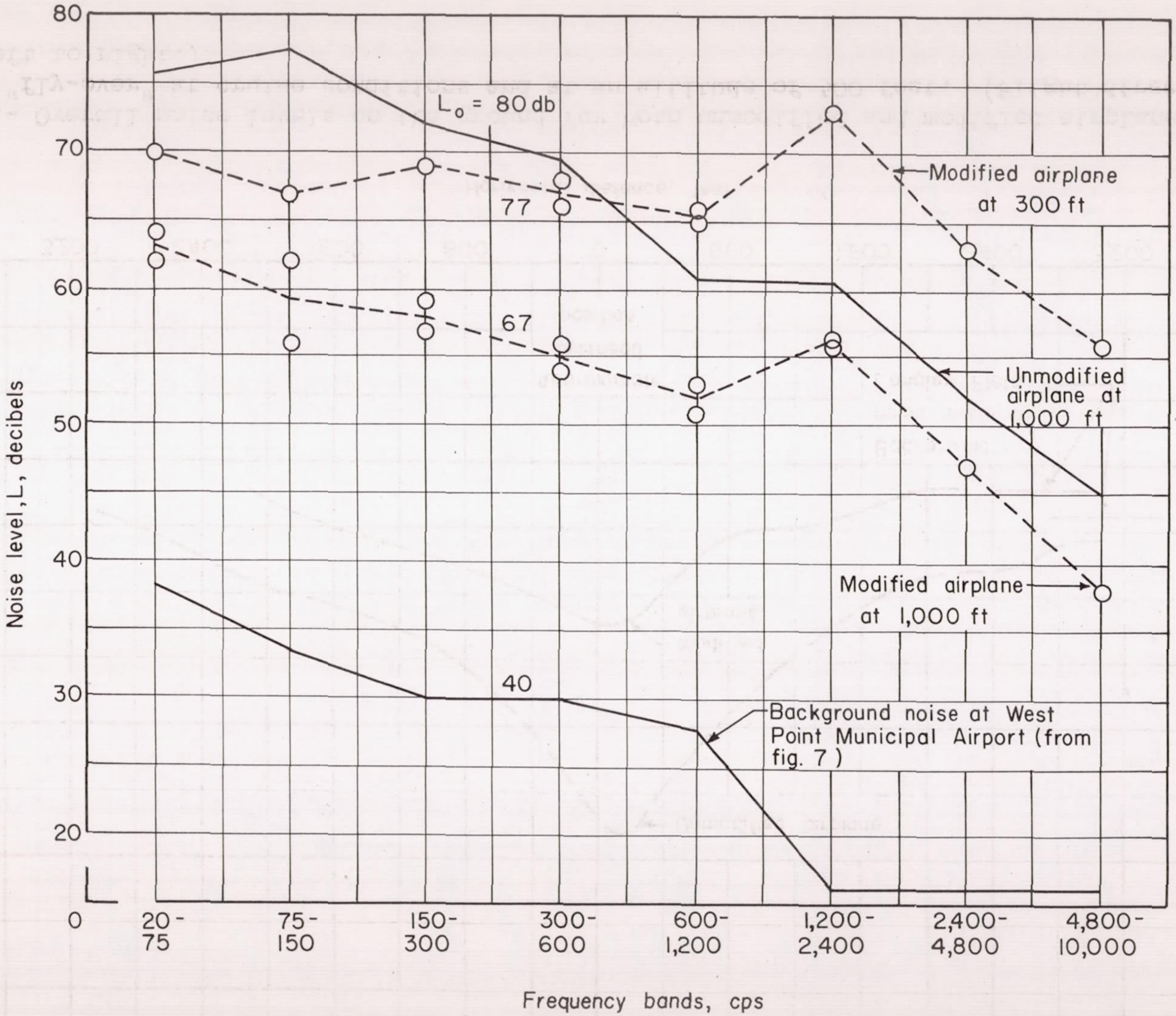


Figure 15.- Noise spectra of modified airplane during cruise flight at two altitudes. Curve for unmodified airplane during cruise at 1,000 feet altitude included for comparison.

