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Statistical Comparisons of Aircraft Flyover Noise Adjustment Procedures for Different Weather Conditions

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SUMMARY

Measured aircraft flyover noise spectra obtained under widely different weather conditions have been adjusted according to a proposed national standard recommended by Working Group S1-57 of the American National Standards Institute (ANSI). The spectra and effective perceived noise level (EPNL) results were statistically compared with the same measured spectra adjusted according to an alternate procedure presented in the Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 866A. Additionally, the tone corrected perceived noise level (PNLTM) one-third-octave spectra and EPNL values were compared with spectra and EPNL values obtained under almost ideal weather conditions (isothermal profile and no wind) which were chosen as a reference. This study also evaluated three ways to model the weather conditions through which the sound propagated. All data analyzed were obtained from a large data base resulting from a test program conducted to study flyover noise variability for a wide range of meteorological conditions. These data were generated by constant-thrust, level flyovers of a turbofan engine powered airplane.

The results of the adjusted and unadjusted noise data compared with the reference measured noise data indicated a wider spread of values between the adjusted data than for the unadjusted data. The results obtained by using the proposed ANSI procedure gave values which more closely represented the reference data than did results obtained by using the ARP 866A procedure. Results obtained by using either the layered or mean of the mean weather representation in either procedure also gave values more closely representative of the measured reference data than did the results obtained by using the mean 10-m weather measurement.

INTRODUCTION

As the public becomes more aware of noise in the environment, the need to account for the effect of the atmosphere on aircraft sound propagation has become increasingly important for both airframe manufacturers and community planners. Procedures are needed to adjust measured noise levels to those which would be expected to have been measured under a standard weather condition because aircraft noise testing must be done at many climatically diverse sites. For aircraft noise certification, a standard defined by the Federal Aviation Regulation (FAR) 36 requires noise testing to be done when values of temperature and relative humidity fall within a given range (ref. 1). Noise data acquired within this range of atmospheric parameters are then adjusted or corrected to the FAR 36 standard.

Procedures to adjust atmospheric absorption effects on sound propagation (refs. 2 to 8) depend on assumptions to model the temperature and relative humidity of the atmosphere. From the many methods available, the ARP 866A procedure (used in ref. 1) and a procedure recommended as a national standard by the ANSI-S1-57 Working Group (refs. 3 to 4) have received wide attention.

Although both procedures have been used to some extent to adjust noise measurements from which the EPNL calculations were made, only the ARP 866A procedure has been applied to complete spectra of aircraft flyover noise.

The purpose of this paper is to compare these two flyover noise adjustment procedures, ARP 866A and the recommended ANSI standard, by applying the statistical analysis of variance (ANOVA) technique. The atmospheric absorption calculation method of each procedure was used to adjust flyover noise spectra obtained under three widely different weather conditions to a chosen measured reference weather condition. Each condition was represented in three different ways. These adjusted noise data and associated EPNL values were statistically compared with each other and with unadjusted measured noise data obtained at the time of the reference weather condition. Numerical levels of confidence ar associated with the results obtained by using the ANOVA technique.

SYMBOLS

A	reference weather condition
B	nonreference weather condition; thermal inversion to aircraft flight altitude
C	nonreference weather condition; strong low-level thermal inversion
D	nonreference weather condition; hot and dry, outside FAR 36 recommendation
F	quantity under study in F-distribution
f	frequency, Hz
H_o	statistical hypothesis of equality of means
t	time, sec
$\alpha_{0.05}$	type I error probability at 5-percent level of significance
μ	population mean value
σ	sample standard deviation

Subscripts:

0	unadjusted for weather
1	ARP 866A weather adjustment obtained by using layered meteorology
2	ARP 866A weather adjustment obtained by using mean 10-m meteorology
3	ARP 866A weather adjustment obtained by using mean of 10-m and aircraft altitude meteorology

4	proposed ANSI-S1-57 weather adjustment obtained by using layered meteorology
5	proposed ANSI-S1-57 weather adjustment obtained by using mean 10-m meteorology
6	proposed ANSI-S1-57 weather adjustment obtained by using mean of 10-m and aircraft-altitude meteorology
ν_1	numerator degrees of freedom
ν_2	denominator degrees of freedom

Abbreviations:

AGL	above ground level
ANOVA	analysis of variance
ANSI	American National Standards Institute
ARP 866A	aerospace recommend practice 866A
EPNL	effective perceived noise level, dB
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
PNLT	tone corrected perceived noise level, dB
PNLTM	maximum tone corrected perceived noise level, dB
SAE	Society of Automotive Engineers
SPL	sound pressure level

A bar (¯) over a symbol indicates mean value.

APPARATUS AND MEASUREMENT METHODS

TEST AIRCRAFT

The data presented in this paper came from a test program which involved flying a turbofan engine powered airplane over microphones at Fresno, California and Yuma, Arizona. This jet transport was flown in level flight at constant thrust at a mean altitude of 346 m. The noise data, weather data, aircraft position, and operating conditions were continuously recorded during the aircraft flyover (ref. 9).

AIRCRAFT POSITIONING

Cameras and optical techniques were utilized to determine the altitude, speed, and time of the aircraft over each measurement station. As the aircraft passed overhead of each measurement station, the shutter of a camera was manually released and simultaneously a signal was recorded on the acoustic data tape When the distance between the cameras, the time between shutter release signals on the tape, the aircraft wing span, and the camera focal length were known, the ground speed and altitude of the aircraft were computed. The shutter releas signal also provided an indication of the overhead passage time of the test aircraft.

ATMOSPHERIC MEASUREMENTS

The general test arrangement is shown schematically in figure 1. Two weather measurement systems were used to obtain temperature, humidity, wind speed, and wind direction data. One system developed by the FAA was installed in a small general avaition aircraft and measured temperature and dew point as this aircraft flew from the ground surface to an altitude of 900 m before and after each noise test series (nominally every 30 min). The other weather system measured wind direction and speed, temperature, and humidity at 10 m AGL.

ACOUSTIC MEASUREMENTS

Acoustic measurements were made with microphones placed at two locations (for redundancy) along the ground track. At each location, a microphone was placed over concrete on a 1.2-m stand and oriented for grazing incidence. Eac microphone signal was recorded on a frequency modulation tape recorder which h essentially flat response from 20 Hz to 10 kHz (ref. 10).

METEOROLOGICAL DATA

SELECTION

The primary requirement for selecting weather data was to have good acoustic data. The reference weather condition required no wind and an isothermal (or nearly so) profile up to the test aircraft overflight altitude. Mean valu of the temperature and relative humidity had to be well within the ranges spec fied in FAR 36. Three nonreference weather conditions were chosen for comparative purposes. The requirements for these conditions were that they have nonisothermal profiles with strong inversions between the test aircraft and th ground. Also, mean values of the temperatures and relative humidities were required to lie outside and at the extremes of the FAR 36 ranges. These requi ments permitted a comparison of a wide range of weather conditions used in th two noise adjustment procedures.

