MEASUREMENT OF SOUND LEVELS ASSOCIATED WITH AIRCRAFT, HIGHWAY AND RAILROAD TRAFFIC

By

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Technical Development Service

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INDIANAPOLIS, INDIANA

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SUMMARY

Data were obtained concerning sound levels produced at different distances by aircraft of various sizes and engine power ratings, and under take-off, climb, and cruise conditions. Sound level readings were obtained, under controlled flight conditions, for six aircraft varying from a single engine private-owner type of 65 hp to a two-engine commercial type of 2400 hp total Additional measurements were made with miscellaneous private, commercial, and military type aircraft in the general airport traffic Frequency analyses were made of the sound produced by the controlled aircraft.

Additional sound level measurements were made with highway truck and passenger car traffic, and with railway freight and passenger trains. Readings were obtained at different distances from the traffic path.

The test results are presented in terms of sound intensity levels, corresponding loudness levels, and as loudness relative to the approximate loudness of the average voice in conversation at a distance of three feet.

Variation of intensity and loudness levels with distance is shown for all aircraft and traffic sound sources and for various test conditions. Loudness level contours, showing location relative to the runway of positions of equal peak loudness level, are given for the take-off and climb of each controlled aircraft. Comparative sound intensity level values for all aircraft models tested are presented.

In general, the results show that the various aircraft models tested produce sound intensity levels ranging from 78 to 103 decibels at a distance of 500 feet from the airplane during take-off. With aircraft in flight, the intensity level decreases about 6.5 to 8.5 decibels for each doubling of distance from the airplane.

Sound produced by large aircraft in climb reduces to the arbitrary reference loudness level of 70 phons at about 3000 feet distance For small aircraft the corresponding distance is about 1000 feet, and for trailer trucks and railway traffic a similar distance of about 1000 feet is obtained

INTRODUCTION

The problem of noise levels created by aircraft in the vicinity of airports has become increasingly acute during the past several years The importance of this problem has grown with increasing number of private and commercial aircraft in use and, in particular as a result of the establishment or expansion of airports in residential communities.

The complete solution of this problem ultimately must come through reduction of propeller and engine noises in aircraft, if all criticism of aircraft noise is to be avoided. Airplane and propeller manufacturers now are working toward this end in co-operation with private and governmental research organizations. However, until a solution is reached, and as an aid to such solution, a knowledge of sound levels actually existent in airport vicinities is urgently required

During June, 1946 the Technical Development Service of the Civil Aeronautics Administration conducted sound level tests at a proposed airport at Malvern, Pennsylvania. These tests were not sufficiently complete for general application of the data obtained. In April, 1947 an additional test program was commenced to provide more complete and fundamental data. This report covers the results of such tests.

The purpose of the present tests was to determine sound levels in the vicinity of airports associated with particular aircraft, and comparative sound levels produced by highway and railway traffic. An additional purpose was to determine relative sound levels produced by various models of aircraft, and to obtain fundamental data which may be of incidental use in noise reduction design.

The presentation of sound level data in such form as to have technical significance, and at the same time to be understood readily by non-technical readers, is difficult. For clearer presentation there has been included in this report a section containing an elementary discussion of the properties of sound, methods of sound level measurements, and definition of terms. In addition, all final data are given in terms of relative loudness, which is believed to provide a simple and direct indication of the loudness of sound as heard by the average ear, related to a familiar and recognizable value.

Acknowledgement is made to the Aeronautics Commission of Indiana for the use of the Stinson airplane used in the tests, and to the Bob Shank Airport of Indianapolis where a portion of the tests were conducted.

PROPERTIES OF SOUND AND PRINCIPLES OF SOUND LEVEL MEASUREMENT

The principles of sound level measurements and properties of sound are discussed in detail in various standard texts. The present brief and elementary reveiw of these principles is given as a guide for interpretation of the test results presented in this report.

Sounds in air exist as successive waves of compression and rarefaction, traveling at a velocity dependent upon the ratio of the pressure and density of the air. For dry air at standard sea-level pressure and 0 degrees C temperature, the velocity of sound is approximately 1087 feet per second

The number of sound waves which pass a fixed reference point in the air per unit time determines the sound frequency, or pitch The maximum range of sound frequencies which can be heard by the human ear is from approximately 16 to 20,000 cycles per second. All normal sounds, including those types considered in this report, are a complex combination of a large number of sounds of different frequency.

The characteristics of a particular type of sound which determine its magnitude and nature are the particular frequencies present in the sound, the relative energies posessed by each component wave, and the total energy of all component waves.

The sound intensity is a measure of sound wave energy, and is defined as the rate of flow of sound energy through a unit area perpendicular to a given direction at a given measuring point. Absolute sound intensity is measured in terms of watts per square centimeter

Normally, sound intensity is more conveniently measured by the decibel scale, which expresses the existent sound intensity at a given point as a function of the ratio of the absolute sound intensity to a reference sound intensity level More exactly, the difference D in decibels between two sound intensities I_1 and I_2 is expressed by

$$D \quad 10 \log_{10} I_1 / I_2$$

A standard reference level of sound intensity has been chosen as 10^{-16} watts per square centimeter, which corresponds approximately to the minimum intensity audible to the human ear at 1000 cycles per second.

The intensity level of a particular sound is the difference, in decibels, between the intensity of this sound and the intensity at the standard reference intensity level An intensity level of 20 decibels corresponds roughly to that of a barely audible whisper, and represents an absolute intensity of 100 times the reference intensity. An intensity level of 60 decibels represents an absolute intensity of 1,000,000 times the reference intensity An intensity level of 100 decibels represents an absolute intensity 10^{10} times that of the reference intensity.

The intensity level scale does not correspond, except in an approximate manner to the loudness as heard by the average human ear. This variation is related to change in sensitivity of the human ear with the sound frequency and intensity level. The average ear is most sensitive at a frequency of 2000 to 3000 cycles per second, and is relatively insensitive to low intensity sounds at the lowest and highest audible frequencies.

For example, a tone of 1000 cycles per second with a 70-decibel intensity level will sound to the average human ear of equal loudness as a sound of 70 cycles per second with an intensity level of 80 decibels Similarly, a sound of 1000 cycles per second and 40-decibel intensity level will sound of equal loudness as a sound of 70 cycles per second with an intensity level of 67 decibels.

Various sound intensity levels at different frequencies which appear of equal loudness to the average human ear are, by definition, of equal loudness level The unit of loudness level is the "phon" For convenience, the loudness level scale is taken so as to coincide with the intensity level scale for a sound of 1000 cycles per second. Standard curves showing variation of loudness level with intensity level and frequency are shown in Figure 1, as given in American Standards Association Standard Z24.2-1942.

Sound level readings are, by definition, the readings given by a standard sound level meter. As loudness level curves define sounds of equal loudness, as heard by the ear, it is generally desired to interpret sound level readings in terms of loudness level Such interpretation is complicated by the fact that normal sounds are composed of many frequency components rather than a single frequency

In order to facilitate such interpretation, standard sound level meters are arranged so that three weighting networks can be used. The three networks provide different frequency response characteristics which provide, respectively. (1) flat response, which approximates the response of the ear at intensity levels of about

100 decibels, (2) a weighted response which approximates the response of the ear at an intensity level of 70 decibels, and (3) a weighted response which approximates the response of the ear at an intensity level of 40 decibels

With the selective use of these three weighting networks in the sound level meter, approximate loudness levels may be obtained by direct reading over a wide range of intensity levels and for sounds containing various frequency components

The loudness level, as previously mentioned, defines only the intensity levels at which sounds of different frequency appear of equal loudness to the ear. However, loudness level does not provide a direct measure of relative loudness perceived by the ear For example, a loudness level of 100 phons appears more than 40 times as loud to the average ear as a loudness level of 50 phons, rather than twice as loud.

Loudness, as perceived by the average human ear, is measured in loudness units, and provides a measure of the relative loudness of a sound of particular loudness level compared to a sound with a loudness level of zero phons A sound with a loudness level of 100 phons will have a loudness of 88,000 loudness units, and will appear to be about 2-1 3 times as loud to the average ear as a sound with 90 phon loudness level corresponding to 38,000 loudness units A curve relating loudness in loudness units to the loudness level in phons is shown in Figure 2, as given in American Standards Association is Standard Z24 2-1942

For the purposes of this report, the term relative loudness is further introduced This term is not standard, but expresses the ratio of the loudness units corresponding to any loudness level to the 7950 loudness units obtained at a loudness level of 70 phons The relative loudness may be converted to standard loudness units by multiplying by the factor 7950

The 70-phon loudness level was chosen as the reference level for relative loudness because of its approximate correspondence to the loudness level produced by an average voice in normal conversation at a distance of three feet The relative loudness, therefore, represents approximately the loudness of a sound heard by the average ear as compared to the loudness of average conversation at a three-foot distance On this basis, a sound with loudness level of 100 phons has a relative loudness of 11 1, or appears about eleven times as loud to the ear as the reference conversation level

It is seen that analysis of sound level readings is complex, and that some variation exists in choice of the most useful and significant form in which to present sound level data In this report, the data have been presented principally in terms of intensity level, loudness level, and relative loudness

The degree of annoyance associated with a particular sound is dependent partially upon the objective characteristics of the sound, such as its intensity, the magnitude of particular frequency components, and the sound duration However, degree of annoyance also is associated with numerous psychological factors dependent upon the individual listener and his reaction to the particular sound. Such psychological factors, other than those average values which are incorporated in determination of loudness level and loudness units, cannot be measured or considered in a study of the present nature.

EFFECT OF ATMOSPHERIC CONDITIONS AND TERRAIN UPON SOUND PROPAGATION

The general effects of variations in atmospheric conditions upon propagation of sound have been discussed by numerous investigators [1] It has generally been concluded that the most important atmospheric factors in this connection are local variations or gradients in the wind velocity, humidity, etc , which cause refraction and bending of sound waves through variation in the velocity of sound

For example, air saturated with moisture at 50 degrees F will propagate sound at a velocity of about 2.5 feet per second faster than dry air Where local variations or gradients exist in the moisture content of the air, the sound waves will tend to be refracted or bent generally in the direction of the driest air strata

Variation of wind velocity or temperature with altitude causes similar apparent bending of the sound path For a wind velocity gradient with the velocity increasing with altitude, which is a common condition, the sound waves will tend to bend toward the ground when traveling in a downwind direction, and away from the ground when traveling in an upwind direction Under such circumstances, it is possible that at moderate distances a sound will be heard with greater intensity upwind than downwind

Variation of atmospheric pressure causes no variation in the sound velocity, so long as the ratio between the pressure and density remains constant

During the actual time of conduct of the present tests, covering a total period of about two months, the wind velocity varied from about 5 to 20 miles per hour, with a few cases of higher velocities with a maximum of 25 miles per hour. The relative humidity varied from 40 to more than 80 percent, the temperature varied from 40 to 90 degrees F, the barometric pressure varied from 28 85 to 29 30 inches of mercury, the sky conditions varied from clear to overcast with 1000-foot ceiling. In general, no large local variations or gradients for the various factors were obtained at one time, except for humidity with the overcast condition

The test results obtained showed no correlation with such variations in atmospheric conditions, and in general were consistent in spite of such variations It may be concluded that, at the relatively short distances involved in the present tests (usually less than 6000 feet) normal variations in atmospheric conditions have little effect At greater distances the effects probably are much more significant

As a simple test of such conclusion, as related to wind velocity, the Beech C-45 airplane was flown around a two-mile square pattern with the sound measuring equipment at the center of the square The airplane was flown four times around the pattern at a 1500-foot altitude and at a 500-foot altitude, with the sound level recorder operating continuously The wind velocity at ground level was 12 mph, at 2000-foot altitude it was 14 mph, and at 5000-foot altitude it was 27 mph, all in the same direction

[1] Lord Rayleigh - "Theory of Sound", Vols. 1 and 2

The largest variation in average peak sound level reading, as the airplane passed the center section of each leg of the pattern, was 2 decibels. The highest average reading was obtained as the airplane was downwind from the sound recorder The 2-decibel variation obtained was considered about the limit of accuracy for the test results generally, with all sources of error included

Variables other than atmospheric, which can materially effect the sound level are terrain, trees, houses, and other local obstructions No general rule can be given to correct for these factors, as each case would itself require a special application and be variable with the seasons of the year and from day to day These factors may either raise or lower the sound level, and a general quantitative estimate cannot be made For a position shadowed from the sound source, such as behind foliage, a building, or knoll, attenuated sound waves may reach the observing point, but stronger waves may be reflected from other objects or refracted by atmospheric conditions to increase the sound level at that point From this it can be seen that the sound level at a given distance may be lower or higher than the normal value, depending upon the particular shadowing, reflection, and refracted wave conditions

TEST EQUIPMENT

An Electrical Research Products, Inc , Type R A. - 277 Sound Frequency Analyser and Type R A - 246 Graphic Level Recorder (See Figure 3), later referred to as the ERPI instrument, was used for these tests in conjunction with a General Radio Company, Type 759-B Sound Level Meter (See Figure 4), later referred to as the GR instrument.

The Sound frequency analyser was calibrated at the National Bureau of Standards and precise corrections were obtained The analyser passes frequencies of a five-cycle band width Both instruments are equipped with nondirectional microphones The General Radio instrument is powered by dry batteries, while the Electrical Research Products instrument was powered in the field by a 115 volt - 60 cycle a.c , portable gasoline-powered generator. A frequency meter was used in adjusting the power supply to a 60-cycle frequency, while a variable transformer was used to control the voltage output The power supply unit was located at sufficient distance from the microphones to avoid interference with sound levels being measured.

In order to prevent wind interference in the microphones, a "cage", 15 inches square and 18 inches high, was built around each microphone as shown in Figure 5 These "cages" were constructed of a light wood frame and covered with a layer of loosely woven open mesh Calibration of the microphones with and without these cages indicated no change in sound level readings

For the determination of the distance and altitude of passing aircraft, two transit-type sights, one of which is shown in Figure 6, were used. Each consists of a horizontally revolving head with a vernier azimuth circle calibrated to five minutes of arc, and a crosshead sight rotating in a vertical plane with a vernier quadrant also calibrated to five minutes of arc. A bubble level was mounted on the crosshead sight for leveling the instrument.

Standard telephone headsets were used to aid in simultaneous reading of each instrument. All units were coordinated by the use of three Army Type BC-322 portable radio transceivers

TEST PROCEDURE

A - AIRCRAFT

The aircraft sound level measurements were obtained at the Weir Cook Municipal Airport at Indianapolis, and at picked locations, within eight miles of the Municipal Airport, which were relatively flat and open and at which relatively low normal sound levels existed. A portion of the small aircraft measurements were obtained at the Bob Shank Airport on the outskirts of Indianapolis. The tests were divided into two major phases, (1) controlled tests with the aircraft pilot using definite engine power settings and following specified flight paths with relation to the measuring equipment, (2) uncontrolled tests with sound level measurements obtained with airplanes in the general airport traffic.

The controlled tests were carried out with six aircraft.

AIRCRAFT	H.P RATING
Douglas C-47	2400
Beech C-45	900
North American SNJ-4	600
Stinson 150	150
Cessna 140	85
Aeronca Champion	65

The uncontrolled tests included aircraft from 65 hp power rating to commercial and military aircraft of about 5700 hp maximum

Controlled Aircraft Take-Off Measurements

Sound level measurements of aircraft during take-off runs were obtained on the airport at various measured distances to the side and rear of the runway in use One transverse cross-line along which measurements were taken was established at the approximate point where the particular aircraft left the ground. A second transverse cross-line was established at the starting point of the take-off run A longitudinal measuring line was established directly to the rear of the airplane in line with the runway

Measurements were taken with the two sound level meters placed at alternate locations along the line upon which the readings were being obtained The location points along the line were spaced so as to provide an approximate 5 to 10-decibel drop between successive locations Six to eight measuring points were used along each line, with the furthest point being approximately 6000 feet from the runway

The recorder unit of the ERPI apparatus was used to obtain all readings with that instrument The record obtained provides a time variation of the sound level as well as a measurement of the peak sound intensity. Measurements with the GR instrument were read directly from the meter

For each instrument location, one take-off run of the airplane was made in the controlled tests. In cases where the reading obtained was questionable due to interfering sound, the take-off run was repeated.

For the controlled tests with the Douglas C-47 and Beech C-45 airplanes, sound level readings along the transverse line at the take-off starting position, and the longitudinal line to the rear of the airplane, were obtained with the aircraft engines being run momentarily at full power without the aircraft moving. With all other aircraft used in the controlled tests, an actual take-off run was made for such instrument location.

Controlled Aircraft Climb and Cruise Measurements

Sound level measurements of controlled aircraft in climbing and cruising phases of flight were obtained by placing the sound measuring equipment at fixed locations along an isolated open road removed from the airport, and flying the aircraft in an upwind direction across a specified point on the road The airplane was caused to cross the road with standard rate of climb and climbing power as used after normal take-off for the particular airplane, and at altitudes of 200, 400, 600, 800, and 1000 feet Further level flights were made across the road at cruising power, and at 400, 800, and 1200 feet altitude

The two sighting instruments were placed on the road 1000 feet to each side of the desired aircraft crossing point, and measurements were made of the angle from the horizontal to the line of sight to the airplane, at each sighting point, as the airplane crossed the road

One series of airplane passes was made for each location of the sound measuring equipment, and a particular pass was repeated if the reading obtained was uncertain. After each series of airplane passes, the measuring equipment was moved to a new location on the road, until a maximum distance of 6000 feet from the point of airplane crossing was reached The locations of the measuring points were spaced to give an approximate 5 to 10-decibel difference in sound level at successive points. The two sound level meters were used at alternate measuring points along the transverse road line.

Frequency Spectrum Measurements

Frequency analysis of the sound produced by each airplane used in the controlled tests was made with the airplane operated at approximately cruising power. With the Douglas C-47 and the Beech C-45, the frequency measurements were accomplished by operating the aircraft engines on the ground with the airplane stationary, and placing the measuring equipment 300 feet to the side of the airplane in line with the propellers.

With the other aircraft used in controlled tests, the frequency measurements were made by flying the airplane in a continuous close circle at low altitude around the measuring equipment, attempting to hold constant the distance between the airplane and the microphone

During each test an overall sound level record was made, and separate recordings were made for the frequency band from 10 to 1000 cycles per second, and for the band from 100 to 10,000 cycles per second

Sound Levels of Miscellaneous Aircraft Traffic

Sound level measurements of miscellaneous aircraft traffic were obtained in the airport vicinity at known locations with respect to the runway in use. The sighting instruments were used for all readings obtained with aircraft in flight. In such case, the sights were located at known points relative to the runway and to the sound measuring equipment, and at a distance apart of 2000 feet Azimuth and vertical angle readings were obtained as the airplane passed the sound measuring equipment, so that the airplane altitude and its distance from the sound measuring equipment could be computed.

Each aircraft, for which a sound level measurement was obtained, was identified according to its manufacturer and model. A record was also made to indicate whether the airplane was in take-off or climb condition. In the case of commercial transport aircraft, the particular air line operator was noted

Numerous readings were taken with the sighting instruments, of small aircraft after they had completed their first turn in the take-off traffic pattern, and of large aircraft about one minute after take-off from the airport. The purpose of such readings was to obtain a check on the normal take-off path of the various aircraft under existing wind conditions, and thereby relate altitude of the airplane after take-off with distance from the take-off point.

B - HIGHWAY AND RAILROAD TRAFFIC

Sound level measurements of highway truck and passenger car traffic were obtained at a flat and open section of U.S. Highway 40 west of Indianapolis.

Measurements were taken at various distances from the road, until a maximum distance was reached at which the sound level decreased to a value of 60 to 65 decibels.

Each vehicle with which a sound level reading was obtained was identified according to type, and the vehicle was timed over a measured distance to determine its velocity The recorder unit of the ERPI sound measuring equipment was used to obtain variation of the sound level with time.

During this series of measurements, frequency analysis tests were made upon a 1939 Model Ford sedan and a 1941 Model Ford panel truck The frequency spectra of the two vehicles were measured with the vehicles stationary and with the engine and rear wheels running at a speed corresponding to 40 mph. No satisfactory method could be devised for obtaining such a frequency measurement with the vehicle in motion and with the available measuring equipment

Sound level measurements of freight and passenger train railway traffic were obtained in a manner similar to that used in the highway tests. Measurements were taken along the main route of the Pennsylvania Railroad and the New York Central Railroad west of Indianapolis.

The frequency spectrum measurement of railway traffic was obtained with long trains, which took sufficient time in passing to permit scanning the necessary frequency band.

C - GENERAL

During the tests relating to highway and railway traffic, and upon the Douglas C-47 and Beech C-45 aircraft, the two sound level meters were used with both the flat and the 70-decibel weighting networks In general, the flat weighting network was used where the peak sound intensity was greater than 85 decibels, and the 70-decibel network was used for peak sound intensities between 60 decibels and 85 decibels. For reasons discussed in the following section of this report, subsequent measurements obtained with all other aircraft were made with the flat weighting network only.

During all tests, a record was maintained of the general existent atmospheric conditions, including wind velocity and direction, barometric pressure, temperature, relative humidity, and cloud formations. Such data were obtained from the U.S. Weather Bureau at the Indianapolis Municipal Airport. No means were available for measuring instantaneous variations of these factors at the time of individual tests and at the various airplane altitudes used.

DATA CORRECTION METHODS

A - CORRECTIONS FOR ELECTRICAL RESEARCH PRODUCTS, INC. SOUND LEVEL METER

In the analysis of the sound level data, it is desired to convert all readings obtained with the sound level meters to equivalent loudness level and loudness units, which provide a measure of the loudness as heard by the average human ear. The sound level meter does not provide loudness level values directly, except in an approximate manner at only two intensity levels in the range covered by these tests. The following method was used to correct all readings obtained with the ERPI instrument, and to convert such readings to loudness level values.

It was found that a "zero" correction to the reading obtained with the ERPI recorder is required for the effect of the wind screen around the microphone, and for differences between the recorder reading and the meter reading. With proper adjustment of the recorder stylus, readings within plus or minus 0.5 decibels of the meter reading were obtained.

To correct the ERPI meter readings to true intensity level values, an analysis of the frequency spectrum measurement was first made for each specific sound source. The relative sound intensities determined from such analyses, for each 100-cycle band in the sound spectrum, are shown in Table I for each specific noise source

The method of correction for specific sound sources, as outlined in American Standards Association Standard Z24.3 - 1944, was followed to determine the correction to be applied to readings obtained with each sound source.

In this computation the 100-cycle band intensity values given in Table I were used in conjunction with the calibrated meter frequency response.

Corrections were determined in this manner for readings obtained with the ERPI instrument using both the flat and 70-decibel weighting networks, correcting each reading to the true flat response condition. These corrected readings, therefore, represent true sound intensity level values

The correction procedure outlined in American Standards Association Standard Z24 3 - 1944 was also utilized to determine a correction value for converting readings from the objective true flat response curve to the objective 70-decibel response curve for each specific sound source. Such correction values then were applied to the standard 70-decibel response curve to determine an effective frequency representing each sound source. The effective frequency for each specific sound source, given in Table I, has no physical significance, but represents the single frequency of sound which provides the same difference in corrected reading between the flat and the 70-decibel weighting networks as obtained with the specific sound source used

This effective frequency was used to convert all sound intensity values for each source to corresponding loudness level values. This was accomplished by considering each sound as composed only of this one effective frequency, and converting intensity level values to loudness level values for this frequency as given by standard loudness level curves in Figure 1.

The procedure described above provides only approximations to true loudness level values However, the degree of approximation is considered at least as close as that obtained by the conventional procedure of utilizing only the standard weighting networks incorporated in the sound level meter with no interpolation for intermediate intensity values The procedure used also provides consistent curves for the plotted readings, without an artificial sharp break at an arbitrary level intermediate to the standard loudness levels furnished by the meter weighting networks.