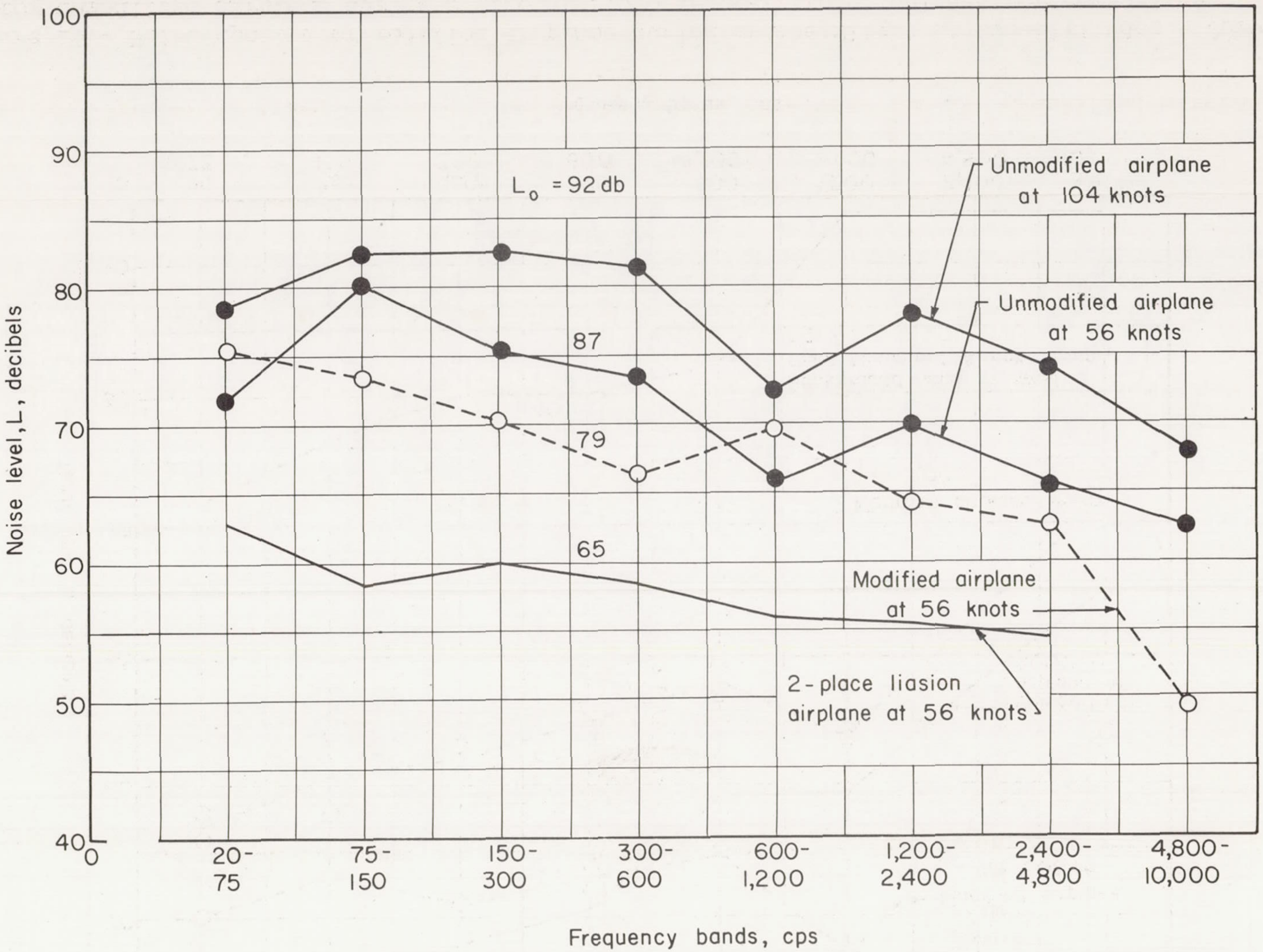
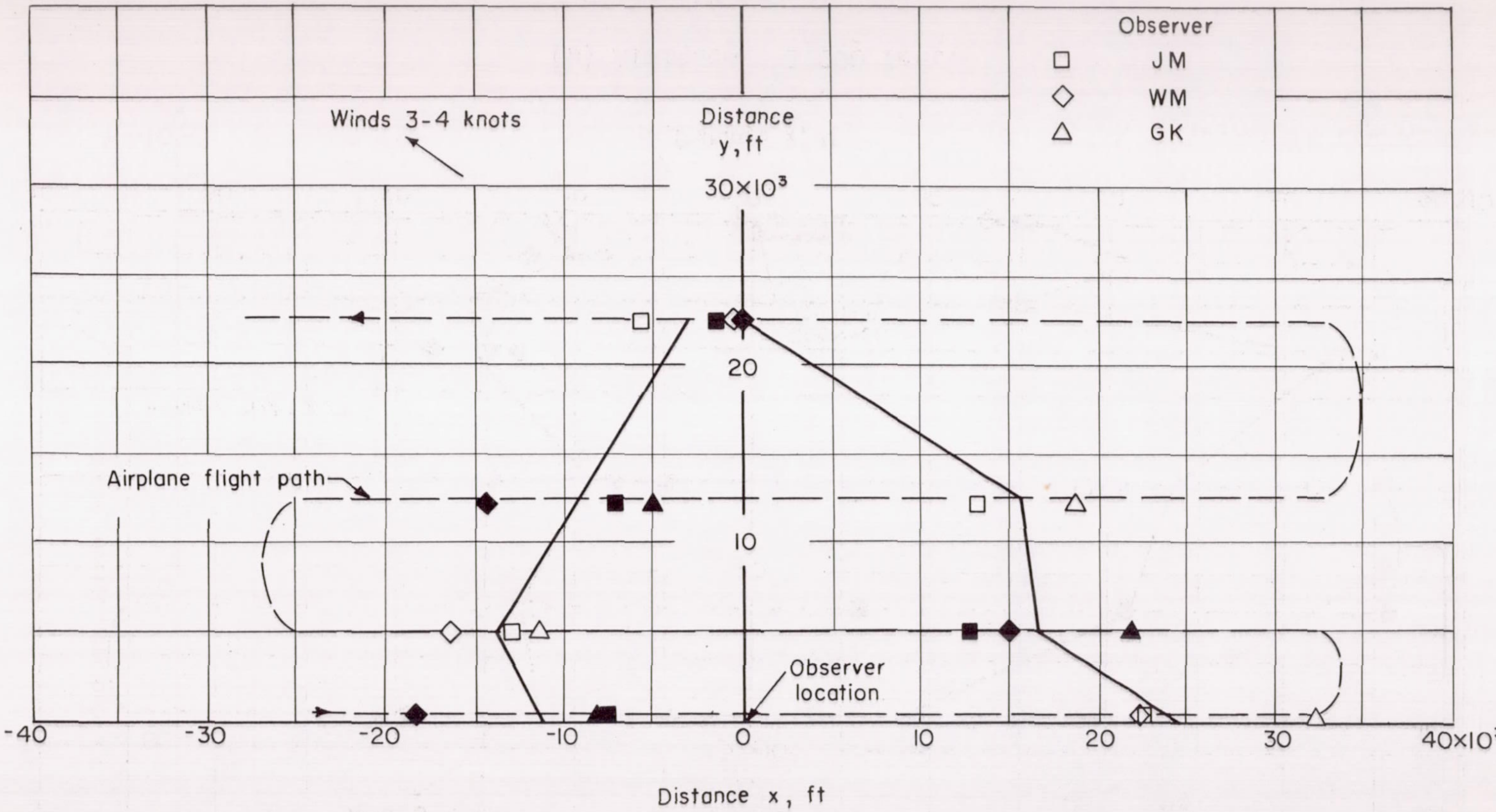
