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THE PROPAGATION OF SOUND FROM AIRPORT GROUND OPERATIONS

by Peter A. Franken and Dwight E. Bishop

Prepared by
BOLT BERANEK AND NEWMAN INC.
Van Nuys, Calif.
for Langley Research Center

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SUMMARY

An experimental study has been performed to investigate the sound propagation losses associated with aircraft ground operations. Downwind propagation is emphasized in the study, because the highest levels observed on the ground generally occur when the receiver is downwind from the source. The noise from the initial part of jet aircraft takeoff was found to be the most reliable high-level source for the study. Noise measurements were made at Los Angeles International and Denver Stapleton Airports.

The data acquisition and reduction procedures utilized in the program are summarized. The data have been grouped according to various meteorological parameters, and the results are compared with those of previous workers. The results show a pronounced increase in low-frequency attenuation, reaching a maximum in the frequency range of 125 to 250 Hz. They indicate also that the "standard" values of atmospheric absorption are too large above 2,000 Hz.

All valid data and a simple engineering procedure for estimating downwind propagation losses are given in appendices.

INTRODUCTION

The operation of aircraft in and around airports has become a major contributor to the American urban and suburban noise environment. Effective planning of such matters as airport layout or adjacent land usage therefore requires realistic estimates of the aircraft noise in nearby areas (refs. 1 and 2). These noise estimates depend upon a knowledge of the source characteristics of the various aircraft and the losses associated with propagation from the source to the receiver. Considerable engineering information is available describing the variety of common aircraft noise sources currently encountered. Under Contract NAS1-5063 the National Aeronautics and Space Administration has sponsored an experimental study by Bolt Beranek and Newman Inc. to investigate the propagation losses associated with aircraft ground operations. Noise measurements on this program were made at Los Angeles International and Denver Stapleton Airports, over the period from 22 December 1965 to 11 August 1966.

In general, propagation from a source on the ground to a receiver on the ground will be most favorable when the wind is blowing in the direction from the source to the receiver (downwind propagation). Also, the lobes of maximum noise from a turbojet engine lie in the rear quadrants of the aircraft, which is also generally in the downwind direction. For these reasons, the highest noise levels observed in nearby areas will generally be associated with downwind propagation. Hence downwind propagation will be emphasized in this study.

THE MEASUREMENT PROGRAM

Data Acquisition

Although modern airports are indeed noisy places, it is difficult to find an airport noise source that permits consistent measurements out to 2,000 m, a typical distance of interest in our present program. Originally it was planned to use three sources of noise for the measurement program: propeller aircraft runups at the end of a runway prior to takeoff; jet engine runups during ground maintenance operations; and jet aircraft runups prior to takeoff. Field experience indicated that only the third source was consistently useful for the measurement program.

Noise generated by propeller aircraft during ground runup was generally insufficient in intensity to permit reliable measurements at any sizable distance. Noise from jet engine runups during ground maintenance operations was generally unreliable for sound propagation measurements, both because most maintenance operations were restricted to partial power operations, and because the ground runup schedules were unpredictable and reduced the amount of data that could be acquired in any given period.

Use of the noise from jet aircraft during the initial part of the aircraft takeoff roll imposed some significant limitations that must be considered in planning the program. Because most jet transport aircraft started their takeoff roll before or immediately upon reaching full thrust, the noise source was constantly changing in magnitude and geometrical location. Thus, each aircraft takeoff produced a time-varying signal with a useable duration of about 5 to 10 seconds. The fact that the signal amplitude and geometrical location were changing rapidly with time introduced the need for careful time correlation of the recordings made in the field. Such correlation added little to the field measurement effort but introduced the need for considerable care and attention during data reduction.

For any set of measurements, three observation stations were employed, as shown in fig. 1. Station 1, the inner station, was positioned just off the airport runway. The intermediate Station 2 and the outer Station 3 were located on line with Station 1; i.e., Stations 1, 2, and 3 formed a radial extending outward from the airport. During each measurement session data were usually taken on two or more different radials. Over the course of the program, the distances from the aircraft source to the stations ranged from 46 to 180 m for Station 1, from 590 to 1,140 m for Station 2, and from 900 to 2,770 m for Station 3.

Simultaneous magnetic tape recordings were made at all stations. Annotation by the observer at Station 1, recorded directly on the tapes at each of the stations, signaled the start of each event and provided synchronization for all three stations. One 1,000-Hz blip was placed on the Station 1 tape as the aircraft moved past position A, shown in fig. 1. A second 1,000-Hz blip was placed on the tape as the aircraft moved past position B on its takeoff roll. The recorded signal between the two blips denoted the useable position of the signal at Station 1 for that event.

Figure 2 illustrates the instrumentation at each station. The citizen band radios were used for communication between the stations, and for transmitting annotation from Station 1 to Stations 2 and 3. A Bruel and Kjaer (B + K) 1/2" condenser microphone was employed at Station 1, while a 1" microphone was used at each of the outer stations. The B + K 4220 pistonphone was used for field calibration. The microphone height of Station 1 was maintained at five feet above the ground. At Stations 2 and 3, microphone heights were maintained at 10 to 12 feet above the ground.

For several sets of measurements, General Radio (GR) 1560-P5 ceramic microphones with GR 1560-P40 preamplifiers were used instead of the B + K microphone systems, since it was anticipated that the ceramic microphones would be more reliable during high humidity or rainy conditions. Due to difficulties encountered in calibrating the ceramic microphones with the available B + K pistonphone, and the absence of high humidity conditions, the ceramic microphones were not extensively used.

Meteorological conditions were noted at each station at approximate hourly intervals. Wet and dry bulb temperatures, wind speed and direction, barometric pressure, and cloud cover were recorded. A variety of meteorological equipment was employed, with the most accurate equipment usually kept at the outermost position, Station 3. Figure 2 shows the meteorological equipment normally employed at Station 3.

Hourly sequence surface weather observation data were obtained from the U.S. Weather Bureau offices located at the Los Angeles and Denver Airports, for each measurement period. In the data analysis, the Weather Bureau information was relied upon as the primary descriptor of the weather, with field measurement data used to supplement the Weather Bureau information.

Weather Bureau radiosonde information was utilized to estimate temperature profiles. Because only one radiosonde measurement per day was regularly scheduled at Los Angeles, special arrangements were made with the Weather Bureau to provide special radiosonde measurements at times close to field measurement periods. In the classification of weather data, radiosonde temperature profiles were studied to classify temperature profiles as negative, neutral, or positive. Lapse rates of -2° C or less per 1,000 ft were classified as negative, lapse rates of -2 to $+2^\circ$ C were classified as neutral, and rates of $+2^\circ$ C or greater were classified as positive. In the absence of applicable radiosonde data, lapse rate classifications were estimated, based upon time of day and local surface weather conditions.

Data Reduction

The instrumentation diagrammed in fig. 3 was used to reduce the noise data. The data were analyzed in octave frequency bands from 31.5 to 4,000 Hz center frequencies and plotted on graphic level charts. The start of each event, indicated by annotation on the tape, was marked on the graphic level charts for each station. With these marks as reference points, the 1,000-Hz blips on the Station 1 tape were then used to locate on all the charts the time segments which would represent the same sample of sound if the propagation time between the stations were zero. From knowledge of the distances of Stations 2 and 3 from Station 1, the speed of sound, and the paper speed of the graphic level charts, the displacement of these time segments due to the propagation time was found. The noise levels were then read from the appropriate place on the graphic level charts for each station.

Correction factors were applied to the data to compensate for the frequency response characteristics of the microphone and cathode follower and the various tape recorder combinations used in recording and playing back the tapes. For each event the noise levels at Stations 2 and 3 were then subtracted from the levels at Station 1, yielding values for the sound attenuation from Station 1 to Station 2 and from Station 1 to Station 3. The effects of inverse-square spreading were determined from the measurement geometry and subtracted from the sound-pressure-level differences. As described in the following discussion, various amounts were also subtracted for classical and molecular absorption.

After all corrections for instrumentation and allowances for inverse-square spreading and classical and molecular absorption were made, the sound-pressure-level differences were entered on punched cards, together with the associated distances and meteorological data. Digital computer analyses produced the following information for various groupings of the data:

(a) mean values and standard deviations of attenuation

(b) maximum and minimum values of attenuation

(c) mean values and standard deviations of distance

(d) number of samples

MEASUREMENT RESULTS

The data reduction procedure described in the previous section provides sound-pressure-level differences associated with pairs of measurement stations. It is convenient to consider that these differences contain three components that may be treated independently:

(1) classical attenuation

(2) molecular attenuation

(3) miscellaneous meteorological and ground effects

The classical and molecular absorptions are often grouped together under the term "standard" atmospheric absorption. Reference 3 is a current engineering procedure for estimating this standard absorption. We will designate the attenuation associated with the miscellaneous meteorological and ground effects as "excess attenuation", and it is this excess attenuation that is of interest in the present program.

Summary of Previous Investigations

To provide an orientation to the presentation of our measurement results, it will be useful for us to begin by summarizing work done previously in studies of downwind propagation (refs. 4-10). This summary is presented in table I and figs. 4-9. (The results of Hayhurst (ref. 10) have been analyzed and presented in such a form that they cannot be compared with the values of excess attenuation obtained by other workers.) All of data in figs. 4-9 have had inverse-square losses and standard atmospheric attenuation removed, although there may be small differences in the values of standard attenuation losses used by the various workers.

Wiener and Keast (ref. 5) developed a summary chart (fig. 5) for downwind propagation over open level ground. The summary chart shows no attenuation up to a "breaking point", beyond which the attenuation increases at approximately 3 dB for each doubling of distance from the source. The location of the breaking point is inversely proportional to the center frequency of the band of interest. Wiener and Keast observe an exception to this general behavior, in the 300-600 Hz frequency band, for an angular sector of 30° in the downwind direction. They report no data below 300 Hz that might indicate whether this behavior extends to lower frequencies. It is interesting to note that the Ingard results in fig. 4 also show significantly greater attenuation in the 300-600 Hz band than at higher frequencies. Several later investigations, including the present study, have observed this marked increase in low-frequency attenuation. In the case of the present study, it will be seen that this attenuation extends down to 31.5 Hz.

Figure 6 presents the range of attenuation values observed by Dneprovskaya, Iofe, and Levitas over the distances of 1,000 to 4,000 meters (ref. 6). These results show attenuations that are essentially constant around 15 dB between 300 and 1,600 Hz, increasing markedly above 1,600 Hz. This behavior is at variance with the behavior reported by any other investigators. It is possible that this behavior is associated with a special feature of the ground surface or geometry.

Parkin and Scholes have performed two extensive sets of measurements of sound propagation over open ground (refs. 7 and 8). In general they found that attenuation values varied somewhat between the two sites. A set of results for 3,600-ft propagation distance from each site is shown in fig. 7.

The last item in table I is a draft of a proposed procedure for estimating excess attenuation effects. This draft has been prepared recently by the Society of Automotive Engineers (ref. 9). It contains two figures pertinent to downwind propagation of noise from ground operations, and these are given in figs. 8 and 9. Figure 8 applies for cases of no wind. These cases are considered to be of relative unimportance, because the SAE document states that winds in excess of 5 mi/hr (approx. 2-1/2 m/sec) exist over 80% of the time at the ten major United States airports considered. Figure 8 shows the presence of a low-frequency attenuation maximum, and the SAE document ascribes this maximum to destructive interference between direct sound and sound partially reflected from the ground surface. It is stated also that the presence of a wind greater than 5 mi/hr destroys this interference effect. Therefore, the recommended attenuation curves presented in the SAE document, which are for a wind velocity of 10 mi/hr, do not contain the low-frequency absorption maximum. These recommended attenuation curves are shown in fig. 9.

Results of the Present Program

As the previous section pointed out, the attenuation data from this program were analyzed for several different wind and temperature conditions. The nature of the draft SAE document (ref. 9) suggests that we begin our presentation of results by examining the effects of wind speed. We initially use the SAE procedure for estimating standard atmospheric attenuation (ref. 3). Figures 10 and 11 present the mean values of excess attenuation for absolute wind speeds less than and greater than 5 m/sec, and tables II and III present the corresponding information on standard deviations s and number of data samples. In these and the following figures, the three distance ranges correspond to distances less than 1,000 m, between 1,000 and 2,000 m, and greater than 2,000 m. The mean values corresponding to these three ranges are approximately 800 m, 1,600 m, and 2,150 m, respectively. These mean values vary slightly, depending on the particular parameters used for analyzing the data.

Our first comment on figs. 10 and 11 concerns three features of unusual behavior in the frequency bands above 1,000 Hz:

(1) The attenuation values become negative, representing "amplifications" that are as large as 40 dB and 50 dB at the highest frequencies.

(2) The order of the mean attenuation curves becomes inverted, so that the largest distances show the smallest (rather than the largest) attenuations.

(3) The standard deviations become large, with typical values rising from 6 dB to 12 dB below 1,000 Hz to 30 dB and 40 dB at 4,000 Hz.

Although it is true that we expect greater level fluctuations at high frequencies than at low frequencies, the fact that the increases in standard deviation are coupled with these other effects suggests strongly that the procedure for standard atmospheric attenuation at high frequencies has generated values that are very high. In other words, by using the standard atmospheric attenuation values in reference 3, we have artificially introduced "amplifications" at the higher frequencies and have also increased the scatter in the data. Following this reasoning, we recalculated the high-frequency attenuation values, modifying the SAE procedure in two steps. In one set of data (figs. 12 and 13), we have halved the values obtained from the SAE procedure in the frequency bands centered at 2,000 and 4,000 Hz. In the second step (figs. 14 and 15) we have omitted the standard SAE attenuation completely. Since the standard attenuation values for bands below 500 Hz are taken to be 0, the omission of the standard attenuation does not affect our results below 500 Hz.

The results of these modifications in the standard attenuation are shown in figs. 12-15, corresponding to figs. 10 and 11. From the figures and their corresponding tables, it may be seen that the removal of half of the standard attenuation in the highest frequency bands reduces the artificial "amplifications" of figs. 10 and 11 and reduces the standard deviations. Complete removal of the standard attenuation drives the resulting attenuation values negative and suggests that we have now overcorrected by removing all high-frequency attenuation. In the remainder of this report, we will present results utilizing the halved SAE standard attenuation values at 2,000 and 4,000 Hz. [Appendix A presents all attenuation values obtained during the program. No SAE standard attenuation is included in the data in the Appendix, but the meteorological conditions are given, so that other values of standard attenuation may be applied to the data, if desired.]

Figures 10-15 show the maximum low-frequency attenuation around 250 Hz observed by Parkin and Scholes. In addition, our results indicate that this attenuation extends considerably lower in frequency than reported by Parkin and Scholes. These low-frequency differences may be due to the details of the differences in ground cover. The Parkin and Scholes data were taken over open flat terrain, while our measurements were made in residential areas in the vicinity of major airports, with intervening houses and other obstructions between the aircraft source and measurement positions.

The data figures and tables present the mean values and standard deviations of excess attenuation in a variety of forms. The results are given for wind speeds less than and greater than 5 m/sec (figs. 12 and 13 and tables II and III); wind speeds less than and greater than 3 m/sec (figs. 16 and 17 and tables IV and V); wind vector components less than -1 m/sec, between -1 and +1 m/sec, and greater than +1 m/sec (figs. 18, 19, and 20 and tables VI, VII, and VIII); negative, neutral, and positive temperature gradients (figs. 21, 22, and 23 and tables IX, X, and XI); and all data (fig. 24 and table XII). In reviewing these figures and tables, we do not find any form that appears to give a more consistent presentation than that based on absolute wind speed. It is interesting that the use of the wind vector component as the describing parameter does not improve the presentation. In fact, in general it increases the standard deviations over the corresponding values obtained when the absolute wind speed is used as the describing parameter.

A test for differences in mean values indicates that the mean values must differ by 2.8 dB or more in order for their difference to be statistically significant, to the 5% significance level. This result was obtained utilizing typical values of 10 dB for standard deviation and 50 for number of samples. The minimum significant difference is directly proportional to the standard deviation and inversely proportional to the square root of the number of samples.

In summary, our inspection of the excess attenuation data indicates three major features:

(1) There is a pronounced increase in low-frequency attenuation. In our data this increase reaches a maximum in the frequency range of 125 to 250 Hz,

the frequency range of considerable interest for turbojet engine noise. This feature was seen to some extent in the data of Ingard (ref. 4) and Wiener and Keast (ref. 5), and Parkin and Scholes (refs. 7 and 8). The draft of the proposed SAE document on excess attenuation minimizes the importance of this low-frequency attenuation.

(2) The standard attenuation values provided by the existing SAE document (ref. 3) are too large for frequencies of 2,000 Hz and above. This effect may be of particular interest for large bypass-ratio turbofan engines, because such engines may have strong pure-tone components in the frequency range above 2,000 Hz.

(3) There is considerable scatter in propagation data obtained over distances of 1,000 to 2,000 m. Under the most favorable conditions, the values of standard deviations are in the range of 6 dB to 12 dB. Also, the behavior of the excess attenuation curves below 250 Hz differs markedly from site to site (see figs. 7 and 13), and appears to be strongly dependent on the nature of the terrain.

Development of an Engineering Procedure

As has been pointed out earlier, the values of excess attenuation that are obtained depend strongly on the nature of the terrain over which the sound propagates. Therefore, any procedure based on the data obtained in this report should be restricted in application to situations similar to those studied in this report, namely, flat terrain and residentially developed areas. Because this situation is often found in the vicinity of present-day large airports, it is reasonable to develop a procedure from the data obtained in this program.

The data results also indicate that none of the analyses with the various meteorological parameters showed any better correlation than that with absolute wind speed. Because the average wind velocity at about sixty airports in the United States has been found to be about 10 mi/hr (about 5 m/sec), we will use the data for wind speeds greater than 5 m/sec to develop our procedure. A cross-plot of these data as a function of propagation distance is shown in fig. 25, for the frequency bands below 1,000 Hz. Although there is considerable scatter in the data above

1,000 Hz, we believe that the results indicate that the extra ground attenuation in this high-frequency region may be taken as zero, if the SAE standard attenuation values have been halved at 2,000 and 4,000 Hz. Figure 25 shows that the data for the 125 and 250 Hz frequency bands are quite close. A test of the differences between these bands shows that these differences are not statistically significant, to the 5% significance level. Therefore, in the following discussion we will treat the data from the 125 and 250 Hz frequency bands as a single group.

Because of the procedure utilized for choosing measurement locations during this program, our propagation data are grouped at three distances, approximately 800, 1,650, and 2,050 m. It would be desirable if other data could be used to describe the behavior of the excess attenuation curves at other distances. It might be thought that the extensive Parkin and Scholes data could provide this information at positions less than about 1,200 m. However, the Parkin and Scholes data cannot be used for this purpose, because they were taken at test sites that are very different from those used in the present study, i.e., open flat grassy terrain rather than houses. One measure of the difference that may be ascribed to these differing test situations may be seen by comparing figs. 7 and 13, especially at frequencies below 100 Hz. In this range the Parkin and Scholes data show an amplification of typically 4 dB, where the data from the present study show attenuations of that amount or greater.

Using the excess attenuation data for the three propagation distances, we have suggested how attenuation curves might be drawn over the first 2,000 m. We have also attempted to plot these data in such a form to investigate whether or not they show the 3 dB-per-double-distance shape suggested by Wiener and Keast for downwind propagation, or the 6 dB-per-double distance shape suggested by the theoretical analysis of a point source over a plane of finite impedance (ref. 11); however, no such behavior can be observed. The suggested curves in fig. 25 may also be compared with the corresponding curves given in the draft SAE procedure for downwind propagation (figs. 8 and 9). It may be seen that the present results differ markedly from the draft SAE procedures.