B - CORRECTIONS FOR GENERAL RADIO SOUND LEVEL METER

No accurate calibration of the frequency response of the GR sound level meter was available for these tests. Use of a microphone extension cable added to the GR instrument also required a large correction to be applied to readings obtained with this meter All readings obtained with this instrument, therefore, were corrected by comparison to readings obtained with the calibrated ERPI meter

The procedure used in determining such correction was to plot all readings obtained with both meters upon the basis of sound level against distance between the microphone and source for each separate test condition. The ERPI meter readings were plotted after correction to true sound intensity values and the GR meter readings were plotted as read on the meter.

An average curve was drawn through each set of points, and the average difference in decibels between the two curves was taken as the correction to be applied to individual readings obtained with the GR meter

The corrections determined in this manner varied from about plus 11 to plus 22 decibels for different specific sound sources The plus 11-decibel correction corresponds approximately to the microphone cable correction.

Arter application of this correction to the GR meter readings, these readings were considered to represent intensity level values Conversion to loudness level values then was made in a manner identical to that used for the ERPI instrument.

TEST RESULTS AND DISCUSSION

A - Controlled Sound Level Measurements with Douglas C-47 Airplane

The Douglas C-47 airplane used for the controlled tests was powered by two Pratt and Whitney SIC 3-G engine installations with three-bladed constant speed propellers The propeller gear reduction was 0.5625, and the propeller diameter was 138 inches

The operation of the engines and airplane for the various test conditions was as follows

	ENGINE			RATE OF CLIMB	INDICATED AIR SPEED	PROPELLER TIP SPEED
	rpm	Man. Press. in Hg.	hp	ft./min.	mph	ft./sec.
Take-off Run	2600	40	1030	--	--	882
Climb after Take-off	2100	30	600	500	120	715
Cruise	2000	27	550	--	150	681

The intensity levels in each 100-cycle frequency band, as measured from the frequency analysis record for the Douglas C-47 airplane, are shown in Table I. The relative intensity levels for each band, as compared to the intensity for the 1000-cycle band, are also shown The sound intensity is concentrated principally in the 100, 200, and 400 cycle bands, which correspond to predominant engine and propeller frequencies. At frequencies greater than 1700 cycles per second, the intensity level is so low as to provide negligible contribution to the overall intensity.

Corrected intensity level readings for take-off, climbing, and cruising conditions with the Douglas C-47 airplane are plotted against airplane-to-microphone distance in Figure 7

Figure 7 shows the experimental points determined for the cruising power condition and the climbing power condition, with airplane altitudes varying from 200 feet to 1200 feet and the airplane-to-microphone distances varying from 200 feet to about 6000 feet. The average intensity level curve drawn through the points for the climb conditions shows a definite upward trend at the lower end of the curve The cause for this upward trend is not known, but possibly may be explained by ground reflection or atmospheric effects which are not evident at shorter ground distances.

No systematic separation of experimental points for the climbing condition was found when separate plots were made for the different altitudes of the airplane at the time of reading

The slope of the straight line portion of the intensity level curve for both the cruising and climbing conditions is about 8.5 decibels for each doubling of distance These figures provide fair agreement with the 6 decibels expected from theory, which neglects ground, atmospheric, and air attenuation effects.

The loudness level curves corresponding to the intensity level curves for the climbing and cruising conditions also are shown in Figure 7. Loudness level values from this curve may be converted to loudness units by the relationship given in Figure 2.

There further is shown in Figure 7 corresponding data and curves obtained at various side distances from the runway opposite the point where the airplane started the take-off run, and opposite the point where the airplane left the ground Data obtained directly behind the starting point of the airplane in line with the runway are also shown

The intensity level readings obtained to the side of the airplane ground-run show higher values for the shorter airplane-to-microphone distances than for corresponding distances with the airplane in either climbing or cruising flight. At the greater distances, a very rapid decrease in intensity level is obtained

These observed relationships are probably associated with reflection and attenuation effects of the ground, which are not obtained in such degree after the airplane reaches an altitude of about 200 feet, and with variation in engine power settings for the take-off and climb conditions

The slopes of the straight line portion of these curves correspond closely to the slopes of the curves shown in Figure 7 for the cruising and climbing conditions

The intensity level readings obtained behind the airplane are much lower in value than readings obtained at identical distances to the side of the airplane at the start of the take-off run. The slope of the curve, however, has about the same value

Data are plotted in Figure 13 to show the variation in intensity level at various angular positions around the right side of the airplane at a constant distance of 300 feet from a point midway between the two propeller hubs For this test condition an engine rpm of 2600, and a manifold pressure of 40 inches Hg were used This pattern is not necessarily symmetrical for both the right and left sides of the airplane, due to direction of rotation of the propellers. The right side of the pattern normally registers higher levels. Maximum intensity is found at an angle of 15 to 30 degrees behind the propeller line, and a large decrease in intensity is found directly behind the airplane This is in agreement with the measurements made behind the airplane during the take-off run as compared to readings taken at the side. A noticeable difference was observed in the character of the sound at the side and behind the airplane, but a separate frequency analysis was not made for the latter condition. This noticeable drop in sound intensity directly behind the airplane is probably due to the contour of the sound pressure wave set up by the propeller coupled with a possible shielding effect of the airplane structure.[2]

The loudness level curves for the take-off and climb conditions, shown in Figure 7, are combined and plotted in Figure 14 as loudness level contours around the airplane take-off path and the climb path after take-off. These contours show locations of equal peak loudness level during the airplane take-off and climb.

For this contour arrangement, a straight take-off path was assumed, together with a rate of climb of 500 feet per minute, an air speed of 120 mph, and zero wind velocity. Correction of the contours for different climb or wind conditions may be readily made if the aircraft engine power and rpm remain constant. For example, a 20 mph wind velocity will cause the airplane to reach an altitude of 1000 feet at a distance, from the take-off starting point, about 3530 feet less than that indicated. An expansion of the distance scale along the take-off and climb path, so that the 1000-foot altitude point coincides with this decreased distance, will provide a satisfactorily accurate corrected contour plan.

A variation of engine power or rpm will cause variation of the loudness level contours for which no simple correction can be made.

An abrupt change in position of the lower loudness level contour lines is evident as the airplane leaves the ground on take-off and climbs to about 200-foot altitude The exact shape of the contour lines in this region has not been closely defined by the present data. The experimental points opposite the take-off point and the point corresponding to an airplane altitude of 200 feet were joined in what appeared to be the most reasonable manner.

The observed changes in contour shape in this transition period from take-off to climb conditions are associated with the ground effects, and the variations in power settings, already mentioned in connection with the corresponding variations in the basic curves shown in Figure 7.

The relative loudness, corresponding to each loudness level contour line is shown in a table associated with the contour plot These figures indicate directly the loudness, as heard by the human ear, relative to the 70-phon loudness level.

The data given in Figure 7 for cruising conditions is replotted in Figure 20 to show variation in loudness level with altitude of the airplane and with ground distance Corresponding relative loudness is shown in a table on the figure. It is seen that

[2] Theodore Theodorsen and Arthur A. Regier - "The Problem of Noise Reduction With Reference to Light Airplanes", National Advisory Committee for Aeronautics Technical Note No. 1145.

the Douglas C-47 with cruising power will sound about 2-1/2 times as loud with the airplane directly overhead at 1000-foot altitude as it will sound when flying at the same altitude, but over a point on the ground one-half mile from the observer.

B - Controlled Sound Level Measurements with Beech C-45 Airplane

The Beech C-45 airplane used in the controlled tests was powered by two 450 hp Pratt and Whitney Model B5 Wasp Junior engines with direct-drive Hamilton two-bladed constant speed propellers. The diameter of these propellers was 99 inches The airplane and engine operating conditions for various test conditions were as follows

	ENGINE			RATE OF CLIMB	INDICATED AIR SPEED	PROPELLER TIP SPEED
	rpm	Man. Press in Hg.	hp	ft./min.	mph	ft /sec.
Take-off Run	2300	34	400	--	--	1000
Climb after Take-off	2300	30	330	500	125	1000
Cruise	1900	26	210	--	165	821

The measured intensity level, in decibels, for each 100-cycle per second frequency band, is shown in Table I The intensity level for each band relative to the 1000-cycle per second band is also shown. The greatest intensity readings were obtained in the 100, 200, and 400-cycle bands, similar to that shown for the Douglas C-47.

The corrected intensity level curves for the take-off, climbing, and cruising conditions, and associated loudness level curves, showing the variation in sound level with airplane-microphone distance, are shown in Figure 8. It can be seen that, with distance plotted on a logarithmic scale, the intensity level relationship for the climbing condition is a straight line with the intensity decreasing with increased distance. The rate of decrease is about 6 5 decibels for each doubling of distance from the airplane. The loudness level, which is related to the loudness as perceived by the average human ear, does not exactly follow this straight line variation, but shows a progressively greater decrease below the straight line as the intensity level decreases.

For the cruising condition, the intensity level relationship again is a straight line, but with less slope than that for the climbing condition Lower sound level readings for the shorter airplane-to-microphone distances are obtained for cruising condition as compared to the climbing condition. These lower readings can be attributed principally to the higher engine power used in climbing The loudness level for the cruising condition also shows a more gradual but greater deviation from the intensity level curve.

The intensity and loudness level curves for points opposite the start of take-off, opposite the airplane when it first becomes airborne, and directly behind the airplane in line with the runway, are also shown in Figure 8. The intensity level curves for these three test conditions do not follow the straight line variation that is found for the climbing condition. This can be attributed to ground effects, which apparently cause the sound level to drop rapidly at the greater distances

For points directly behind the airplane, the intensity and loudness levels are much less than for points at right angles to the airplane path. The intensity and loudness levels for points opposite the start of take-off are one to two decibels lower than at points opposite the airplane as it becomes airborne. For both of these conditions, however, the levels are appreciably less for the greater distance than with the take-off and cruise conditions.

The semi-circular pattern of the intensity level around the right side of the Beech C-45 airplane, at a constant distance of 300 feet, is shown in Figure 13. For this test a constant engine rpm of 2300, and manifold pressure of 34 inches Hg were used. This pattern shows that the intensity level is the greatest at an angle of 15 to 45 degrees behind the propeller line, compared with a maximum at about 15 to 30 degrees for the Douglas C-47.

Loudness level contours around the Beech C-45 airplane take-off and climb paths are plotted in Figure 15 As in the case of the Douglas C-47, a straight take-off path was assumed, with a rate of climb of 500 feet per minute, an air speed of 120 mph, and a zero wind velocity.

The loudness level curve for the cruising condition, shown in Figure 8, is replotted in Figure 21 to show the variation in loudness level with altitude and with distance to the side of the cruising path.

C - Controlled Sound Level Measurements with North American SNJ-4 Airplane

The North American SNJ-4 airplane used for the controlled tests was powered by a 600 hp Pratt and Whitney Wasp Junior engine with a direct drive two-bladed constant-speed propeller of 108 inches diameter

The airplane and engine operation data for the various test condition were as follows

	ENGINE			RATE OF CLIMB	INDICATED AIR SPEED	PROPELLER TIP SPEED
	rpm	Man. Pres. in Hg.	hp	ft./min	mph	ft /sec
Take-off Run	2300	33	600	--	--	1084
Climb after Take-off	2300	32	580	600	125	1084
Cruise	1850	26	400	--	155	872

From the frequency analysis test on the SNJ-4, the measured levels for each 100-cycle band are shown in Table I, together with the relative intensity levels for each band as compared to the 1000-cycle band These data show that the frequencies between 50 and 500 cycles per second make the greatest contribution to the overall intensity. However, frequencies between 50 and 150 cycles per second show the highest peak of intensity. The contribution of frequencies above 1000 cycles per second to the overall level is practically negligible

The intensity and loudness level curves for the take-off, climbing, and cruising conditions are shown in Figure 9. The intensity level curve has a fairly uniform rate of change in the slope, with practically no straight line portion. The single-engine SNJ-4 airplane has an intensity level of 108 decibels during the climb for a straight line distance of 250 feet, as compared to 102 decibels intensity level reading for the twin-engined Beech C-45 at the same distance. The loudness level curve coincides with the intensity level curve for measurements at distances from 650 to 1500 feet, while at lesser and greater distances there is a gradual divergence.

For the cruising condition, also shown in Figure 9, a plot of the intensity level values produces an approximate straight line. The slope of this line causes a decrease of about 5 5 decibels for each doubling of distance. The loudness level curve has a gradual downward divergence from the intensity level curve as would be expected, and the divergence is accelerated only slightly for the latter portion of the curve

Curves are also shown in Figure 9 for corresponding data obtained at various distances at right angles to the runway opposite the point when the airplane starts its take-off run, and also opposite the point where it becomes airborne. In this figure, likewise, is the plotted curve for data measured directly behind the aircraft at the start of take-off Somewhat similar curves were obtained for the two groups of points to the side of the airplane, with the greatest intensity and loudness levels observed opposite the point at which the aircraft becomes airborne for airplane-microphone distances greater than 1000 feet For the points directly behind the SNJ-4 airplane on take-off, the levels are about 20 units lower at a distance of 500 feet than for either of the side lines, and decrease rapidly for distances over 1000 feet

To obtain the constant loudness level contour pattern for the take-off and climb condition, the curves from Figure 9 have been combined and replotted in Figure 16 It is shown in Figure 16 that relatively high loudness level values are found as far away as one mile while the airplane is taking off, with slightly higher values obtained as it climbs to 200 feet altitude A loudness level of 60 phons is obtained for the SNJ-4 airplane for a distance of 8300 feet, compared to 60 phons at about 6000 feet for the Douglas C-47

As will be shown later, it appears that the test SNJ-4 airplane gave five to eight phons higher loudness level values than the uncontrolled AT-6 aircraft (identical airplane) for the same distances This may be attributed to individual characteristics of the test model, as well as different techniques of operation The exceptionally high sound levels produced by this model airplane may partially be due to the high propeller tip speed (1084 feet per second) obtained with the direct drive engine-propeller arrangement.

The loudness levels for the cruising condition at various side ground distances are shown in Figure 22. The SNJ-4 loudness level curves for this condition approximate the twin-engined Beech C-45 curves

D - Controlled Sound Level Measurements with Stinson 150 Airplane

The Stinson 150 airplane used for the controlled tests was powered by a Franklin 150 hp engine with two-bladed fixed-pitch propeller. The propeller diameter was 74 inches. The engine exhaust system incorporated a muffler.

The operation of the engine for the various test conditions was as follows·

	ENGINE		RATE OF CLIMB	INDICATED AIR SPEED	PROPELLER TIP SPEED
	rpm	hp	ft./min	mph	ft./sec.
Take-off Run	2450	140	--	--	792
Climb after Take-off	2450	140	500	85	792
Cruise	2300	135	--	120	743

The measured and relative intensity levels, for each 100-cycle band which contained significant components, are shown in Table I. The maximum energy is seen to be in the 100-cycle band, with most remaining energy between 150 and 350 cycles per second. At frequencies above 2200 cycles per second the energy contribution becomes insignificant.

Corrected intensity level readings for the take-off, climbing, and cruising conditions of the Stinson 150 airplane are shown in Figure 10, plotted against airplane-to-microphone distance Also shown are the corresponding loudness level curves.

The intensity level curve for the climbing condition appears to be a straight line, although some dispersion of experimental points was obtained. The corresponding curve for the cruising condition appears to curve slightly, although a straight line would provide a reasonable fit for all points except at the low intensity end. The slope of the straight line for the climbing condition is about 6.6 decibels for each doubling of distance, and the corresponding slope for the cruising condition is about 7.0 decibels.

In Figure 10 are also shown the intensity level and loudness level values for locations behind the aircraft starting point, and to the side of the runway opposite the starting point and the take-off point. The intensity level curves show a definite gradually decreasing slope. The intensity levels obtained for the runway side positions correspond approximately to values obtained for the climb condition for equivalent distances, but the levels behind the aircraft on take-off are lower in value.

The changing slope of the intensity level curves again may be explained by the reflecting and attenuating effects of the ground In this case it appears that at short distances the additional energy reflected from the ground results in an apparent low rate of attenuation, but at large distances energy is reflected to greater heights, or is lost during the reflection process, so that a rapid apparent attenuation is obtained.

Loudness level contours for the Stinson 150 airplane are plotted in Figure 17, as obtained from the take-off and climb data given in Figure 10.

For the plotting of these curves, a rate of climb of 500 feet per minute, and an air speed during climb of 85 mph, were assumed. As in the case of the Douglas C-47 airplane previously discussed, correction may be made to the assumed take-off and climb path for wind velocity, air speed, or rate of climb, without changing the contour shape, but correction for different power settings would be complex

Changes in shape of the loudness level contours again are observed as the airplane progresses along the take-off run and starts to climb. Probable reasons for such variation have been discussed in connection with other aircraft.

The loudness level curve for the cruising condition, as shown in Figure 10, is replotted in Figure 23 to show variation in loudness level for various distances to the side of the aircraft path and for different aircraft altitudes. Corresponding relative loudness is also indicated

E - Controlled Sound Level Measurements with Cessna 140 Airplane

Controlled tests were carried out on a 1946 unmuffled Cessna Model 140 airplane The powerplant was a four-cylinder 85 hp Continental engine, with a 74-inch two-blade propeller. The airplane and engine operating conditions for the various test conditions were as follows.

	ENGINE		RATE OF CLIMB	INDICATED AIR SPEED	PROPELLER TIP SPEED
	rpm	hp	ft./min.	mph	ft /sec
Take-off Run	2200	75	--	--	712
Climb after Take-off	2250	76	500	75	728
Cruise	2250	76	--	100	728

The intensity levels for the cruise condition, as measured for each 100-cycle per second band, are shown in Table I The intensity level for each band relative to the 1000-cycle per second band is also shown in the same table. The sound intensity for this airplane is concentrated principally in the 50 to 250-cycle frequency range. This is a slightly lower band than for the Douglas C-47 and Beech C-45 airplanes. Above 1100 cycles per second the intensity is very low, and contributes little to the overall intensity level.

For the take-off, climb, and cruise condition, the corrected intensity level readings for the Cessna 140 airplane are plotted against the microphone-to-airplane distance in Figure 11. The loudness levels for these conditions are likewise shown The intensity level curve for the climbing condition is a straight line until the airplane-microphone distance is 1700 feet, where the curve begins to slope upward in a manner similar to that of the Douglas C-47 Again the reason for this is unknown, unless it can be attributed to ground effects which are not influential at the shorter distances The slope of the straight line portion of the intensity level curve for the climb condition corresponds to a decrease of 6.7 decibels for each doubling of distance.

For the cruising condition, shown in Figure 11, the intensity level curve is a straight line to 1300 feet distance, beyond which it bends downward as in the case of the Beech C-45. For the straight line portion of the curve, the slope is less than for the climbing condition, and at no point does the cruising intensity level become as high as for the climbing condition The cruising loudness level curve follows the cruising intensity curve with slightly more downward displacement than for the climbing condition.

Data and curves are also shown in Figure 11 for readings obtained at various side points opposite the start of take-off, and opposite the point where the airplane becomes airborne The data for various points directly behind the starting point of the airplane, and in line with the runway, are also shown For a distance of about 200 feet, the intensity and loudness curves all correspond for both of the side locations For the longer distances, the intensity level and loudness level curves for the points opposite the position where the plane becomes airborne bend down very rapidly in a diverging manner, with the loudness curve dropping at a high rate For points opposite the start of take-off, the downward curvature of the intensity and loudness level curves is even greater, particularly beyond 1000 feet.

For the line directly behind the aircraft on take-off, the intensity level curve has the same slope as the straight line portion of the climbing intensity level curve, but the level is about 6 decibels lower. The loudness level curve has a slight downward curvature with more overall divergence from the intensity level curve than for all other conditions

The variation in intensity level at various angular directions around the right side of the Cessna 140 airplane is shown in Figure 13. The maximum intensity level for this airplane is at an angle of 15 degrees back from the propeller line. The levels for this airplane, however, do not vary widely with angular direction. The intensity level in front of the plane at 300 feet is only three decibels more than directly behind the airplane, while opposite the propeller it is 11 decibels more than behind the airplane.

Contour patterns for loudness levels of 60, 70, 80, and 90 phons are shown in Figure 18. This contour pattern varies considerably from the patterns for the other aircraft The maximum loudness levels for the Cessna 140 appear to be opposite the take-off starting point For all other airplanes tested, the maximum is reached opposite a point 2000 to 6000 feet from the start of take-off Inasmuch as this test was run on the same day and under the same conditions as for the Aeronca airplane, it is believed this variation is caused by an inherent characteristic of the airplane It was noted above that relatively little variation in loudness level exists for angular locations around the airplane at a distance of 300 feet. Inasmuch as the sound waves are of a more uniform intensity for all directions than is evident with the other aircraft, it is possible that after the airplane take-off the ground effects diminish, and the sound energies are more evenly dispersed in all directions with less energy in any one direction at a particular instant.

The cruising condition data given in Figure 11 are replotted in Figure 24 to show the variation of loudness level with ground distance to the side of the airplane path, and for different airplane altitudes.

F - Controlled Sound Measurements with Aeronca Champion Airplane

The two-place Aeronca Champion airplane used in the tests was powered by a 65 hp Continental engine with two-bladed propeller. The propeller diameter was 72 inches. No exhaust muffler was incorporated

The operation of the engine and airplane for the various test conditions was as follows

	ENGINE		RATE OF CLIMB	INDICATED AIR SPEED	PROPELLER TIP SPEED
	rpm	hp	ft /min	mph	ft /sec.
Take-off Run	2300	65	--	--	723
Climb after take-off	2300	65	400	65	723
Cruise	2150	60	--	85	675

The measured and relative intensity levels for each 100-cycle frequency band, as determined from the frequency analysis record for this airplane, are given in Table I The sound energy is seen to be concentrated in the 100-cycle band, with most of the remaining energy in the range from 150 to 350 cycles No significant sound intensity is present at frequencies greater than 2200 cycles per second.

In Figure 12 are shown the intensity level data for the take-off, climbing, and cruising conditions plotted against airplane-to-microphone distance.

The average curve for intensity level in climb is close to a straight line, but shows a slight decrease in slope with distance. The corresponding curve for the cruising condition shows a similar tendency Some dispersion of points is obtained at the moderate distances, but reasonably good curves are defined

The average slope of the intensity level curve for both the climbing and cruising conditions is about 6.3 decibels for each doubling of distance.

With this airplane the intensity levels measured opposite the starting point coincide closely to those obtained opposite the take-off point. The average curve for both conditions shows a decreasing slope from 100 to 400 feet distance, and a constant decrease of about 7 decibels for each doubling of distance at distances greater than 400 feet This curve falls slightly below the curve obtained for the climbing condition

The intensity level curve for locations behind the airplane on take-off shows relatively low intensity values, as was found with most of the other aircraft tested

Data plotted in Figure 13 show the variation in intensity level at different angular positions around the airplane. The data were obtained at a constant distance of 200 feet from the propeller hub, and with the engine running at full throttle, or about 2200 rpm. A maximum intensity is observed at an angle of about 15 degrees behind the plane of the propeller. A minimum level again is found to the rear of the airplane

The loudness level curves for the take-off and climb conditions, given in Figure 12, are replotted in Figure 19 as loudness level contours, and show locations at which peak loudness levels of the values indicated are obtained during the take-off run and climb of the airplane. The assumed straight climb path of the airplane, as shown on the contour plot, is based upon a rate of climb of 400 feet per minute and an airspeed in climb of 65 mph.

The loudness level contours for this airplane are relatively smooth and free from rapid variations in slope, as compared to those obtained for most of the other airplanes tested.