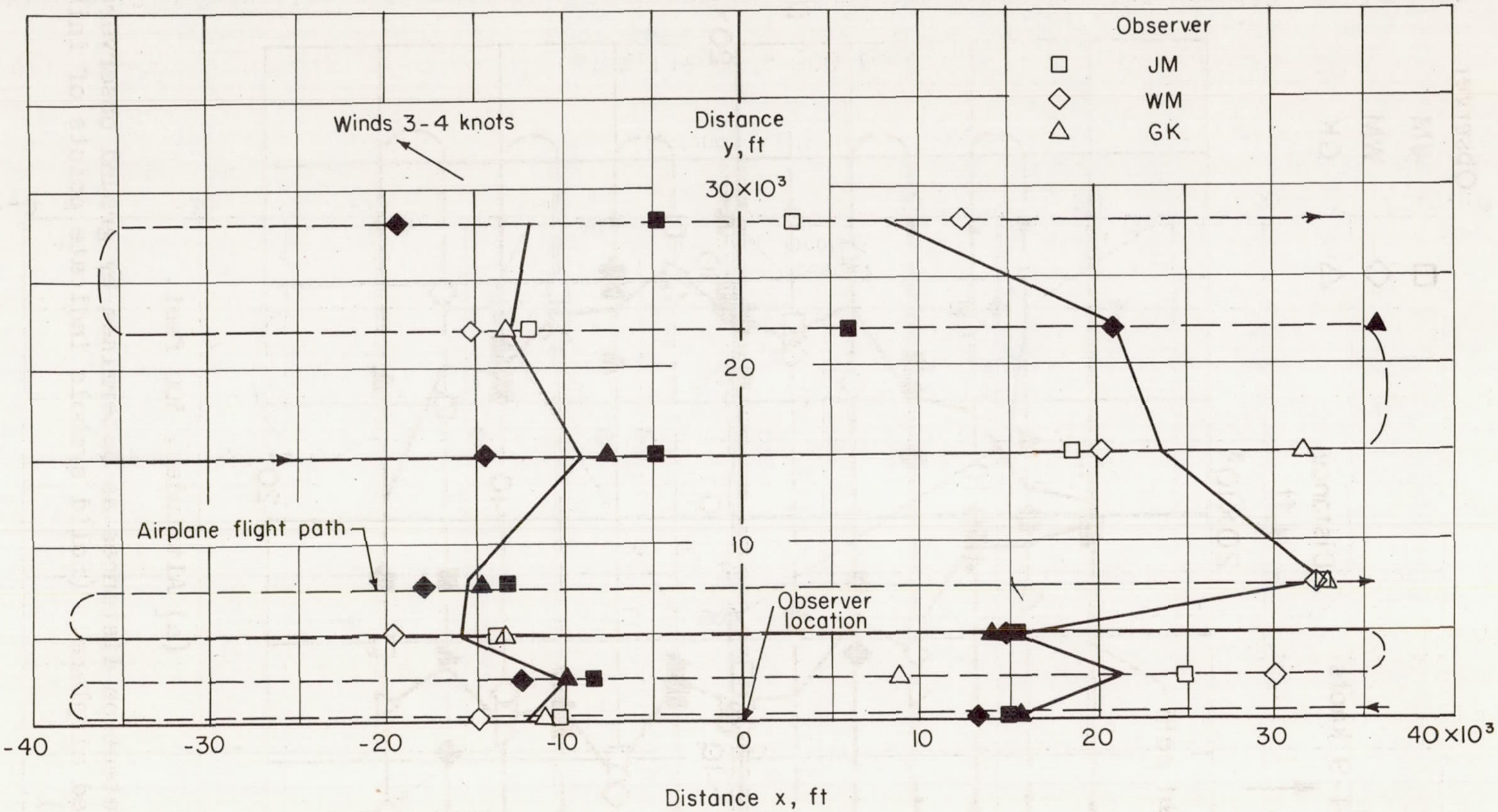