REDUCTION

The four weather conditions were represented in three ways. The first representation was called the layered data. Temperature and relative humidity data measured by the weather aircraft were plotted as a function of time up to the test aircraft overflight altitude. From these data, vertical profiles for each weather condition were determined for each noise test flight. Because there were four or five noise flights for both the reference and nonreference conditions, the mean-value profiles (with the associated standard deviations) were calculated. For computational purposes these profiles were divided into layers of 30.5-m increments.

Figures 2 to 4 present these layered data. For identification purposes the reference condition A is represented by a solid-line curve. The nonreference conditions B, C, and D are represented by the dashed-line curves. Bars on the lines represent the standard deviations. The standard deviation for the reference is not represented because it is so small.

Figure 2 presents a comparison of the reference condition A with the nonreference condition B. Condition A is seen to be very nearly constant up to the test aircraft flyover altitude. Condition B represents a steady thermal inversion up to the flyover altitude.

Figure 3 compares the reference condition A with the layered model for weather condition C, which is chosen for analysis because of the strong thermal inversion to 30.5 m and then the isothermal behavior beyond 30.5 m. Weather condition C is considered to be a good representation of a hot and dry condition above the inversion and is similar to that of figure 4. Figure 4 compares the eference weather condition A to weather condition D, which is chosen to epresent a hot, dry environment that is very nearly isothermal.

The second method to represent the four weather conditions was to use sinle values for both the temperature and relative humidity and was called the ean 10-m model. This model was obtained by continuously recording the temperaure and relative humidity at 10 m AGL and then by calculating the mean values ssociated with each weather condition.

The third method to represent the weather conditions was to use single vales for both the temperature and relative humidity and was called the mean 10-m ircraft-altitude model or mean of the mean. This model was obtained for each eather condition by calculating the mean value of the mean values of the temerature and relative humidity measured at 10 m AGL and at the overflight ltitude.

Figure 5 presents the FAR 36 (ref. 1) ranges for temperature and relative humidity as a window with the FAR 36 standard point and the mean values f temperature and relative humidity obtained at 10 m AGL for the weather conitions A, B, C, and D used in this paper. Figure 5 also shows the wide pread in weather conditions used in the two noise adjustment procedures of his study.

ACOUSTIC DATA

SELECTION

No unusual selection process was applied to the acoustic data. Data studied met the standards required for research; for example, no extraneous background noise, a high signal-to-noise ratio, and good calibration levels.

REDUCTION

A schematic representation of the data reduction is presented in figure 6. Five noise flights were reduced for the reference weather condition A and for weather conditions B and D. Four noise flights were reduced for weather condition C. Refer to figure 6 and note that time histories (block ①) of each noise overflight were obtained along with one-third-octave band spectra every 1/2 second (block ②). The data were then corrected for spherical spreading, microphone response, wind screen, barometric pressure, free-field response, and recording system response (block ③) (ref. 10). Time histories of the PNLT data (block ④) were computed and the maximum value (PNLTM) of each time history was obtained. Each PNLTM spectrum (block ⑤) for the noise flights was then adjusted by using different weather conditions (block ⑥) represented as in block ⑦ of figure 6. According to the two procedures, ARP 866A (ref. 2) and proposed ANSI standard (refs. 3 and 4) (block ⑧) and the EPNL values were calculated. Thus there were four or five sets of unadjusted and adjusted PNLTM one-third-octave spectra with the associated EPNL values for the weather conditions. From these data, the mean-value PNLTM spectra and EPNL values were calculated ⑨. The mean-value PNLTM spectrum and EPNL measured under the reference weather condition A are called the reference acoustic data. Mean-value PNLTM spectra and EPNL values computed for weather conditions B, C, and D are called nonreference data. An example PNLTM time history, typical of those studied, is presented in figure 7 along with the associated PNLTM one-third-octave band spectrum.

Since there were three ways (layered, mean 10 m AGL, and mean of mean) to represent the many weather conditions, it was useful to devise a matrix to faci itate the analysis. This matrix is presented in table I. Alphanumeric characters are assigned to the various weather conditions. Thus B_3 implies the mean-value spectrum for five PNLTM spectra for weather condition B, adjusted according to ARP 866A by using the mean of the mean of the 10-m and aircraft-altitude weather measurements.

In the determination of the PNLTM one-third-octave spectra obtained by using the layered meteorology, refraction effects due to the temperature and wind-speed gradients were determined and were observed to be negligible, as noted in reference 8. For all PNLTM spectra, the atmospheric absorption coefficient included the turbulence scattering effect accounted for by the empirical relationship developed in reference 6. In order to use the procedure of reference 3, a bandwidth correction procedure was developed and implemented. The approach taken was to express the bandwidth correction in terms of the ratio of the absorption adjusted power transmitted through the band to the absorption adjusted power computed at the band center frequency. Depending on the test situation, other methods may be desired (ref. 11).

ANALYSES AND RESULTS

Two forms of data analyses were used to study the comparisons of the two adjustment procedures. The first analysis form, the arithmetic technique, consisted of determining the arithmetic differences between the mean-value reference PNLTM spectrum levels and the mean-value nonreference unadjusted and adjusted PNLTM spectrum levels. The second analysis form consisted of using statistical analysis, the ANOVA technique, to compare the mean EPNL values of the reference and nonreference unadjusted and adjusted spectra. Table I facilitates the following discussion.

ARITHMETIC TECHNIQUE

Unadjusted Spectra

The PNLTM spectra measured under reference A and nonreference meteorological conditions B, C, and D are presented in figures 8, 9, and 10, respectively. In these figures, the B_0, C_0, and D_0 spectra have not been weather adjusted according to either the ARP 866A or proposed ANSI standard. The vertical bars represent the ±1 standard deviation of the reference spectrum levels about the mean value. Similar magnitudes of the standard deviations were noted in the three nonreference mean-value spectra but have been omitted from figures 8 to 10 for the purpose of clarity. The data presented in these figures indicated that the mean values of the reference spectrum A and noneference spectra B_0, C_0, and D_0 agree to within 1 dB in 14 out of 21 onethird bands shown for the data taken during weather condition B (fig. 8), 8 out of 21 for weather condition C (fig. 9), and 15 out of 21 for weather condition D (fig. 10). The application of the two adjustment procedures to the nonreference data was expected to improve this agreement.