The relative loudness, corresponding to each loudness level contour line, is shown in Figure 19. These values indicate directly the relative loudness as heard by the human ear, and as compared to loudness of normal conversation at a three-foot distance.

The data given in Figure 12 for the cruising condition are replotted in Figure 25 to show the variation in loudness level with distance to the side of the airplane path, with the airplane at different altitudes. It is seen that for practically all cruising conditions, except when the airplane is at very low altitude and almost overhead, the loudness level on the ground is less than the 70-phon reference level.

G - Sound Level Measurements with Uncontrolled Aircraft in General Airport Traffic

Sound level data were obtained with various miscellaneous aircraft during take-off and climb procedures in the general airport traffic. For each sound level measurement, the airplane altitude and its distance from the microphone pick-up were measured. All data were obtained with the aircraft on the take-off run or at relatively low altitude in the climb after take-off.

The sound level data obtained in this manner for different aircraft are plotted against airplane-to-microphone distance in Figure 27. Only a few measurements were obtained with certain aircraft, and considerable dispersion of points is observed with some aircraft where numerous readings were secured. In most cases reasonably good relationships are obtained. In order to simplify the plotting of the data for cases where two or more aircraft models appear to have the same average curve within the limits of estimation, the individual sets of data are combined and plotted as for one airplane.

A general description of the powerplant installation for each of the aircraft included in Figure 27 is given in Table II Horsepower and propeller speed values given are for rated conditions, and may not correspond exactly to actual conditions when the sound level readings were obtained.

As the curves shown in Figure 27 are based upon data obtained with a variety of individual pilots and aircraft for each airplane model, each curve represents an approximate average condition Individual aircraft intensity level readings vary from this average by a maximum of two to three decibels for the large aircraft, and by seven to eight decibels for the smaller aircraft.

The data obtained for the Douglas DC-3 airplane are of particular interest. Although insufficient data were obtained to provide accurate average curves and definite conclusions, a difference appears to exist between sound levels produced by airplanes of this model according to the model of engine used. The airplanes with Wright installations appear to produce intensity level values about five decibels greater than with the Pratt and Whitney installation. This variation in level may be associated with difference in engine power used during take-off.

The relatively large variation in individual test results obtained with the Aeronca and Taylorcraft airplanes might be associated partly with variation in student pilot technique More dispersion in individual sound level readings was obtained with these aircraft than with any of the other aircraft tested.

The slopes of the various curves shown in Figure 27 are reasonably uniform, and have an average value of about 6.0 decibels drop for each doubling of distance. This average value is in general agreement with that obtained for the take-off condition in the controlled tests.

A considerable variation was noted in the characteristics of the sound emitted by the various aircraft, as heard by the ear. The multi-engine aircraft generally appear to produce a fairly uniform sound, but with low frequency pulsations or beats which are more discernible as distance from the airplane increases Such beats are observable upon the records obtained by the sound level recorder.

The military training aircraft, such as the BT-13 and the AT-6, produce a very sharp and rapid pulsing effect during take-off which effects the ear strongly but which is not always distinguishable upon the sound record. The unusual effect upon the ear appears to be associated with the nature of the sound rather than its intensity.

The small low-powered aircraft generally produce a fairly uniform sound to the ear, without prominent pulses.

H - General Discussion of Aircraft Sound Level Data

Included in Table III, with the intensity level data for miscellaneous aircraft at a 500-foot distance during take-off, are the corresponding values for the aircraft used in the controlled tests. The values given for the controlled aircraft are the average of the values for the take-off and climb conditions. The comparison between identical aircraft in the controlled tests and the uncontrolled tests is close in most cases. The principal exception is the intensity value for the SNJ-4 airplane compared to the AT-6 airplane, in which case the sound levels for the SNJ-4 appear appreciably greater. This difference may be associated with variations in engine power used.

The intensity level data given in Table III are plotted in Figure 28 against the logarithm of the rated engine horsepower, or actual horsepower when known. A reasonably good straight line relationship is obtained except for one experimental point, which represents the SNJ-4 airplane used in the controlled tests. All other points fall within 3.5 decibels of the average curve shown.

The plotted points are distinguished in Figure 28 according to propeller tip speed, but not according to other factors which are known to influence intensity of generated sound. However, no consistent effect of propeller tip speed is observable in the plotted data

The relatively close relationship between sound intensity and total engine power, as shown in Figure 28, is considered surprising However, as pointed out previously, the exact power values and tip speeds were not known in the case of the miscellaneous traffic data, and could be computed only approximately from standard engine and airplane descriptions. It may possibly be concluded that in most normal aircraft design the different factors effecting sound production vary together in such manner as to maintain a simple relationship between sound intensity produced and size of the power plants. The total engine power apparently is the predominant factor.

The slope of the curve shown in Figure 28 corresponds to an increase of 3 6 decibels for each doubling of power This approximates the 3.0-decibel increase theoretically obtained by doubling the sound intensity of any sound source.

The relative loudness, or loudness relative to the 70-phon conversational level as previously defined, is given for all tested aircraft in Table III. It is shown that the small aircraft of less than 100 hp are about twice as loud as this reference loudness level. For aircraft with total engine power less than 300 hp, the relative loudness is 3 4 or less The maximum loudness was obtained for the Douglas DC-4 airplane, with a value of 14.6 times the reference conversation loudness.

Five of the aircraft listed in Table III, with intensity levels also plotted in Figure 28, utilized engine exhaust mufflers. These aircraft were the North American Navion, Beech Bonanza, Stinson 150, Bellanca, and the Piper Cub No significant difference in sound level generally is noted between the muffled and unmuffled aircraft, the largest difference being measured for the Piper Cub with a decrease in intensity level of about three decibels It may be concluded that engine exhaust muffling has little effect upon sound intensity, as the sound is produced principally by the propeller.[2]

The duration of aircraft sound is difficult to express, as the sound level is continually changing and the shape of the sound level vs time curve varies with distance from the airplane and with airplane velocity. In general the duration of aircraft sound above a 70-phon loudness level, and at distances from the aircraft less than 1000 feet, varies from 10 to 30 seconds. The duration of aircraft sound above the 70-phon level generally tends to increase with distance, with the peak loudness decreasing

I - Sound Level Measurements with Highway and Railway Traffic

The measured intensity level data obtained with railway traffic involving steam locomotives are given in Figure 29, as plotted against the logarithm of the distance from the track. Also shown is the loudness level curve corresponding to the average intensity level curve.

This conversion of intensity level to loudness level is based upon the measured frequency distribution data given for railway traffic in Table I.

The data plotted in Figure 29 include both passenger and freight trains pulled by steam locomotives, and travelling at different velocities. No systematic variation was noted for type or speed of train

The sound level produced by trains appears to be fairly uniform as the train passes the measuring point No attempt was made to measure peak intensities associated with whistles or particular locomotive noise, although such short duration peaks sometimes are of high intensity.

It is seen from Figure 29 that an approximate straight line relationship between intensity level and logarithm of distance is obtained for distances less than about 200 feet. The slope of this line corresponds to a decrease of about 2.5 decibels for each doubling of distance Beyond 200 feet distance the curve drops with increasing rapidity. The nature of this curve is very similar to that obtained with aircraft on the ground, and probably is similarly explained by ground effects.

If comparison is made of the railway train intensity level, given in Figure 29 for a 500-foot distance, to intensity level produced by aircraft at a similar distance, as given in Table III, it will be seen that the train traffic produces about the same level as small aircraft types.

[2] ibid

The results of sound level measurements on highway truck and passenger car traffic are shown in Figures 30 and 31. The frequency distribution data for a typical light passenger car and panel truck are given in Table I

The variation in individual readings for highway traffic sound levels is very large. Such variation appears to be dependent upon differences in individual vehicles of each general class, and to some extent upon the velocity of travel. However, only a general tendency could be seen for increase of sound intensity with vehicle velocity, and no specific separation of points could be made

The curves given in Figures 30 and 31 represent the approximate maximum and minimum intensity levels, and corresponding loudness levels, for each class of vehicle. The difference between maximum and minimum envelope curves is 15 to 20 decibels, and 15 to more than 30 phons

If the maximum curves only are considered, it is observed that a shape and slope generally similar to that found with aircraft is obtained The slope is of such value as to cause a 3.0 to 3.5 decibel decrease in intensity for each doubling of distance.

A definite difference in sound levels produced by the different classes of trucks and the passenger cars is observed The smaller trucks produce loudness levels about four phons less than the large semi-trailer trucks, and the passenger cars produce levels about seven phons less than the large trucks.

The maximum intensity level curves for the passenger car and truck data were not extended to a distance which lowered the value to 60 or 65 decibels Upon the basis of the aircraft and railway traffic curves, similarly obtained with the sound source on the ground, it is probable that the curves for highway traffic may be extrapolated to a distance of 1000 to 2000 feet without serious error

The duration of highway traffic loudness levels above the 70-phon level is about four seconds for passenger cars, and about 10 to 20 seconds for trucks, at a distance of 100 feet For railway traffic the duration varies greatly with length and velocity of train In all cases a tendency exists for duration to increase with distance from the traffic lane, but with decreasing peak intensity

METHODS OF APPLICATION OF DATA

The data given in this report for loudness level of aircraft are presented in a form which may not always be applicable for direct use in particular cases The following discussion is intended to indicate the method by which the data may be applied to individual cases, and the manner in which consideration may be given to other variables not included in the tests

The tests involving aircraft take-off and climb, for which the highest sound levels normally are obtained as compared to other flight conditions, were carried out with straight climb paths The tests also were carried out in flat country, and at picked locations where interference of trees, houses, and other obstructions was a minimum. Where similar conditions exist, direct application of the data may be made.

Traffic of small aircraft around airports normally does not follow a straight-line climb path, but rather a pattern which requires a 90-degree left turn when the airplane reaches a specified altitude in the climb path after take-off After further climb, the aircraft normally makes a 45-degree right turn to leave the traffic pattern The specified direction and altitude of pattern turns vary according to different airport requirements.

The data given in this report may be applied to any particular traffic arrangement if the specified flight path of the aircraft is known. As an example, a 65 hp Aeronca, following a take-off flight pattern as stated above, with pattern turns at 400 and 600-foot altitude, will produce a loudness level contour pattern as shown in Figure 26. These contours were obtained by locating the airplane turn points upon the straight take-off path shown in Figure 19, and replotting the actual airplane path to consider such turns. The appropriate sections of the sound level contours then were rotated to match the revised airplane path. An estimate was made at each turning point regarding connection of contour lines to obtain continuity.

The solid contour lines shown in Figure 26 represent the condition with no wind, and are obtained directly from Figure 19. The dotted contour lines represent the condition where the airplane is taking off into a 25 mph wind. This is approximately the maximum wind velocity with which an airplane of this type would be flown

The maximum loudness level at any fixed point on the ground, associated with take-off and climb of the 65 hp Aeronca, is indicated by the maximum level shown at the point as the solid curves are moved to the position of the dotted curves.

The loudness level contours for each aircraft tested may be applied to other different flight paths in a similar manner

To obtain loudness level contours for aircraft of models different from those for which contours are shown, some knowledge of the sound level produced by the specific airplane must be obtained. A knowledge of the loudness level produced by the aircraft at climbing power, and at one distance from the airplane, is sufficient to provide a reasonably accurate contour pattern. Such loudness level values for a distance of 500 feet are shown for a number of miscellaneous airplane models in Table III.

With the loudness level at a definite distance being known, comparison may be made to one of the tested aircraft for which loudness level contours are given, and which most closely resembles the aircraft being considered. The difference in loudness level for the two aircraft at the same distance provides a correction value which may be applied to the contour curves for the known tested aircraft to obtain the corresponding curves for the untested aircraft.

For example, it is shown in Table III that the loudness level for the Douglas DC-4 airplane is about seven phons greater than for the Douglas C-47 aircraft tested. This difference of plus seven phons may be applied to all loudness level contours for the Douglas C-47 airplane to obtain the contours for the Douglas DC-4 airplane, with proper correction being made for differences in flight path. This method is not precise, but will provide a reasonably accurate contour pattern.

The effect of terrain upon the loudness level contours may be very great, as discussed in a previous section of this report. Generally, no correction can be made for this factor except in an approximate qualitative manner However, the loudness level values determined for the aircraft under climbing or cruising conditions probably may be applied to particular cases of variable terrain with reasonable accuracy if the immediate location where the loudness level value is desired is reasonably open in nature, within sight of the airplane, has no close steep hills or other possible reflecting surfaces; and where proper correction to the airplane-to-microphone distance is made to consider local variations in ground elevation.

The effect of trees, houses, or other local obstructions in the vicinity of a particular location also may be large, but again may be considered only qualitatively. The same conditions hold for sound levels within buildings produced by aircraft or other outside sources In all such cases, the actual existent loudness levels may be higher or lower than that shown by the contour curves for the particular location, depending upon whether attenuation and shadowing effects of obstructions are greater or less than reflection and resonance effects. In general, a location thickly covered by high trees, or inside of a house with closed and tight-fitting windows, may be expected to have appreciably lower loudness levels than those shown by the contours for the particular relative location

The application of loudness level data for passenger cars, trucks, and railway trains may be made directly if the type of traffic and the distance from the road are known. The effect of terrain and other variables will be similar to that obtained with aircraft

For the interpretation and application of all data the intensity level in decibels, the loudness level in phons, the loudness in loudness units, or the relative loudness, may be used. These various units provide, respectively, a measure of the sound energy, the energy levels heard with equal loudness by the average ear, the perceived loudness relative to the approximate lower threshold of hearing, and the perceived loudness relative to the loudness of normal conversational voice at a three-foot distance.

CONCLUSIONS

1 The sound intensity associated with conventional aircraft is dependent principally upon the total power being delivered by the aircraft engine or engines. Propeller tip speed is known to influence substantially the level of sound produced, and it has been shown by other investigators that very low tips speeds, in combination with intensive exhaust muffling, will result in greatly decreased sound intensity The number of propeller blades, the propeller tip clearance, the airplane velocity, and other factors also are known to influence the sound level produced. It may be concluded from the present data that, in conventional aircraft with no exhaust muffling, and with moderate variation in propeller tip speed and other factors influencing sound production, no systematic effect of these miscellaneous variables can be readily observed, and the sound level associated with the aircraft is determined principally by the delivered engine power

2 The intensity level of aircraft noise, at a distance of 500 feet from the airplane during take-off, varies from about 78 decibels for small aircraft to 103 decibels

for the Douglas DC-4 airplane. These intensity values correspond, respectively, to about 1.4 and 14 6 times the loudness of the average voice in conversation at a distance of three feet

3. Airplane sound intensity level varies approximately inversely as a power of the distance from the airplane. For most aircraft this relationship is such as to cause a 6.0 to 8 5 decibel increase in intensity level for each doubling of distance.

4. The effect of the ground upon the rate of decrease of sound intensity with distance is not observable when the airplane altitude is greater than about 200 feet. With lower aircraft altitude, and with the airplane on the ground during the take-off run, the sound apparently is reenforced by ground reflections at short distances, and is rapidly attenuated by ground effects at greater distances.

5. The intensity level directly behind the airplane during the ground take-off run is relatively low in magnitude, and is attenuated rapidly with distance.

6. The effect of engine exhaust mufflers upon sound intensity of aircraft appears to be small.

7. Automotive highway traffic produces sound intensity levels which vary widely for individual vehicles. Maximum intensity level for semi-trailer trucks is about 89 decibels at a 50-foot distance, and 78 decibels at a 400-foot distance. Maximum values for lighter trucks are about four decibels less, and for passenger cars are about seven decibels less

8. Railway traffic produces sound intensity levels of about 96 decibels at 50-foot distance and 84 decibels at 400-foot distance No consistent variation was noted between passenger and freight trains, or between trains of different velocity.

9. Automotive and aircraft sound sources have all principal frequency components with significant energy at frequencies of 500 cycles per second or less

10 Normal variations in wind velocity, relative humidity, cloud conditions, and other atmospheric factors apparently have little effect upon progatation of sound at distances less than about one mile. At greater distances atmospheric variations probably have much larger effect

11. Effect of variation in terrain is important in connection with sound propagation In general, obstacles such as hills, buildings, or foliage directly between the observer and the sound source may have some attenuating or shadowing effect. Such obstacles to the side or rear of the observer may have a strengthening effect due to sound reflections. However, no generally applicable quantitative corrections can be made for such conditions.

TABLE I - INTENSITY LEVELS IN DECIBELS FOR 100 CYCLE PER SECOND FREQUENCY BANDS OF ALL SOUND SOURCES USED IN CONTROLLED TESTS

FRE-QUENCY BANDS	AIRCRAFT												AUTOMOBILE		PANEL TRUCK		FREIGHT TRAIN	
	DOUGLAS C-47		BEECH C-45		NORTH AMER SNJ-4		STINSON Model 150		CESSNA Model 140		AERONCA Champion		1939 Ford Sedan		1941 Ford		Steam Locomotive	
C P S	Meas-ured	Rela-tive	Meas-ured	Rela-tive	Meas-ured	Rela-tive	Meas-ured	Rela-tive	Meas-ured	Rela-tive	Meas-ured	Rela-tive	Meas-ured	Rela-tive	Meas-ured	Rela-tive	Meas-ured	Rela-tive
10-50	78 6	-0 6	89 4	32 4	56 3	-3 5	50 6	- 3	61 2	11 1	55 3	4 2	84 9	15 1	80 4	8 5	68 5	2 4
100	98 2	19 0	91 6	34 6	78 1	18 3	71 7	20 8	63 5	13 4	71 6	20 5	79 9	10 1	82 7	10 8	81 6	14 5
200	98 7	19 5	81 0	24 0	69 9	10 6	69 1	18 3	58 6	8 5	65 2	14 1	82 2	12 3	83 9	11 9	80 7	13 6
300	87 3	8 1	79 3	22 3	67 6	8 3	63 9	13 1	52 4	2 3	63 9	12 8	76 5	6 6	78 6	6 6	77 1	10 0
400	92 3	13 1	83 5	26 5	65 0	5 2	58 0	7 2	49 4	- 7	58 6	7 5	76 4	6 5	76 1	4 1	72 9	5 8
500	87 3	8 1	76 6	19 6	67 0	7 2	60 7	9 9	48 3	-1 8	54 9	3 8	77.7	7 9	80 4	8 5	72 0	4 9
600	86 0	6 8	75 1	18 1	62 5	2 7	54 7	3 9	50.2	1	55 0	3 8	75 4	5 6	76 3	4 3	70 5	3 4
700	81.8	2 6	75 1	18 1	59 1	-0 7	56 0	5 2	51 2	1 1	58 6	7 5	73 9	4 0	71 6	- 3	69.0	1 9
800	82 6	3 4	70 6	13 6	59 4	-0 4	55 0	4 2	49 7	- 5	56 9	5 8	74 5	4 7	72 5	6	68 0	8
900	87 2	8 0	64 9	7 9	59 3	-0 5	52 2	1 4	50 3	2	54 2	3 1	72 5	2 6	72 5	5	68 0	8
1000	79 2	0 0	57 0	0 0	59 8	0 0	50 9	0 0	50 1	0 0	51 1	0 0	69 8	0 0	72 0	0 0	67 1	0 0
1100	72 0	-7 2			53 2	-6 6	45 8	-5 1	44 0	-6 1	49 4	-1 7	59 9	-9 9	63 4	-8 6		
1200	67 7	-11 5			51 9	-7 9	45 5	-5 4	36 2	-14 0	50 8	- 3	60 5	-9 3	58 9	-13 0		
1300	73 9	-5 3			52 1	-7 7	44 5	-6 4	34 3	-15 8	44 5	-6 6	59 1	-10 7	56 5	-15 5		
1400	66.0	-13 2			54 1	-5 7	46 5	-4 4	33 3	-16 8	46 8	-4 3	54 8	-15 0	56 7	-15 3		
1500	62 0	-17 2			48 8	-11 0	48 4	-2 5	33 8	-16 3	50 0	-1 1	59 5	-10 4	62 0	-10 0		
1600	64 0	-15 2			50 1	-9 7	45 3	-5 5	33 8	-16 3	46 6	-4 5	57 3	-12 1	64 6	-7 4		
1700	68 2	-11 0			51 6	-8 2	46 6	-4 2	34 0	-16 1	46 2	-4 9	59 4	-10 5	60 8	-11 2		
1800					50 2	-9 6	44 5	-6 4			44 8	-6 3	55 5	-14 3	56.1	-15 9		
1900					51 8	-8 0	46 7	-4 2			47 8	-3 3	57 6	-12 2	56 7	-15 3		
2000					51 8	-8 0	45 2	-5 7			46 5	-4.7	56 0	-13 9	55 8	-16 2		
2100							46 0	-4 9			43 8	-7 3						
2200							43 5	-7 4			45 0	-6 1						
Overall Intensity Computed	102 3		94 5		79 5		74 5		67 2		73 5		89 2		89 1		85 9	
Overall Intensity Measured	102		96		77		75		67		72		85		87		85	
Effective Frequency C P S	180		120		155		160		140		155		175		190		180	

TABLE II - SPECIFICATIONS OF AIRCRAFT FOR WHICH SOUND MEASUREMENTS WERE MADE

AIRPLANE MODEL	POWER PLANT				PROPELLER		PROPELLER	PROPELLER	PROPELLER TIP SPEEDS			INDICATED AIR SPEED	
	NO	MANUF	H P	TYPE EXHAUST	BLADE TYPE	NO	RATIO	DIAMETER Inches	TAKE-OFF Ft Per Sec	CLIMB Ft Per Sec	CRUISE Ft Per Sec	CLIMB M P H	CRUISE M P H
Aeronca Champion 7AC	1	Conti-nental	65	No Muffler	Fixed Pitch	2	D D	72	723	723	675	65	90
Luscombe Silvaire 8A	1	Conti-nental	65	No Muffler	Fixed Pitch	2	D D	72	739	739	675	65	105
Piper Cub J3C-65	1	Conti-nental	65	Muffler	Fixed Pitch	2	D D	72	739	739	675	65	75
Taylorcraft BC-12D	1	Conti-nental	65	No Muffler	Fixed Pitch	2	D D	72	739	739	675	65	95
Cessna 140	1	Conti-nental	85	No Muffler	Fixed Pitch	2	D D	74	800	792	792	70	105
Bellanca Cruisair Senior	1	Franklin	150	Muffler	Fixed Pitch	2	D D	74	663	792	792	70	150
Stinson Voyager 150	1	Franklin	150	Muffler	Fixed Pitch	2	D D	74	792	792	743	70	120
Beech Bonanza 35	1	Conti-nental	165	Muffler	Adjustable Pitch	2	D D	90	925	883	804	100	175
Fairchild PT-19	1	Ranger	175	No Muffler	Fixed Pitch	2	D D	86	890	752	678	80	100
Navion NA-145	1	Conti-nental	185	Muffler	Adjustable Pitch	2	D D	86	735	828	792	100	150
Stinson Detroiter	1	Lycoming	260	No Muffler	Adjustable Pitch	2	D D	99 5	1000	777	789	70	90
Vultee BT-13	1	Pratt & Whitney	450	No Muffler	Controllable Pitch	2	D D	108	1084	1010	962	100	135
North American SNJ-4	1	Pratt & Whitney	600	No Muffler	Constant Speed	2	D D	108	1084	1084	872	125	155
Cessna T-50	2	Jacobs	225	No Muffler	Constant Speed	2	D D	93	913	812	752	110	150
Beech C-45	2	Pratt & Whitney	450	No Muffler	Constant Speed	2	D D	99	1000	1000	821	125	165
Douglas DC-3 & C-47	2	Pratt & Whitney	1200	No Muffler	Hydromatic	3	5625 1	138	882	715	681	120	150
Douglas DC-3	2	Wright	1425	No Muffler	Hydromatic	3	5625 1	130	862	705	661	120	150
North American B-25	2	Wright	1900	Jet Stacks	Hydromatic	3	4375 1	150	719	575	575	185	225
Douglas DC-4	4	Pratt & Whitney	1450	No Muffler	Hydromatic	3	50 1	157	930	752	688	135	190