Figure 16.- Octave-band frequency analysis of noise from modified and unmodified airplanes during power-off glides. l = 75 feet.



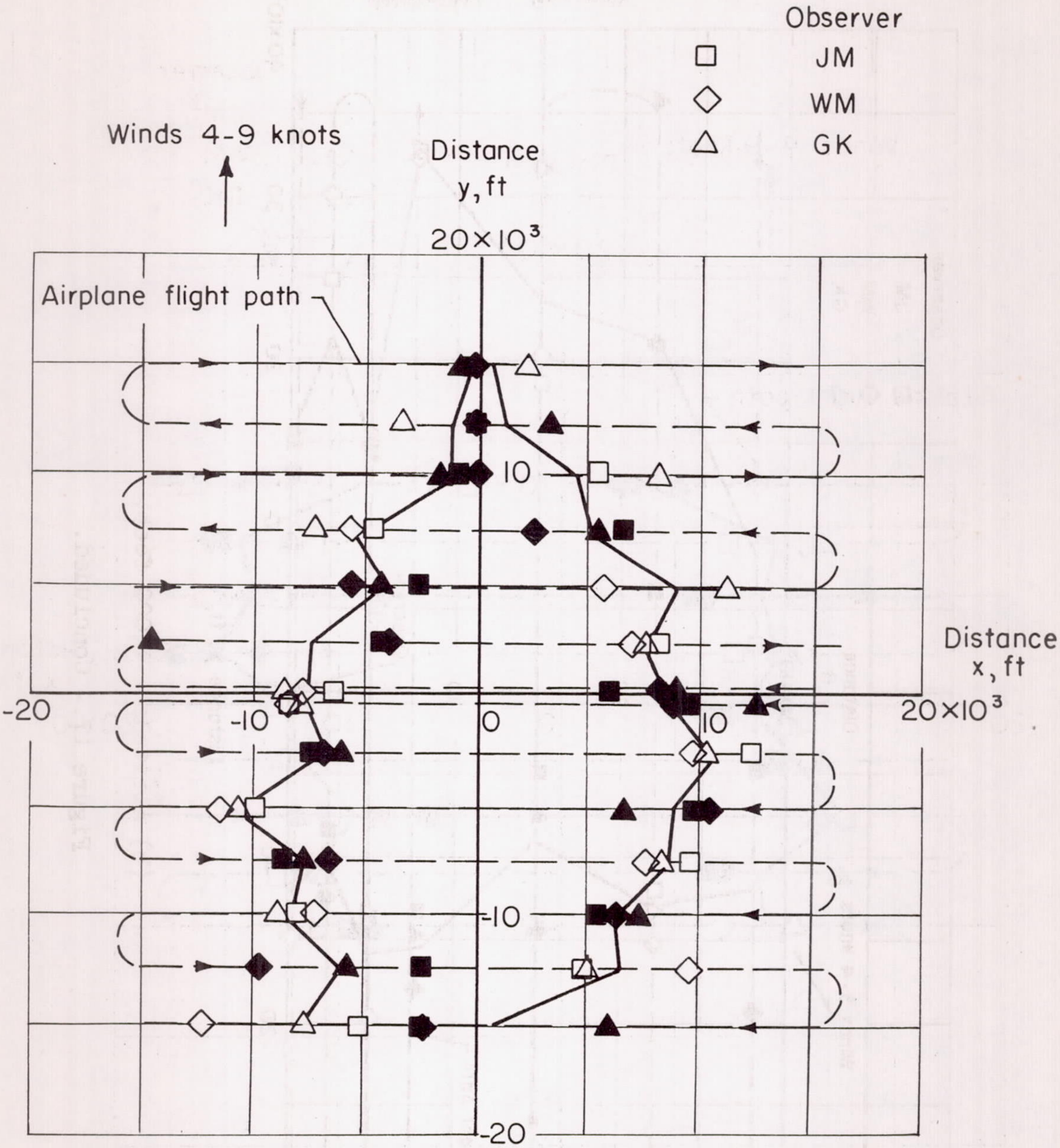
(a) Altitude = 300 feet.

Figure 17.- Detection distances as determined by ground observers for the unmodified airplane. (Solid symbols indicate points of initial detection.)



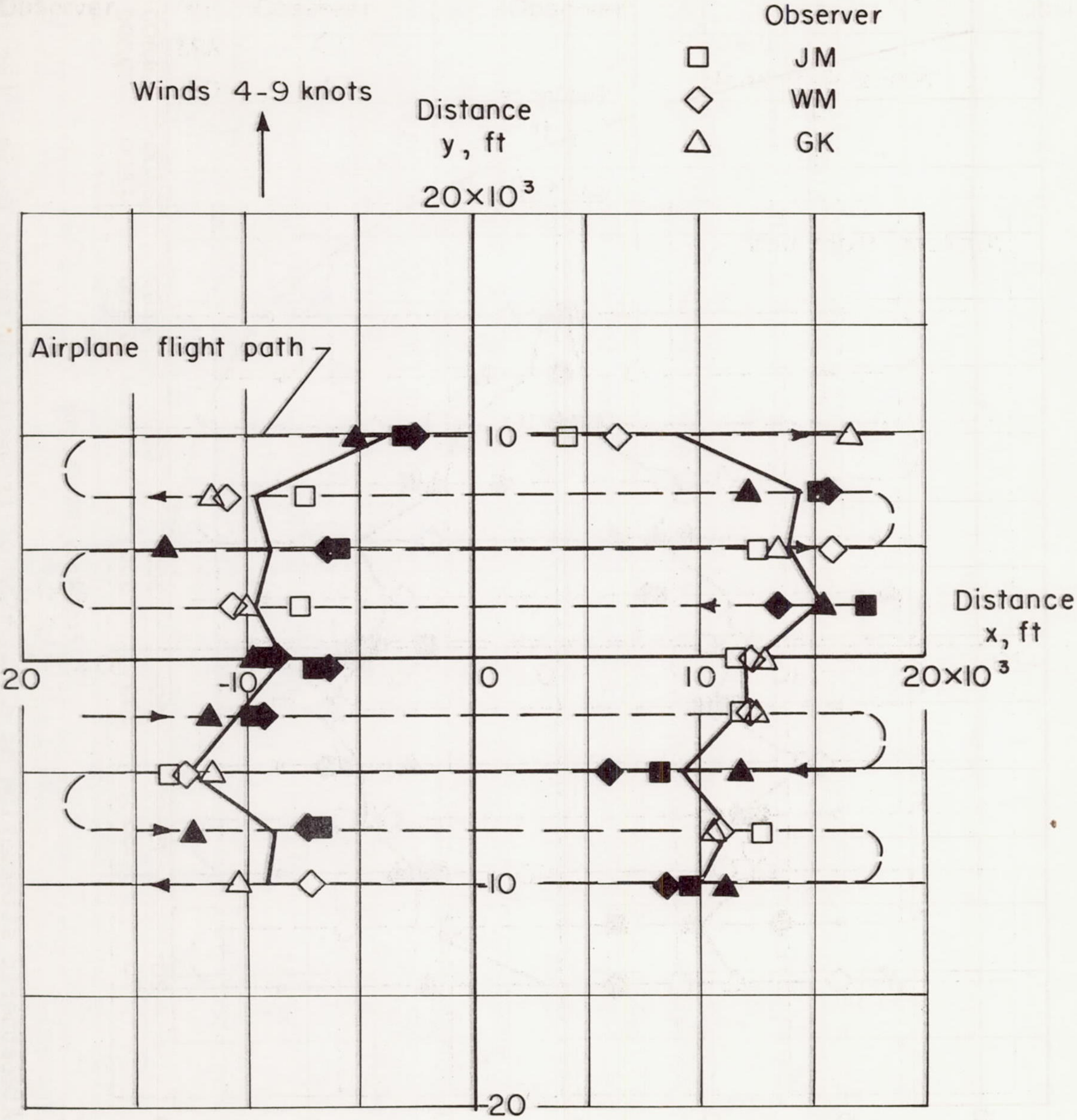
(b) Altitude = 1,000 feet.