The suggested curves in fig. 25 are used in Appendix B to form the basis of new suggested procedures for estimating downwind propagation losses.

CONCLUSIONS

This study of the excess attenuation associated with the downwind propagation of noise from an aircraft on the ground over distances of 1,000 to 2,000 meters provides the following conclusions:

(1) The attenuation data show a pronounced increase in low frequencies. This increase reaches a maximum in the frequency range of 125 to 250 Hz, a range of considerable interest for turbojet engine noise.

(2) The standard attenuation values associated with classical and molecular absorption are too large for frequencies of 2,000 Hz and above. This effect may be of particular interest for large bypass-ratio turbofan engines.

(3) Under the most favorable conditions, the values of standard deviations associated with propagation over distances of 1,000 to 2,000 meters are in the range of 6 dB to 12 dB.

(4) A simple engineering procedure for estimating downwind propagation losses has been developed. This procedure incorporates the three features described previously in these conclusions.

Bolt Beranek and Newman Inc.
Los Angeles, California
4 January 1967

TABLE I. - PREVIOUS WORK ON DOWNWIND PROPAGATION

Investigators	Range	Results
Ingard (ref. 4)	to 1,500 ft	fig. 4
Wiener and Keast (ref. 5)	to 4,500 ft	fig. 5
Dneprovskaya, Iofe, and Levitas (ref. 6)	1.5 to 5 km	fig. 6
Parkin and Scholes (refs. 7 and 8)	to 3,600 ft	fig. 7
Draft of SAE AIR 923 (ref. 9)	to 4,000 ft	figs. 8 and 9

TABLE II. — EXCESS ATTENUATION: DATA SCATTER FOR WIND SPEED LESS THAN 5 m/sec

Band Center Freq, Hz	Number of Samples	s, dB (fig. 10)	s, dB (fig. 12)	s, dB (fig. 14)
< 1,000 m				
31.5	145	12.8	12.8	12.8
63	144	10.6	10.6	10.6
125	138	11.2	11.2	11.2
250	139	11.1	11.1	11.1
500	137	11.6	11.6	11.8
1,000	133	11.9	11.9	11.0
2,000	130	12.9	12.6	10.9
4,000	99	14.4	13.2	11.6
1,000-2,000 m				
31.5	76	15.6	15.6	15.6
63	70	14.9	14.9	14.9
125	65	12.2	12.2	12.2
250	72	16.1	16.1	16.1
500	72	17.1	17.1	17.2
1,000	65	14.4	14.2	13.1
2,000	53	19.0	15.8	13.5
4,000	25	49.2	28.9	9.6
> 2,000 m				
31.5	52	10.7	10.7	10.7
63	50	8.8	8.8	8.8
125	55	9.7	9.7	9.7
250	58	10.7	10.7	10.7
500	48	12.8	12.8	12.3
1,000	42	14.0	14.0	12.4
2,000	37	18.3	15.2	12.1
4,000	18	41.6	22.2	10.5

TABLE III. — EXCESS ATTENUATION: DATA SCATTER FOR WIND SPEED GREATER THAN 5 m/sec

Band Center Freq, Hz	Number of Samples	s, dB (fig. 11)	s, dB (fig. 13)	s, dB (fig. 15)
< 1,000 m				
31.5	53	10.9	10.9	10.9
63	53	8.9	8.9	8.9
125	50	7.1	7.1	7.1
250	50	6.6	6.6	6.6
500	51	7.4	7.4	7.5
1,000	48	6.9	6.9	6.9
2,000	45	5.3	5.7	6.3
4,000	42	6.8	6.9	7.4
1,000-2,000 m				
31.5	16	10.3	10.3	10.3
63	11	9.8	9.8	9.8
125	18	6.4	6.4	6.4
250	17	6.0	6.0	6.0
500	17	7.7	7.7	8.7
1,000	15	7.7	7.7	8.3
2,000	13	6.5	9.3	9.0
4,000	6	19.5	18.3	21.6
> 2,000 m				
31.5	23	11.3	11.3	11.3
63	23	7.5	7.5	7.5
125	23	8.1	8.1	8.1
250	28	8.3	8.3	8.3
500	26	8.6	8.4	9.1
1,000	21	8.9	8.9	9.4
2,000	16	8.1	7.8	8.2
4,000	7	31.3	20.7	13.2

TABLE IV. – EXCESS ATTENUATION: DATA SCATTER FOR WIND SPEED LESS THAN 3 m/sec (fig. 16)

	< 1,000 m		1,000-2,000 m		> 2,000 m	
Band Center Freq, Hz	Number of Samples	s, dB	Number of Samples	s, dB	Number of Samples	s, dB
31.5	112	12.4	49	15.9	38	12.0
63	109	10.1	41	15.9	35	9.5
125	102	10.8	39	11.8	37	10.0
250	106	9.6	44	17.3	38	12.4
500	103	11.3	45	18.9	30	14.8
1,000	99	11.6	37	13.5	28	15.7
2,000	97	12.0	32	15.3	27	14.0
4,000	85	13.2	17	22.0	14	18.5

TABLE V. – EXCESS ATTENUATION: DATA SCATTER FOR WIND SPEED GREATER THAN 3 m/sec (fig. 17)

	< 1,000 m		1,000-2,000 m		> 2,000 m	
Band Center Freq, Hz	Number of Samples	s, dB	Number of Samples	s, dB	Number of Samples	s, dB
31.5	86	12.1	43	9.8	37	9.6
63	88	10.5	40	10.8	38	7.2
125	86	9.2	44	10.2	41	8.4
250	83	10.7	45	10.6	48	7.9
500	85	10.9	44	11.1	44	8.9
1,000	82	10.5	43	12.9	35	9.8
2,000	78	10.4	34	15.2	26	12.7
4,000	55	9.3	14	29.7	11	26.8

TABLE VI. — EXCESS ATTENUATION: DATA SCATTER FOR WIND VECTOR COMPONENT LESS THAN -1 m/sec (fig. 18)

	< 1,000 m		1,000-2,000 m		> 2,000 m	
Band Center Freq, Hz	Number of Samples	s, dB	Number of Samples	s, dB	Number of Samples	s, dB
31.5	46	11.4	30	8.2	21	7.4
63	45	11.7	28	8.0	21	6.8
125	43	11.2	30	8.1	23	7.1
250	45	11.0	30	9.5	24	8.6
500	43	13.9	31	8.1	17	11.5
1,000	43	15.2	30	9.9	15	14.4
2,000	40	13.6	23	15.5	12	15.3
4,000	29	18.1	9	35.6	7	14.2

TABLE VII. — EXCESS ATTENUATION: DATA SCATTER FOR WIND VECTOR COMPONENT BETWEEN -1 and +1 m/sec (fig. 19)

	< 1,000 m		1,000-2,000 m		> 2,000 m	
Band Center Freq, Hz	Number of Samples	s, dB	Number of Samples	s, dB	Number of Samples	s, dB
31.5	57	12.2	38	18.2	15	15.4
63	54	9.6	33	18.1	14	11.7
125	49	12.3	28	13.0	13	13.8
250	53	10.6	34	18.8	16	15.4
500	50	10.0	31	21.9	11	13.4
1,000	47	10.0	27	14.6	8	22.2
2,000	49	11.8	27	16.5	10	15.5
4,000	37	12.5	15	24.1	4	3.5

TABLE VIII. – EXCESS ATTENUATION: DATA SCATTER FOR WIND VECTOR COMPONENT GREATER THAN 1 m/sec (fig. 20)

	< 1,000 m		1,000-2,000 m		> 2,000 m	
Band Center Freq, Hz	Number of Samples	s, dB	Number of Samples	s, dB	Number of Samples	s, dB
31.5	95	12.6	24	12.0	34	9.1
63	98	9.8	20	14.2	33	6.7
125	96	8.2	25	12.6	34	7.9
250	91	8.6	25	12.8	38	6.7
500	95	8.8	27	12.8	38	8.5
1,000	91	8.2	23	14.9	33	8.4
2,000	86	8.7	16	12.5	27	9.5
4,000	74	8.3	7	22.0	12	13.1

TABLE IX. – EXCESS ATTENUATION: DATA SCATTER FOR NEGATIVE TEMPERATURE GRADIENT (fig. 21)

	< 1,000 m		1,000-2,000 m		> 2,000 m	
Band Center Freq, Hz	Number of Samples	s, dB	Number of Samples	s, dB	Number of Samples	s, dB
31.5	109	13.7	34	17.9	38	13.5
63	109	11.6	23	20.6	38	9.7
125	101	11.9	28	11.6	34	11.4
250	102	12.5	32	18.7	38	12.4
500	101	12.4	33	20.8	34	13.5
1,000	96	12.1	25	13.3	25	14.1
2,000	96	11.0	21	15.7	23	15.2
4,000	88	12.2	6	20.8	6	8.8

TABLE X. — EXCESS ATTENUATION: DATA SCATTER FOR NEUTRAL TEMPERATURE GRADIENT (fig. 22)

	< 1,000 m		1,000-2,000 m		> 2,000 m	
Band Center Freq, Hz	Number of Samples	s, dB	Number of Samples	s, dB	Number of Samples	s, dB
31.5	52	10.8	29	9.4	19	6.4
63	54	8.5	30	10.3	17	7.4
125	51	6.7	30	9.6	23	5.9
250	53	7.7	29	9.0	24	6.6
500	51	10.4	26	6.7	21	9.1
1,000	50	9.5	26	9.8	17	12.0
2,000	45	8.9	24	12.4	15	10.8
4,000	40	9.5	18	18.3	7	11.1

TABLE XI. — EXCESS ATTENUATION: DATA SCATTER FOR POSITIVE TEMPERATURE GRADIENT (fig. 23)

	< 1,000 m		1,000-2,000 m		> 2,000 m	
Band Center Freq, Hz	Number of Samples	s, dB	Number of Samples	s, dB	Number of Samples	s, dB
31.5	37	12.5	29	7.5	18	6.4
63	34	11.4	28	9.4	18	5.7
125	36	10.2	25	11.1	21	8.2
250	34	10.6	28	12.2	24	8.4
500	36	10.6	30	13.2	19	10.1
1,000	35	11.9	29	14.4	21	10.3
2,000	34	15.1	21	14.0	15	12.0
4,000	12	18.7	7	43.8	12	13.2

TABLE XII. - EXCESS ATTENUATION: DATA SCATTER FOR ALL DATA (fig. 24)

	< 1,000 m		1,000-2,000 m		> 2,000 m	
Band Center Freq, Hz	Number of Samples	s, dB	Number of Samples	s, dB	Number of Samples	s, dB
31.5	198	12.8	92	14.8	75	10.8
63	197	10.8	81	14.3	73	8.3
125	188	10.5	83	11.3	78	9.2
250	189	11.0	89	14.7	86	10.3
500	188	11.5	89	15.7	74	11.8
1,000	181	11.4	80	13.3	63	12.7
2,000	175	11.5	66	15.1	53	13.5
4,000	140	12.3	31	27.8	25	22.1