TABLE III - COMPARATIVE SOUND LEVEL MEASUREMENTS OF AIRCRAFT RECORDED DURING TAKE-OFF AT A DISTANCE OF 500 FEET

AIRPLANE MODEL	INTENSITY LEVEL DB	APPROXIMATE LOUDNESS LEVEL PHONS	LOUDNESS L.U. X 10^{-3}	LOUDNESS RELATIVE TO 70 PHON LOUDNESS LEVEL
Douglas DC-4	103	103	116	14.6
Douglas DC-3 (Aver.)	100	100	88	11.1
Douglas DC-3 (P & W)	98	98	74	9.3
Douglas DC-3 (Wright)	102	102	106	13.2
* Douglas C-47	96	96	62	7.7
North American B-25	98	98	74	9.3
North American AT-6	95	95	57	7.2
* North American SNJ-4	101	101	97	12.2
Beech C-45	94	94	53	6.7
* Beech C-45	94	94	53	6.7
Cessna T-50 (2ENG)	94	94	53	6.7
Vultee BT-13	91	91	42	5.3
Fairchild PT-19	89	88	32	4.0
Navion NA-145	87	86	27	3.4
Bellanca	87	86	27	3.4
Beech Bonanza	85	84	23	2.9
Stinson Detroiter	85	84	23	2.9
Stinson 150	85	84	23	2.9
* Stinson 150	86	85	25	3.1
Cessna 140	81	79	16	2.0
* Cessna 140	83	82	20	2.5
Luscombe 8A	81	79	16	2.0
Aeronca	81	79	16	2.0
* Aeronca Champion	81	79	16	2.0
Taylorcraft	81	79	16	2.0
Piper Cub	78	74	11	1.4

* Controlled Tests

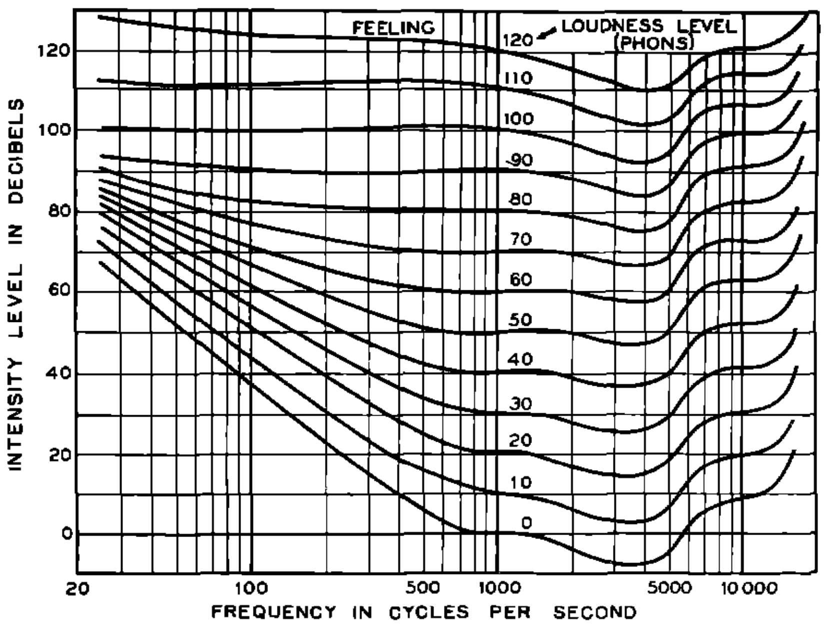


FIGURE 1 VARIATION OF LOUDNESS LEVEL WITH INTENSITY LEVEL AND FREQUENCY (FROM A S A STANDARD NUMBER Z24 2-1942)

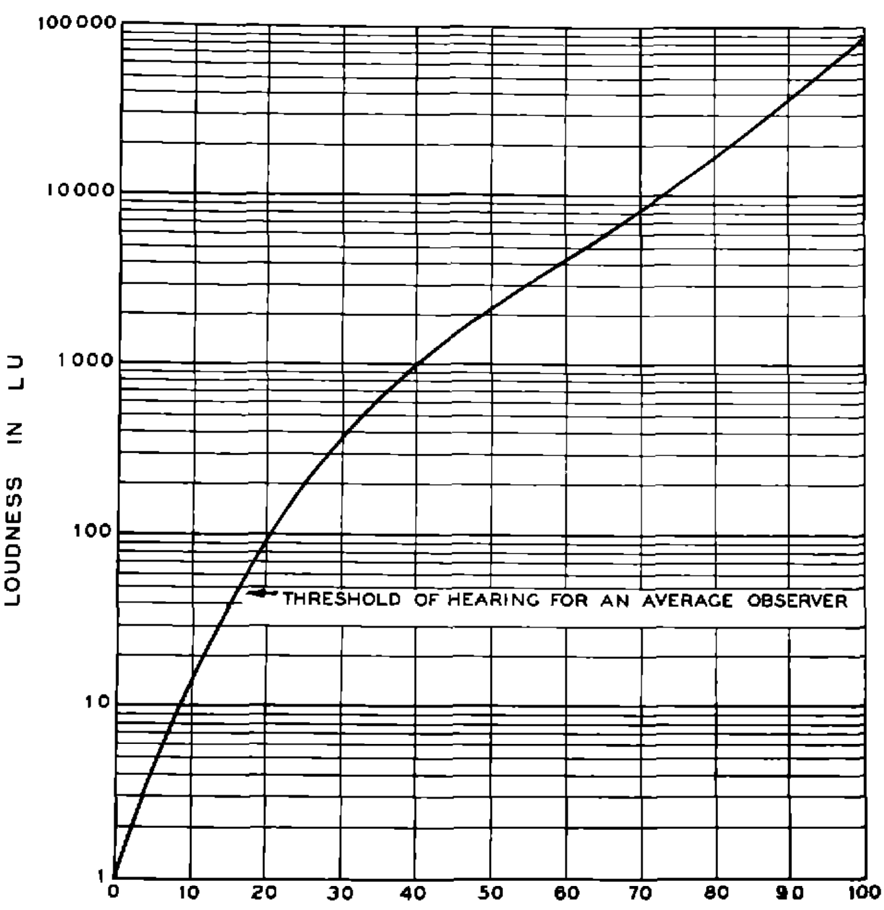


FIGURE 2 VARIATION OF LOUDNESS WITH LOUDNESS LEVEL (FROM A S A STANDARD NUMBER Z24 2 - 1942)

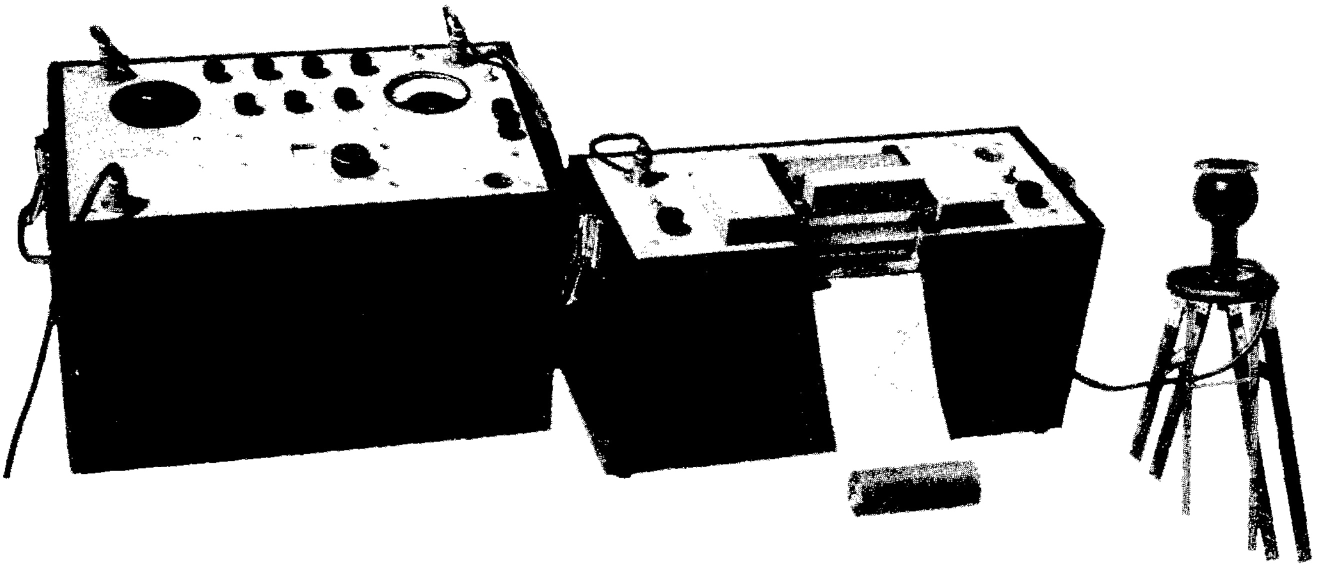


FIGURE 3. ELECTRICAL RESEARCH PRODUCTS, INC. SOUND MEASURING EQUIPMENT

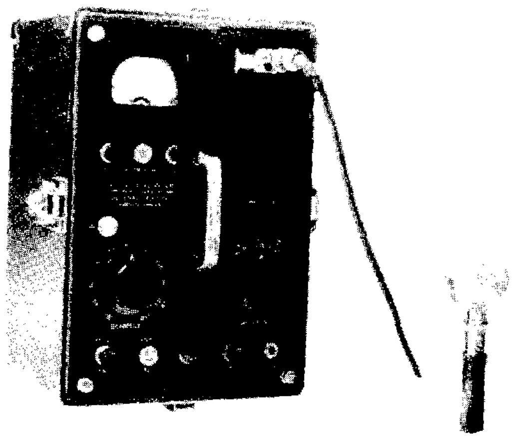


FIGURE 4. GENERAL RADIO CO. SOUND LEVEL METER

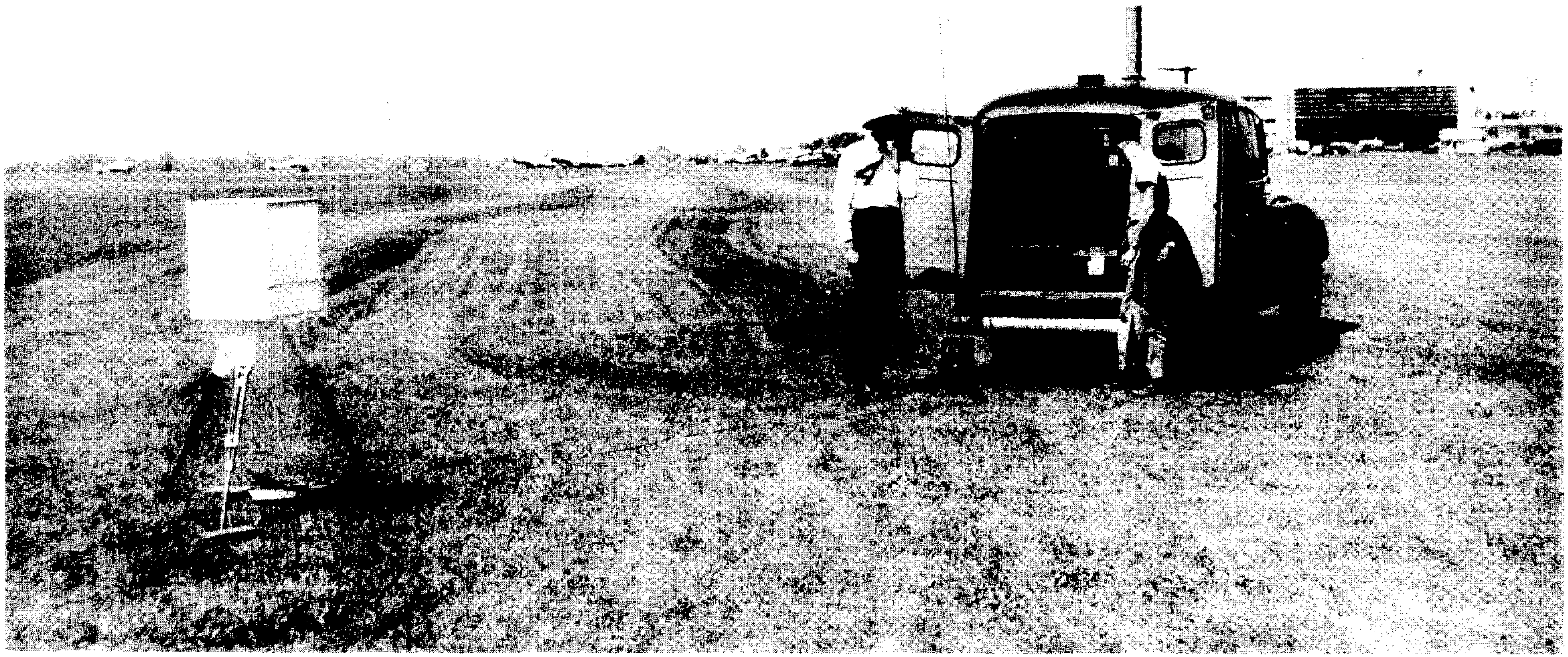


FIGURE 5. FIELD SET-UP OF SOUND MEASURING EQUIPMENT

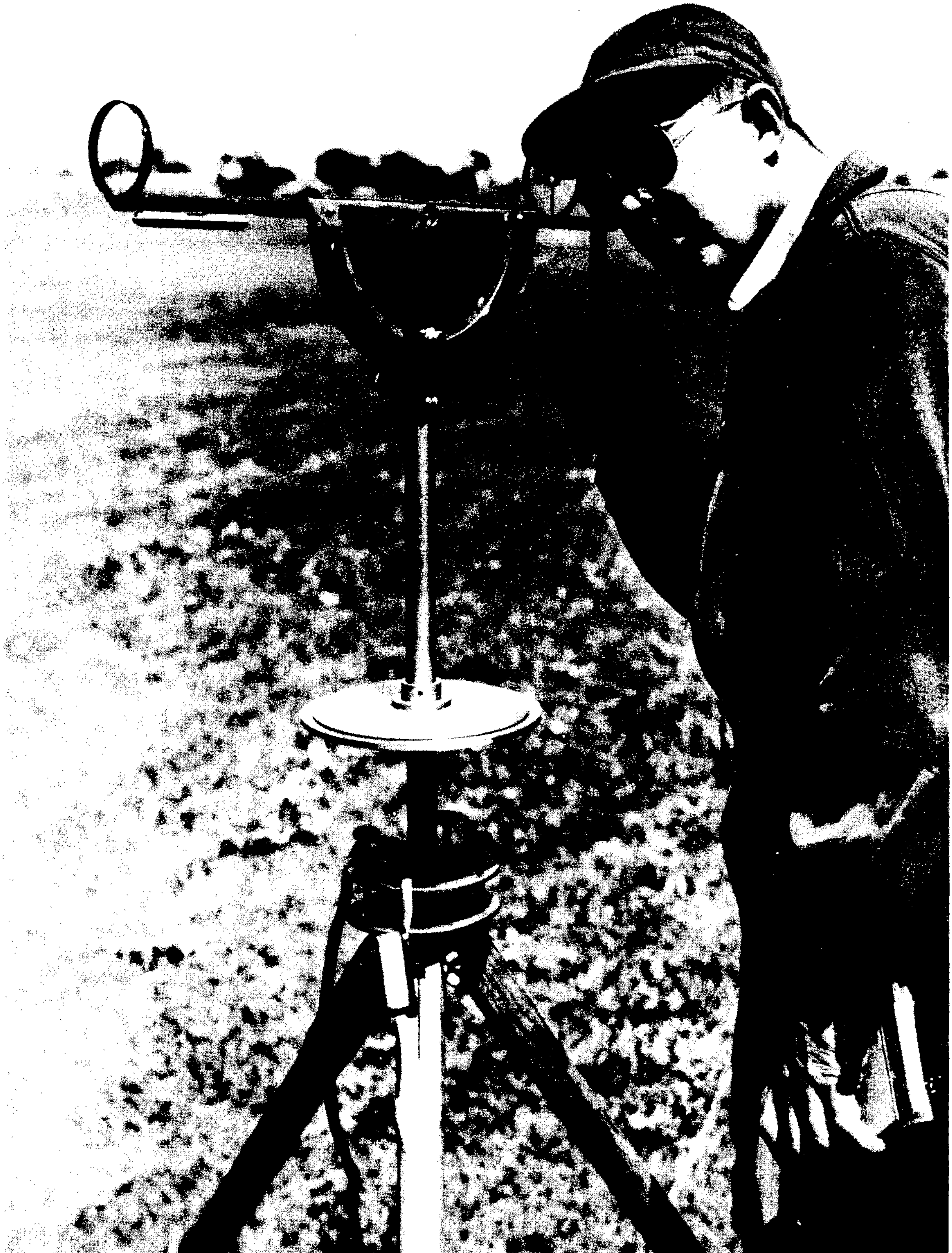


FIGURE 6. SIGHTING INSTRUMENT FOR MEASUREMENT OF AIRCRAFT POSITION AND ALTITUDE

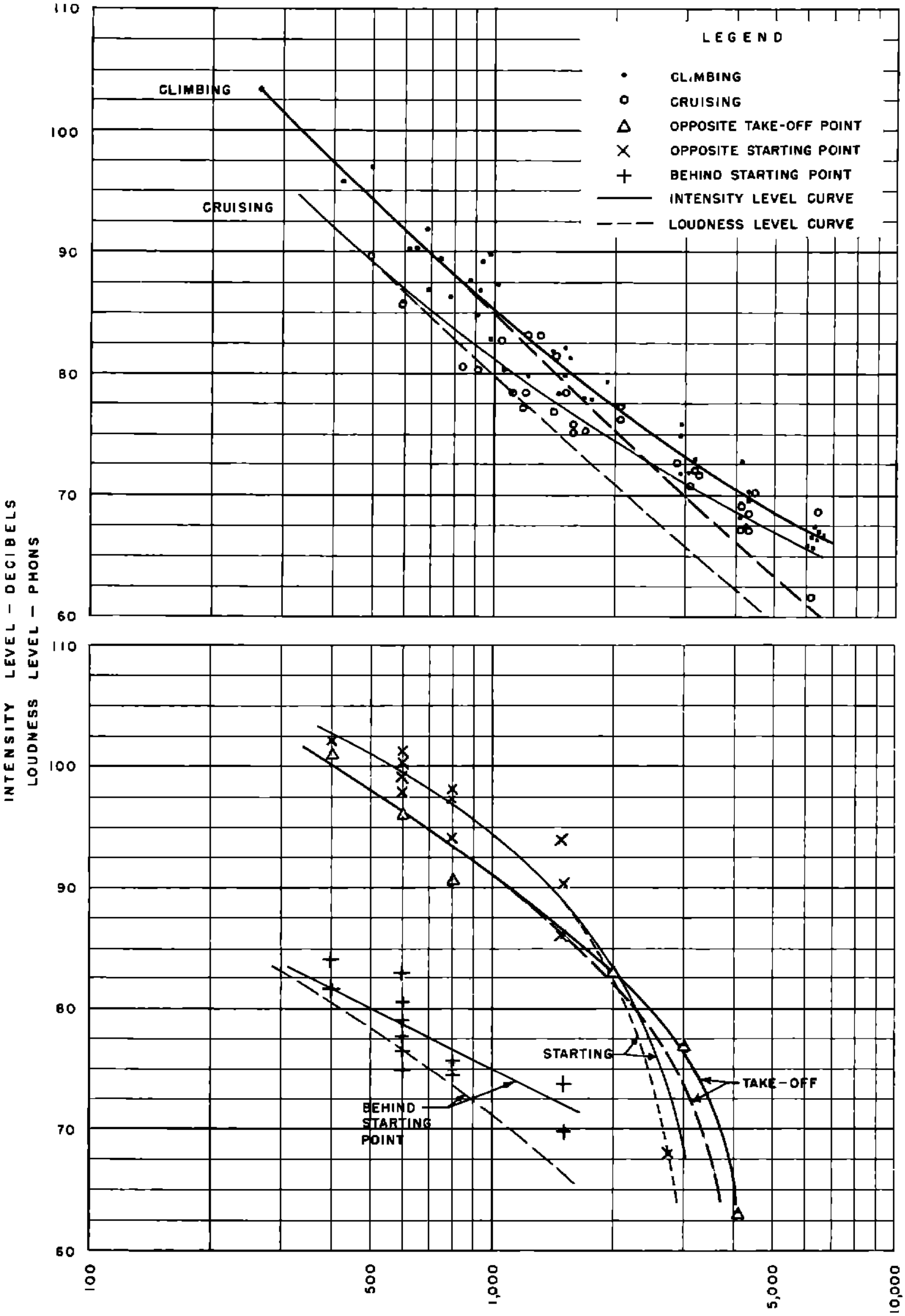


FIGURE 7 VARIATION OF INTENSITY LEVEL AND LOUDNESS LEVEL WITH DISTANCE FOR TAKE-OFF, CLIMB, AND CRUISE CONDITIONS OF DOUGLAS C-47 AIRPLANE

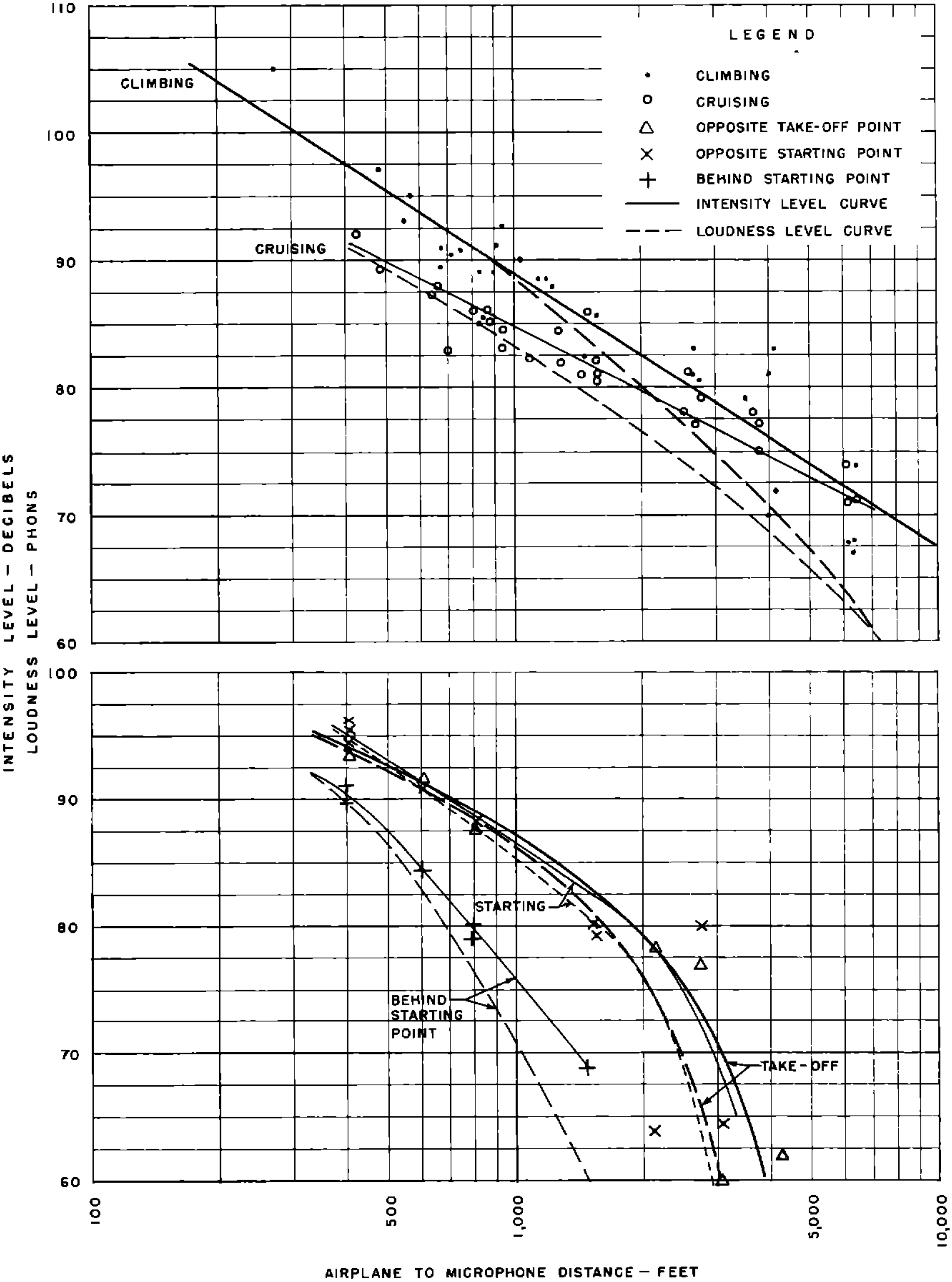


FIGURE 8 VARIATION OF INTENSITY LEVEL AND LOUDNESS LEVEL WITH DISTANCE FOR TAKE-OFF, CLIMB, AND CRUISE CONDITIONS OF BEECH C-45 AIRPLANE