Adjusted Spectra

Layered Meteorology

There were three sets of adjusted data, one for each weather condition epresentation. The first set of results discussed are those obtained by using the ARP 866A (ref. 2) and the proposed ANSI-S1-57 (ref. 3) adjustment procedures n conjunction with the layered meteorology data. Example results B_1 and B_4 or weather condition B are presented and compared to the mean reference noise pectrum A in figure 11. Recall that condition B is identified as a thermal nversion through which the sound propagated from the aircraft altitude to the round.

Figure 11 indicates that the adjusted spectra B_1 and B_4 are equivalent n shape and are a little higher in level than the reference spectrum below

200 Hz. Above 200 Hz the adjusted spectrum levels are slightly lower than the reference spectrum. For both the adjusted spectra, 11 out of the 21 one-third-octave bands analyzed had arithmetic differences within 1 dB of those of the reference spectrum. This is in contrast to the arithmetic differences in 14 out of 21 bands of the unadjusted spectrum B_0 of figure 8 being within 1 dB of the reference spectrum bands.

In a similar manner the spectrum levels of C_1, C_4, D_1, and D_4 were studied. The spectrum shapes were similar to those of figure 11. The results of the study indicated that the C_1 spectrum had 9 and the C_4 spectrum had 10 out of 21 one-third-octave band levels which were within 1 dB of the reference. This is in contrast to 8 out of 21 band levels being within 1 dB for the unadjusted C_0 data (fig. 9) which are compared to the reference. The D_1 and D_4 spectra had 8 out of 21 band levels within 1 dB of the reference spectrum, whereas the unadjusted D_0 spectrum of figure 10 had 15 band levels within 1 dB of reference spectrum A.

Mean 10-m Meteorology

The second set of results studied were those obtained by using the two adjustment procedures (refs. 2 and 3) and the mean 10-m weather representation. Adjustments were again made to the noise data of the nonreference weather conditions B, C, and D. Example results are presented in figure 12 which shows the mean-value spectra of the ARP 866A and ANSI adjustments applied to the noise spectra for weather condition B. This figure shows spectra B_2 and B_5 to be essentially equivalent, being identical at and below 2500 Hz and less than 1/2 dB apart above 2500 Hz. These spectra are generally slightly below the reference spectrum values. Both the ANSI and ARP 866A spectra had 10 out of 21 one-third-octave bands within 1 dB of the reference spectrum. This contrasts with 14 out of 21 bands for the unadjusted spectrum B_0 which was shown in figure 8.

The study of the adjusted spectrum levels C_2, C_5, D_2, and D_5 of weather conditions C and D indicated that they have shapes similar to figure 12. The results of subtracting each adjusted spectrum level from the reference A level showed that for each of the C data, 6 out of 21 band levels were within 1 dB of the reference. These are in contrast to the unadjusted C_0 data of figure 9 where 8 out of 21 band levels were within 1 dB of the reference A spectrum. The D_2 spectrum had eight and the D_5 spectrum had nine one-third-octave band levels within 1 dB of the reference A spectrum. This is in contrast to the unadjusted D_0 spectrum of figure 10 where 15 out of 21 band levels were within 1 dB of the reference.

Mean of Mean 10-m and Aircraft-Altitude Meteorology

The third set of results studied were those obtained by using the methods of references 2 and 3 and the weather representation resulting from an arithmetic average of the mean values of the temperature and relative humidity measured at 10 m and at the aircraft flight altitude. Example results of applying the adjustment procedures with this weather representation to the nonreference noise data are presented in figure 13 which shows the ARP 866A (B_3) and ANSI (B_6) spectra for weather condition B compared with reference A. Observe that the B_3 and B_6 spectra are equivalent. At 50 Hz these spectra fall about 1 dB below the reference value. Above 50 Hz to 400 Hz the adjusted spectra are about 1 to 2 dB above the reference values. From 400 Hz to 500 Hz they tend to fall about 1 dB below the reference values. From 400 Hz to 500 Hz they tend to fall about 1 dB below the reference, with the exception of 2000 Hz where there is about a 4-dB drop below the reference value. These adjusted mean-value spectra are observed to have 11 out of 21 one-third-octave band levels within 1 dB of the reference level. This compares with 14 out of 21 bands for the unadjusted spectra B_0 of figure 8.

As in the previous data, a study indicated that the adjusted C_3, C_6, D_3, and D_6 spectra had a shape similar to the B_3 and B_6 data. Similar arithmetic differences were also calculated. Both the C_3 and C_6 spectra had 8 out of 21 one-third-octave band levels which were within 1 dB of the reference A data. These data equaled the C_0 data of figure 9 where 8 out of 21 band levels were within 1 dB of the reference. Both D_3 and D_6 spectra had 7 out of 21 band levels within 1 dB of the reference. These data are in contrast to 15 out of 21 band levels for the unadjusted D_0 spectrum which were within 1 dB of the reference levels of figure 10.

Table II was constructed to summarize the results of the previous discussion. This table shows the number of one-third-octave band levels of the unadjusted mean spectra B_0, C_0, and D_0 (figs. 7, 8, and 9) and of the adjusted mean spectra (B_1 to B_6, C_1 to C_6, and D_1 to D_6) which were within 1 dB of the mean reference A spectrum levels over the frequency range of 50 Hz to 5000 Hz. Note that for the majority of the combinations of adjustment procedures and weather representations, that is, 14 out of 18 combinations, the adjustments did not appear to bring the spectra any closer to the reference spectrum than the already existing measured unadjusted PNLTM spectra. In order to study these results further, a statistical analysis was made of the unadjusted and adjusted EPNL values of the PNLTM spectra represented by table II.

STATISTICAL TECHNIQUE

As mentioned previously, noise certification of commercial aircraft requires EPNL values to meet FAA certification criteria (ref. 1). Thus it was of interest to analyze the EPNL values resulting from the PNLTM spectra. Because of the large matrix of unadjusted and adjusted values obtained for different weather conditions and representations, the analysis of variance (ANOVA) technique of statistical analysis (refs. 12 and 13) was employed. This analysis is classical and permits two results. One result is the determination of the ranges on the means and standard deviations of the data so as to estimate the reliability of the conclusions and range estimates. The other result is the testing of differences among the mean values of two or more data populations.

The ANOVA permits the hypothesis to be made that the mean values of the conditions examined do not differ significantly from those differences which may be due only to the randomness of the data. For these analyses the level of significance chosen was 5 percent. If there are no rejections, or significant differences, then it may be assumed that any observed differences between the means are due solely to the random error of the experiment. The probability that this assumption is not true is less than 5 percent. If a rejection of the hypothesis occurred, that is, a significant difference existed among the means, the method of Sheffê was used to determine which means differed in the hypothesis (ref. 14). In all these analyses small sample size concepts (ref. 12) were used because there were four or five data runs per weather condition.