Figure 17.- Concluded.



(a) Altitude = 300 feet.

Figure 18.- Detection distances as determined by ground observers for the modified airplane. (Solid symbols indicate points of initial detection.)



(b) Altitude = 1,000 feet.

Figure 18.- Concluded.

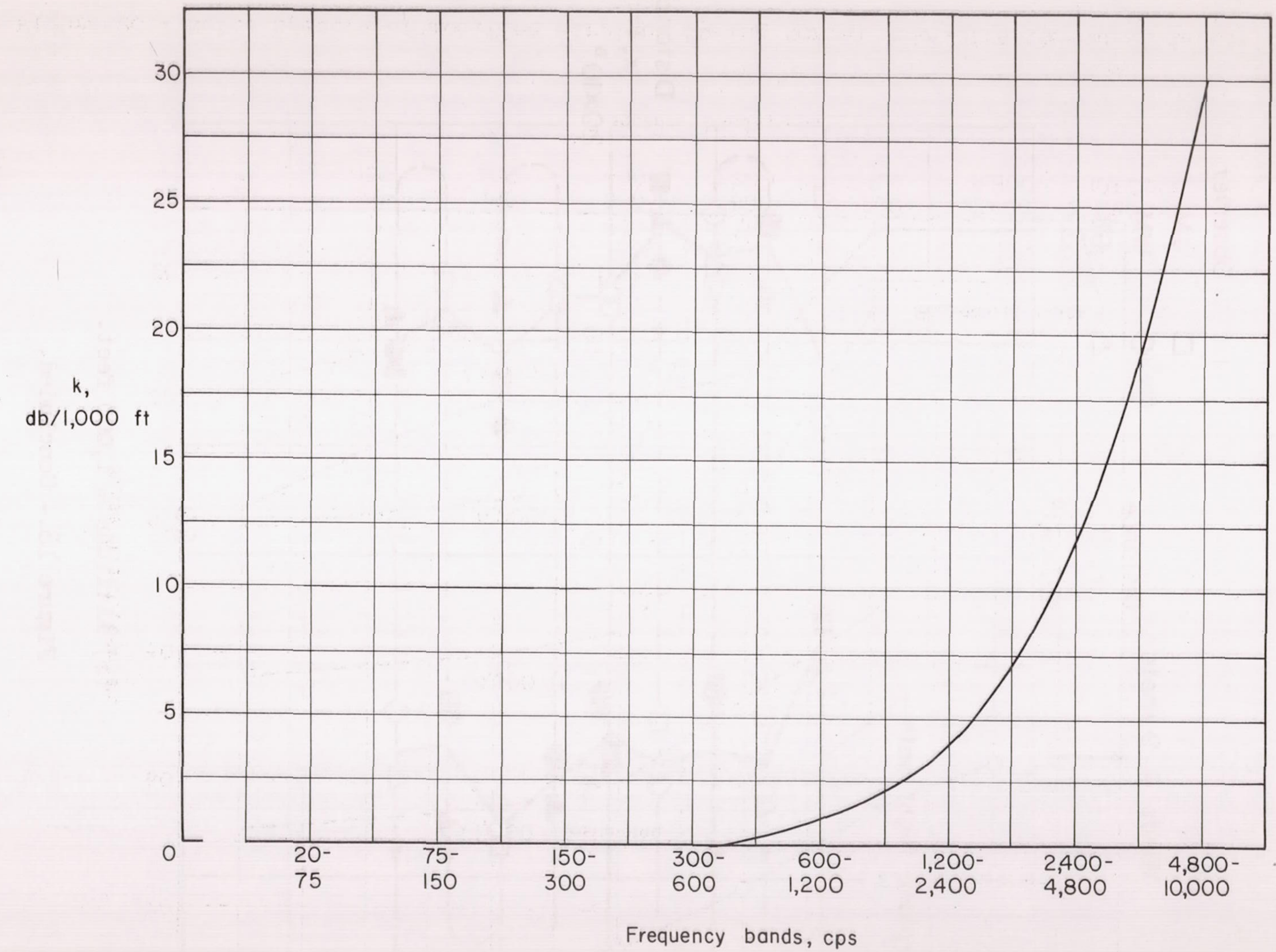


Figure 19.- Atmospheric attenuation as a function of frequency in octave bands. (Estimated from data of ref. 7.)