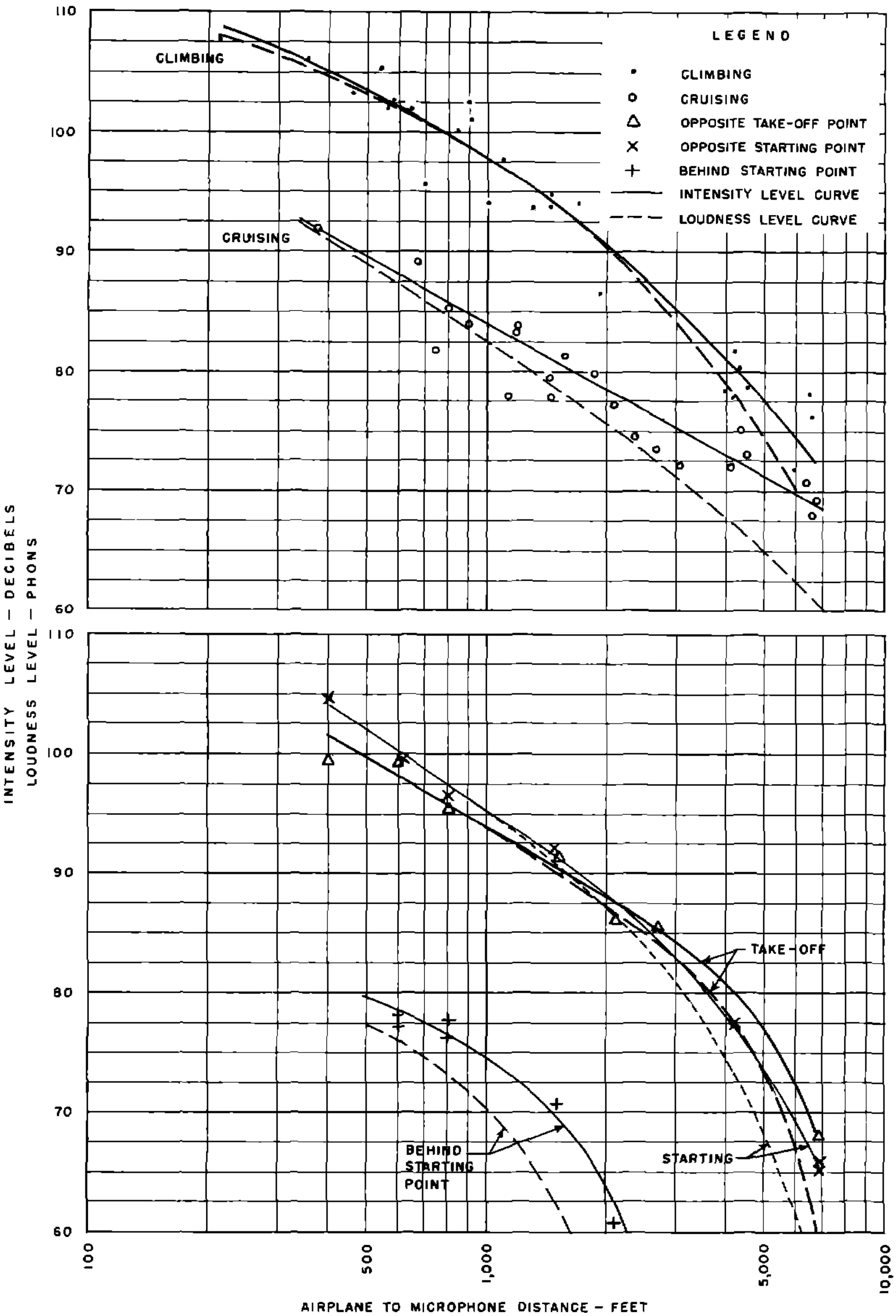


FIGURE 9 VARIATION OF INTENSITY LEVEL AND LOUDNESS LEVEL WITH DISTANCE FOR TAKE-OFF, CLIMB, AND CRUISE CONDITIONS OF NORTH AMERICAN SNJ-4 AIRPLANE

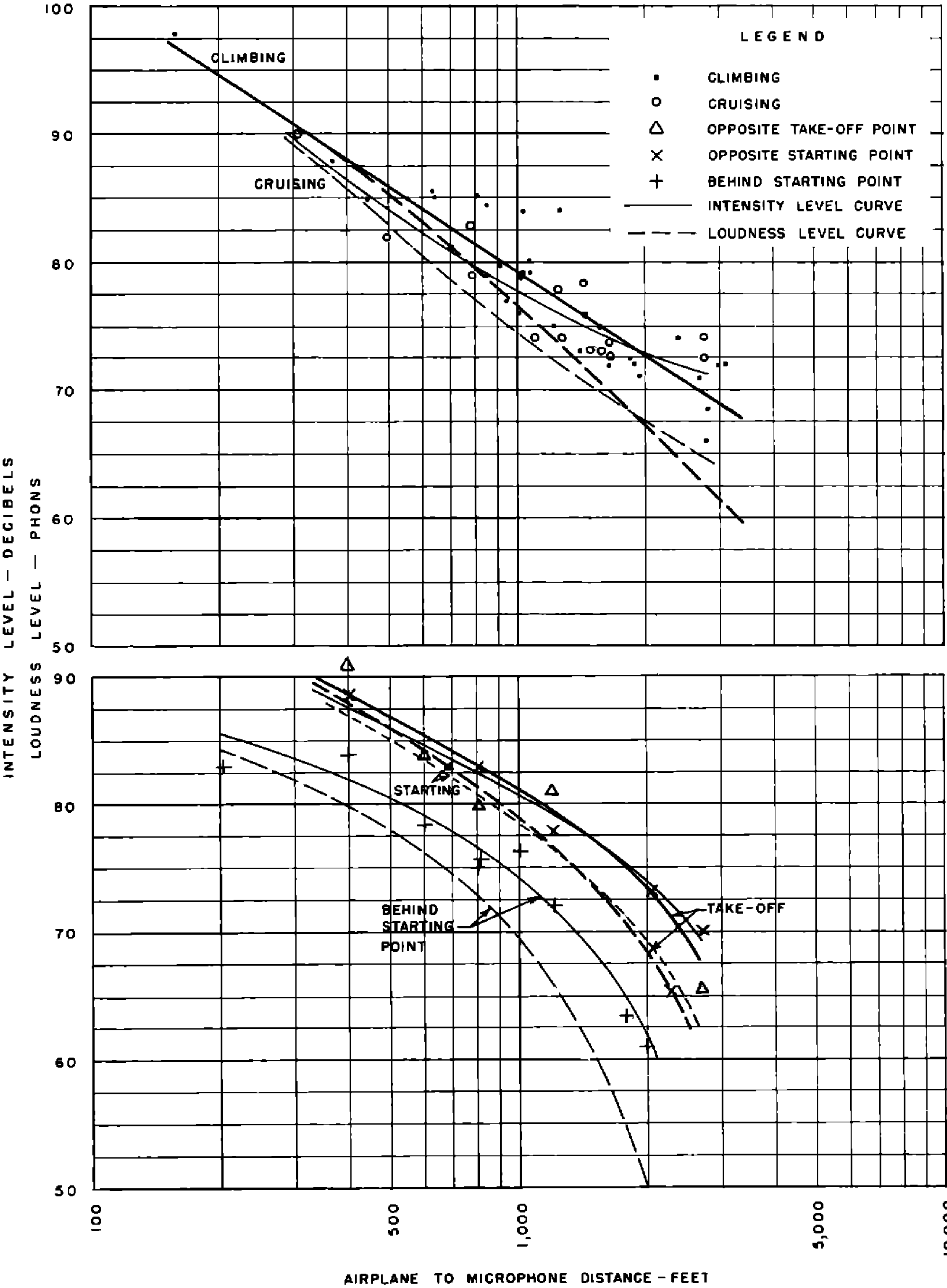


FIGURE 10 VARIATION OF INTENSITY LEVEL AND LOUDNESS LEVEL WITH DISTANCE FOR TAKE-OFF, CLIMB, AND CRUISE CONDITIONS OF STINSON 150 AIRPLANE

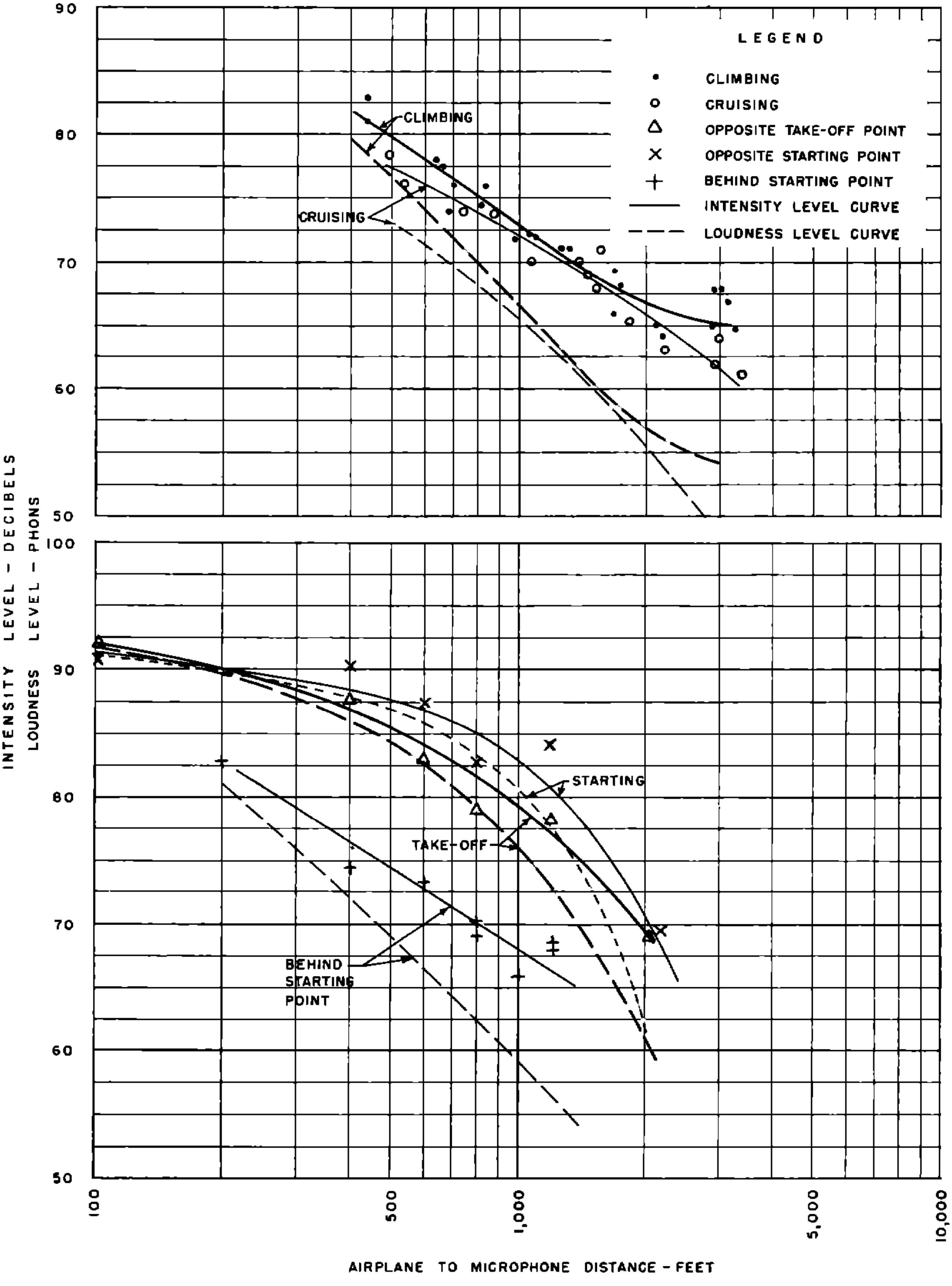


FIGURE 11 VARIATION OF INTENSITY LEVEL AND LOUDNESS LEVEL WITH DISTANCE FOR TAKE-OFF, CLIMB, AND CRUISE CONDITIONS OF CESSNA 140 AIRPLANE

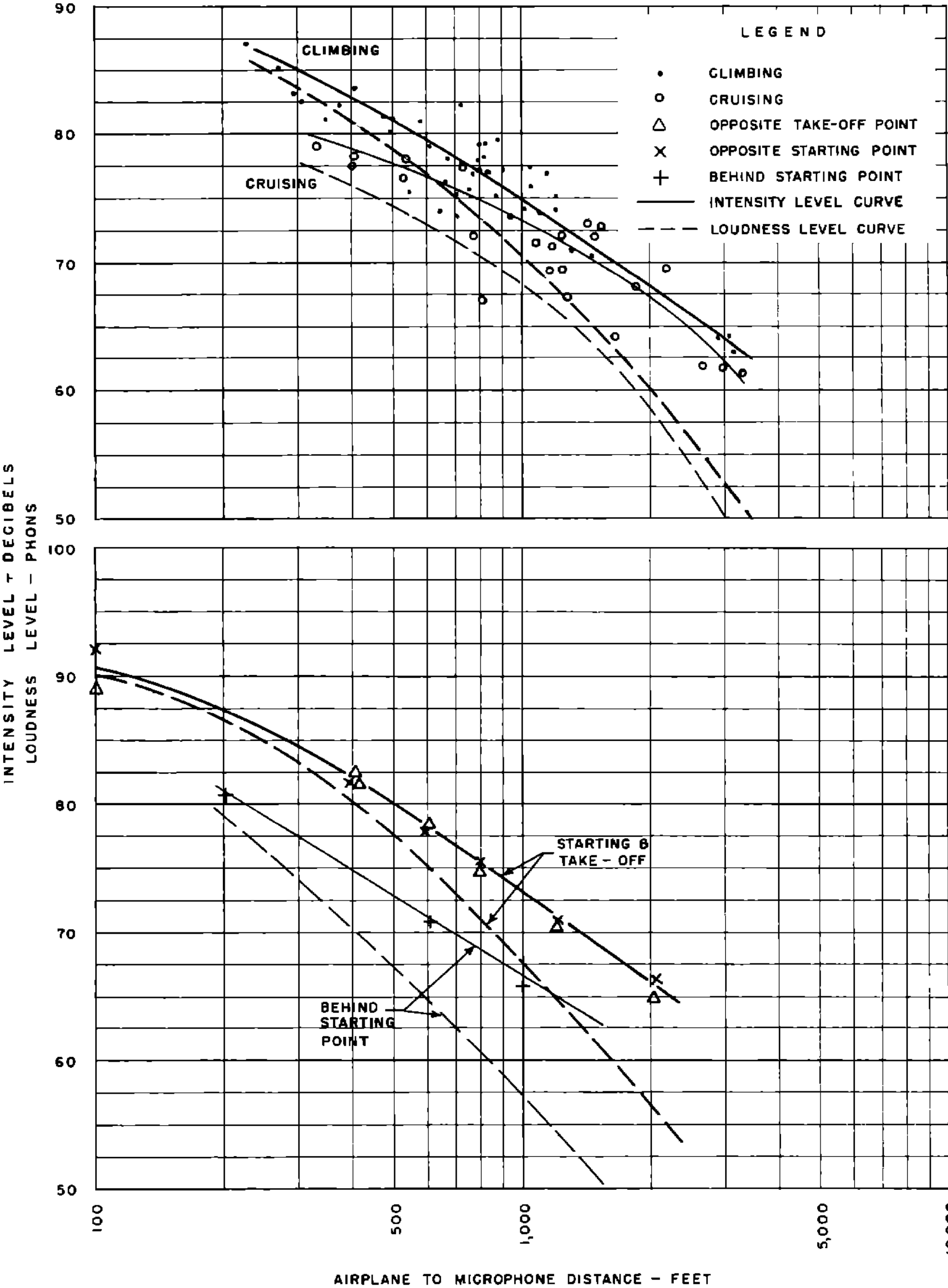


FIGURE 12 VARIATION OF INTENSITY LEVEL AND LOUDNESS LEVEL WITH DISTANCE FOR TAKE-OFF, CLIMB, AND CRUISE CONDITIONS OF AERONCA CHAMPION AIRPLANE