Table III presents the EPNL data of the overflights and results of the reliability analysis. The computed adjusted and unadjusted EPNL values for the various data flights associated with the weather conditions A, B, C, and D are presented. The magnitude range on the data, mean value, standard deviation and 95-percent confidence internal of the mean and standard deviation are also presented.

A study of the table indicates that for the unadjusted and adjusted data of weather conditions B, C, and D and for the reference data A, the data magnitude range is less than or equal to 2 dB with 87 percent of the data in the range of 0.9 dB to 1.4 dB. The standard deviation was always less than or equal to 0.8 dB with 87 percent of the data in the range of 0.4 dB to 0.6 dB. The 95-percent confidence intervals for the means and standard deviations were computed to provide a way of stating how close the sample mean and the standard deviation are likely to be to the true population value.

The mean values of the unadjusted and adjusted EPNL data of table III were arithmetically compared with the mean value of the reference data. Table IV presents these contrasts. The results of subtracting the EPNL mean value of the reference condition $\bar{A}$ from the unadjusted EPNL mean values for the different weather conditions $\bar{B}_0$, $\bar{C}_0$, and $\bar{D}_0$ and from the adjusted EPNL mean values $\bar{B}_1$ to $\bar{B}_6$, $\bar{C}_1$ to $\bar{C}_6$, and $\bar{D}_1$ to $\bar{D}_6$ are given. Note that wherever a positive sign appears by a value in table IV under an adjustment procedure column, the procedure tended to overadjust the data by that value. Conversely, whenever a negative sign appears, the implication is that the weather condition was underadjusted by that value. Table IV shows that for the weather conditions B and C the data were underadjusted by both ARP 866A and ANSI-S1-57 procedures and for the weather condition D both methodologies overadjusted the values as compared with the reference. The unadjusted mean EPNL values for the different weather conditions were generally closer to the reference mean value than the adjusted values.

The magnitude of the EPNL mean value by which either the ANSI-S1-57 or ARP 866A adjustment procedure came closer to the reference mean value $\bar{A}$ than the other's counterpart is presented in table V. This table shows that for the weather condition B, ANSI-S1-57 was closer than ARP 866A to $\bar{A}$ in one out of three applications and, for the weather condition D, ANSI-S1-57 was closer tha ARP 866A in three out of three applications. This table also indicates that, when the weather conditions B, C, and D were adjusted with the ANSI-S1-57 and ARP 866A procedures, the ANSI-S1-57 method generally gave mean values which were less than the values from the ARP 866A method, regardless of overadjusting or underadjusting. The differences between each method are small, being on the order of 0.2 dB.

The results of the ANOVA tests, at the 95-percent confidence level, are presented in tables VI and VII. The hypothesis proposed is that the mean value of each data set is equivalent $\left(H_O\text{:}\ \mu_A = \mu_{B_0} = \mu_{C_0} = \mu_{D_0}\right)$. A determination was made to accept or reject the hypothesis. Thus, in table VI, if the value in the column F_{ν_1,ν_2} computed is less than the value in the column F_{ν_1,ν_2} distribution, the hypothesis was accepted. If the F_{ν_1,ν_2} computed value was greater than the F_{ν_1,ν_2} distribution value, the hypothesis was rejected and secondary hypotheses were made within the initial hypothesis group. These secondary hypotheses were tested again by obtaining a single number, called the contrast value, and compared to a value obtained by utilizing Scheffé's technique (ref. 14). If the contrast value was less than the Scheffé value, the secondary hypotheses were accepted, and if not, were rejected. Also presented in table VI are the degrees of freedom associated with the tests.

Table VI presents an example hypothesis like that formed for each of the procedures and conditions analyzed. This table indicates that the initial hypothesis, which is that the means of the reference condition A and the unadjusted nonreference conditions B_0, C_0, and D_0 are equal, is rejected. This rejection is determined to be the result of a significant difference between the reference mean EPNL and the nonreference weather condition C mean EPNL. This result may be due to the fact that the atmospheric conditions of C exhibit a very strong ground based inversion. The result is also suggestive that an adjustment may be required for this type of weather condition.

Table VII presents the results of the ANOVA technique as applied to all combinations of procedures and weather conditions and representations. This table indicates that the proposed ANSI-S1-57 methodology gave only one significant difference (C_5) out of nine possibilities as contrasted to the mean reference value. The ARP 866A procedure produced five differences (B_2, C_2, D_1, D_2, and D_3) out of nine possibilities. The mean 10-m weather representation seemed always to produce a significant difference when the ARP 866A procedure was used and did so once when the ANSI-S1-57 procedure was used. Note that the ARP 866A procedure always produced a significant difference when applied to the nonreference weather condition D. Note also that there were four significant differences out of six possibilities when the mean values of the temperature and relative humidity were used in the two procedures.

CONCLUDING REMARKS

Flyover noise data measured under three widely different meteorological onditions (including temperature inversions) were adjusted to levels measured nder a meteorological condition which was chosen to be a reference. Two atmopheric absorption adjustment procedures (Society of Automotive Engineers (SAE) erospace Recommended Practice (ARP) 866A and proposed American National Stanards Institute (ANSI) Working Group S1-57) using three means to represent the eather conditions were employed. Refraction and turbulence scattering effects re included in the analysis where appropriate.

The unadjusted and adjusted effective perceived noise level (EPNL) values associated with the tone corrected perceived noise level (PNLTM) spectra nonreference weather conditions were compared to the reference values. These comparisons were analyzed by using arithmetic difference calculations and statistical analysis of variance. Observations of the results obtained from the analysis were as follows:

(1) The unadjusted PNLTM one-third-octave spectra more closely matched the reference spectrum (both in terms of band levels and EPNL values) than did the adjusted PNLTM one-third-octave spectra. However there was a statistically significant difference at the 5-percent level between the reference EPNL value and the unadjusted EPNL value obtained under a strong low-level thermal inversion (nonreference condition C).

(2) The proposed ANSI-S1-57 procedure using three methods representing widely different weather conditions gave only one significant difference out of nine possibilities (at the 5-percent level) when compared with the reference value. The ARP 866A procedure using the same meteorological measurements gave five significant differences out of nine possibilities when compared with the reference value.

(3) The ANSI-S1-57 procedure produced EPNL values which were arithmetically closer to the reference value than did the ARP 866A procedure, though their differences were small, being on the average of about 0.2 dB.

(4) The EPNL values resulting from using the mean values of the temperatur and relative humidity measured at 10 m AGL showed a significant difference at the 5-percent level compared with the reference value in four out of six tests.