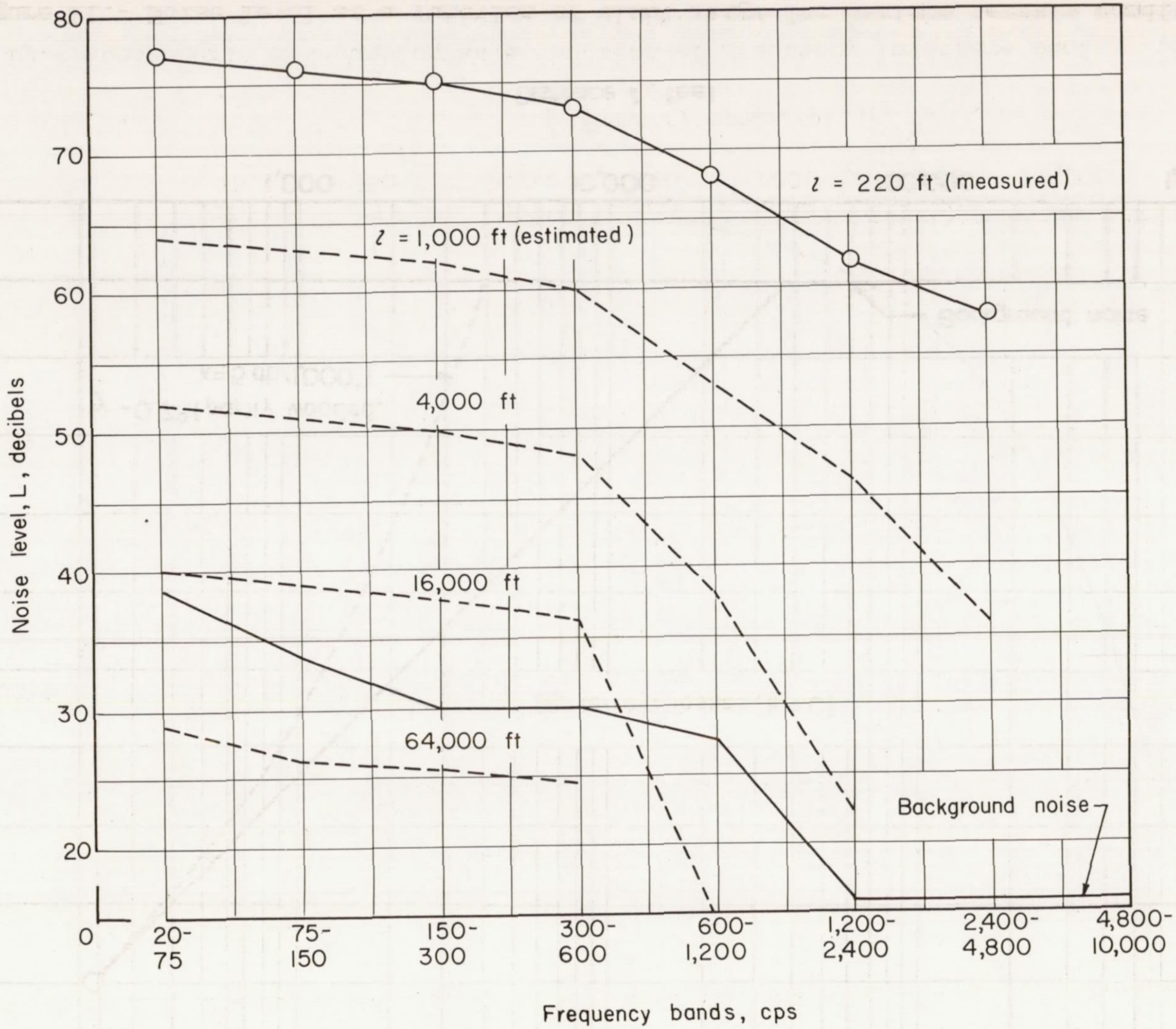


Figure 20.- Noise spectra of modified airplane during normal take-offs for aural detection tests.