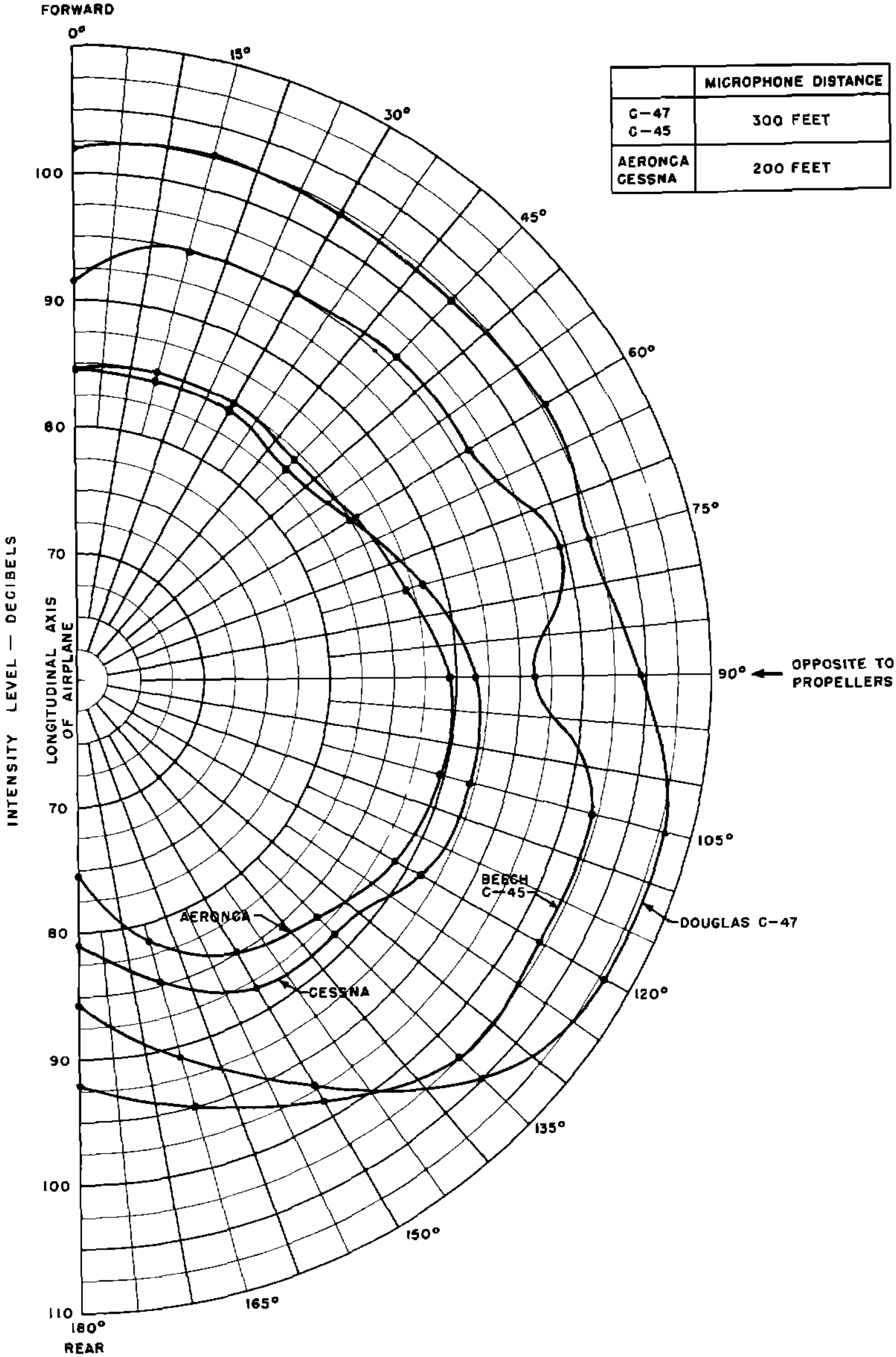


FIGURE 13 VARIATION OF INTENSITY LEVEL WITH ANGULAR POSITION AROUND RIGHT SIDE OF FOUR AIRCRAFT

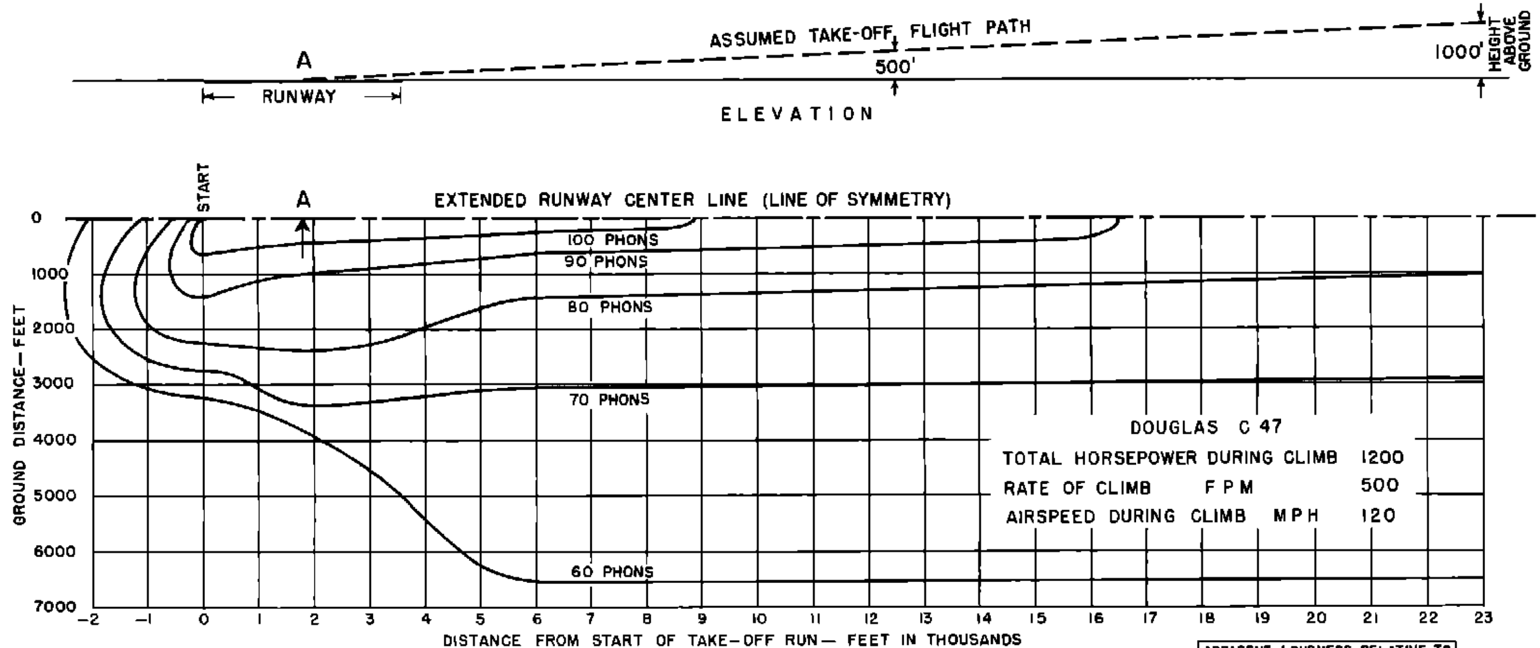


FIGURE 14 POSITIONS OF EQUAL PEAK LOUDNESS LEVEL AROUND STRAIGHT TAKE-OFF AND CLIMB PATH OF DOUGLAS C-47 AIRPLANE

APPARENT LOUDNESS RELATIVE TO 70 PHON LOUDNESS LEVEL	
PHONS	RELATIVE LOUDNESS
100	11
90	4.8
80	2.2
70	1.0
60	0.55

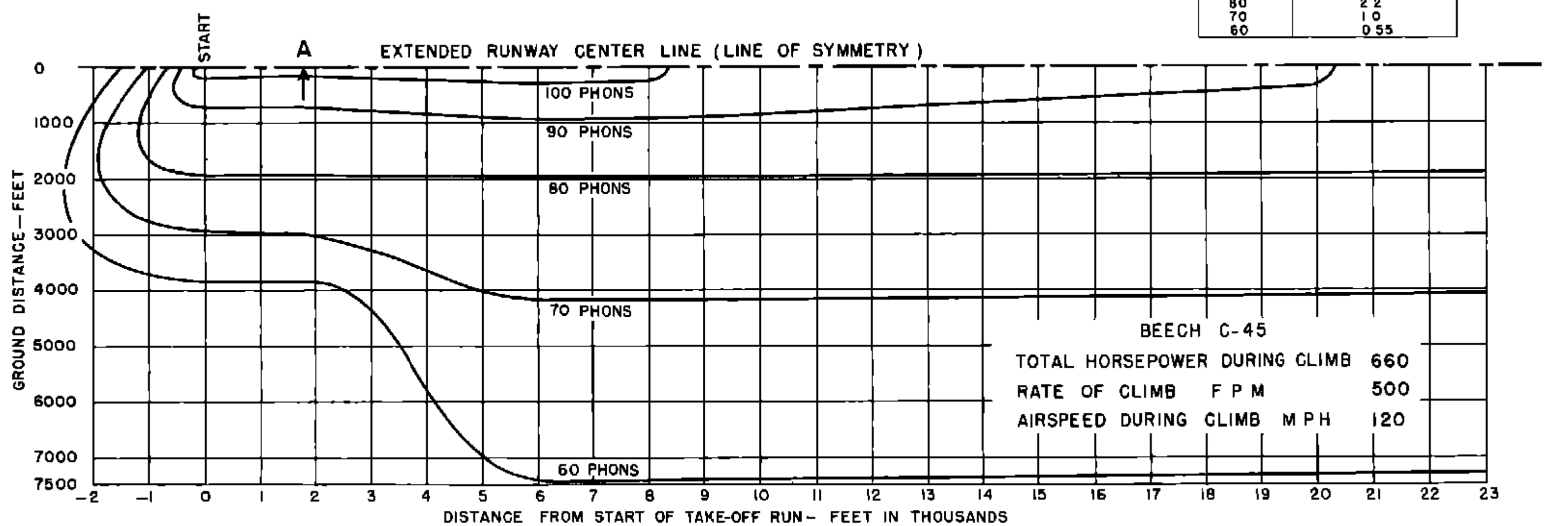
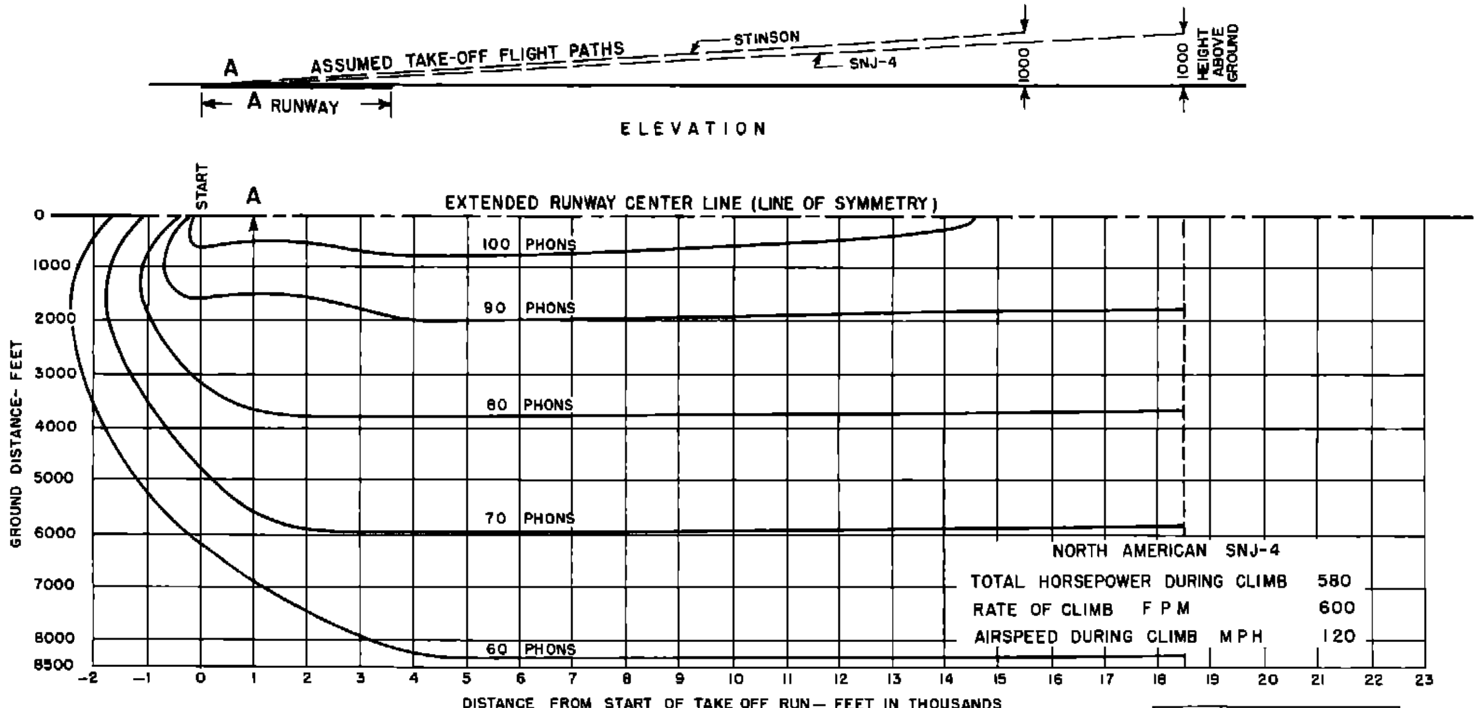


FIGURE 15 POSITIONS OF EQUAL PEAK LOUDNESS LEVEL AROUND STRAIGHT TAKE-OFF AND CLIMB PATH OF BEECH C-45 AIRPLANE



APPARENT LOUDNESS RELATIVE TO 70 PHON LOUDNESS LEVEL	
PHONS	RELATIVE LOUDNESS
100	11
90	4 8
80	2 2
70	1 0
60	0 85

FIGURE 16 POSITIONS OF EQUAL PEAK LOUDNESS LEVEL AROUND STRAIGHT TAKE OFF AND CLIMB PATH OF NORTH AMERICAN SNJ-4 AIRPLANE

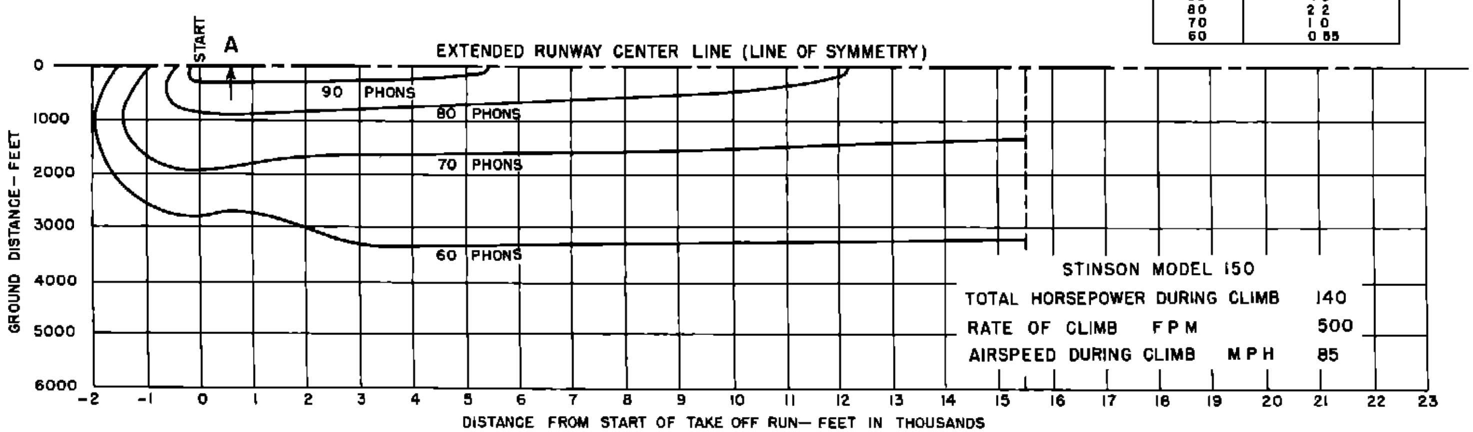


FIGURE 17 POSITIONS OF EQUAL PEAK LOUDNESS LEVEL AROUND STRAIGHT TAKE-OFF AND CLIMB PATH OF STINSON 150 AIRPLANE

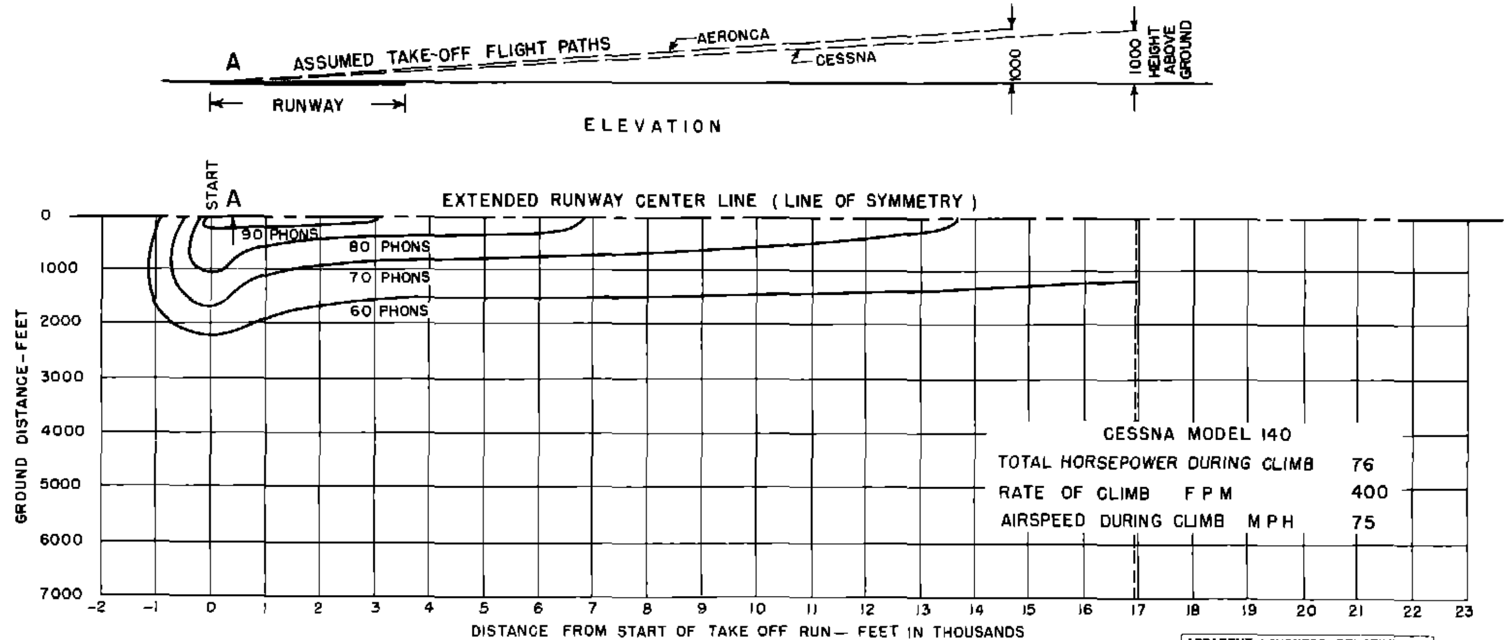


FIGURE 18 POSITIONS OF EQUAL PEAK LOUDNESS LEVEL AROUND STRAIGHT TAKE OFF AND CLIMB PATH OF CESSNA 140 AIRPLANE

APPARENT LOUDNESS RELATIVE TO 70 PHON LOUDNESS LEVEL	
PHONS	RELATIVE LOUDNESS
100	11
90	4.8
80	2.2
70	1.0
60	0.56

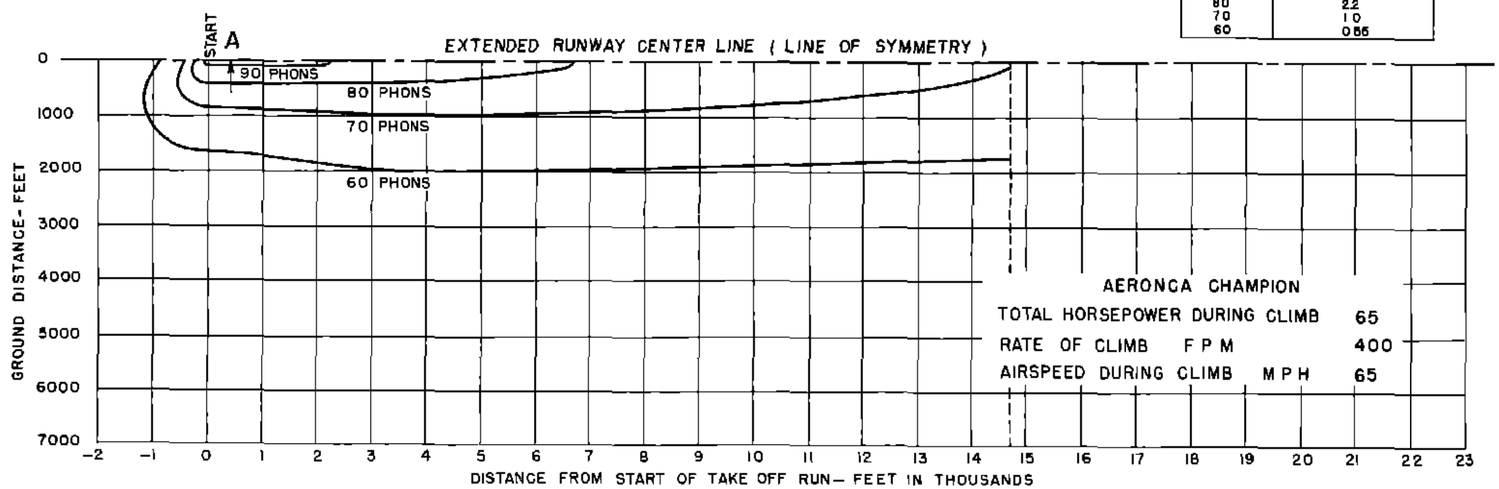
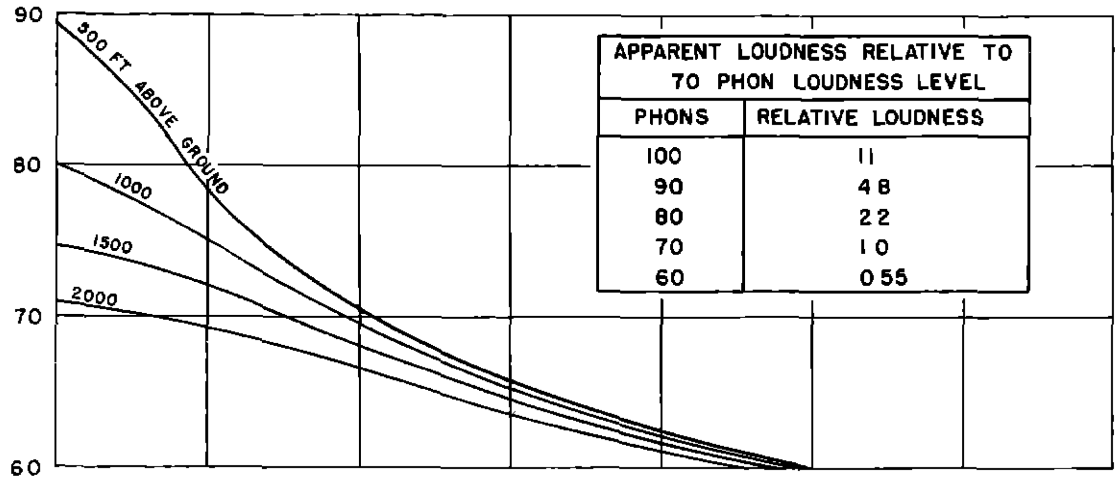