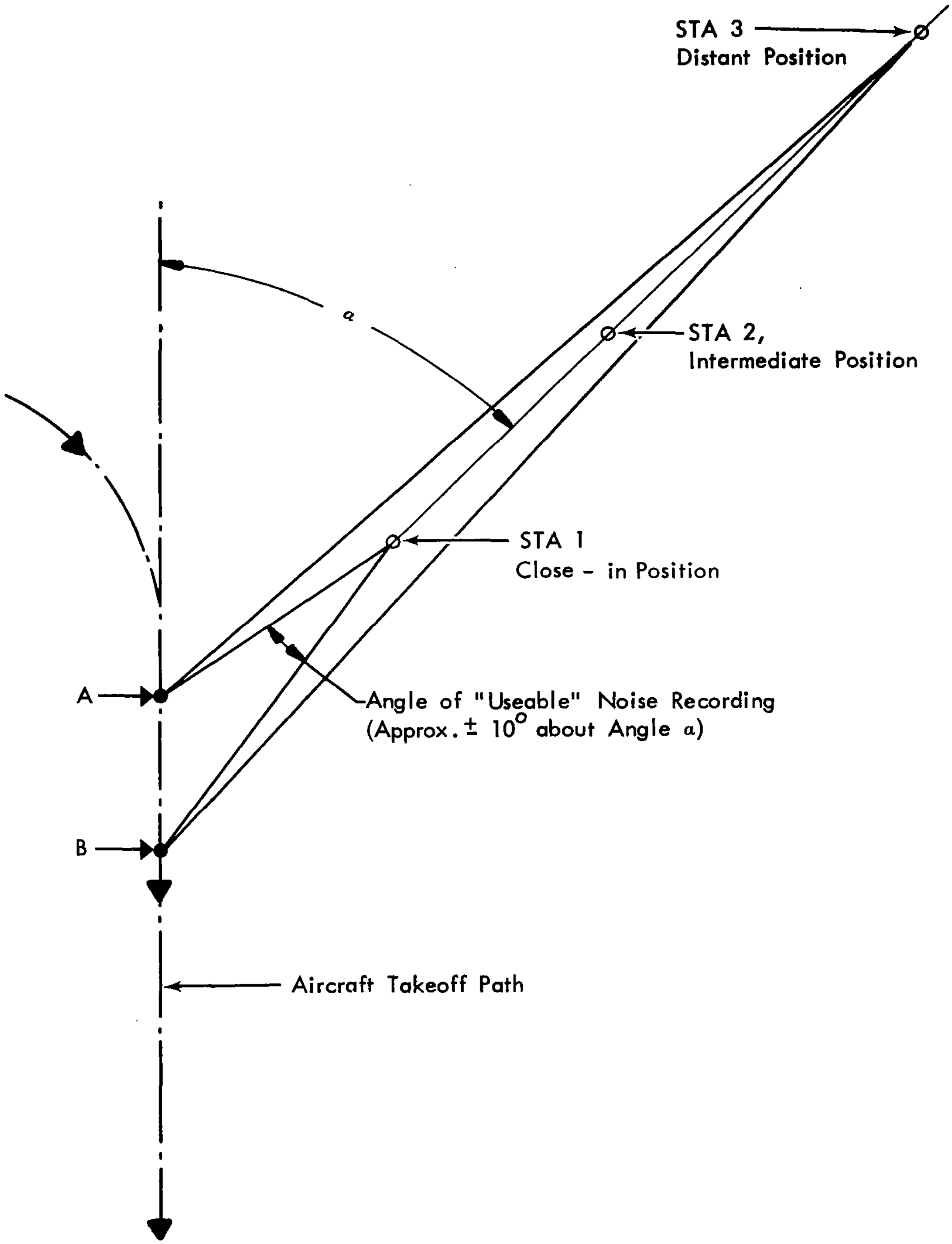

FIGURE 1. SKETCH SHOWING FIELD STATIONS ALONG A MEASUREMENT RADIAL

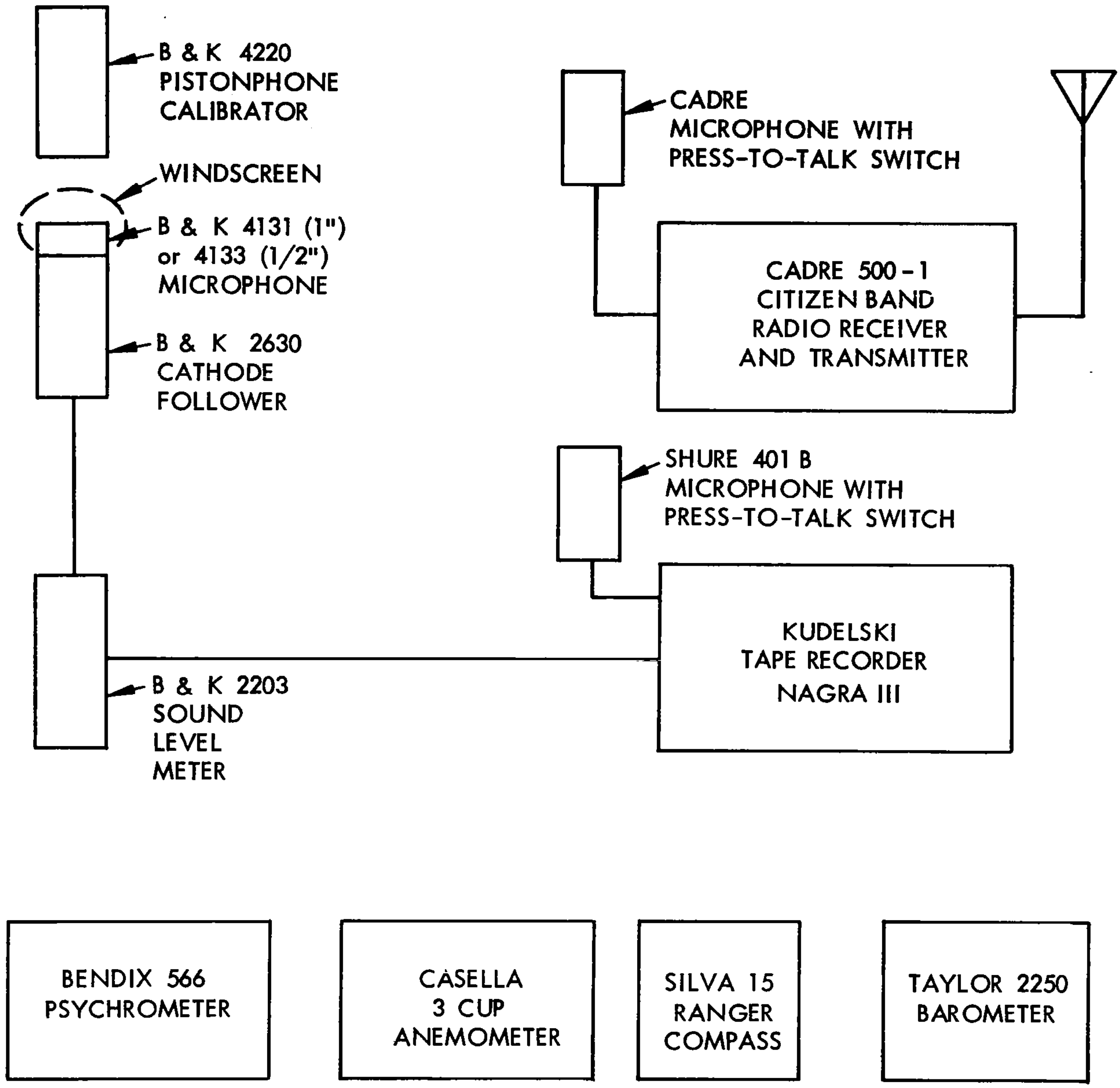

FIGURE 2. DATA ACQUISITION SYSTEM

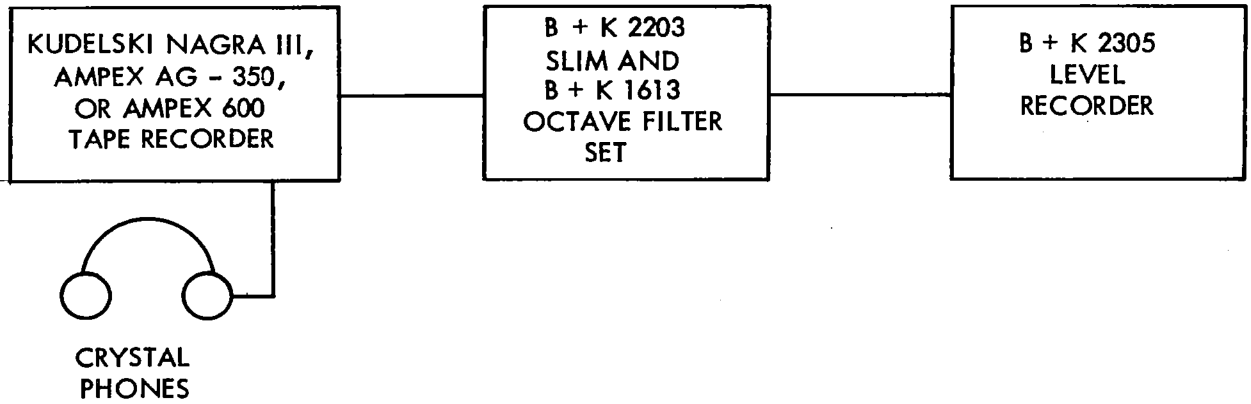

FIGURE 3. DATA REDUCTION SYSTEM

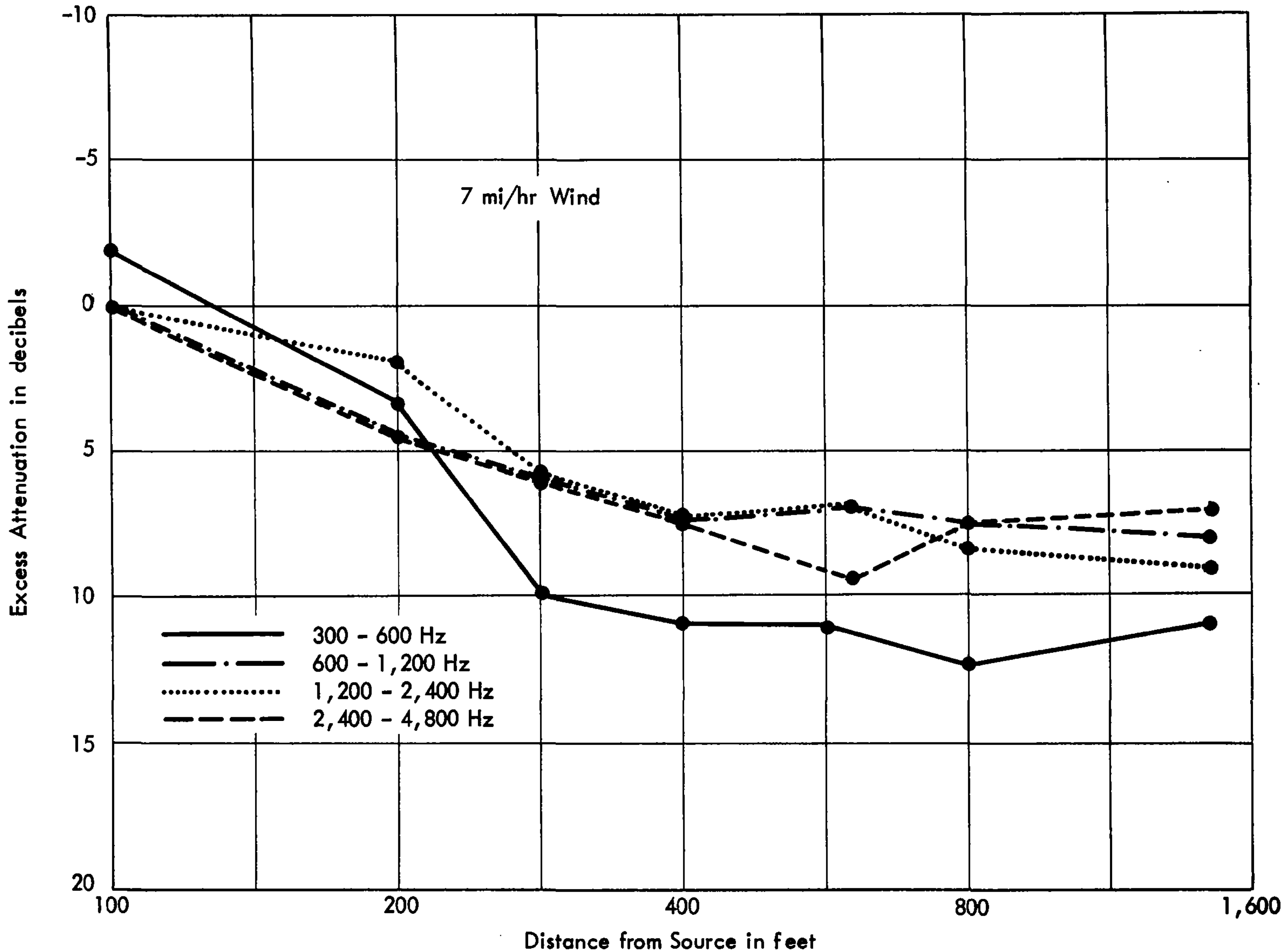

FIGURE 4. DOWNWIND ATTENUATION AS A FUNCTION OF DISTANCE
Based on Ingard (Ref. 4)

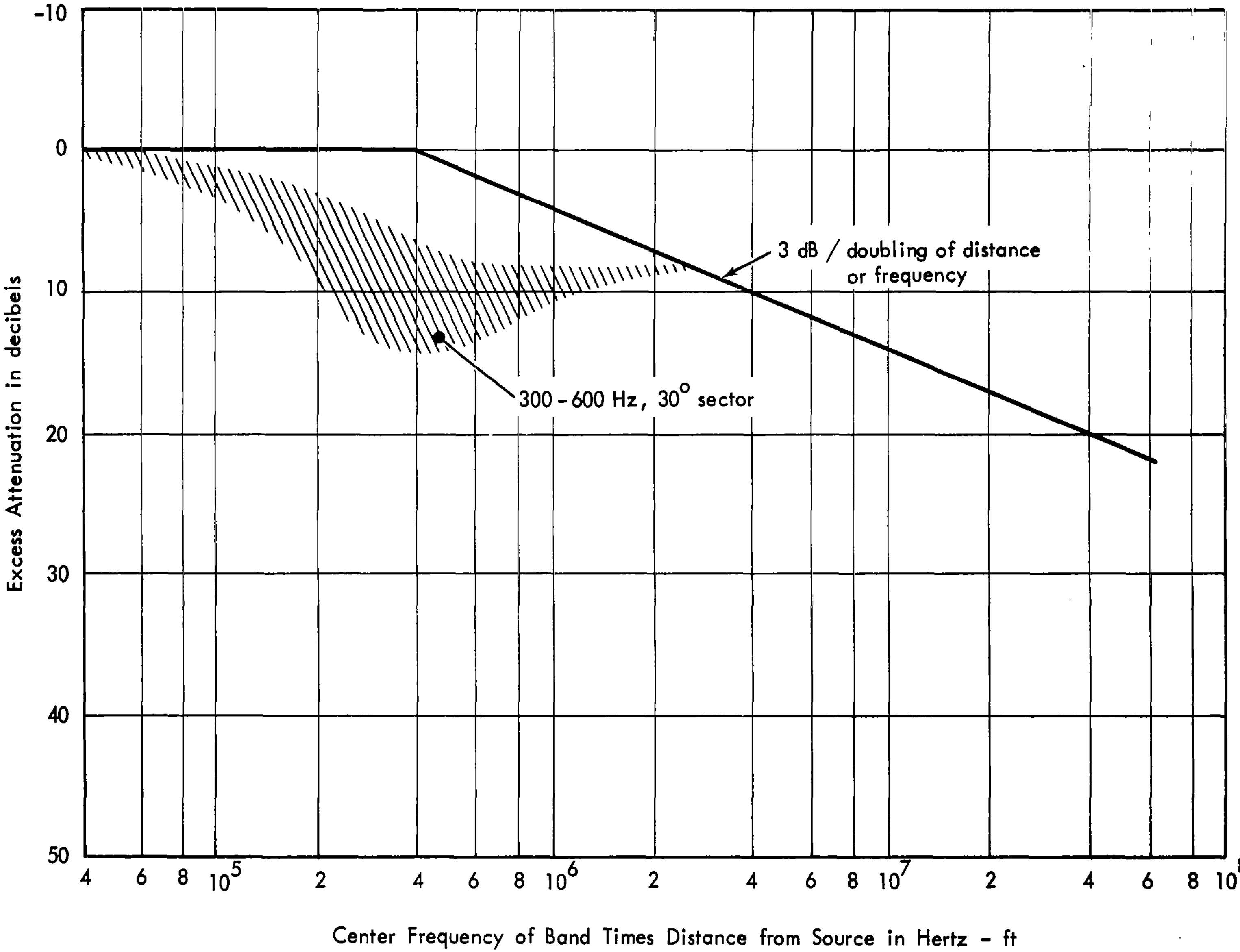

FIGURE 5. SUMMARY CHART FOR DOWNWIND ATTENUATION
Based on Wiener and Keast (Ref. 5)

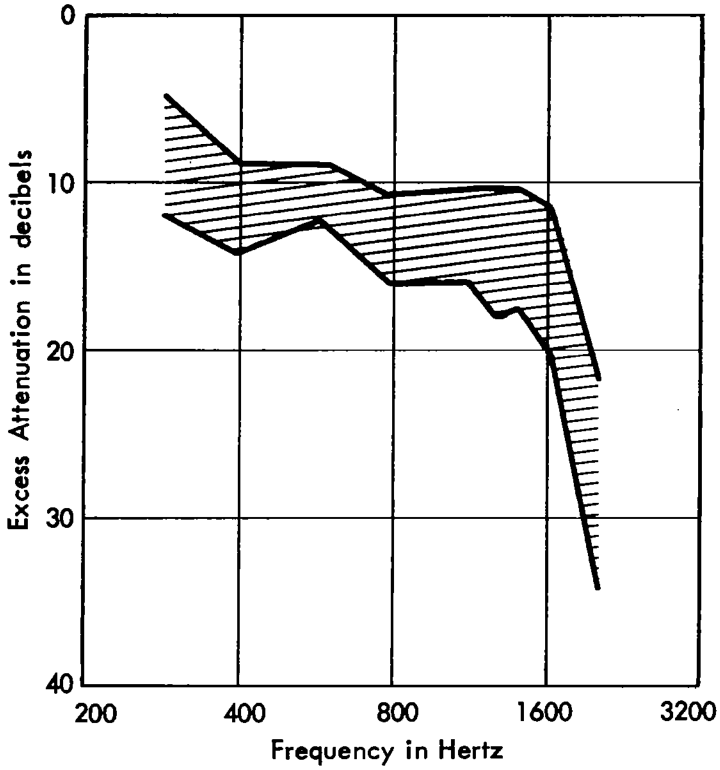

FIGURE 6. DOWNWIND ATTENUATION FOR PROPAGATION DISTANCE OF 1,000 TO 4,000 METERS
Based on Dneprovskaya, Iofe, and Levitas (Ref. 6)

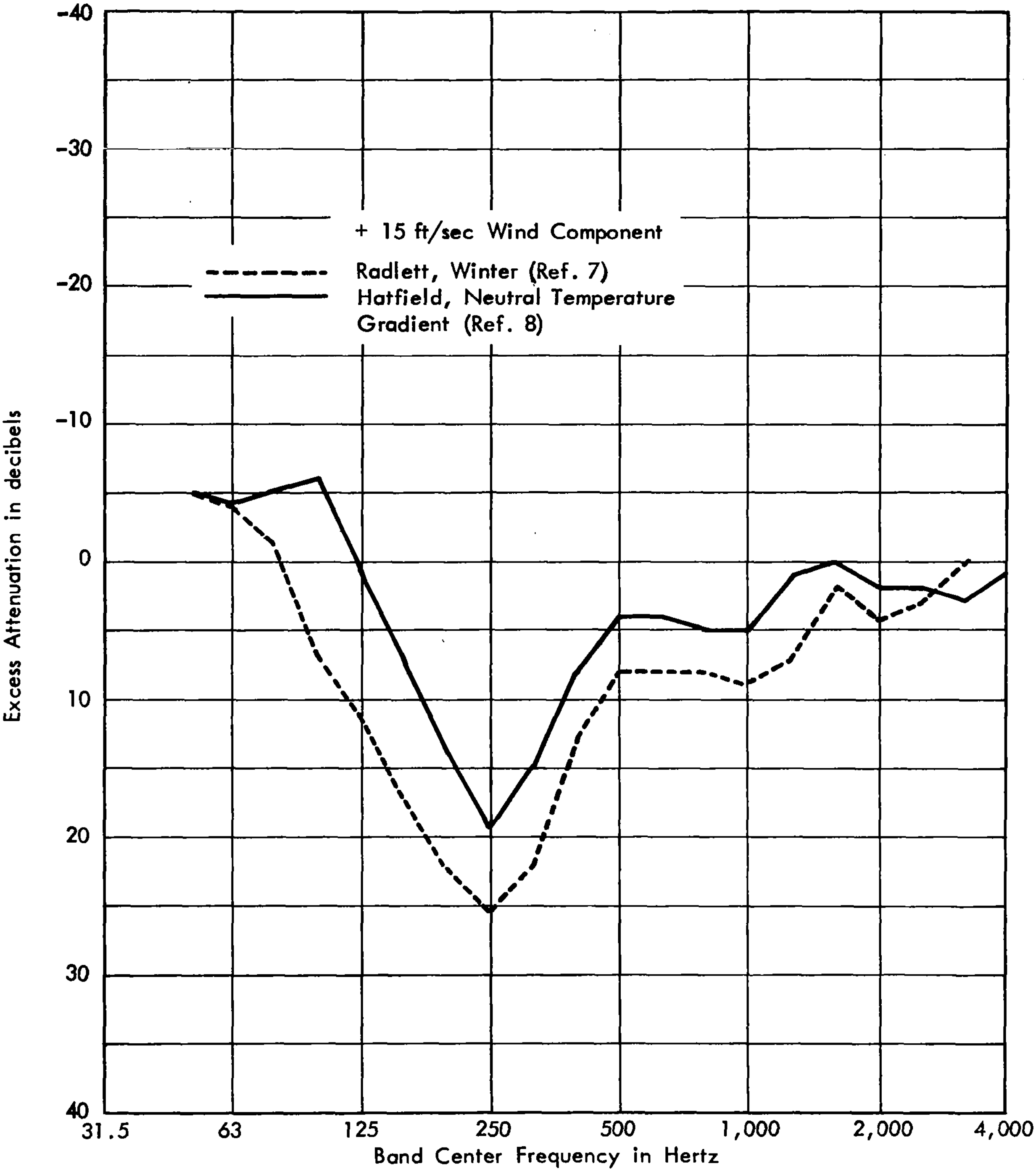

FIGURE 7. MEAN VALUES OF EXCESS ATTENUATION FOR PROPAGATION DISTANCE OF 3,600 FEET
Based on Parkin and Scholes (Refs. 7 and 8)

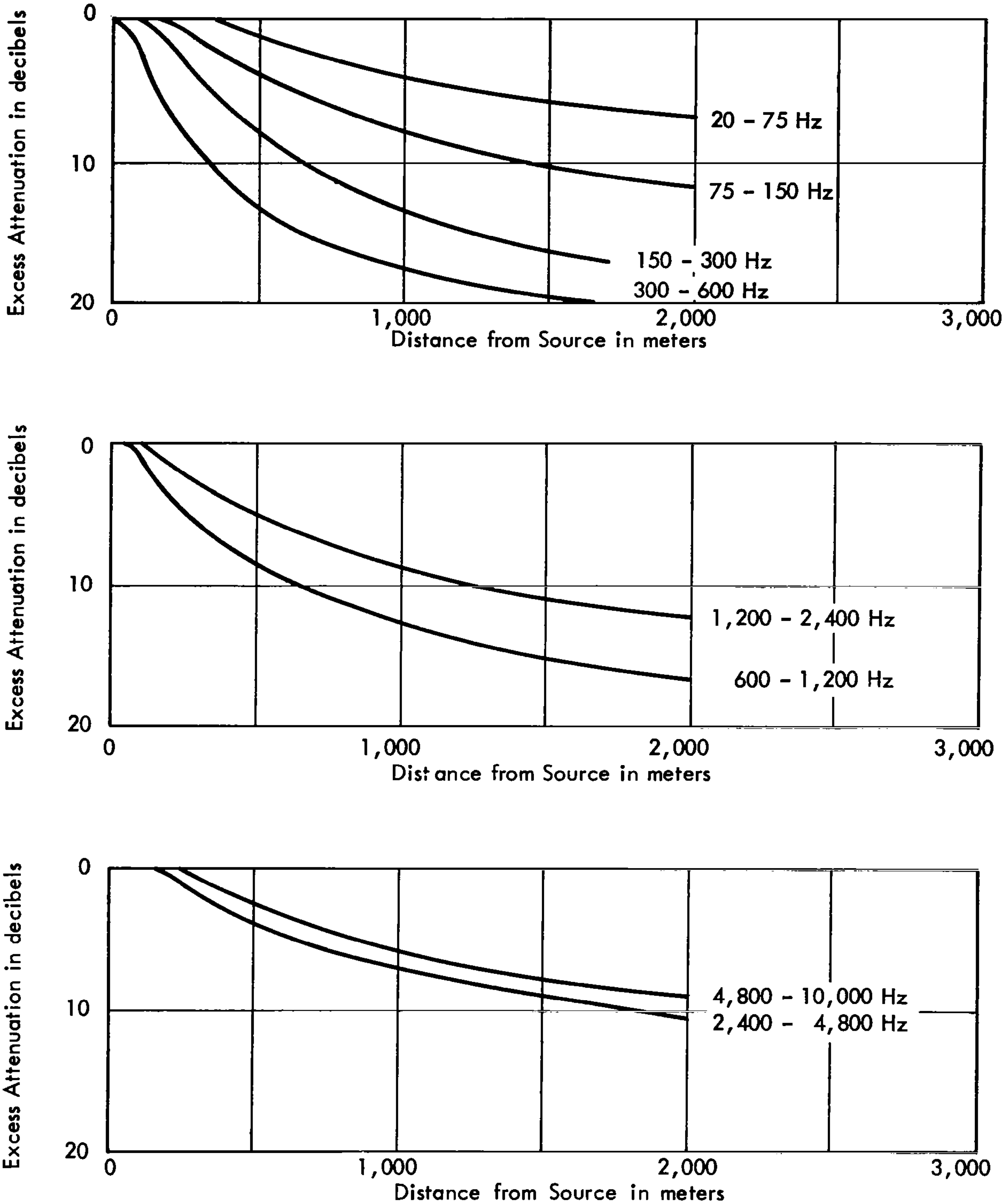

FIGURE 8. DOWNWIND ATTENUATION AS A FUNCTION OF DISTANCE -- NO WIND

Based on SAE Draft Procedure (Ref. 9)

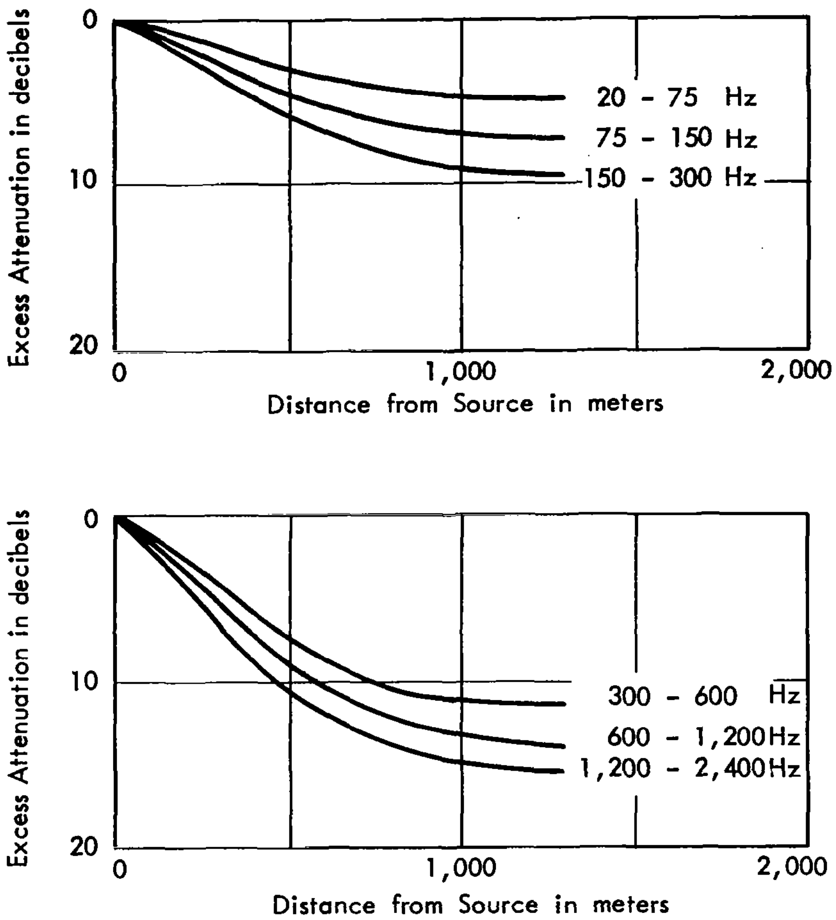

FIGURE 9. DOWNWIND ATTENUATION AS A FUNCTION OF DISTANCE -- 10 mi/hr WIND

Based on SAE Draft Procedure (Ref. 9)