(5) The range of the measured data was on the order of 1 dB with mean valu and standard-deviation confidence intervals obtained at the 95-percent confidence limit.

(6) By use of the analysis of variance technique, an objective assessment of data results was made.

The proposed ANSI-S1-57 procedure, as applied to the data in this paper, seems to offer a better way to adjust aircraft flyover EPNL values than does th current ARP 866A method. Furthermore, when the proposed ANSI-S1-57 procedure i used, the layered analysis meteorological measurement seems to give about the same results as did the mean of the mean-value data taken at 10 m above ground level and at the aircraft flight altitude.

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TABLE I.- ALPHANUMERIC CHARACTER ASSIGNMENT TO COMBINATIONS OF WEATHER CONDITIONS AND ADJUSTMENT PROCEDURES

Weather condition	Unadjusted	ARP 866A			Proposed ANSI-S1-57		
		Layered	Mean 10 m	Mean of mean	Layered	Mean 10 m	Mean of mean
A	---	---	---	---	---	---	---
B	B_0	B_1	B_2	B_3	B_4	B_5	B_6
C	C_0	C_1	C_2	C_3	C_4	C_5	C_6
D	D_0	D_1	D_2	D_3	D_4	D_5	D_6

TABLE II.- NUMBER OF ONE-THIRD-OCTAVE BAND LEVELS OUT OF 21 ANALYZED FOR NONREFERENCE WEATHER CONDITIONS WHICH ARE WITHIN 1 dB OF REFERENCE CONDITION

Weather condition	Unadjusted		ARP 866A						Proposed ANSI-S1-57					
			Layered		Mean 10 m		Mean of mean		Layered		Mean 10 m		Mean of mean	
	Spectrum	No. of band levels	Spectrum	No. of band levels	Spectrum	No. of band levels	Spectrum	No. of band levels	Spectrum	No. of band levels	Spectrum	No. of band levels	Spectrum	No. of band levels
B	B_0	14	B_1	11	B_2	10	B_3	11	B_4	11	B_5	10	B_6	11
C	C_0	8	C_1	9	C_2	6	C_3	8	C_4	10	C_5	6	C_6	8
D	D_0	15	D_1	8	D_2	8	D_3	7	D_4	8	D_5	9	D_6	7

TABLE III.- EPNL DATA

(a) Reference and unadjusted nonreference weather conditions

Statistical data	EPNL, dB	Run
Weather condition A		
	96.8	414
	98.5	415
	96.6	416
	97.0	417
	96.9	418
Mean, $\bar{A}$	97.2	
Data range	1.9	
95% confidence interval on mean . . .	96.2 to 98.1	
σ	±0.8	
95% confidence interval on σ	0.5 to 2.2	
Weather condition B_0		
	97.0	287
	97.2	288
	97.2	289
	97.3	290
	97.9	291
Mean, $\bar{B}_0$	97.3	
Data range	0.9	
95% confidence interval on mean . . .	96.9 to 97.7	
σ	±0.3	
95% confidence interval on σ	0.2 to 1.0	

Statistical data	EPNL, dB	Run
Weather condition C_0		
	96.9	237
	----	---
	95.8	239
	95.5	240
	95.3	241
Mean, $\bar{C}_0$	95.9	
Data range	1.6	
95% confidence interval on mean . . .	94.7 to 97.0	
σ	±0.7	
95% confidence interval on σ	0.4 to 2.7	
Weather condition D_0		
	96.7	118
	96.8	119
	96.8	121
	96.1	122
	96.0	123
Mean, $\bar{D}_0$	96.5	
Data range	0.8	
95% confidence interval on mean . . .	96.0 to 97.0	
σ	±0.4	
95% confidence interval on σ	0.2 to 1.1	

TABLE III.- Continued

(b) Adjusted for weather condition B - inversion to aircraft flight altitude

Run	ARP 866A procedure[a]			ANSI-S1-57 procedure[a]		
	B_1	B_2	B_3	B_4	B_5	B_6
287	96.1	95.3	95.9	96.1	95.4	96.0
288	96.4	95.6	96.2	96.4	95.7	96.3
289	96.5	95.7	96.4	96.5	95.8	96.4
290	96.8	96.0	96.8	96.9	96.1	96.8
291	97.3	96.5	97.3	97.3	96.6	97.3
Statistical data						
Mean	96.6	95.8	96.5	96.6	95.9	96.6
Data range	1.2	1.2	1.4	1.2	1.2	1.3
95% confidence interval on mean . . .	96.1 to 97.2	95.3 to 96.4	95.8 to 97.2	96.1 to 97.2	95.4 to 96.5	95.9 to 97.2
σ	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5
95% confidence interval on σ	0.3 to 1.3	0.3 to 1.3	0.3 to 1.6	0.3 to 1.3	0.3 to 1.3	0.3 to 1.5

(c) Adjusted for weather condition C - strong low-level inversion

Run	ARP 866A procedure[a]			ANSI-S1-57 procedure[a]		
	C_1	C_2	C_3	C_4	C_5	C_6
237	97.8	96.0	96.7	97.3	96.0	96.5
239	97.4	95.3	96.1	96.9	95.4	96.0
240	96.7	94.6	95.4	96.2	94.7	95.3
241	97.0	94.8	95.6	96.5	94.9	95.5
Statistical data						
Mean	97.2	95.2	96.0	96.7	95.3	95.8
Data range	1.1	1.4	1.3	1.1	1.3	1.2
95% confidence interval on mean . . .	96.5 to 98.0	94.2 to 96.2	95.0 to 96.9	96.0 to 97.5	94.3 to 96.2	95.0 to 96.7
σ	±0.5	±0.6	±0.6	±0.5	±0.6	±0.5
95% confidence interval on σ	0.3 to 1.8	0.4 to 2.3	0.3 to 2.2	0.3 to 1.8	0.3 to 2.16	0.3 to 2.0

[a] Values in these columns given in dB.

TABLE III.- Concluded

(d) Adjusted for weather condition D - outside FAR 36 window; hot and dry

Run	ARP 866A procedure[a]			ANSI-S1-57 procedure[a]		
	D_1	D_2	D_3	D_4	D_5	D_6
118	99.1	99.0	99.1	98.8	98.7	98.8
119	99.0	98.9	99.0	99.7	98.7	98.7
121	99.0	98.9	98.9	98.6	98.5	98.5
122	98.1	98.0	97.9	97.7	97.6	97.5
123	98.4	98.3	98.1	98.0	97.9	97.8
Statistical data						
Mean	98.7	98.6	98.6	98.4	98.3	98.3
Data range	1.0	1.0	1.2	1.1	1.1	1.3
95% confidence interval on mean . . .	98.2 to 99.3	98.1 to 99.2	97.9 to 99.3	97.8 to 99.0	97.7 to 98.9	97.5 to 99.0
σ	±0.4	±0.4	±0.6	±0.5	±0.5	±0.6
95% confidence interval on σ	0.3 to 1.3	0.3 to 1.3	0.3 to 1.6	0.3 to 1.4	0.3 to 1.4	0.4 to 1.7

[a] Values in these columns given in dB.