FIGURE 19 POSITIONS OF EQUAL PEAK LOUDNESS LEVEL AROUND STRAIGHT TAKE-OFF AND CLIMB PATH OF AERONCA CHAMPION AIRPLANE



PHONS	RELATIVE LOUDNESS
100	11
90	4 8
80	2 2
70	1 0
60	0 55

FIGURE 20 DOUGLAS C-47

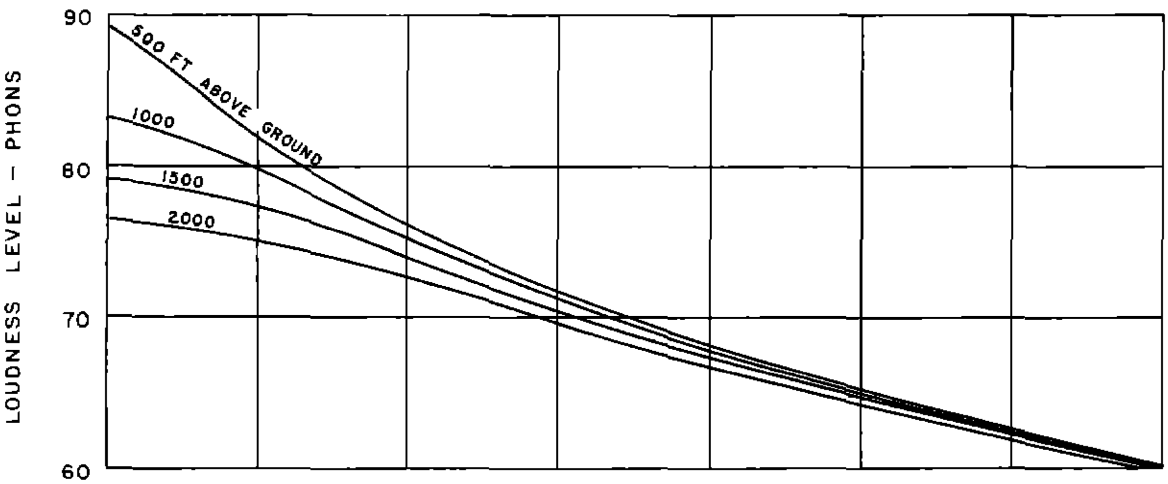


FIGURE 21 BEECH C-45

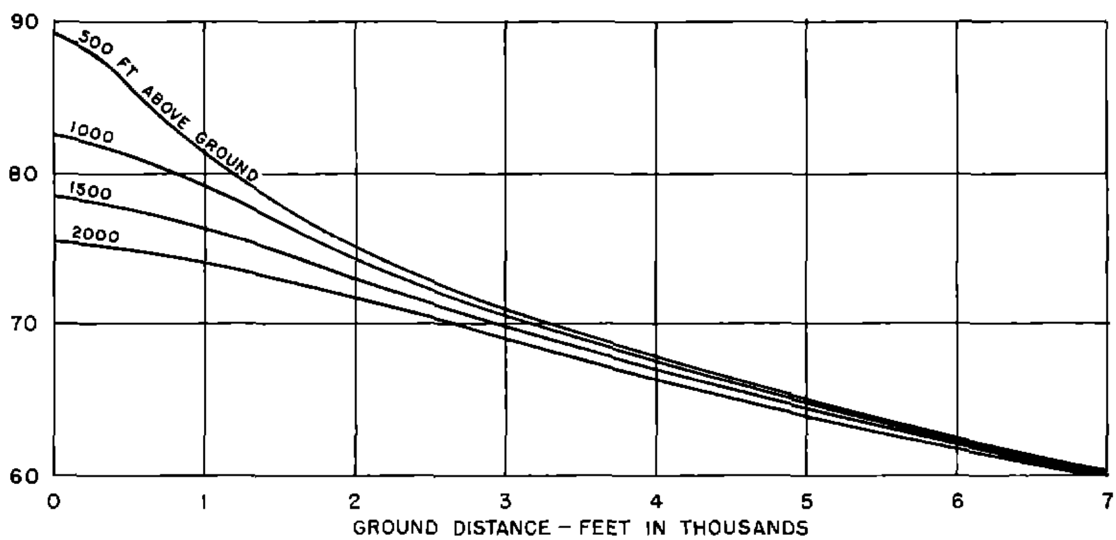


FIGURE 22 NORTH AMERICAN SNJ-4

VARIATION OF LOUDNESS LEVEL WITH AIRPLANE ALTITUDE AND GROUND DISTANCE FOR AIRPLANE IN CRUISING CONDITION

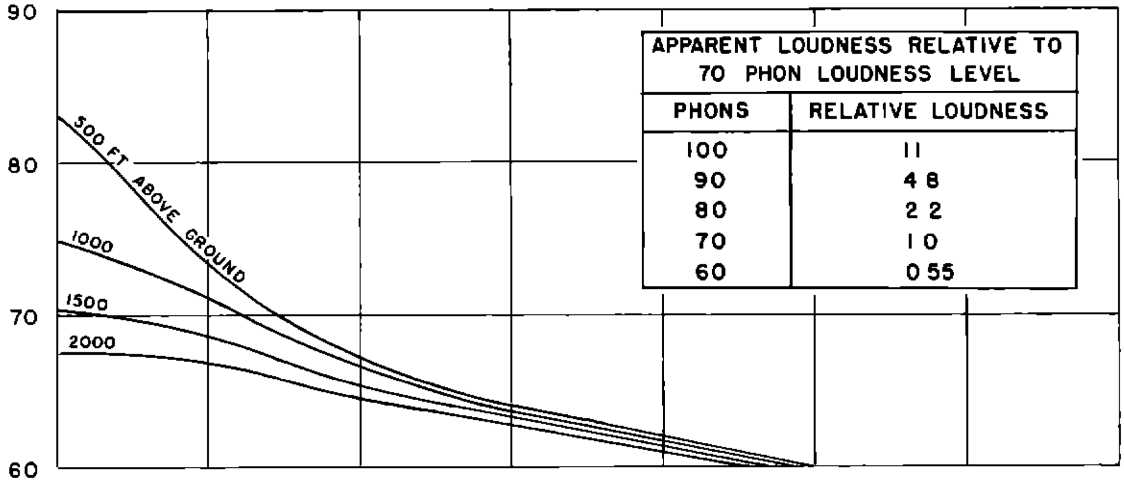


FIGURE 23 STINSON 150

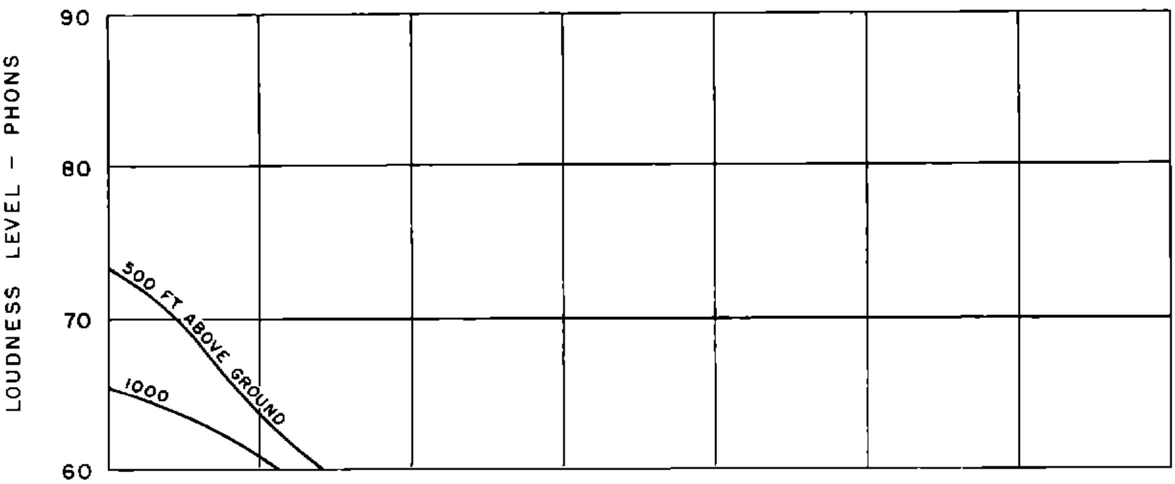


FIGURE 24 CESSNA 140

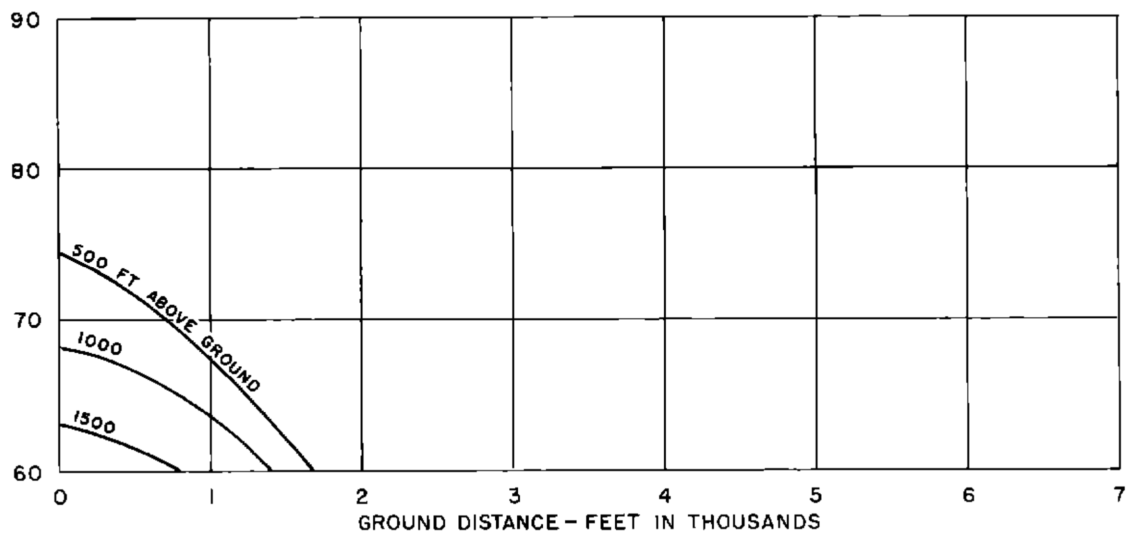


FIGURE 25 AERONCA CHAMPION

VARIATION OF LOUDNESS LEVEL WITH AIRPLANE ALTITUDE AND GROUND DISTANCE FOR AIRPLANE IN CRUISING CONDITION

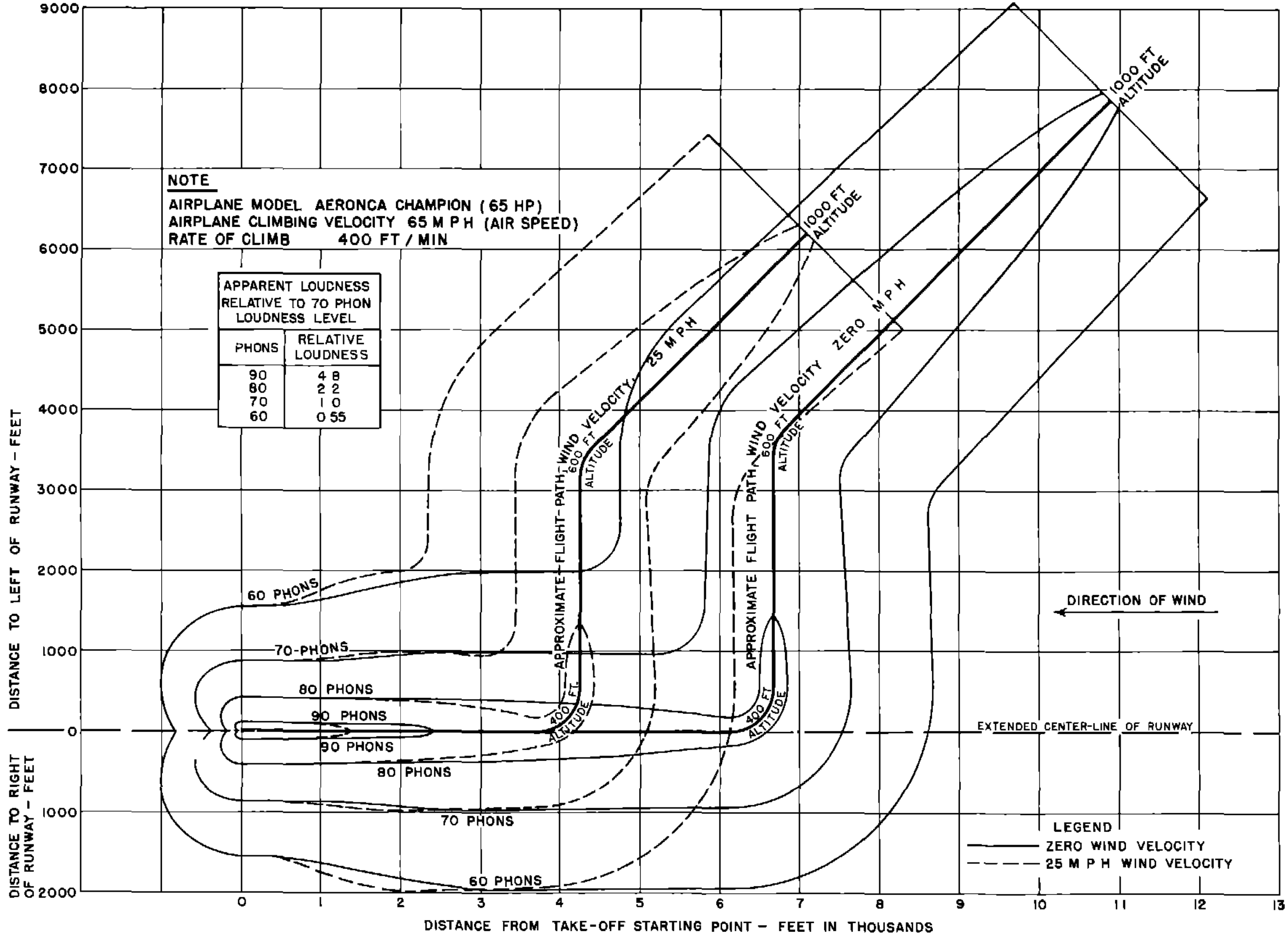


FIGURE 26 POSITIONS OF EQUAL PEAK LOUDNESS LEVEL AROUND TAKE-OFF AND NORMAL PATTERN CLIMB PATH OF AERONCA CHAMPION AIRPLANE

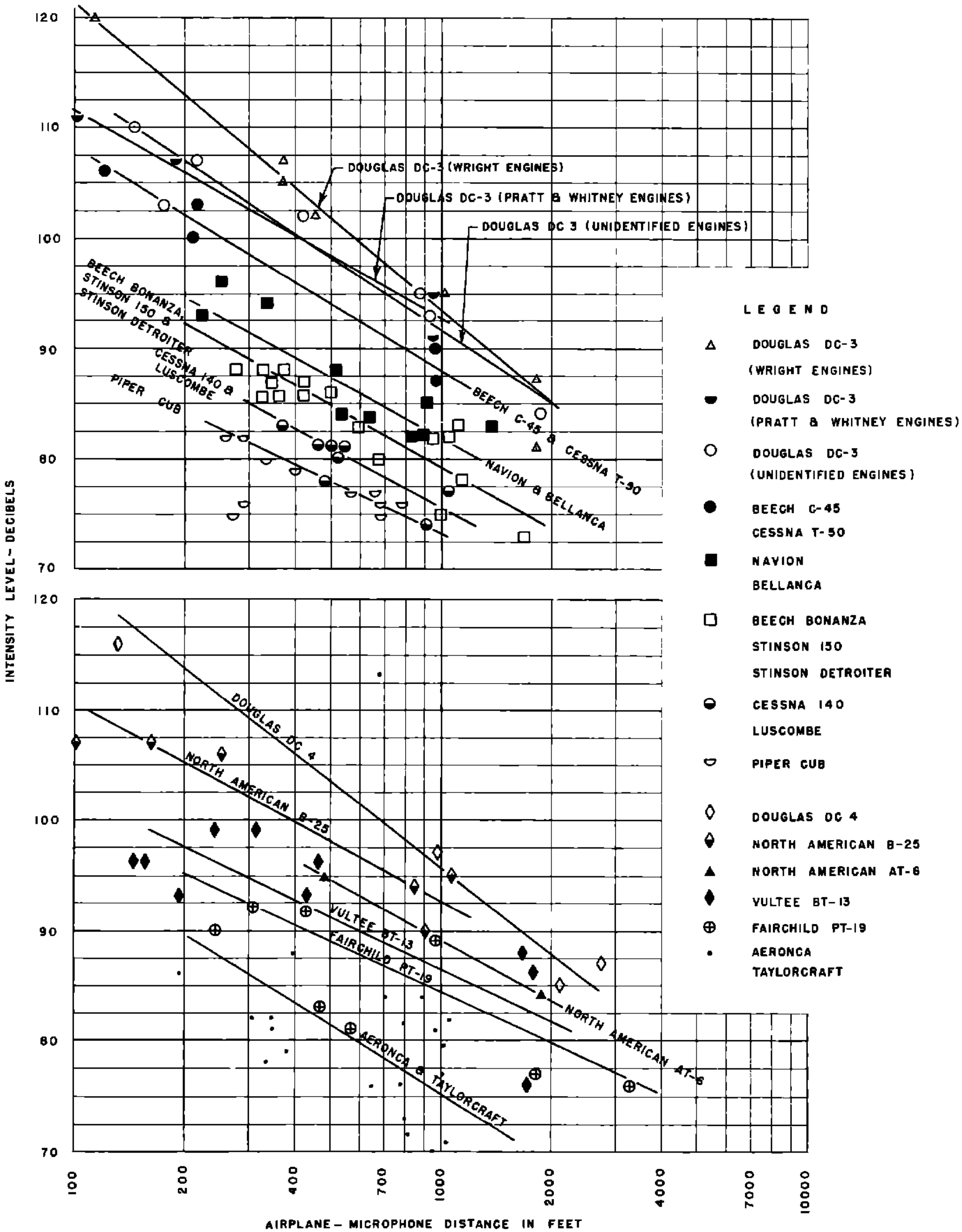


FIGURE 27 VARIATION OF INTENSITY LEVEL WITH DISTANCE FOR TAKE OFF CONDITION OF MISCELLANEOUS AIRCRAFT IN AIRPORT TRAFFIC

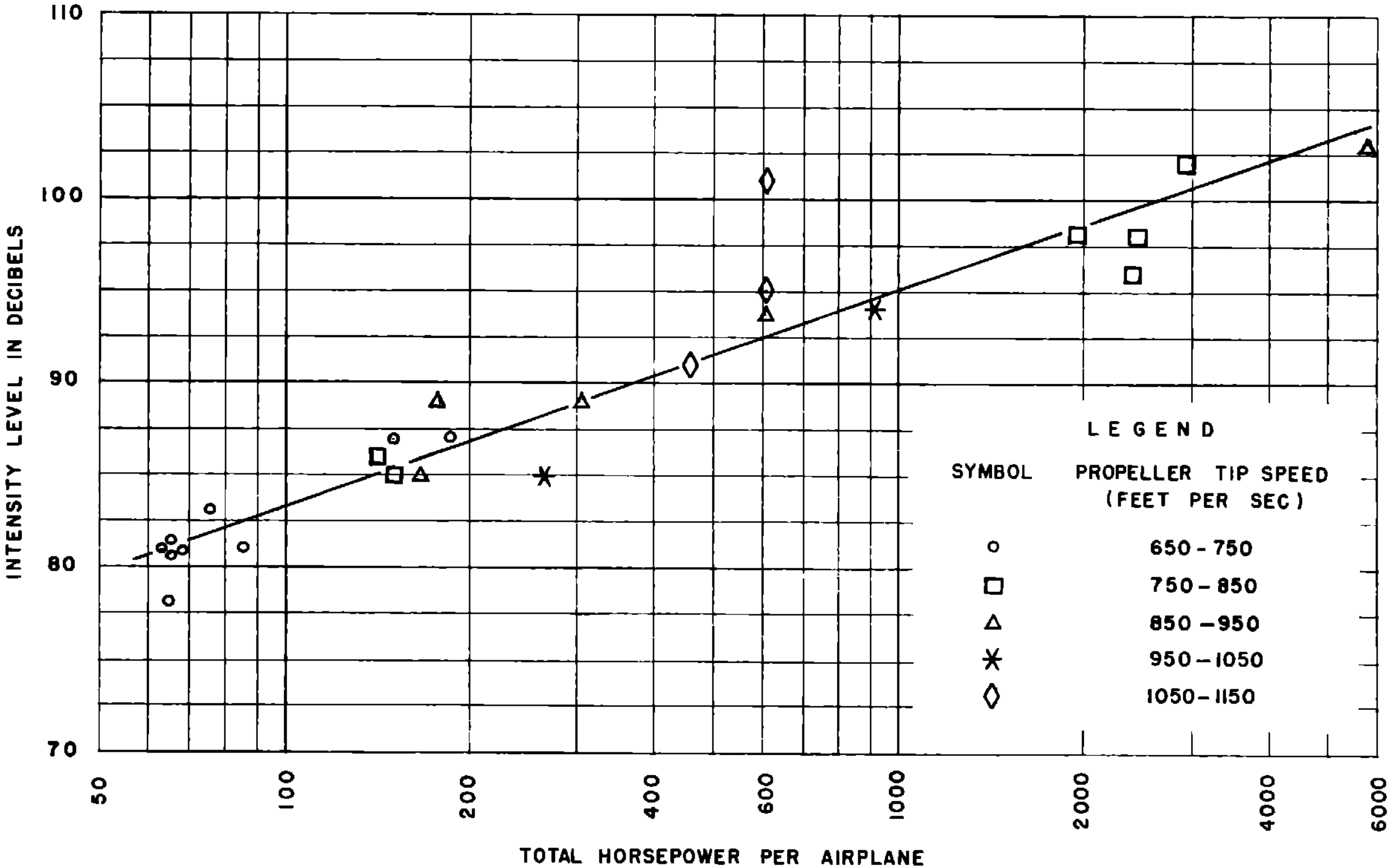


FIGURE 28 VARIATION OF INTENSITY LEVEL WITH TOTAL ENGINE POWER AND PROPELLER TIP SPEED FOR TAKE-OFF OF ALL MEASURED AIRCRAFT AT 500-FOOT DISTANCE

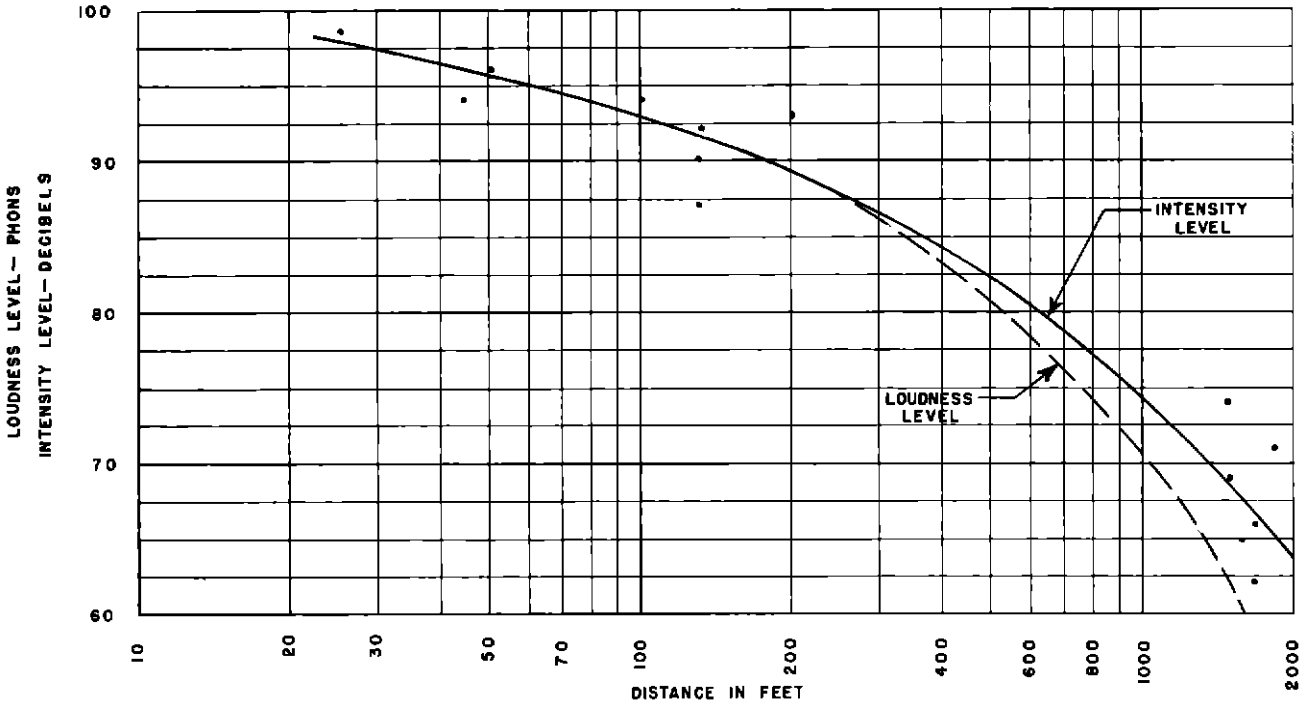


FIGURE 29 VARIATION OF INTENSITY LEVEL AND LOUDNESS LEVEL WITH DISTANCE FOR STEAM DRIVEN RAILROAD TRAIN TRAFFIC

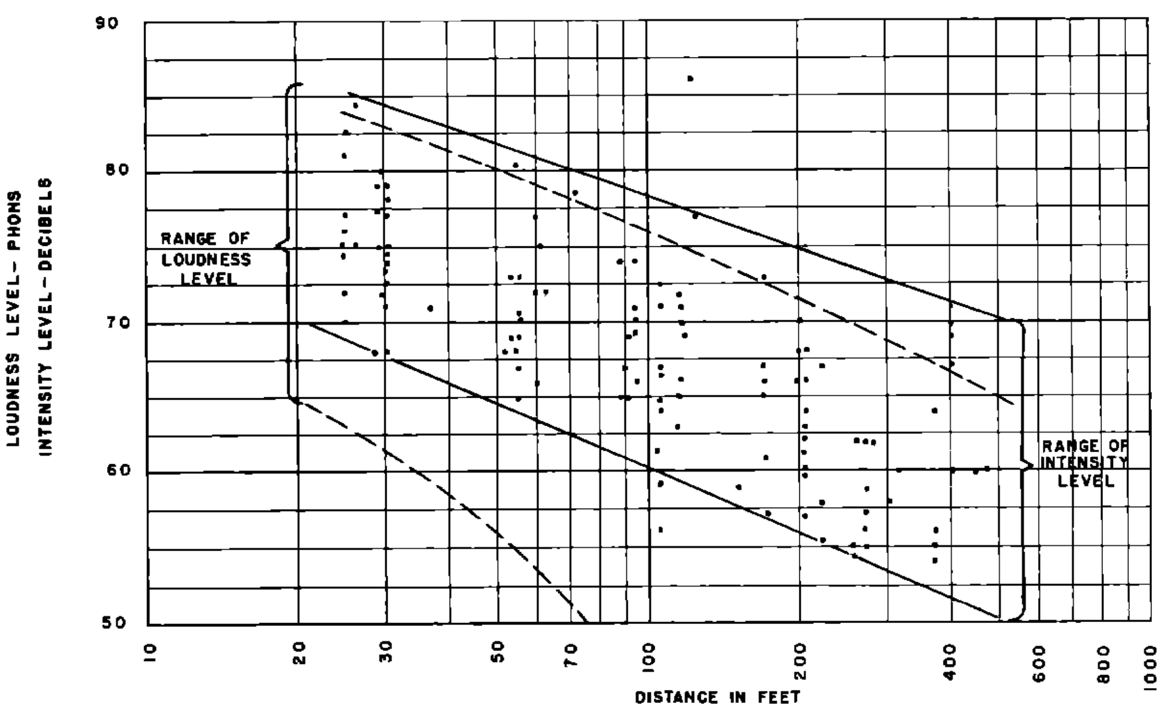


FIGURE 30 VARIATION OF INTENSITY LEVEL AND LOUDNESS LEVEL WITH DISTANCE FOR PASSENGER AUTOMOBILE HIGHWAY TRAFFIC

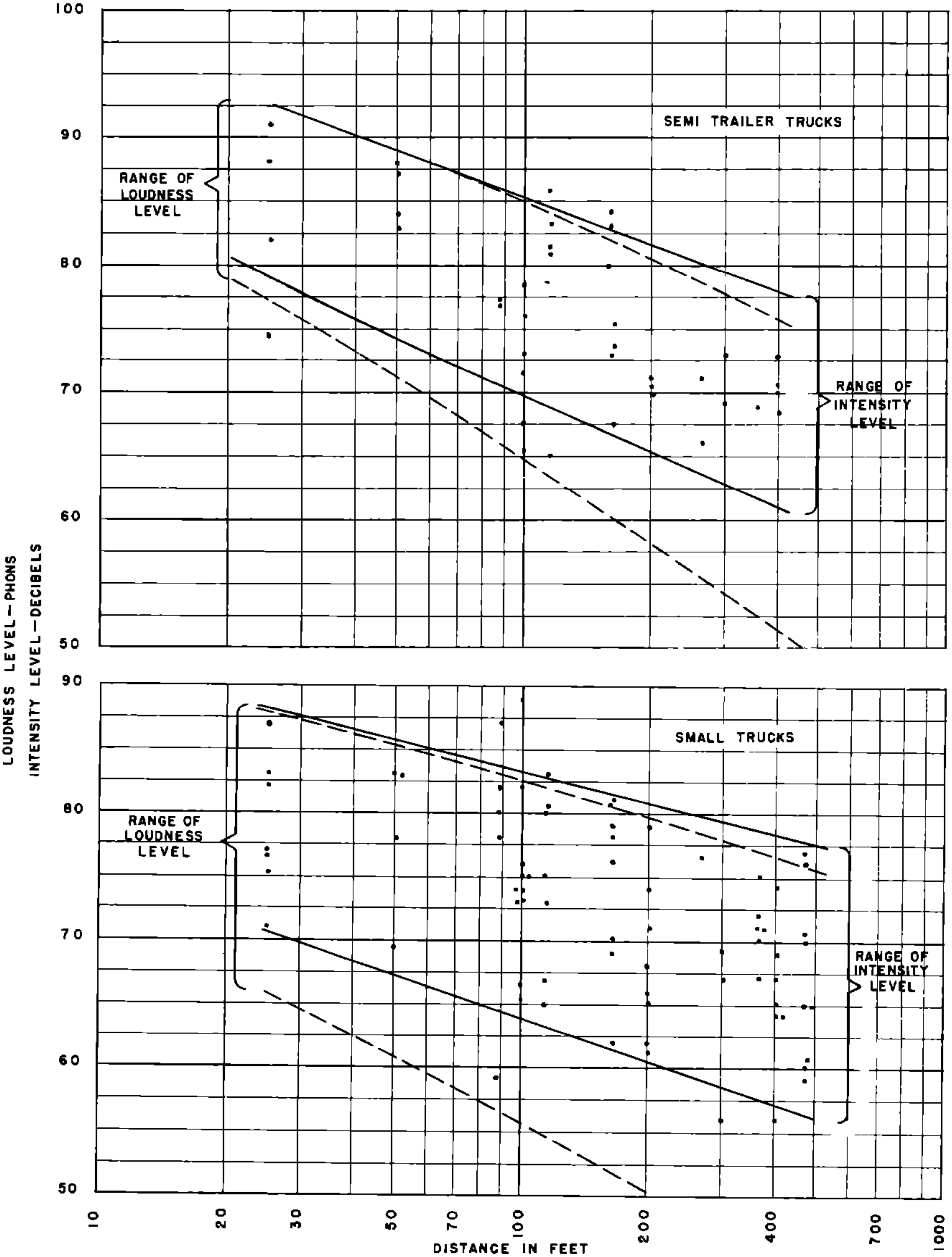


FIGURE 31 VARIATION OF INTENSITY LEVEL AND LOUDNESS LEVEL WITH DISTANCE FOR TRUCK HIGHWAY TRAFFIC

APPENDICES

APPENDIX I

PEAK SOUND LEVELS PRODUCED BY
RAILWAY TRAINS AND HIGHWAY TRUCKS

APPENDIX II

COMPARISON OF LOUDNESS OF SOUND
PRODUCED BY HIGHWAY, RAILWAY AND
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APPENDIX I

PEAK SOUND LEVELS PRODUCED BY RAILWAY TRAINS AND HIGHWAY TRUCKS

In addition to the data given in Figures 29 and 31 of this report concerning sound levels produced by railway and highway truck traffic under normal flat, open road conditions, further data were secured with regard to peak sound levels produced by such sources. The peak levels measured were obtained under the following conditions:

(1) Highway trucks climbing hills in low gear.