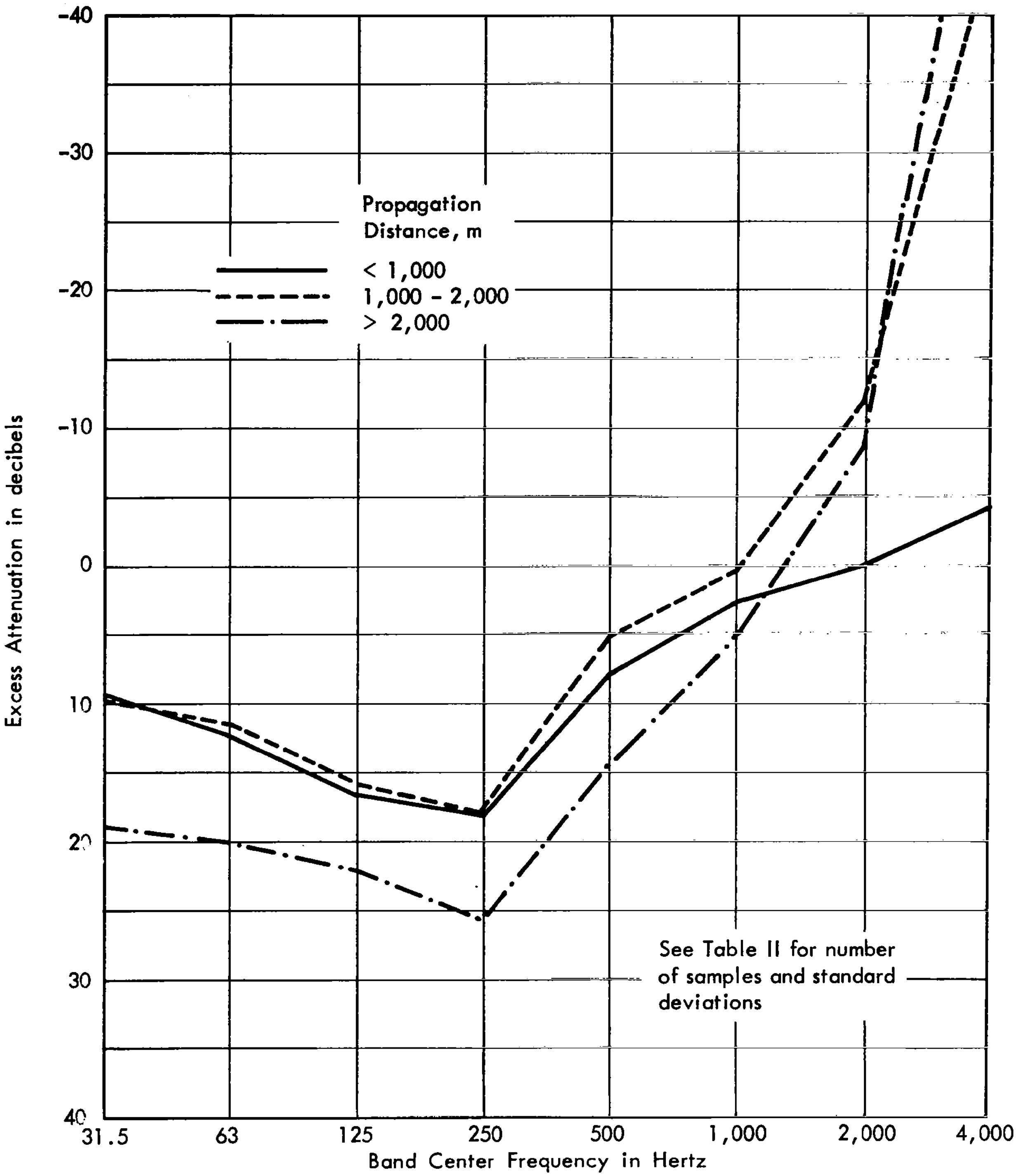

FIGURE 10. MEAN VALUES OF EXCESS ATTENUATION
Wind Speed Less than 5 m/sec -- Standard Attenuation Included

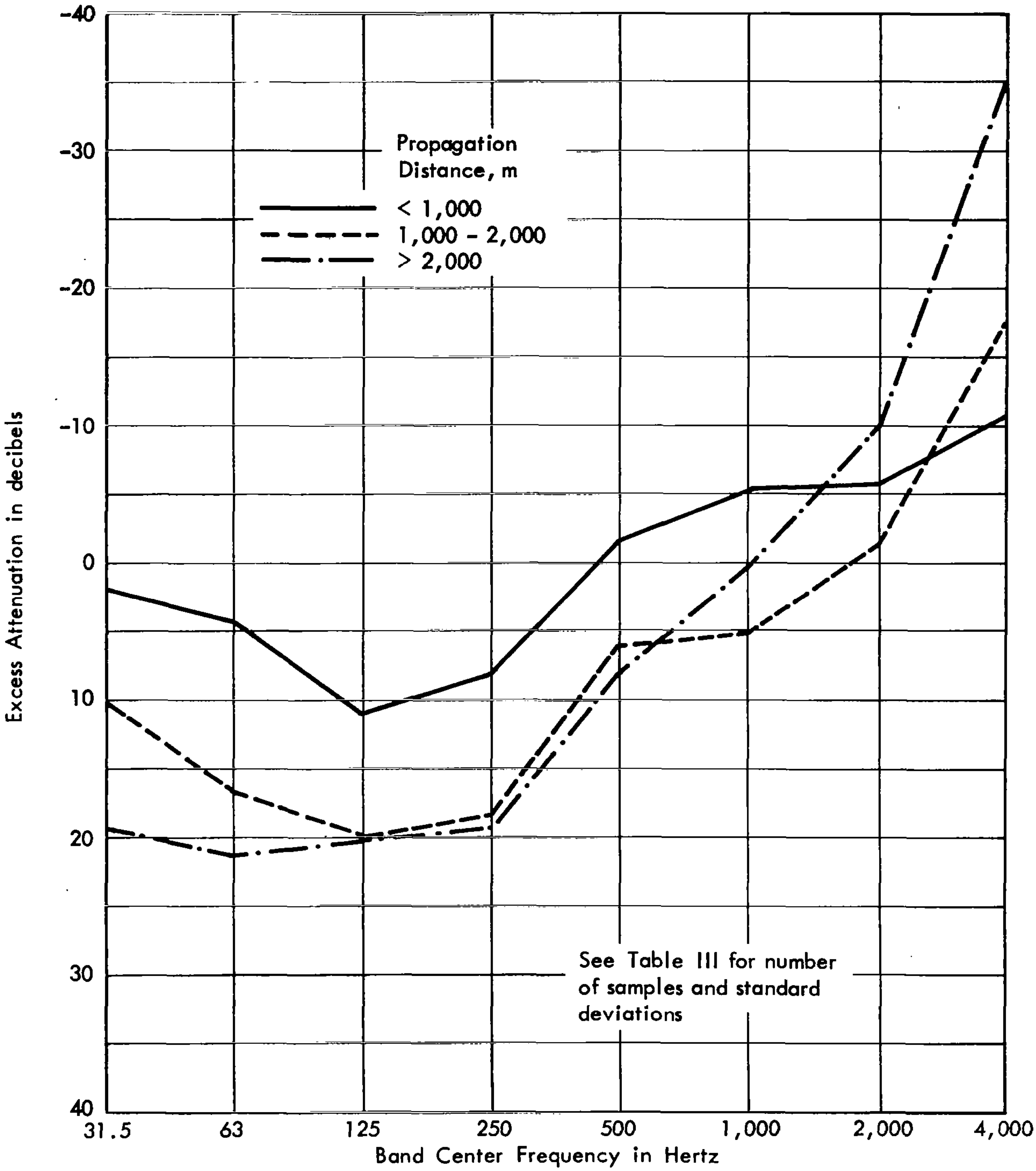

FIGURE 11. MEAN VALUES OF EXCESS ATTENUATION
Wind Speed Greater than 5 m/sec -- Standard Attenuation Included

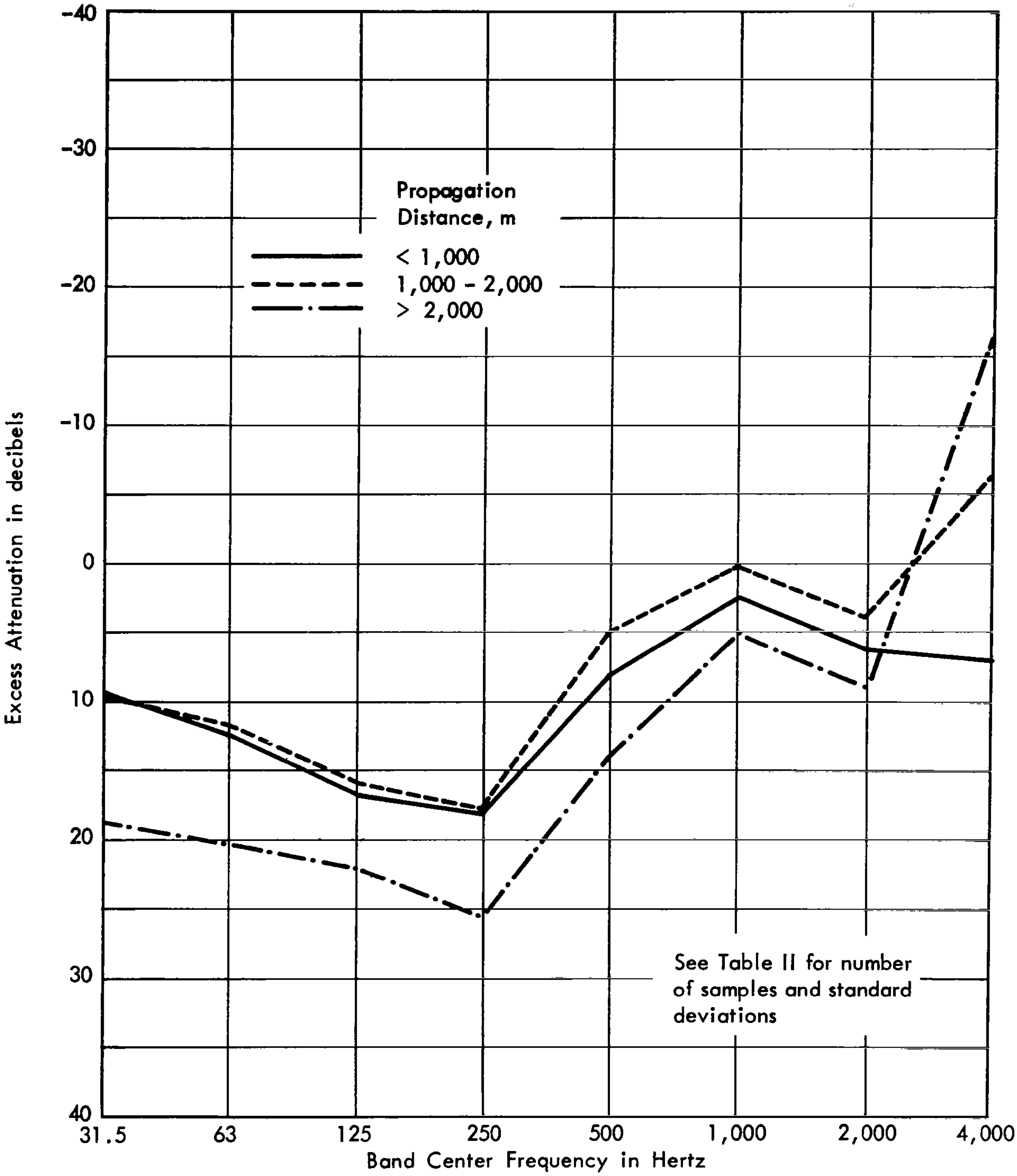

FIGURE 12. MEAN VALUES OF EXCESS ATTENUATION
Wind Speed Less than 5 m/sec -- Standard Attenuation Halved at 2,000 and 4,000 Hz

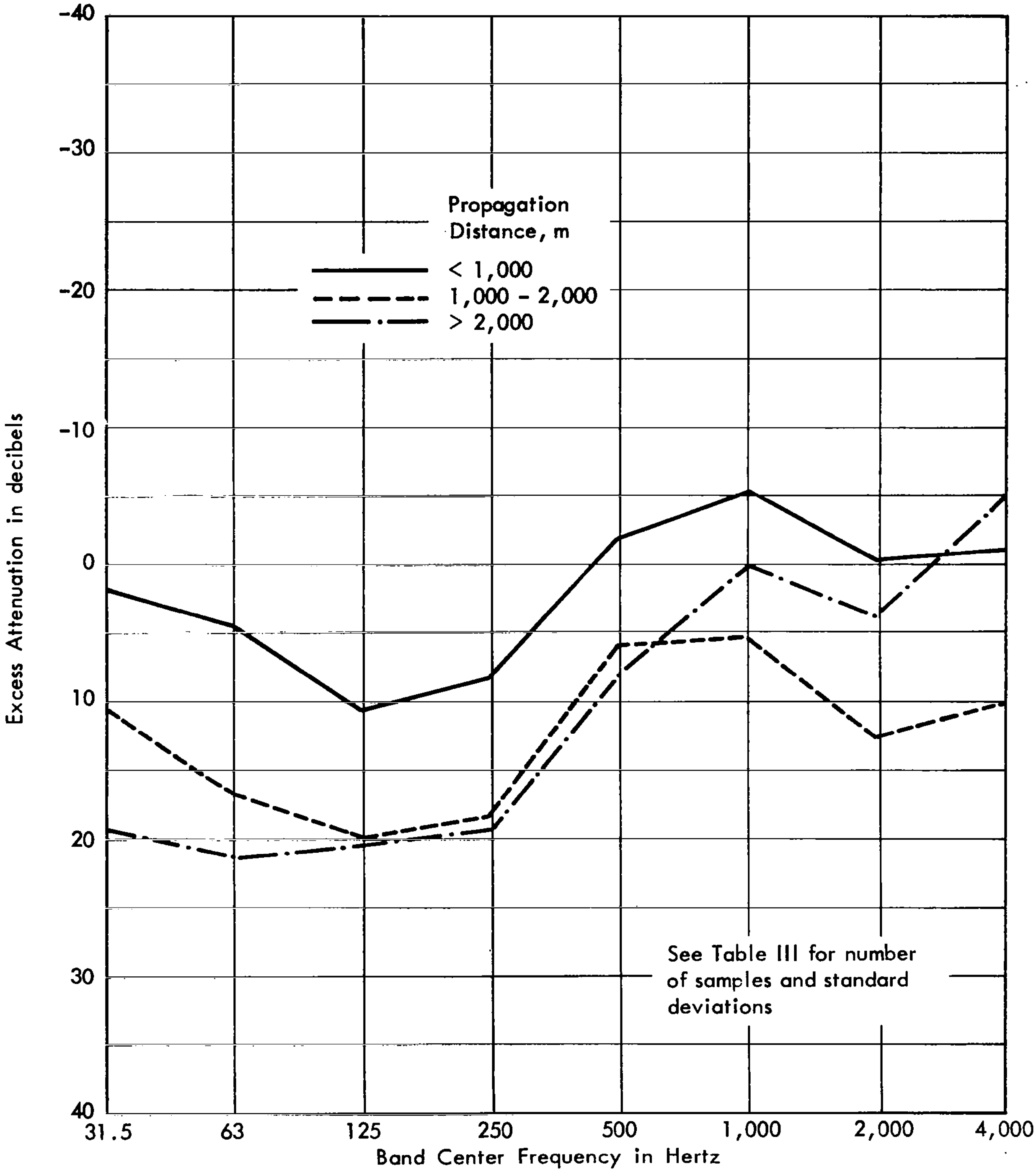

FIGURE 13. MEAN VALUES OF EXCESS ATTENUATION
Wind Speed Greater than 5 m/sec -- Standard Attenuation Halved at 2,000 and 4,000 Hz

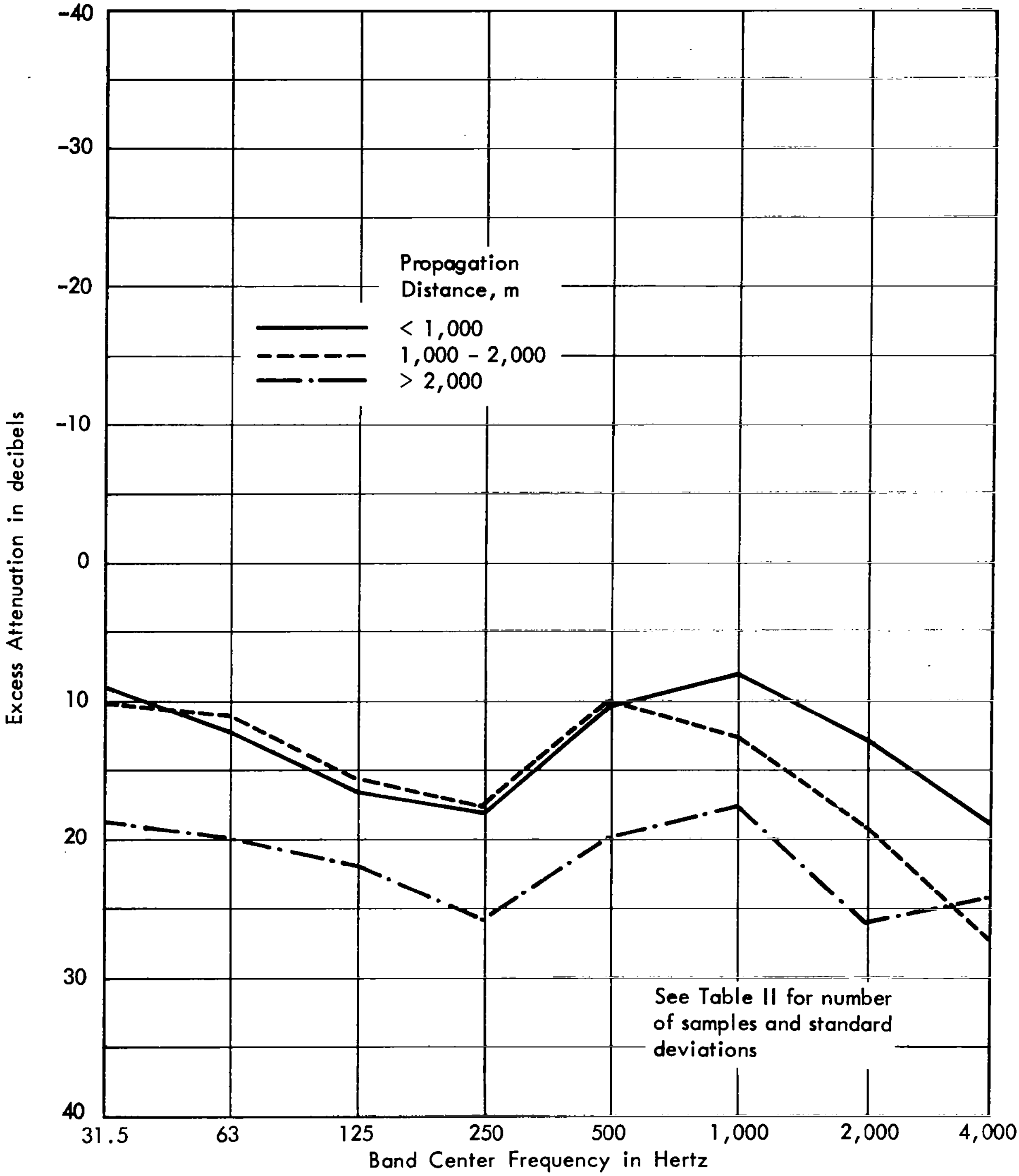

FIGURE 14. MEAN VALUES OF EXCESS ATTENUATION
Wind Speed Less than 5 m/sec -- No Standard Attenuation Included