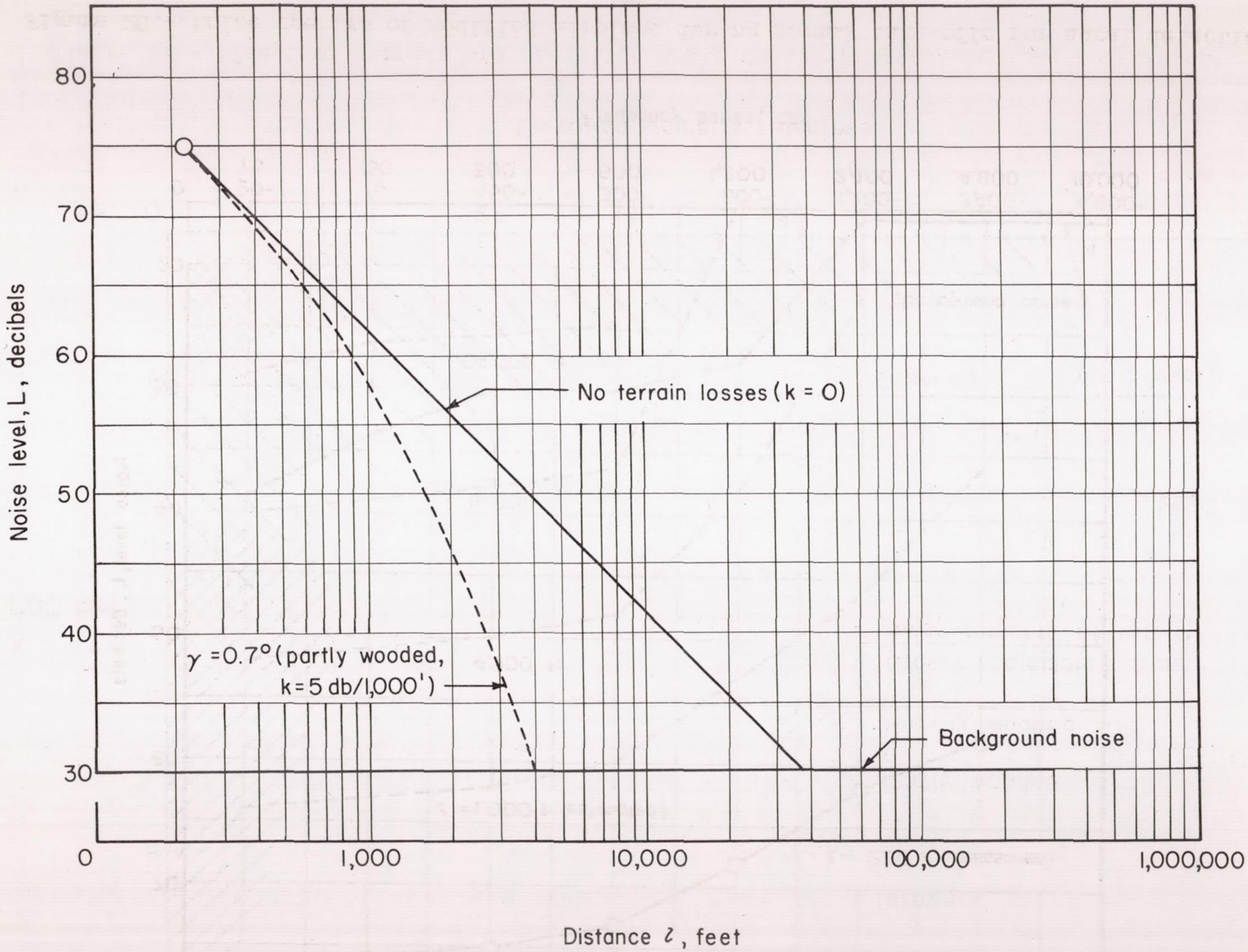


Figure 21.- Noise level as a function of slant range for various terrain conditions.