(2) Highway trucks accelerating in low gear.

(3) Railway trains whistling for crossing.

These conditions were chosen as being representative of relatively common sounds produced by these sources, but which are higher in level than the sound levels given in Figures 29 and 31 for flat, open road conditions.

The data secured for these peak conditions are given in Figure 32. The data are plotted in terms of intensity level, in decibels, and also approximate loudness level, in phons, where possible. No loudness level values are given for the train whistle data, as no accurate sound frequency measurements could be made for this condition and no conversion to loudness level could be carried out.

It is seen from Figures 31 and 32 that semi-trailer trucks climbing or accelerating in low gear produce sound intensity levels 4 to 15 decibels greater than for the level cruise condition, and that the corresponding increase for small trucks is 1.5 to 11.5 decibels. The average values are increased approximately 10 and 4.5 decibels, respectively.

Similar comparison between sound levels shown in Figure 32 as produced by railway trains whistling, and the data of Figure 29 for trains in level cruise condition, show an increase in sound intensity level of 10 to 20 decibels, with an average increase of about 14 decibels.

The general nature of the curves given in Figure 32 is similar to the corresponding curves of Figures 29 and 31, but a lesser dispersion of measured data is observed for the former case.

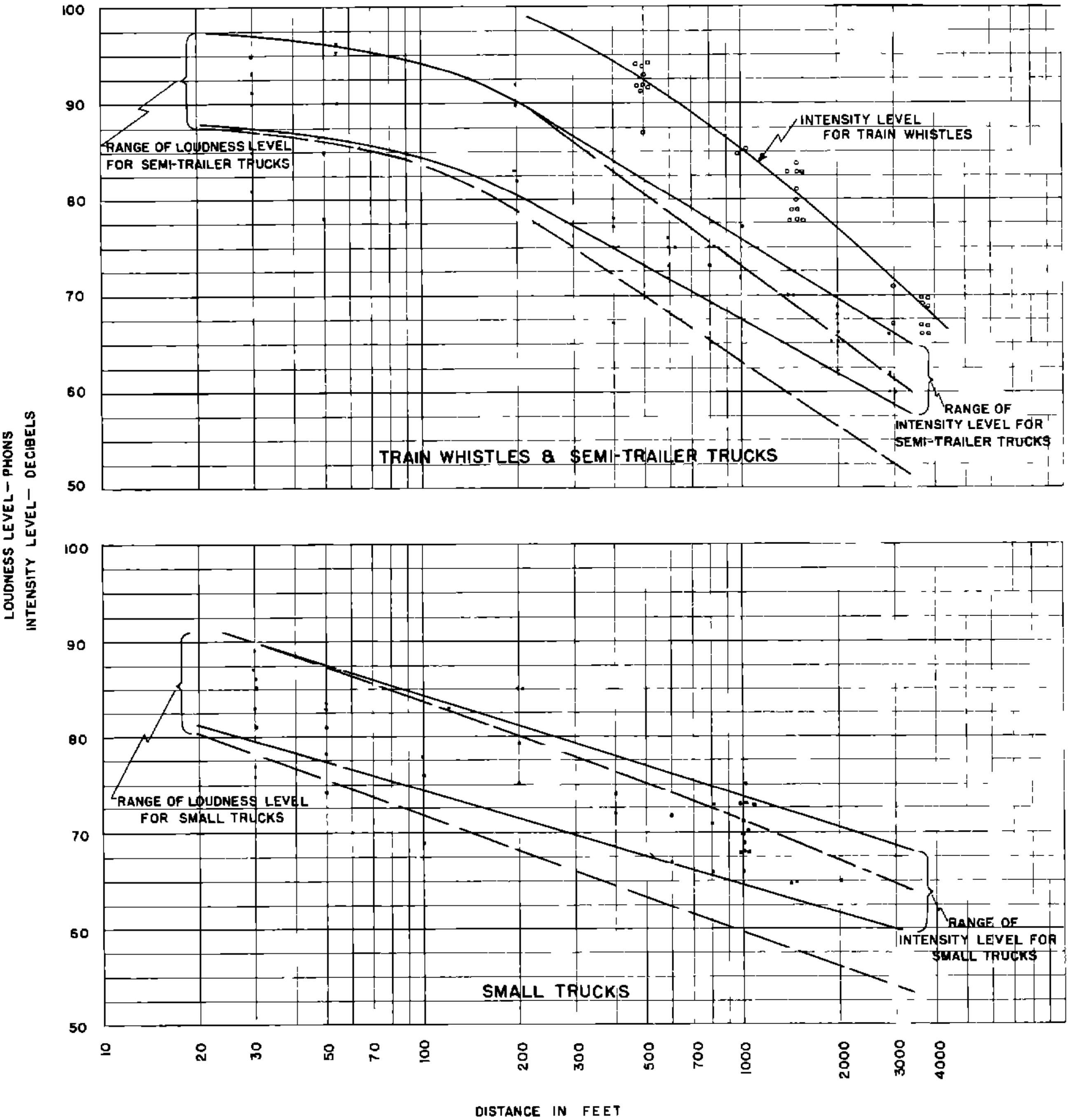

FIGURE 32 VARIATION OF SOUND LEVEL WITH DISTANCE FOR HIGHWAY TRUCK TRAFFIC ACCELERATING OR CLIMBING HILLS AND FOR RAILWAY TRAIN WHISTLES

APPENDIX II

COMPARISON OF LOUDNESS OF SOUND PRODUCED BY HIGHWAY, RAILWAY, AND AIRCRAFT TRAFFIC

DIRECT COMPARISON OF SOUND LEVELS PRODUCED BY VARIOUS SOUND SOURCES, SUCH AS AIRCRAFT, RAILWAY, AND HIGHWAY TRAFFIC, CANNOT BE MADE EXCEPT WITH CONSIDERATION OF THE RELATIVE DISTANCES INVOLVED IN PARTICULAR CASES Aircraft commonly do not pass as closely to ground observers as does surface vehicular traffic, which tends to compensate for higher sound levels produced by most aircraft when compared at equal distance

Variation of loudness of sound with distance from sound source for aircraft, highway, and railway traffic is illustrated in Figures 33 and 34. The loudness values given are average values for each particular condition.

The scale of sound loudness, given in the illustrations shown, is based upon the perceived loudness of sound heard by the average ear relative to the loudness of the normal conversational voice at a three-foot distance Thus, a relative loudness with value of unity is the same approximate loudness as the reference conversational level, and a relative loudness with value of two is approximately twice as loud as the reference level

THE LOUDNESS RELATIVE TO THE REFERENCE CONVERSATIONAL LEVEL CHOSEN HAS NO DIRECT RELATIONSHIP TO MASKING OF CONVERSATIONAL VOICE. Such masking is dependent upon the frequencies present in the sound The reference conversational level is used only to provide a commonly recognizable basis for the relative loudness scale.

Additional data for aircraft, in the form of directly applicable loudness level contour plots, are given in the main text of the report in Figures 14 to 19 inclusive

Comparison of loudness of aircraft sound with that produced by highway or railway traffic may be made in particular cases by considering

(1) The type of aircraft involved
(2) The distance of nearest point of approach of the aircraft to the ground location where comparison is desired
(3) The engine power condition of the aircraft, such as whether it is using cruising or climbing power.
(4) The distance and type of traffic on nearby highways and railroads.

Comparison of three typical cases is given in the following Figure 35. This illustration shows, for each typical case, the distance at which each type of sound source will produce equal definite loudness of sound at the observing point.

Similar comparison may be made in a simple manner for other types of aircraft, and for various known and specific distances from any of the types of sound sources considered, by means of the data given in the previous two figures.

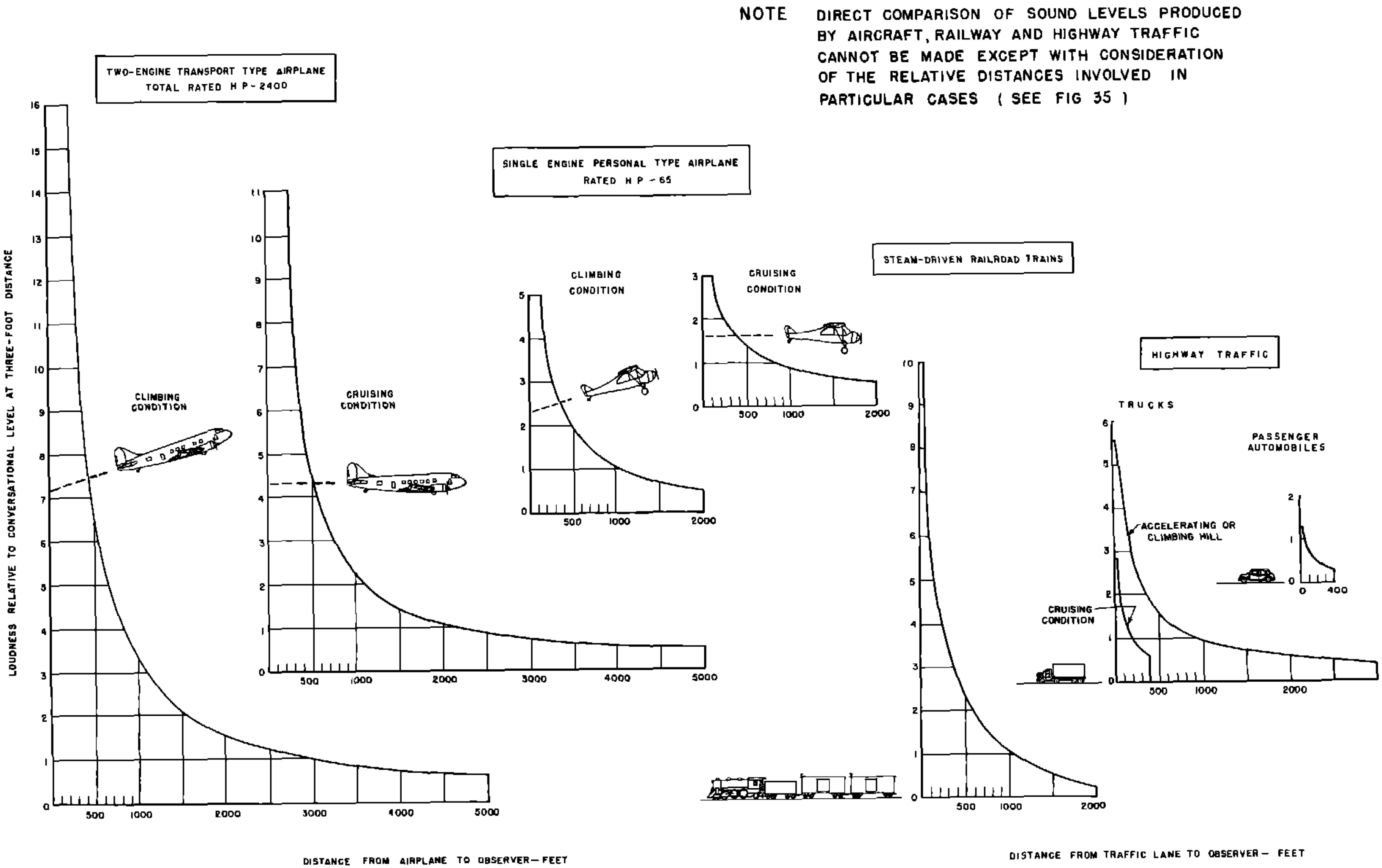

FIGURE 33. VARIATION OF LOUDNESS OF SOUND WITH DISTANCE FROM SOUND SOURCE

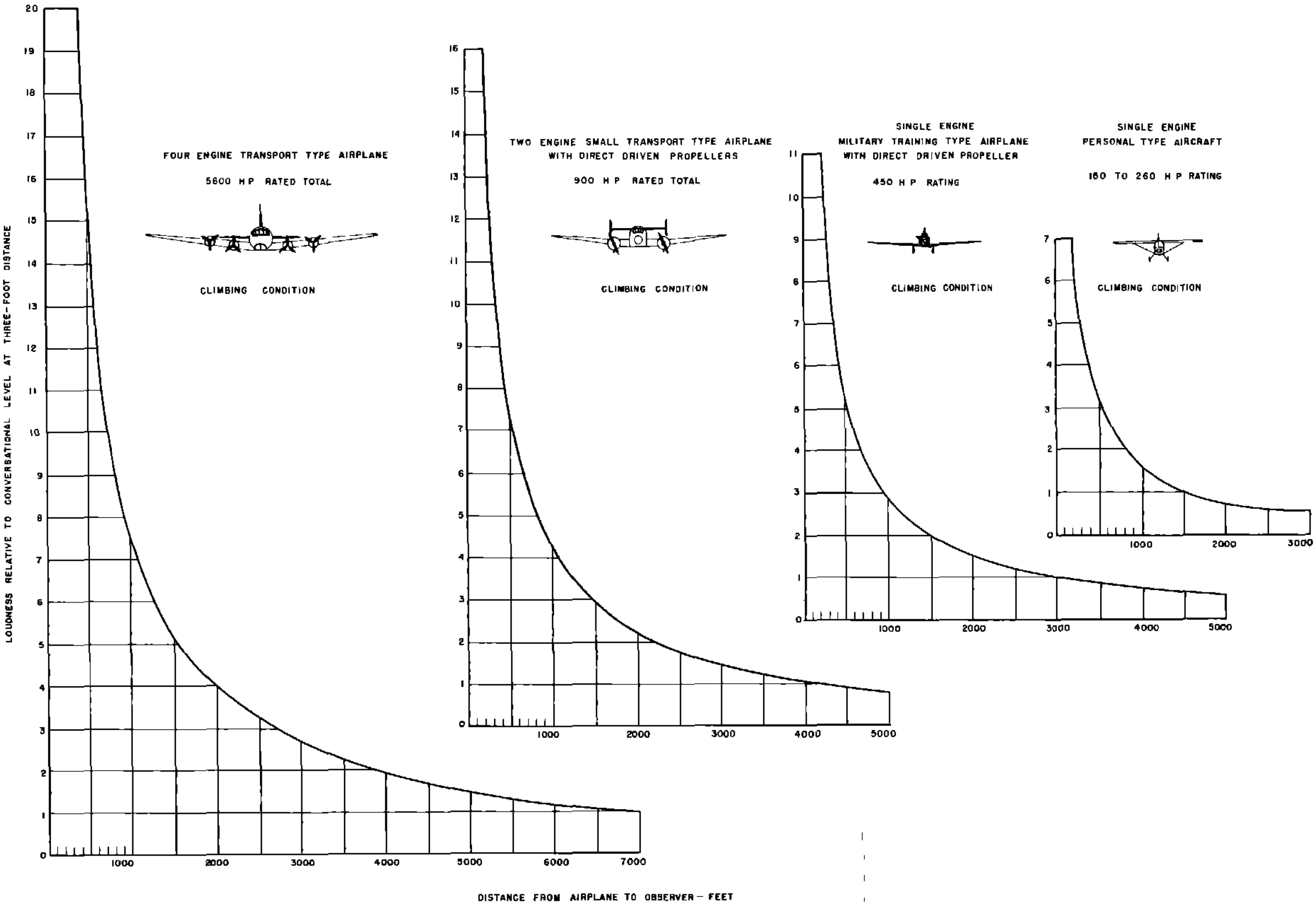

FIGURE 34 VARIATION OF LOUDNESS OF SOUND WITH DISTANCE FROM SOUND SOURCE FOR VARIOUS AIRCRAFT

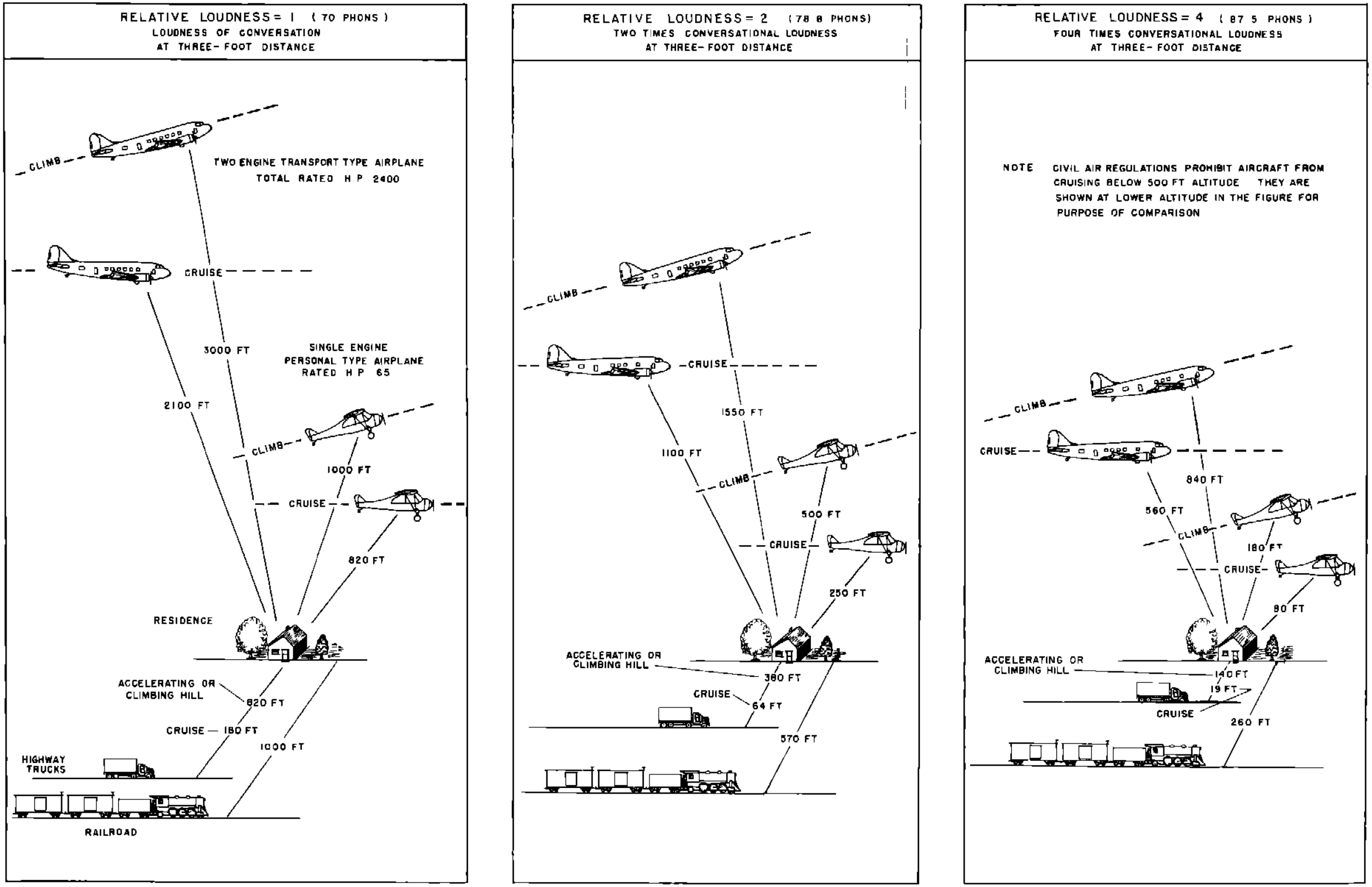

FIGURE 35 THREE TYPICAL EXAMPLES SHOWING DISTANCES AT WHICH DIFFERENT SOUND SOURCES PRODUCE EQUAL LOUDNESS

IN GENERAL, ANNOYANCE CAUSED BY SOUND IS ASSOICATED WITH

(1) THE APPARENT LOUDNESS OF SOUND
(2) THE PARTICULAR FREQUENCY COMPONENTS PRESENT IN THE SOUND.
(3) THE PREVAILING BACKGROUND SOUND LEVEL
(4) THE DURATION OF THE SOUND
(5) THE LENGTH OF TIME BETWEEN OCCURRENCES OF THE SOUND
(6) INDIVIDUAL PSYCHOLOGICAL FACTORS WHICH CANNOT BE EVALUATED, SUCH AS DEGREE OF FAMILIARITY WITH THE SOUND.

In the present report it has been considered that relative loudness of sound less than the reference conversational level probably cannot be considered normally of serious annoyance.

With loudness of sound greater than the reference conversational level, degree of annoyance probably increases gradually with the loudness value However, in each individual case, all of the above factors listed should be considered