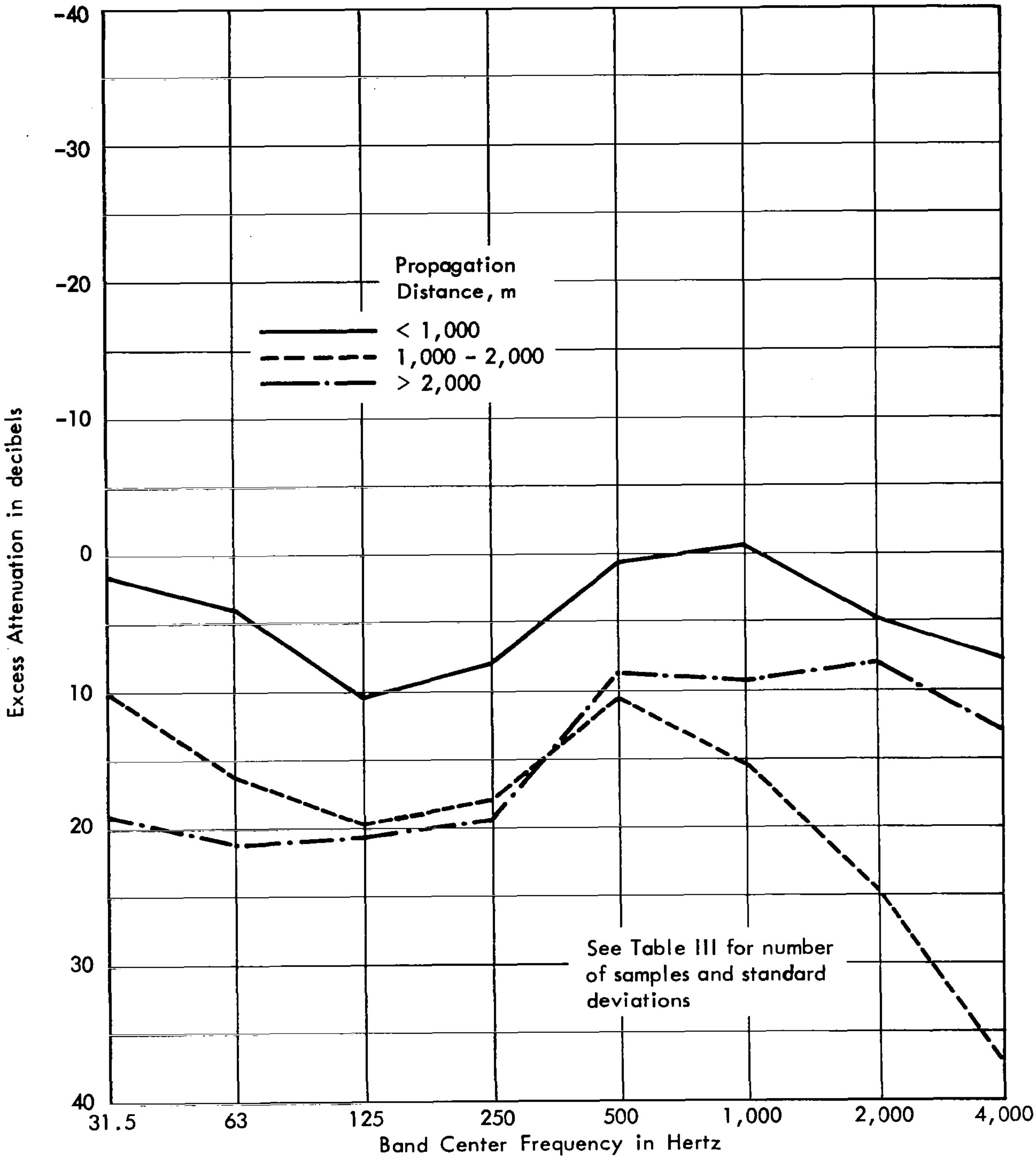

FIGURE 15. MEAN VALUES OF EXCESS ATTENUATION
Wind Speed Greater than 5 m/sec -- No Standard Attenuation Included

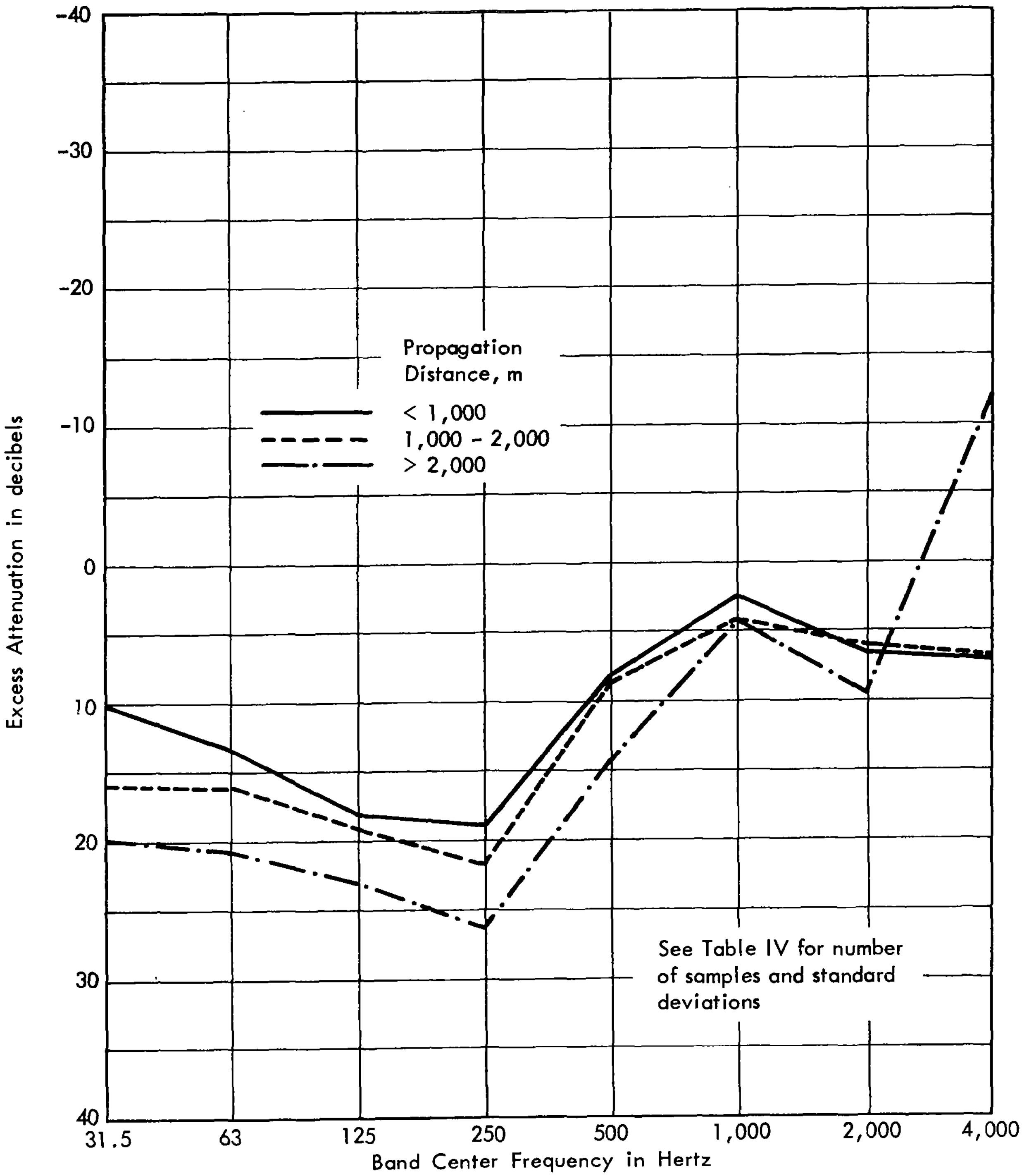

FIGURE 16. MEAN VALUES OF EXCESS ATTENUATION
Wind Speed Less than 3 m/sec

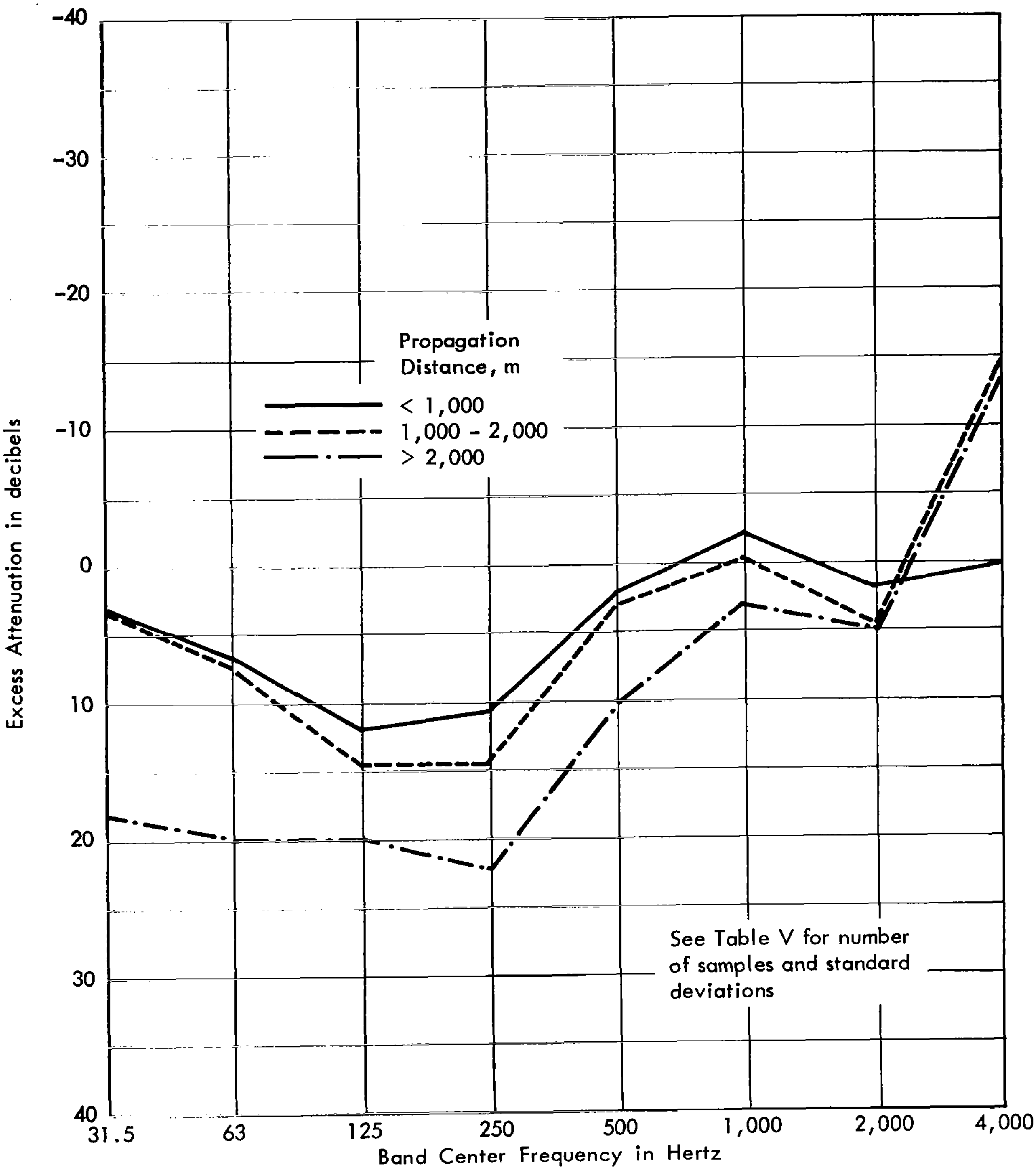

FIGURE 17. MEAN VALUES OF EXCESS ATTENUATION
Wind Speed Greater than 3 m/sec

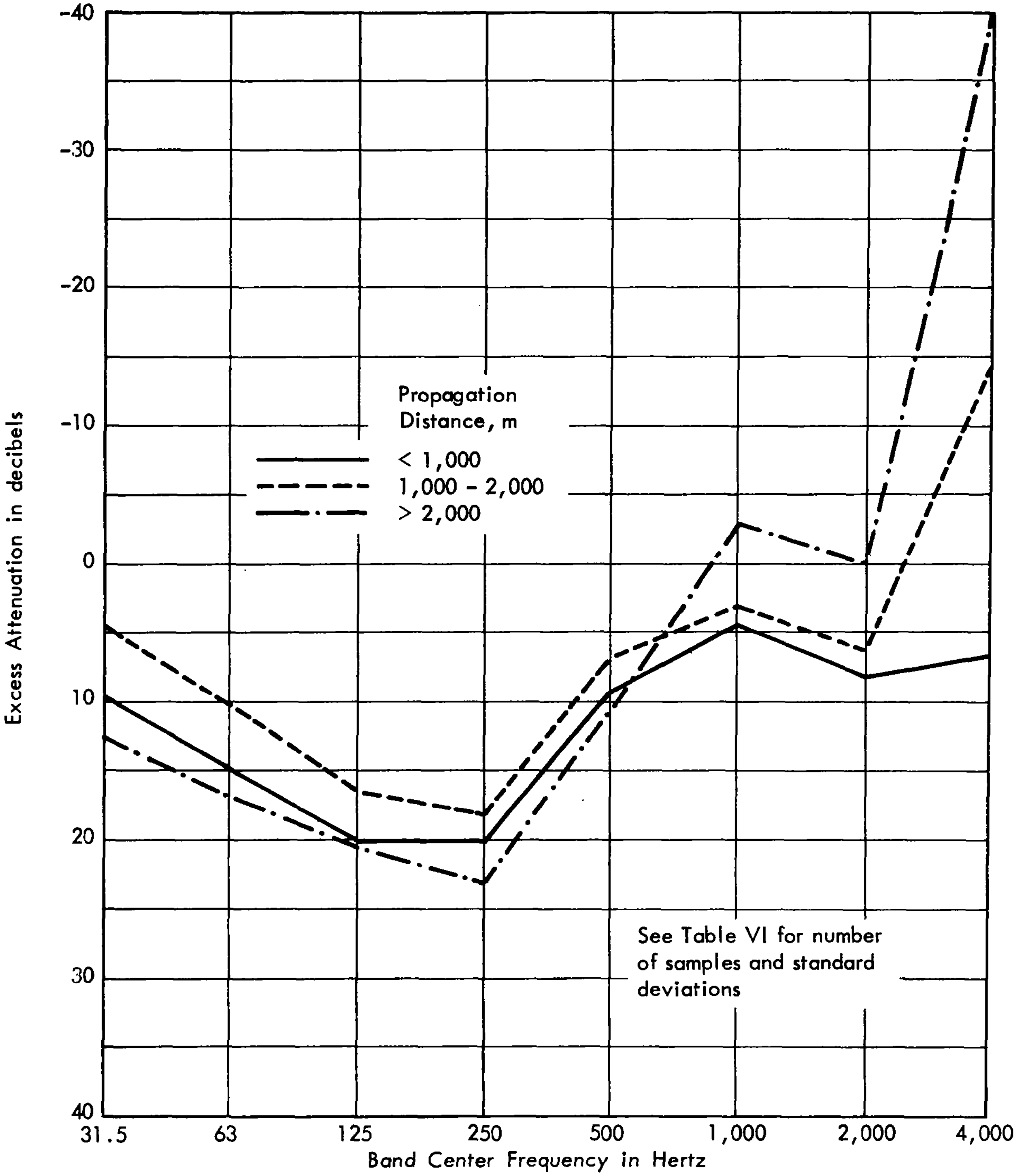

FIGURE 18. MEAN VALUES OF EXCESS ATTENUATION
Wind Vector Component Less than -1 m/sec

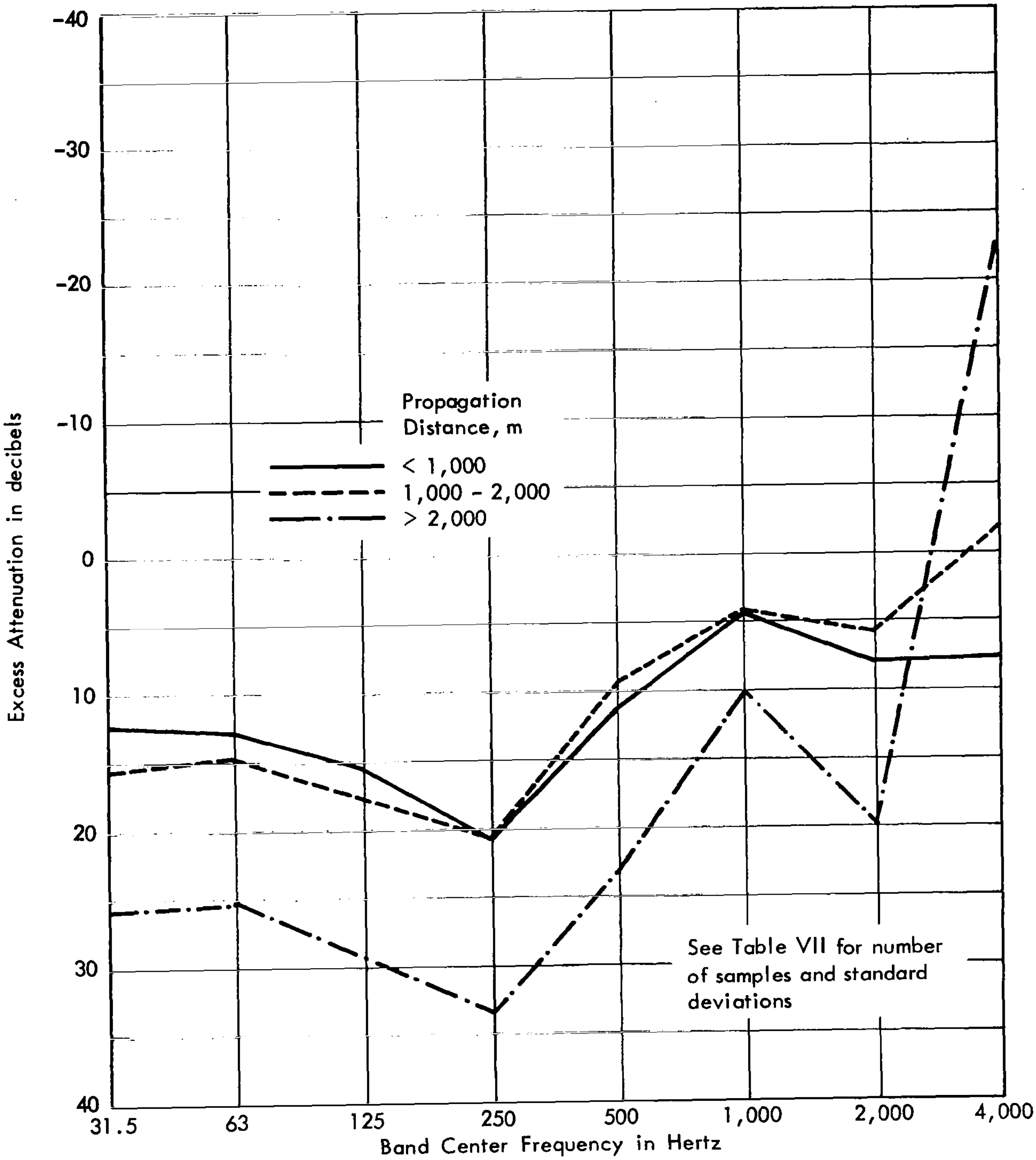

FIGURE 19. MEAN VALUES OF EXCESS ATTENUATION
Wind Vector Component between -1 m/sec and +1 m/sec