TABLE IV.- ARITHMETIC DIFFERENCE OF MEAN EPNL VALUE OF REFERENCE WEATHER CONDITION A SUBTRACTED FROM UNADJUSTED AND ADJUSTED MEAN EPNL VALUES OF NONREFERENCE WEATHER CONDITIONS

[Positive sign indicates value is greater than $\bar{A}$ and implies overadjustment; negative sign indicates value is less than $\bar{A}$ and implies underadjustment]

Weather condition	Unadjusted	Arithmetic difference of $\bar{A}$ from -					
		ARP 866A			Proposed ANSI-S1-57		
		Layered	Mean 10 m	Mean of mean	Layered	Mean 10 m	Mean of mean
A	----	----	----	----	----	----	----
B	+0.1	-0.6	-1.4	-0.7	-0.6	-1.3	-0.6
C	-1.3	-0	-2.0	-1.2	-.5	-1.9	-1.4
D	-.7	+1.5	+1.4	+1.4	+1.2	+1.1	+1.1

TABLE V.- MAGNITUDE OF EPNL VALUE BY WHICH ADJUSTMENT PROCEDURE CAME CLOSEST TO REFERENCE WEATHER CONDITION

Weather condition	Amount that ANSI-S1-57 is closer than ARP 866A to $\bar{A}$ for -			Amount that ARP 866A is closer than ANSI-S1-57 to $\bar{A}$ for -		
	Layered	Mean 10 m	Mean of mean	Layered	Mean 10 m	Mean of mean
B	0	0.1	0.1	---	---	---
C	---	.1	---	0.5	---	0.2
D	0.3	.3	.3	---	---	---

TABLE VI.- EXAMPLE ANOVA RESULTS

	Degrees of freedom		F_{ν_1,ν_2} computed value	F_{ν_1,ν_2} distribution value at $\alpha_{0.05}$	Hypothesis accepted
	ν_1	ν_2			
Initial H_o $(\mu_A = \mu_{B_0} = \mu_{C_0} = \mu_{D_0})$	3	15	5.9	3.2	No
Secondary H_o:					
$\mu_A = \mu_{B_0}$	---	---	[a].16	[b]1.14	Yes
$\mu_A = \mu_{C_0}$	---	---	[a]1.30	[b]1.20	No
$\mu_A = \mu_{D_0}$	---	---	[a].68	[b]1.14	Yes

[a] Contrast value.

[b] Scheffé value.

TABLE VII.- SUMMARY OF SIGNIFICANT DIFFERENCES OF UNADJUSTED AND ADJUSTED NONREFERENCE WEATHER CONDITIONS B, C, AND D VALUES RELATIVE TO REFERENCE A MEAN EPNL VALUES TESTED AT 95% CONFIDENCE LEVEL

Initial hypothesis H_o	H_o accepted	Significant difference from μ_A using -						
		Unadjusted	ARP 866A			Proposed ANSI-S1-57		
			Layered	Mean 10 m	Mean of mean	Layered	Mean 10 m	Mean of mean
$\mu_A = \mu_{B_0} = \mu_{C_0} = \mu_{D_0}$	No	C_0	---	---	---	---	---	---
$\mu_A = \mu_{B_1} = \mu_{B_2} = \mu_{B_3} = \mu_{B_4} = \mu_{B_5} = \mu_{B_6}$	No	---	---	B_2	---	---	---	---
$\mu_A = \mu_{C_1} = \mu_{C_2} = \mu_{C_3} = \mu_{C_4} = \mu_{C_5} = \mu_{C_6}$	No	---	---	C_2	---	---	C_5	---
$\mu_A = \mu_{D_1} = \mu_{D_2} = \mu_{D_3} = \mu_{D_4} = \mu_{D_5} = \mu_{D_6}$	No	---	D_1	D_2	D_3	---	---	---