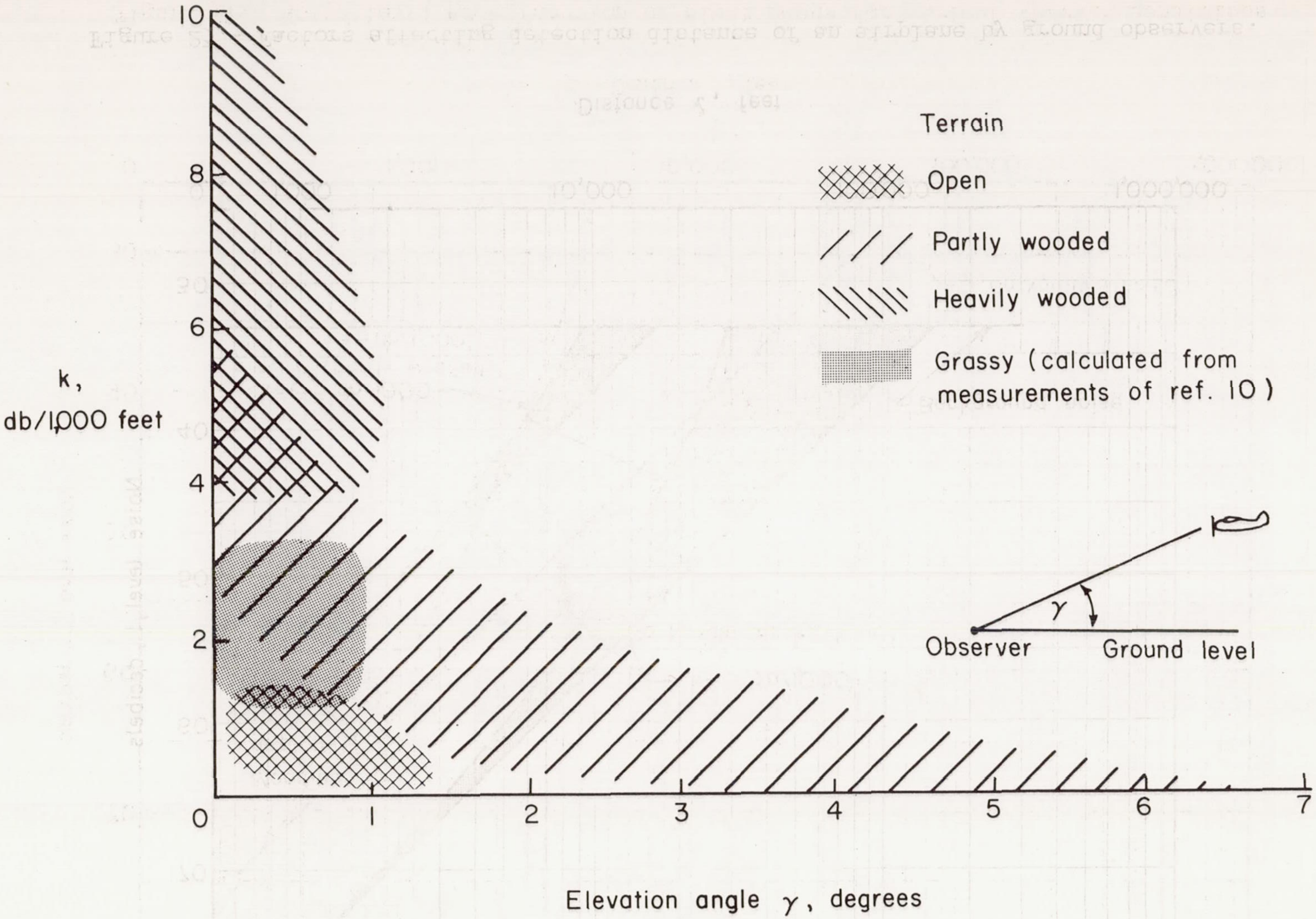


Figure 22.- Effect of terrain and elevation angle on the propagation loss coefficient k.

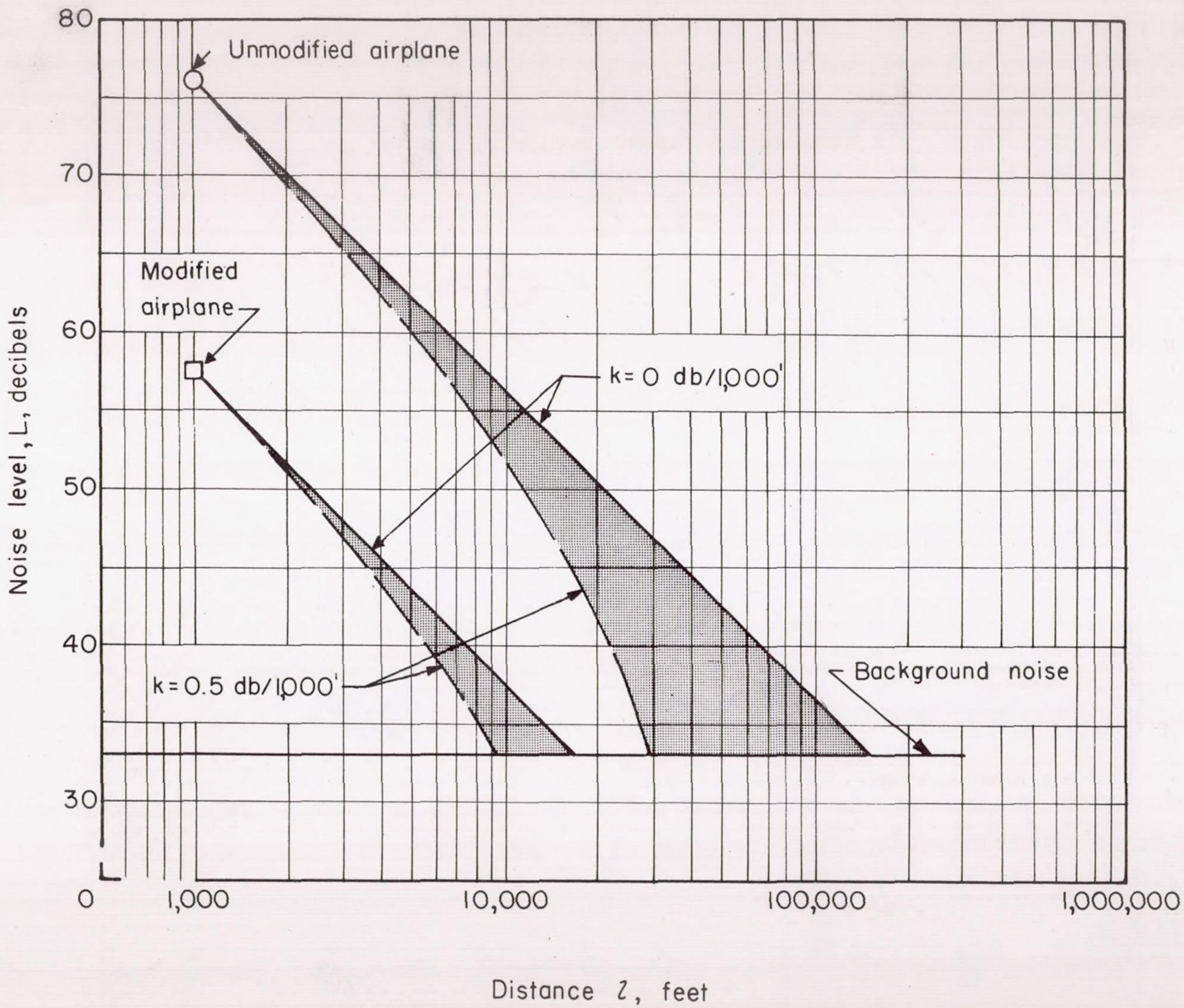


Figure 23.- Factors affecting detection distance of an airplane by ground observers.