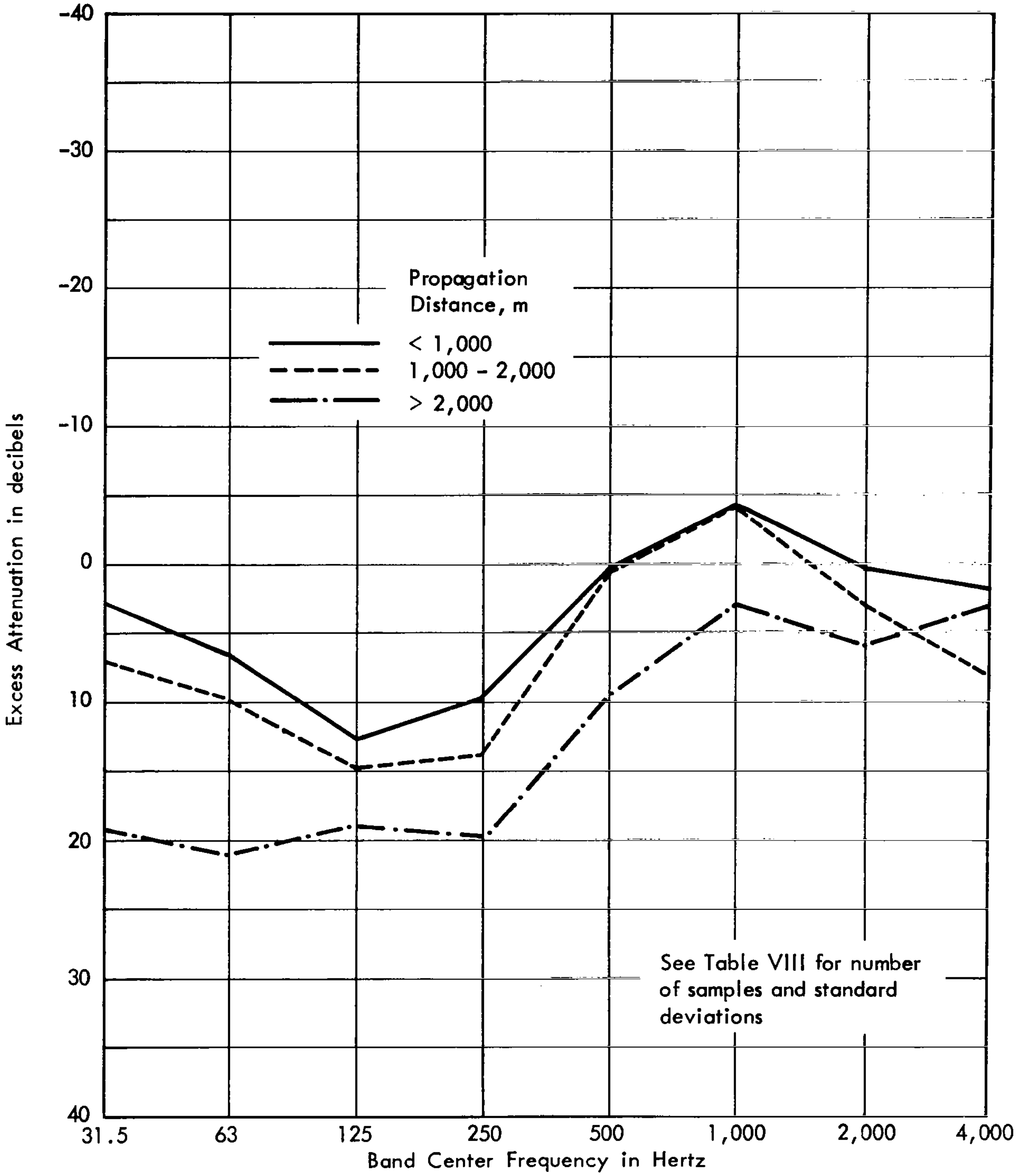

FIGURE 20. MEAN VALUES OF EXCESS ATTENUATION
Wind Vector Component Greater than 1 m/sec