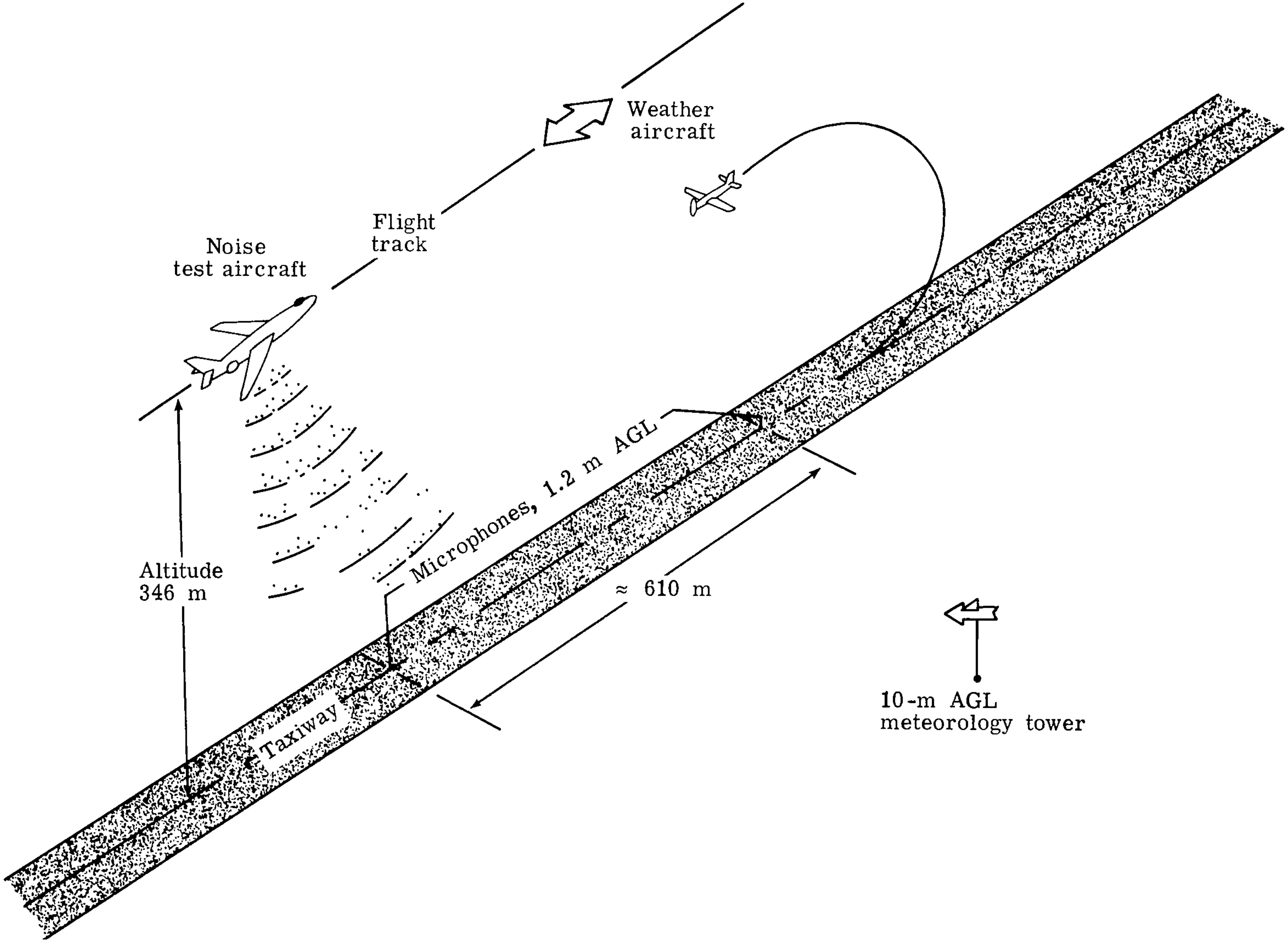

Figure 1.- General test arrangement.

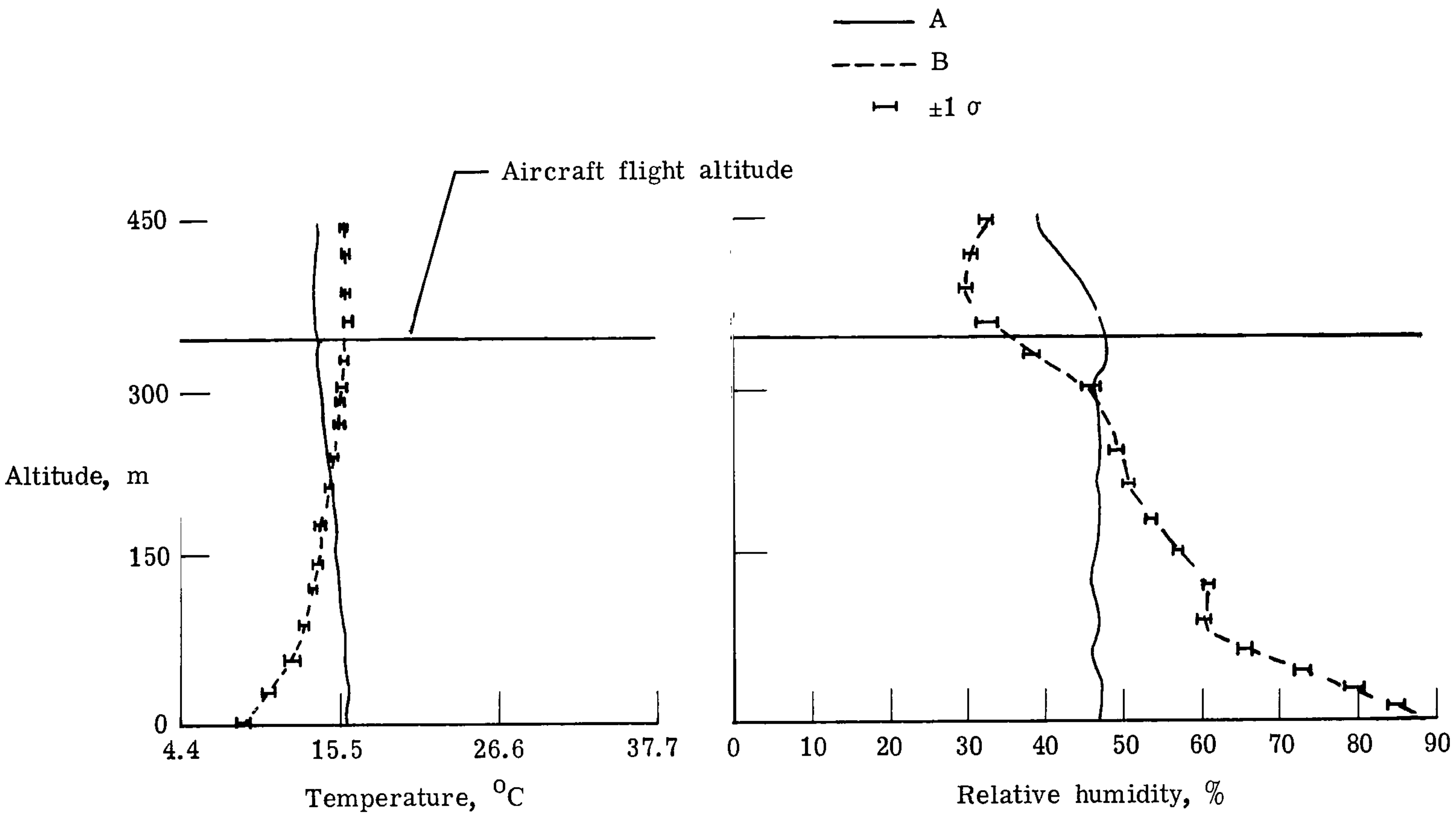

Figure 2.- Layered weather profiles for atmospheric reference A and nonreference B conditions.