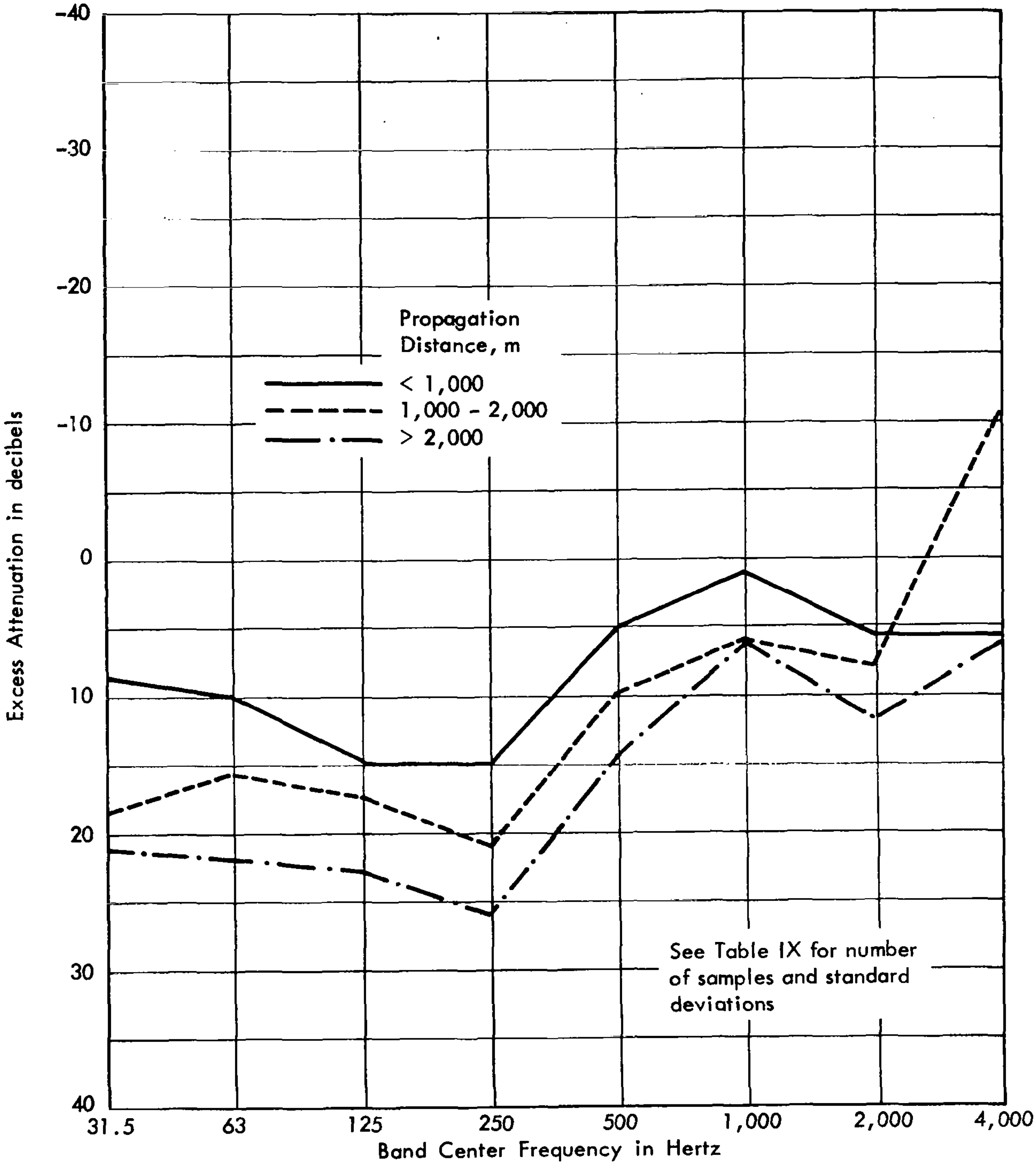

FIGURE 21. MEAN VALUES OF EXCESS ATTENUATION
Negative Temperature Gradient

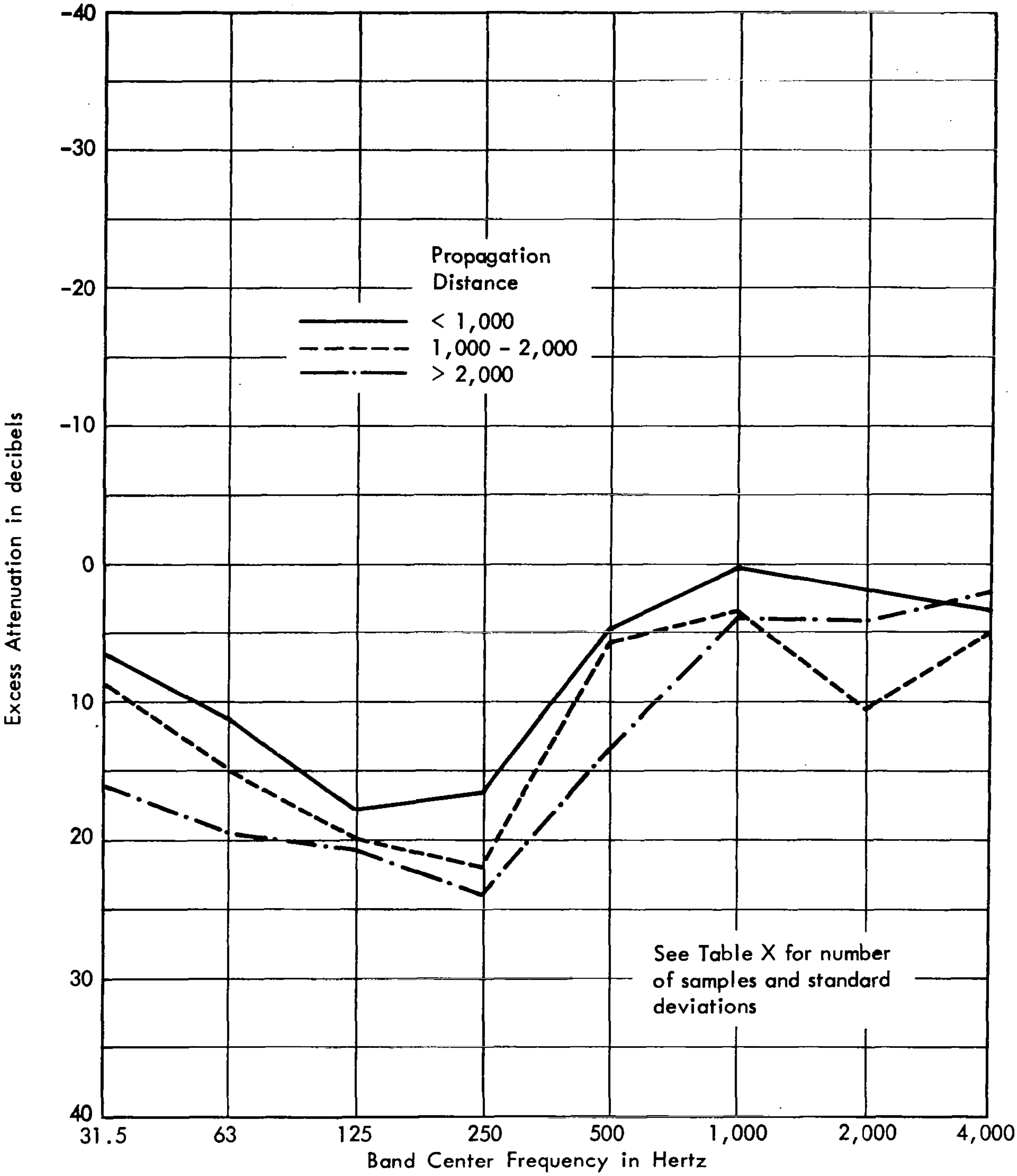

FIGURE 22. MEAN VALUES OF EXCESS ATTENUATION
Neutral Temperature Gradient

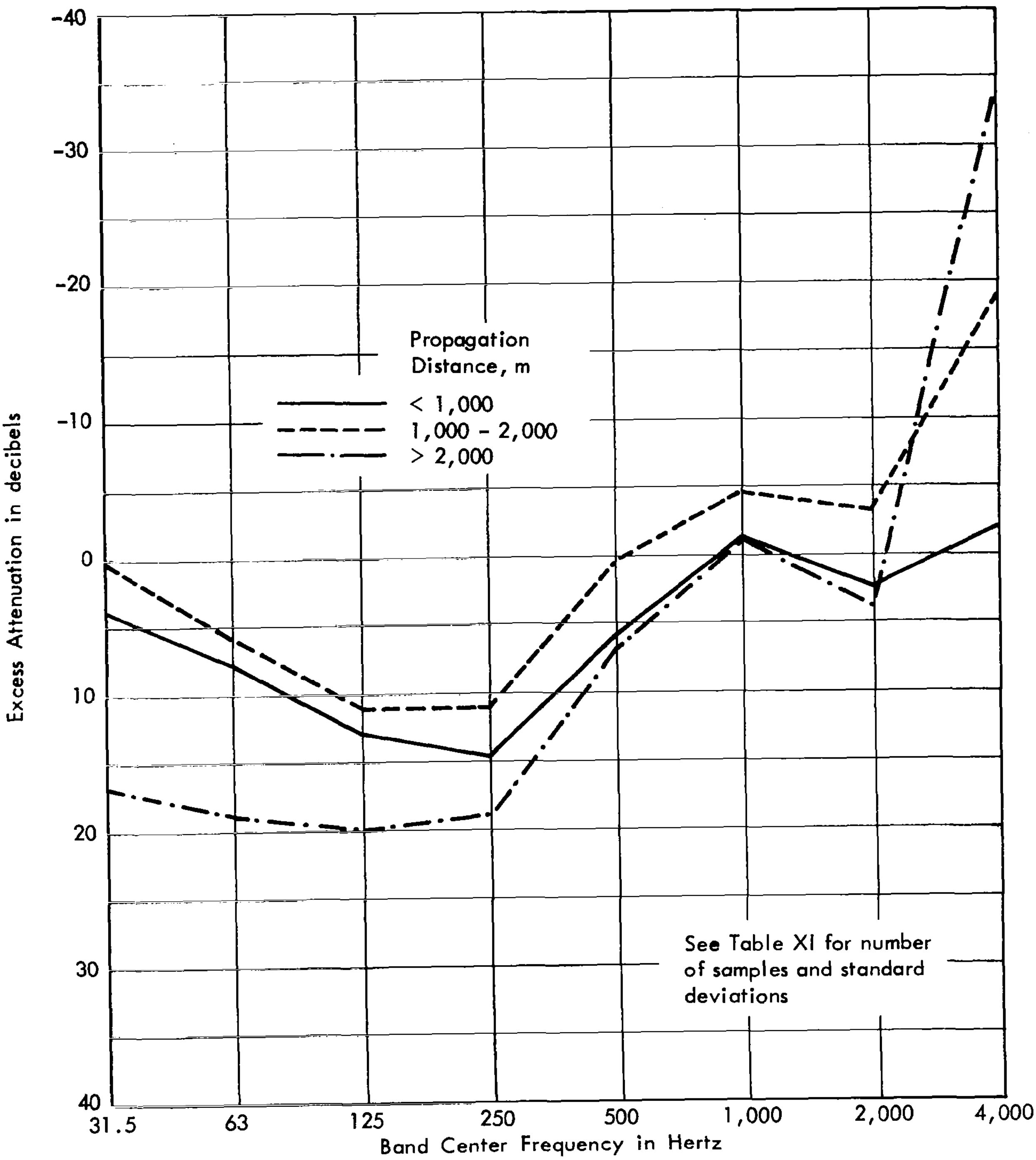

FIGURE 23. MEAN VALUES OF EXCESS ATTENUATION
Positive Temperature Gradient

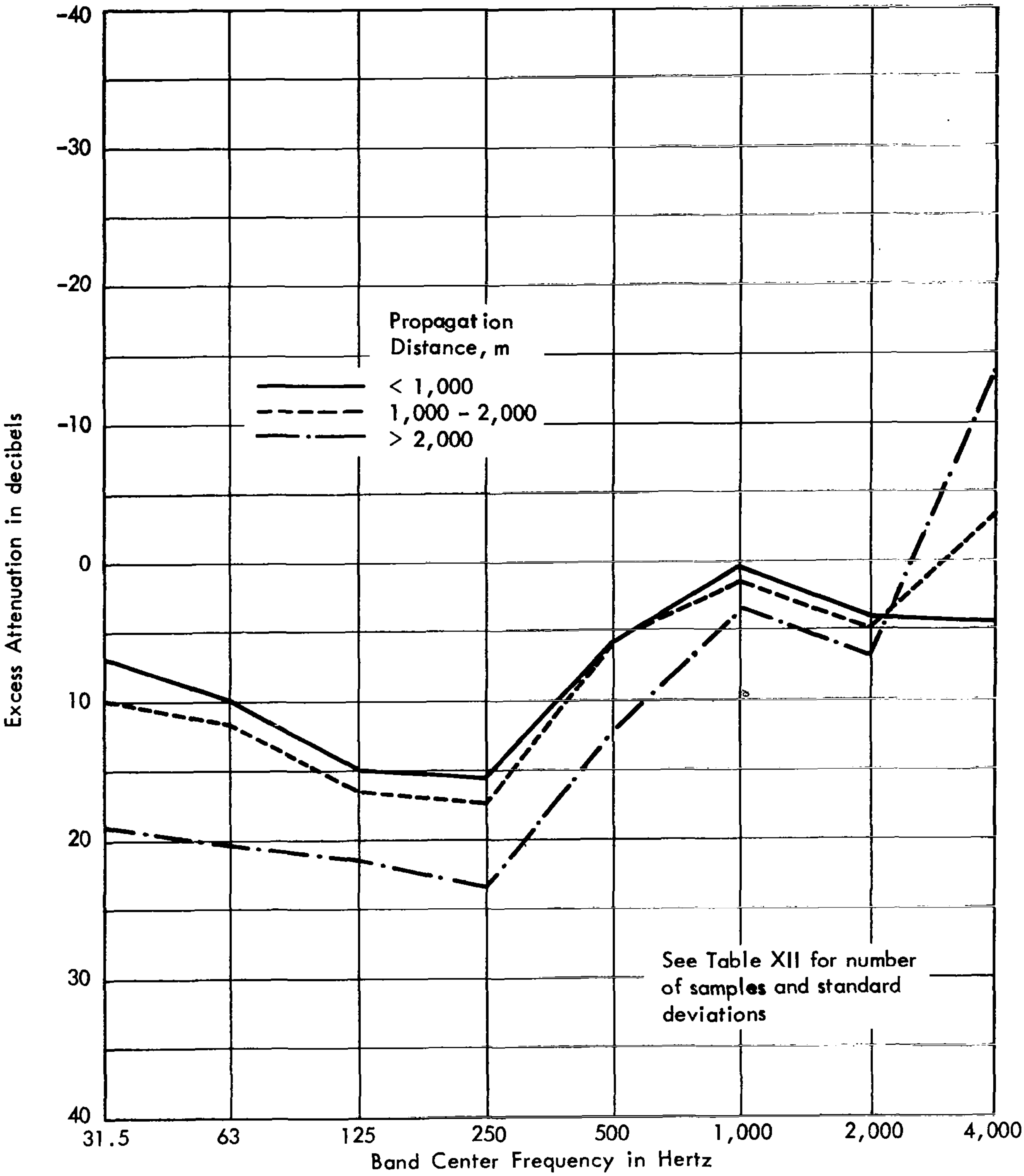

FIGURE 24. MEAN VALUES OF EXCESS ATTENUATION

All Data

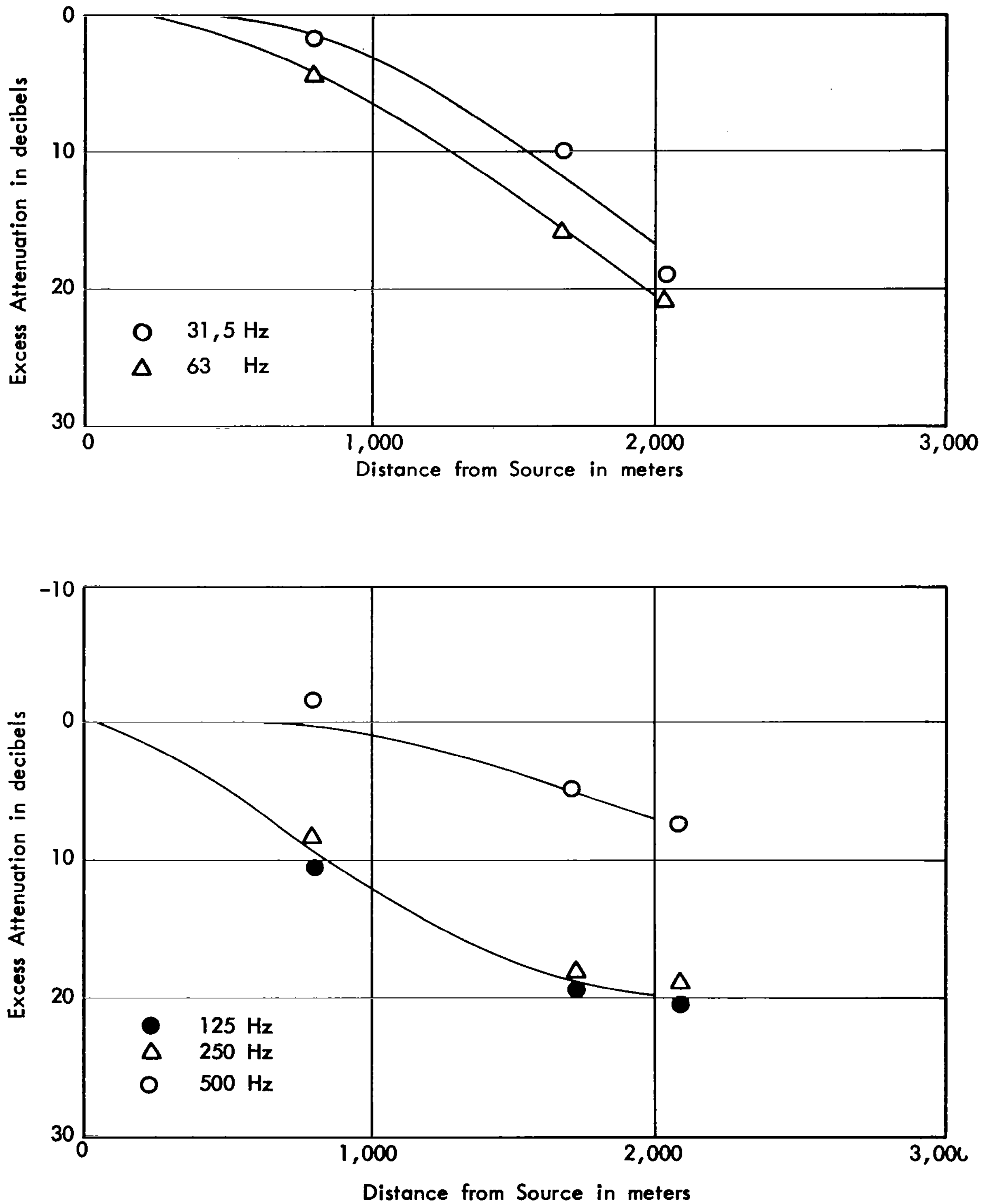

FIGURE 25. CROSS - PLOT OF MEAN EXCESS ATTENUATION RESULTS
Based on Data for Wind Speeds Greater than 5 m/sec

APPENDIX A

ATTENUATION DATA

Table A-1 presents all attenuation values obtained during the measurement program. As explained in the body of this report, the data contained in this table have not been adjusted for standard attenuation. However, the meteorological condition associated with each set of measurements is given, so that the standard attenuation may be applied to the data, if desired.

Table A-2 gives the angular direction of the radials used in the measurement program.

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
22/12	14	3000	L1	50	13	+	5.1	2.6	5	X	X	X	8	8	14	23	25
22/12	15	2090	L1	35	13	+	7.2	-2.6	13	X	X	X	2	X	-10	X	1
									15	X	X	15	11	3	X	X	X
6/ 1	8	1360	L3	48	16	+	3.6	2.3	5	X	3	X	14	11	10	18	X
6/ 1	8	810	L3	36	20	+	3.6	0.6	7	0	4	2	11	8	9	12	18
									8	X	4	X	X	X	X	X	X
6/ 1	10	2110	L3	48	16	+	3.6	2.3	3	X	X	-5	10	2	9	X	X
									5	X	X	X	13	14	10	X	X
6/ 1	10	1660	L3	36	20	+	3.6	0.6	0	X	X	X	X	X	X	X	X
13/ 1	13	760	L3	20	25	-	3.6	0.0	2	X	16	22	44	18	X	X	X
13/ 1	16	796	L3	30	21	-	4.1	0.0	11	X	X	X	X	X	15	17	X
									12	X	X	21	X	17	16	22	35
									13	9	20	22	X	12	6	9	30
3/ 2	10	860	L1	40	16	+	4.6	-4.3	3	17	22	24	25	19	21	29	X
									8	X	X	23	19	15	12	X	X
									10	21	24	28	28	23	19	19	X
									13	18	24	27	27	22	20	24	X
3/ 2	12	1390	L1	35	20	+	2.6	-1.8	14	11	16	20	18	18	14	16	X
									15	17	23	25	28	26	26	X	X
3/ 2	10	2240	L1	40	16	+	4.6	-4.3	8	X	X	24	22	16	16	6	X
									9	16	20	29	24	25	26	X	X
									10	23	24	28	29	21	26	21	13
									13	16	15	16	17	20	21	22	X

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
3/ 2	12	2410	L1	35	20	+	2.6	-1.8	15	25	26	27	32	29	29	26	17
10/ 2	16	1310	L1	25	16	-	8.2	-0.8	5	26	X	31	29	28	31	46	X
									7	11	27	21	19	17	26	24	25
10/ 2	16	2240	L1	25	16	-	8.2	-0.8	2	8	23	31	35	32	X	X	X
									3	6	16	13	28	24	X	X	X
									7	X	27	29	25	27	X	X	X
18/ 2	9	758	L3	76	12	-	3.1	2.4	5	X	3	-9	-20	X	X	X	X
									7	X	6	1	-4	-13	-8	4	10
18/ 2	10	544	L3	76	12	-	2.6	2.0	9	X	12	11	11	3	6	7	15
18/ 2	9	1470	L3	76	12	-	3.1	2.4	7	X	14	12	10	1	15	X	X
24/ 2	22	1530	L3	74	11	-	6.2	-2.1	2	-6	X	13	18	14	11	24	X
2/ 3	22	875	L1	40	8	+	4.7	-3.6	1	2	9	12	13	8	7	9	9
									2	7	5	12	9	4	6	6	X
									3	2	7	11	2	0	0	1	3
									4	4	5	10	5	-6	-2	8	21
									5	8	11	13	15	13	12	13	X
									6	0	13	4	3	-4	-9	8	X
									7	5	8	17	15	15	12	18	X
									8	14	X	X	X	X	21	27	X
2/ 3	23	785	L2	40	8	+	4.6	4.3	9	-22	-10	2	-2	-15	-12	-2	X
									10	-20	-9	2	X	X	X	4	X
									11	-22	X	0	X	X	X	-10	X
									13	-19	-8	-1	-7	-16	-18	-8	X
									14	-23	-13	-2	-3	-9	-11	-2	X
2/ 3	22	1870	L1	40	8	+	4.7	-3.6	4	X	X	X	X	-5	3	4	X
									8	4	6	8	X	5	14	X	X

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
2/ 3	23	1640	L2	40	8	+	4.6	4.3	9	-16	-14	-8	-15	-27	-18	-1	X
									10	-15	-16	-11	-18	-22	-17	3	X
									13	-6	-10	-7	-2	-21	-19	-4	X
									14	-11	-13	-12	-10	-14	-15	X	X
8/ 3	16	1060	D1	45	11	0	7.5	6.5	11	-2	11	13	9	7	5	14	38
									13	3	15	20	17	-1	9	12	35
8/ 3	16	1920	D2	45	11	0	7.5	6.5	8	-5	0	14	10	-4	9	28	75
									9	-2	-1	18	12	6	28	31	X
									13	3	14	19	15	-1	13	28	X
9/ 3	11	1060	D1	28	15	0	2.8	-2.0	2	3	11	5	34	18	22	36	X
									3	X	X	25	33	17	18	48	X
									4	-3	8	19	26	18	17	30	49
									5	8	6	11	12	0	-2	16	X
9/ 3	12	503	D1	21	18	0	3.6	-0.3	8	5	10	16	24	22	18	18	X
									9	1	1	10	12	16	15	19	30
									11	0	1	8	12	18	16	21	X
9/ 3	13	503	D1	21	18	0	4.6	-0.8	0	X	X	X	X	X	X	X	X
9/ 3	18	503	D1	25	16	-	3.5	0.0	0	X	X	X	X	X	X	X	X
9/ 3	11	2700	D1	28	15	0	2.8	-2.0	2	15	21	26	29	21	X	X	X
									3	X	X	31	35	X	X	31	X
									4	-3	X	X	22	X	16	32	X
									5	10	12	20	16	0	-2	22	X
9/ 3	12	1220	D1	21	18	0	3.6	-0.3	8	-3	1	11	19	14	7	17	21
									9	-7	-6	-2	2	7	7	-5	0
									11	-4	3	15	11	X	6	11	31
									14	7	16	X	25	X	29	30	X
9/ 3	13	1740	D1	21	18	0	4.6	-0.8	28	9	17	20	20	9	8	23	27

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
9/ 3	18	1220	D1	25	16	-	3.5	0.0	30	-6	-1	9	13	12	13	27	X
									31	3	2	18	31	18	19	30	X
									32	6	10	23	23	5	27	35	X
10/ 3	11	680	D2	33	12	+	3.8	-0.7	2	7	X	4	0	3	11	23	X
									4	-4	-3	-3	2	4	4	11	X
									5	X	-3	X	X	4	X	X	X
									6	-3	-4	0	8	-2	2	23	X
10/ 3	12	1060	D1	21	18	+	4.3	-3.0	9	2	7	15	25	17	19	X	X
									10	-1	15	18	16	22	27	X	X
10/ 3	13	1060	D1	18	18	+	3.1	-2.4	13	2	8	16	18	12	16	37	X
									14	3	9	18	20	17	17	23	X
									15	6	13	19	19	11	11	X	X
									16	-3	-1	10	5	9	X	X	X
									17	-10	1	X	13	9	7	11	X
									18	-1	8	18	16	12	20	39	X
									19	-2	10	13	13	13	14	X	X
10/ 3	15	680	D2	17	17	-	2.6	1.7	20	-8	-6	-3	3	0	4	14	38
									21	-7	-5	-2	2	0	6	17	X
10/ 3	15	680	D2	17	17	-	2.6	-0.5	22	16	-7	1	6	7	12	26	X
									23	-4	X	-1	4	3	9	20	36
10/ 3	16	503	D1	18	17	-	5.1	5.1	26	-8	-14	-10	-11	1	-5	16	X
									27	-6	-8	-3	7	10	9	26	X
									28	-7	-6	-1	11	7	-1	3	X
									29	-8	-8	0	8	1	-9	10	22
10/ 3	11	1710	D2	33	12	+	3.8	-0.7	4	-5	-2	6	8	5	11	11	25
10/ 3	12	2700	D1	21	18	+	4.3	-3.0	8	18	17	19	23	19	11	15	37
									10	8	25	16	25	24	33	X	X
									12	4	12	11	26	9	8	12	25

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
10/ 3	13	1920	D1	18	18	+	3.1	-2.4	15	12	14	24	16	11	17	18	16
									16	4	3	5	-2	5	9	24	34
									19	4	13	19	21	18	20	27	31
10/ 3	15	1710	D2	17	17	-	2.6	1.7	21	0	X	9	7	4	15	23	28
10/ 3	15	1710	D2	17	17	-	2.6	-0.5	23	-2	-6	23	X	21	17	25	29
10/ 3	16	1740	D1	18	17	-	5.1	5.1	0	X	X	X	X	X	X	X	X
11/ 3	5	1060	D1	79	1	+	0.0	0.0	1	-1	10	17	24	-3	-2	28	24
									2	1	7	10	4	-11	-5	12	X
									3	1	11	13	23	9	19	30	32
11/ 3	5	1060	D1	79	1	+	0.0	0.0	4	0	10	26	25	10	17	24	X
11/ 3	7	503	D1	77	1	+	2.0	-2.0	6	-3	-1	10	17	7	2	12	14
									9	15	14	18	17	15	21	18	30
									10	14	11	12	14	10	15	22	39
11/ 3	5	2700	D1	79	1	+	0.0	0.0	1	8	13	22	12	-5	-1	36	X
									3	8	6	8	6	-2	9	33	X
11/ 3	5	1920	D1	79	1	+	0.0	0.0	4	-2	8	X	14	-7	4	15	X
11/ 3	7	1740	D1	77	1	+	2.0	-2.0	6	0	X	X	X	X	X	X	X
									9	3	4	14	3	6	6	19	X
									10	0	X	0	1	4	13	X	X
18/ 3	9	876	L1	23	23	+	2.6	-0.5	5	19	X	30	27	17	5	23	X
									6	19	X	25	27	19	7	32	X
									11	15	22	21	21	17	12	X	X
									12	18	28	34	34	26	16	X	X
									14	16	22	26	28	24	14	37	X
									16	16	27	26	X	23	13	X	X
									18	13	27	X	31	25	19	35	X

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
18/ 3	10	784	L2	20	25	+	2.1	-1.4	24	12	6	7	14	8	-5	12	-2
									27	0	1	6	13	0	X	-5	X
									29	4	3	13	17	8	-5	2	2
18/ 3	11	784	L2	20	25	+	2.1	-1.4	32	3	2	11	23	14	1	12	X
									37	1	5	13	21	5	-3	2	X
									40	X	X	X	X	X	X	X	13
									41	0	4	8	14	-1	-3	5	24
									43	2	6	11	11	7	-16	-3	20
18/ 3	9	2020	L1	23	23	+	2.6	-0.5	5	24	20	26	26	X	10	30	24
									8	21	18	20	22	X	14	34	32
									14	26	28	29	31	X	19	31	25
									18	17	24	25	26	27	X	29	X
									21	14	13	23	19	20	16	33	30
18/ 3	10	1780	L2	20	25	+	2.1	-1.4	24	11	11	X	10	-5	-4	6	9
18/ 3	11	2020	L2	20	25	+	2.1	-1.4	32	18	16	24	17	19	12	33	3
									35	19	20	20	13	-2	-5	X	X
									36	20	23	27	30	X	X	X	X
									37	12	17	18	17	8	2	X	30
22/ 3	21	876	L1	66	15	0	3.1	-1.1	1	19	28	35	33	31	28	28	28
									3	24	31	X	35	X	30	X	X
									4	25	26	36	38	37	X	X	X
									5	21	24	27	25	18	13	12	25
22/ 3	23	784	L2	70	14	0	2.1	-1.6	8	-1	19	23	26	6	4	11	19
									9	3	9	19	9	-2	7	4	3
									11	2	9	19	20	23	9	15	X
									12	1	7	11	20	10	5	11	13
									13	0	8	12	11	6	14	10	4
									14	10	15	X	17	X	X	X	X
									15	0	7	23	20	-7	4	4	8
									16	-1	6	X	X	X	X	X	X

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
									17	-2	7	21	14	0	1	X	19
									18	2	6	20	17	1	3	8	8
									20	-4	9	18	14	-10	-2	2	5
									19	3	11	25	6	-12	-3	-4	X
									23	-3	0	10	5	-8	-3	2	7
									24	-4	7	7	2	-8	-4	2	4
22/ 3	21	2020	L1	66	15	0	3.1	-1.1	2	X	27	27	30	X	X	X	X
									3	X	X	X	X	34	X	X	X
									4	X	X	X	38	31	26	30	X
									5	20	X	26	27	16	X	X	X
22/ 3	23	1860	L2	70	14	0	2.1	-1.6	13	X	X	32	37	21	30	25	36
									15	20	27	34	20	X	28	27	35
									20	24	26	23	23	9	12	X	X
									23	X	21	18	X	1	X	13	31
									24	21	16	16	21	8	11	21	28
30/ 3	7	876	L1	79	15	-	2.1	-2.1	2	29	39	40	37	27	33	40	46
									3	31	36	39	38	25	25	30	38
									4	30	36	38	39	33	34	40	X
									5	22	28	36	35	31	32	34	X
									6	31	36	40	37	32	35	36	45
									7	31	37	40	38	30	32	38	43
									9	29	33	40	36	44	29	X	41
30/ 3	8	784	L2	77	16	-	2.1	0.7	13	10	14	25	20	-4	X	X	X
									15	8	16	20	17	11	X	19	25
									16	10	14	25	24	15	12	17	24
									19	13	16	30	27	12	X	20	27
									20	11	19	33	28	20	15	19	30
									21	7	18	31	26	15	4	15	25
									22	8	18	29	27	11	9	18	28
									23	6	15	29	23	8	5	7	17
									24	7	16	22	21	20	11	16	26
									26	11	19	25	16	X	X	-4	1

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
									27	15	19	29	26	11	6	16	26
									30	11	12	23	10	17	14	10	8
									31	-10	-2	-2	-8	X	X	-3	4
									32	9	10	13	9	X	X	X	X
									33	-4	4	13	9	0	0	7	7
30/ 3	7	2020	L1	79	15	-	2.1	-2.1	1	9	12	12	13	X	X	X	X
									2	2	7	X	X	X	X	X	X
									5	8	11	11	X	X	X	X	X
									6	X	11	X	X	X	X	11	X
									9	3	9	11	X	X	X	X	X
30/ 3	8	1860	L2	77	16	-	2.1	0.7	11	0	12	15	13	0	9	11	X
									16	5	-3	11	10	-1	7	X	X
									20	X	X	9	X	X	X	X	X
									23	X	-22	-15	X	X	X	X	X
									24	X	-22	-16	-13	-18	-14	-9	X
									28	-12	X	X	-5	-15	X	-11	X
									30	-15	X	X	-17	-21	X	-18	X
									33	X	-22	X	-22	-19	X	X	X
8/ 4	6	876	L1	70	15	-	2.1	0.4	2	39	X	X	40	36	38	44	49
									3	31	X	X	X	41	X	X	X
									4	28	27	35	X	X	X	X	28
									5	25	32	18	39	26	25	23	34
									7	39	36	X	41	32	34	23	X
8/ 4	7	784	L2	63	16	-	1.5	0.0	9	24	14	-2	17	X	X	X	24
									12	25	14	-11	18	21	15	17	20
									13	22	13	-4	20	X	X	9	9
									14	23	17	-4	32	X	X	X	X
									15	25	15	X	25	X	10	19	13
									16	22	15	X	25	14	10	16	26
									18	25	16	5	27	20	8	17	X
									17	25	12	X	20	9	7	10	14
									19	25	17	X	22	X	X	14	14

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
									20	26	17	5	31	23	13	5	16
									21	26	15	X	X	X	3	11	14
									22	24	19	X	25	16	10	X	X
8/ 4	6	2020	L1	70	15	-	2.1	0.4	1	49	X	X	57	54	58	63	X
									2	36	X	X	47	45	48	51	X
									3	35	36	53	45	X	X	X	X
									4	45	41	57	54	X	X	X	X
									5	46	46	36	55	42	X	X	X
									7	41	37	X	38	47	X	32	X
8/ 4	7	1860	L2	63	16	-	1.5	0.0	8	37	X	X	X	X	X	X	X
									9	43	X	X	X	50	X	X	X
									12	41	46	28	61	55	X	X	X
									13	42	34	X	37	X	X	X	X
									14	34	X	X	X	45	X	X	X
									15	43	45	X	58	51	45	X	X
									16	41	X	X	X	X	X	X	X
									17	44	X	X	X	X	45	38	X
									18	36	32	28	48	46	36	X	X
									19	41	38	X	39	X	X	27	X
									20	40	33	X	43	57	X	29	X
28/ 4	22	876	L1	65	15	0	2.6	2.3	1	12	7	7	4	6	-6	1	23
									3	15	16	14	7	14	8	10	20
									5	X	10	18	14	17	10	12	27
									6	X	17	19	20	10	-8	-6	5
									7	13	17	17	11	2	X	X	11
									8	20	22	24	25	24	9	10	27
									9	16	16	14	9	13	-2	10	27
									10	19	16	19	17	12	3	14	24
									11	15	18	20	11	4	-6	0	22
28/ 4	24	784	L2	70	14	0	1.5	0.3	13	-2	4	18	24	6	1	7	14
									19	-6	0	13	9	-4	-7	-2	X
									20	-2	6	26	17	0	-4	2	22

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
									21	-5	2	13	12	5	-7	3	25
									22	0	6	13	16	-3	-7	-2	23
									24	-3	4	15	21	10	3	5	36
									25	-3	4	2	16	0	1	7	20
									27	-6	4	4	15	11	7	10	21
28/ 4	22	2020	L1	65	15	0	2.6	2.3	1	19	20	16	20	18	7	18	34
									3	12	X	14	X	29	X	X	X
									5	19	11	20	22	24	17	16	19
									6	22	25	20	14	16	3	7	17
									8	27	29	26	31	31	18	20	X
									9	18	20	14	17	22	21	23	X
									10	14	19	18	22	17	11	14	41
									11	16	21	18	17	9	0	9	38
28/ 4	24	1860	L2	70	14	0	1.5	0.3	12	14	19	24	14	7	-8	10	24
									13	18	26	27	25	19	11	X	X
									16	15	19	25	22	8	11	21	40
									18	14	21	27	26	13	17	28	29
									19	17	23	33	31	20	21	21	29
									21	16	12	30	20	X	X	X	X
									24	18	34	38	32	11	8	6	24
									25	18	24	20	28	13	X	X	X
									27	14	27	18	32	X	15	17	24
9/ 3	21	1060	D1	42	7	0	3.5	-3.5	33	-3	-5	0	11	X	X	X	X
9/ 3	21	2700	D1	42	7	0	3.5	-3.5	33	15	1	6	31	X	X	X	X
									36	9	18	26	28	X	X	X	X
9/ 8	9	784	L2	67	23	-	2.6	1.3	11	-4	5	15	X	7	3	8	12
									9	-1	5	18	21	13	5	10	16
									7	-5	6	13	X	0	-8	1	12
									5	-4	4	12	12	-3	-12	-9	4
									4	-1	X	17	X	7	5	4	8
									6	0	5	20	17	5	-2	2	6

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
									10	0	7	X	X	-1	-4	0	2
8/ 8	10	876	L1	65	24	-	4.1	2.6	12	13	19	16	12	10	9	X	X
									13	9	15	16	15	9	8	18	X
									16	17	17	24	24	15	12	23	17
									18	20	25	26	28	26	19	27	34
									15	8	9	6	9	9	12	9	9
9/ 8	21	876	L1	88	19	0	2.6	1.3	23	21	25	15	15	12	8	X	20
									25	40	20	25	26	20	14	10	4
									24	24	24	23	27	20	16	13	X
									26	16	16	17	14	8	12	13	13
									27	19	17	17	14	7	10	13	18
									28	22	23	24	26	17	18	15	23
									29	19	28	23	15	3	3	9	X
9/ 8	23	784	L2	85	19	0	2.6	1.7	33	0	4	17	15	5	5	10	X
									35	-2	5	17	9	-6	0	X	X
									36	3	-3	21	22	1	3	X	X
									38	1	8	25	23	2	6	14	14
									30	0	9	20	13	4	4	9	14
									31	1	2	18	13	4	2	10	13
									32	1	5	19	21	7	5	9	9
									34	-2	4	17	12	-3	-7	3	3
									37	-1	7	22	14	1	4	7	9
9/ 8	9	1860	L2	67	23	-	2.6	1.3	11	18	26	27	24	16	14	X	31
									6	23	X	26	25	16	13	18	X
									10	13	X	X	19	4	8	X	X
9/ 8	10	2020	L1	65	24	-	4.1	2.6	12	17	16	17	17	11	X	X	X
									13	16	17	18	20	13	X	X	X
									16	19	18	27	27	20	23	33	X
									18	25	26	29	30	30	31	37	X
									17	18	25	23	25	19	24	34	X
									19	X	25	20	26	23	26	32	31

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
9/ 8	21	2020	L1	88	19	0	2.6	1.3	23	X	X	22	26	19	24	X	X
									24	21	26	22	27	31	22	26	X
									26	18	24	14	24	14	X	X	X
									27	16	X	24	20	14	23	X	X
									22	X	10	13	12	10	13	13	20
									25	14	X	24	20	17	19	7	9
									28	22	28	27	28	22	27	25	X
									29	X	22	19	24	10	18	X	X
9/ 8	23	1860	L2	85	19	0	2.6	1.7	33	11	20	19	X	15	X	X	X
									36	17	9	32	33	20	X	X	X
									38	14	23	X	X	21	24	X	X
10/ 8	11	876	L1	56	26	-	5.6	4.9	49	17	21	21	17	13	7	8	14
									51	13	13	15	14	5	10	10	16
									52	16	14	12	9	-6	-2	2	6
									53	16	18	19	18	10	6	7	14
									45	15	15	14	15	2	-6	5	X
									46	20	15	16	20	11	12	13	20
									47	12	0	8	10	0	3	7	9
									50	17	17	11	8	5	3	3	1
10/ 8	13	784	L2	53	31	1	5.1	7.0	56	-2	5	14	14	0	-3	3	5
									57	-1	8	21	14	0	1	3	6
									58	3	5	20	13	-2	-6	-2	14
									59	-2	5	X	4	-5	-8	9	-5
									60	-2	2	13	7	-1	-5	3	5
									62	-12	-4	6	3	-5	X	X	X
									65	-5	1	10	5	-2	-5	6	11
									67	-4	0	7	1	-1	-6	8	11
									69	4	10	27	14	10	6	2	18
									72	-8	4	X	X	-1	-1	X	9
									74	-6	1	14	7	-3	-4	X	4
									63	-2	1	15	6	0	X	X	3
									64	1	4	15	10	4	2	5	20
									66	0	4	17	8	-5	-13	-8	7

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Continued)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
									70	0	5	4	9	0	-5	1	2
									73	1	5	16	7	-2	-8	X	X
									76	0	3	X	X	X	X	5	-2
10/ 8	14	876	L1	50	28	-	5.1	3.9	77	20	26	9	7	1	-5	-1	16
10/ 8	11	2020	L1	56	26	-	5.6	4.9	39	14	20	20	18	15	15	20	X
									41	11	14	11	14	11	9	15	X
									43	11	12	10	16	10	9	0	X
									44	X	X	X	16	14	14	23	X
									45	11	11	10	10	-1	1	7	X
									49	28	25	27	26	22	24	27	X
									51	20	20	21	23	12	18	22	32
									52	24	19	17	20	6	10	19	30
									53	27	25	26	26	18	16	23	X
10/ 8	13	1860	L2	53	31	-	5.1	1.7	54	X	X	X	12	8	X	X	X
									56	X	X	23	20	5	7	18	X
									57	22	27	27	22	13	16	24	38
									58	25	25	28	X	X	X	X	X
									63	11	X	10	X	3	X	15	X
									64	13	15	8	25	21	22	X	X
									66	X	X	20	22	18	13	21	X
									70	16	17	16	24	17	19	30	X
									71	15	X	X	X	X	X	X	X
									73	15	X	25	19	8	9	X	X
									75	11	24	26	25	16	7	X	X
10/ 8	14	2020	L1	50	28	-	5.1	3.9	77	21	12	18	19	13	11	17	X
11/ 8	17	876	L1	74	26	-	6.2	3.1	78	13	17	18	17	21	10	13	X
									83	13	14	6	6	-4	-3	5	5
									80	15	12	21	13	2	8	10	15
									81	12	12	8	4	1	5	5	5
									84	20	23	21	20	17	20	15	X
									85	17	9	16	22	13	12	14	23

TABLE A-1 — SOUND-PRESSURE-LEVEL DIFFERENCES (Concluded)

DAY/ MONTH	HR	DIST (M)	SITE	REL. HUM.	TEMP (C)	LAPSE RATE (+-0)	WIND SPEED (M/S)	WIND COMP. (M/S)	EVENT	DIFFERENCES IN OCTAVE BANDS 32	63	125	250	500	1K	2K	4K
									86	-7	2	2	8	-7	-7	-1	-10
									88	1	1	6	4	0	1	7	7
11/ 8	18	784	L2	85	22	-	5.1	3.3	89	-10	1	4	1	-11	-6	2	-1
									90	-13	-4	8	9	-13	-7	-5	2
									91	-13	-4	9	2	-7	-1	5	1
									93	-13	-3	7	-4	-12	-5	X	3
									94	-11	-5	11	4	-10	-10	7	8
									95	-9	-10	17	X	X	X	X	X
									96	-10	-1	6	-7	-8	X	-6	2
									97	-12	-2	11	11	8	3	4	X
									98	-11	-1	10	8	4	-3	X	X
									99	-12	-1	8	4	-9	-5	0	3
11/ 8	19	876	L1	85	22	-	5.1	2.6	2	4	-5	2	4	-6	-2	-4	0
									4	10	-4	4	1	-1	-4	0	8
									6	12	5	10	14	9	5	3	12
									7	12	0	9	10	-1	-2	0	6
									1	-13	-5	11	6	-8	-7	0	6
11/ 8	17	2020	L1	74	26	-	6.2	3.1	79	X	31	26	16	13	X	X	X
									81	35	24	X	28	17	X	X	X
									82	26	X	26	31	26	13	X	X
									84	38	34	34	33	27	29	X	36
									85	39	33	32	27	22	22	27	31
									86	27	X	X	X	X	X	X	X
									88	34	27	X	21	19	X	X	X
11/ 8	18	1860	L2	85	22	-	5.1	3.3	0	X	X	19	11	X	X	X	10
11/ 8	19	2020	L1	85	22	-	5.1	2.6	2	8	14	15	17	X	4	8	9
									3	-1	7	5	10	-1	-5	4	X
									4	10	16	17	8	1	10	X	X
									5	9	16	13	16	3	1	14	X
									6	20	27	22	26	15	11	12	X
									7	11	26	29	18	13	20	X	X

TABLE A-2. — RADIALS USED IN THE MEASUREMENT PROGRAM

Site	Runway	Radials Used *
L1	Los Angeles, 25R	30°, 60°, 140°
L2	Los Angeles, 25L	140°
L3	Los Angeles, 24	280°, 340°, 360°
D1	Denver, 35	130°, 160°
D2	Denver, 35	130°, 260°

* Propagation Direction to Nearest 10°, Measured From North to East

APPENDIX B

SUGGESTED PROCEDURE FOR ESTIMATING DOWNWIND EXCESS ATTENUATION

The purpose of this document is to suggest a method for predicting the propagation of noise over open terrain from an aircraft on the ground to other locations in nearby residential areas. The procedure is restricted further to the case of downwind propagation, that is, a nonnegative component of the wind in the direction from the aircraft source to the residential receiver. This case of downwind propagation is expected to be the most favorable for sound propagation to nearby areas. Upwind propagation, i.e., a negative component of wind velocity in the direction of source to receiver, will tend to provide larger values of excess attenuation and under some circumstances produce marked attenuation regions called shadow zones.

For the purpose of this document, the wind velocity will be assumed to be 10 mi/hr. The wind velocity averaged for about sixty airports in the United States has been found to be approximately this value. The source and receiver heights will also be assumed to be approximately 6 ft above the ground.

The following information is required to calculate the attenuation between points A (a convenient reference point located within a few hundred feet of the aircraft) and B (the residential measurement point of interest):

x_A and x_B	distances from aircraft to points A and B, respectively
T	ambient temperature
RH	ambient relative humidity

The total downwind attenuation (TDA) is given as the sum of three components

$$TDA = IA + SA + EA$$

where

IA is inverse square attenuation = $20 \log_{10} (x_B/x_A)$

SA is standard atmospheric attenuation, calculated from SAE ARP 866 (ref. 3) as modified below.

EA is excess attenuation.

Figure B-1 presents plots of excess attenuation (EA) as functions of propagation distance, for frequency bands below 1,000 Hz. For frequency bands at or above 1,000 Hz, EA is taken to be zero.

For frequency bands centered at 1,000 Hz and below, the standard atmospheric attenuation (SA) is calculated directly from SAE ARP 866 as a function of temperature (T) and relative humidity (RH). For frequency bands centered at 2,000 Hz and above, SA is taken as one-half the values obtained from SAE ARP 866, as a function of temperature and humidity.

If 1/3-octave frequency bands are used, the values of TDA for the frequency bands between the octave band center frequencies should be obtained by interpolation from a smoothed curve based on the octave band values. If "commercial" octave bands are used rather than the "preferred" octave bands, the values of TDA should be found using the "preferred" octave bands, and the values at the "commercial" band center frequencies determined by interpolation.

The standard deviations associated with the predicted values of TDA are of the order of 6 dB to 12 dB.

Example: Determine the total downwind attenuation in both preferred and commercial octave bands, between two points that are 100 m and 1,500 m from the aircraft. The temperature is 75° F, and the relative humidity is 60%. See table B-1.

TABLE B-1 — EXAMPLE OF TOTAL DOWNWIND ATTENUATION CALCULATION

Band Center Frequency, Hz	Inverse Square Attenuation, dB	Standard Atmos. Attenuation, dB (SAE ARP 866, fig. 13)	Excess Attenuation, dB (Fig. B-1)	Total Downwind Attenuation, dB
31.5	24	0	8	32
63	24	0	12	36
125	24	0	16	40
250	24	0	16	40
500	24	3	3	30
1,000	24	8	0	32
2,000	24	8	0	32
4,000	24	17	0	41
8,000	24	29	0	53

TABLE B-1 — EXAMPLE OF TOTAL DOWNWIND ATTENUATION CALCULATION (Concluded)

Frequency Band, Hz	Total Downwind Attenuation, dB
37.5-75	35
75-150	39
150-300	41
300-600	33
600-1,200	31
1,200-2,400	32
2,400-4,800	39
4,800-9,600	50

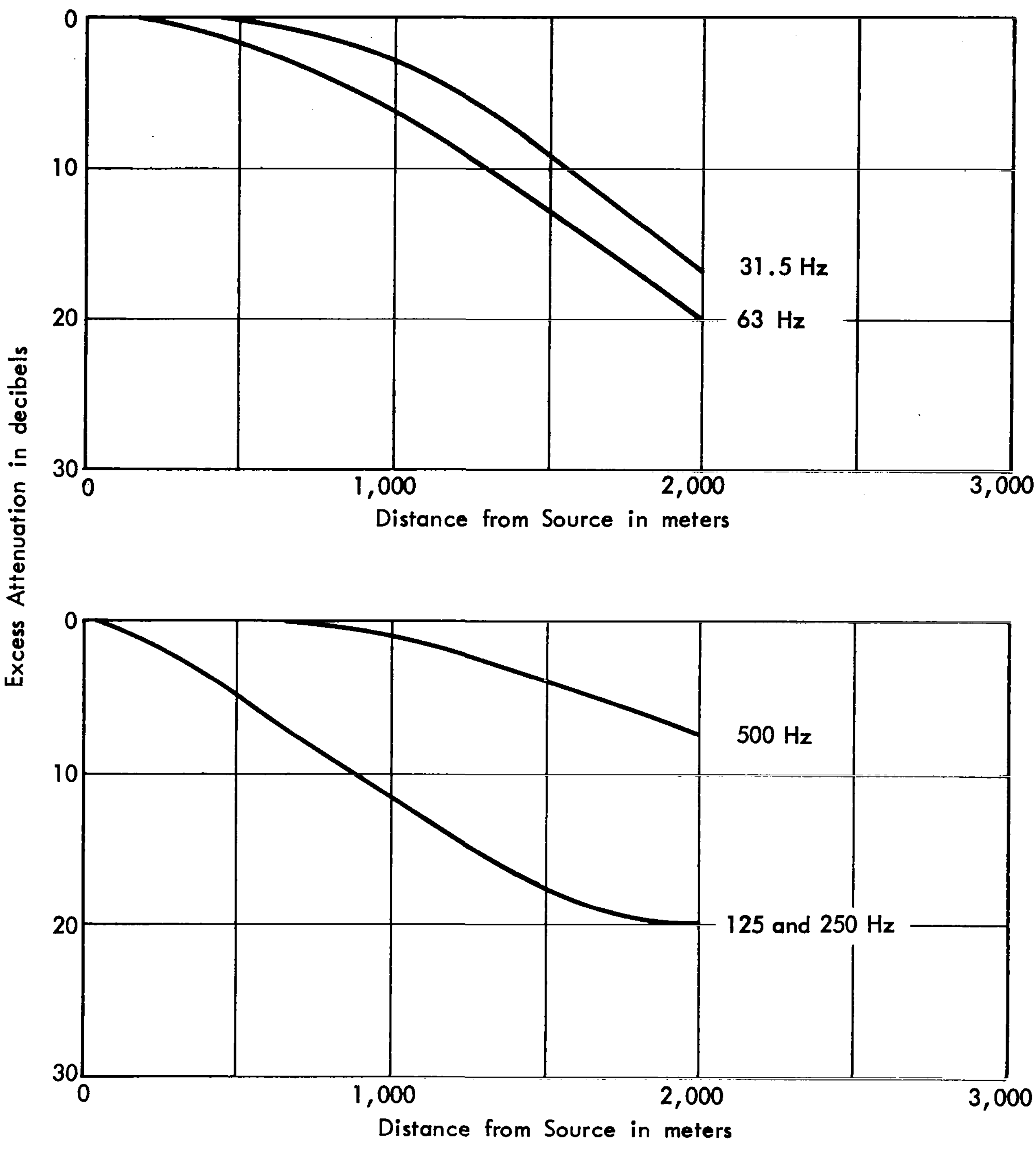

FIGURE B - 1. DOWNWIND ATTENUATION AS A FUNCTION OF DISTANCE

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