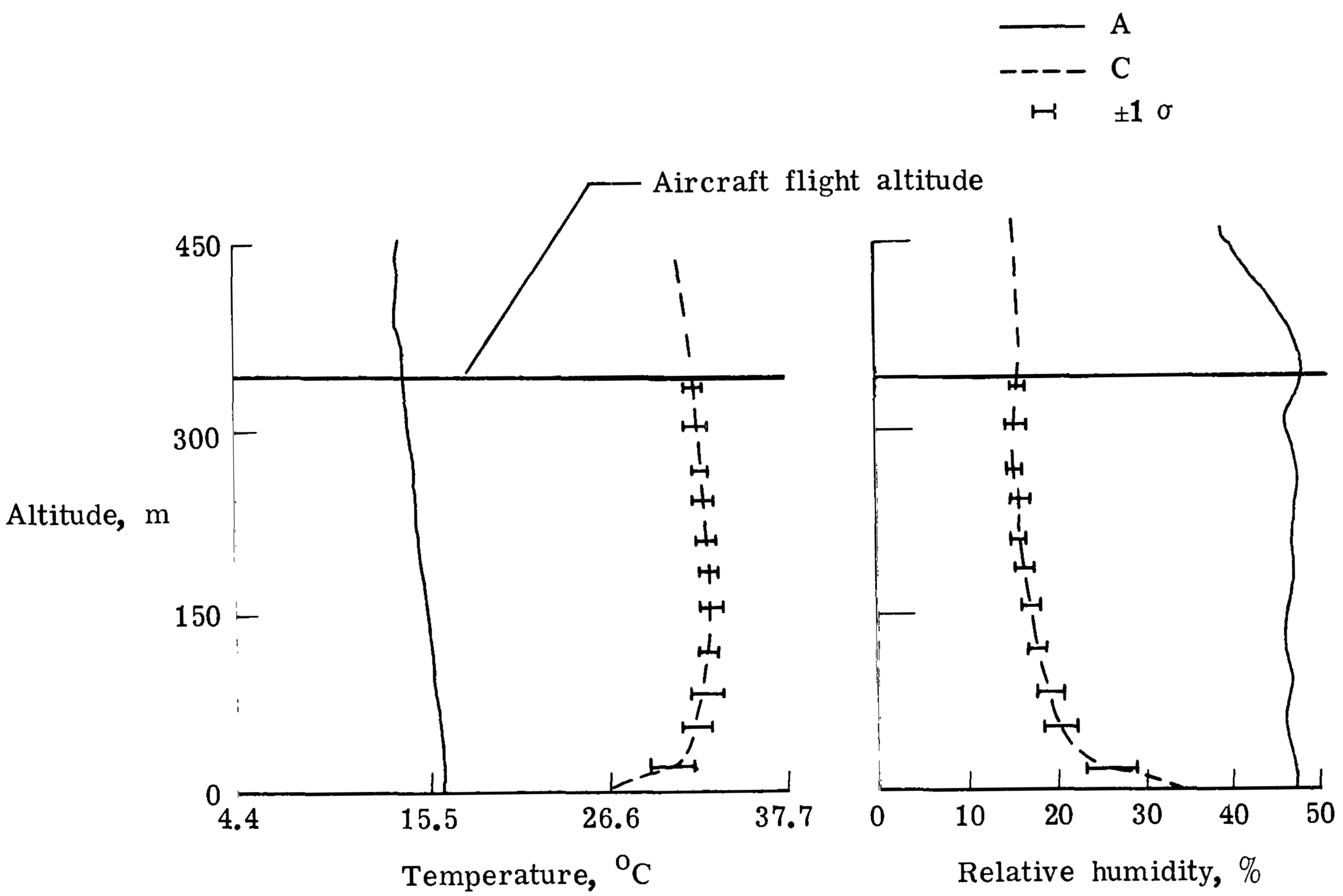

Figure 3.- Layered weather profiles for atmospheric reference A and nonreference C conditions.

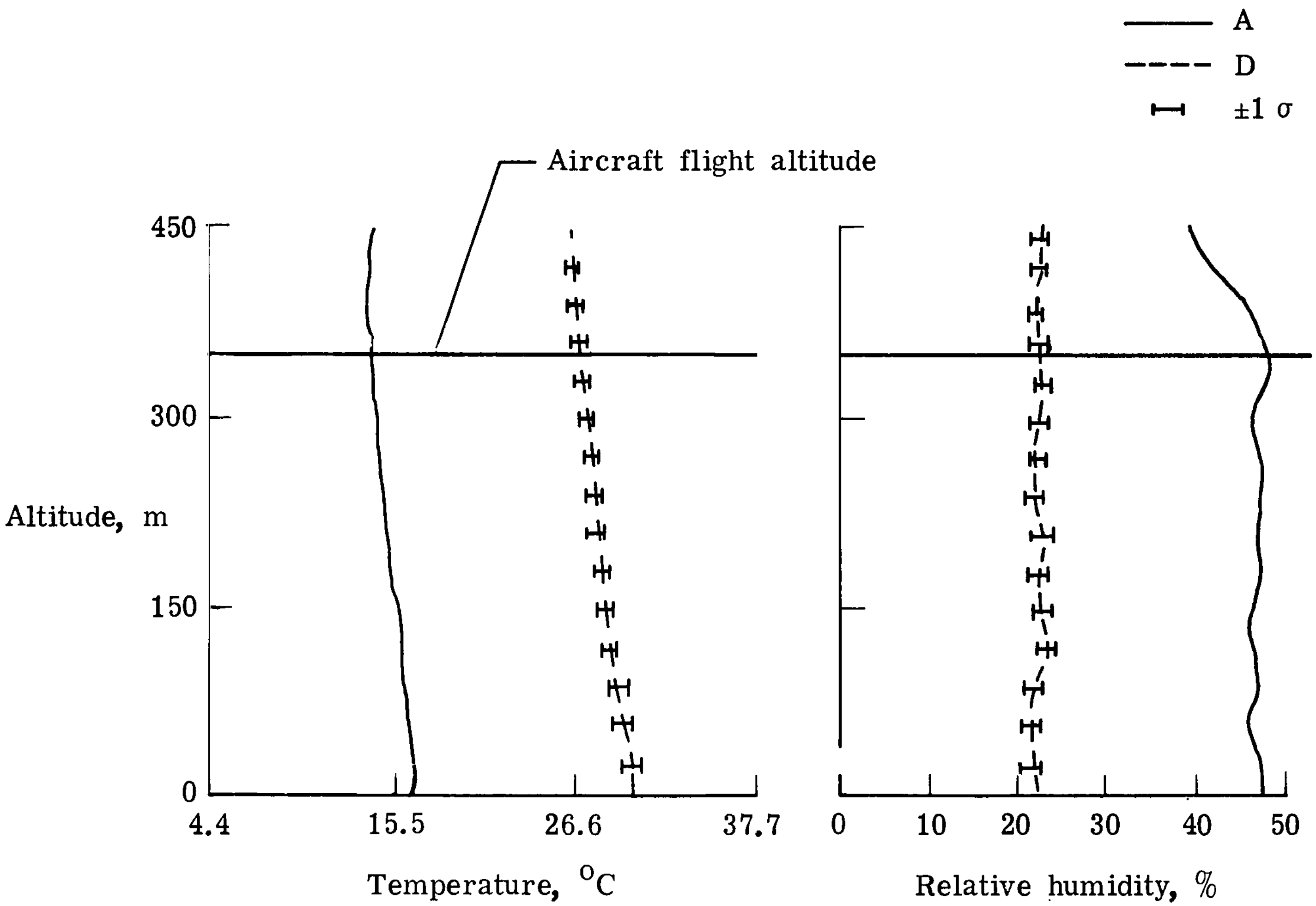

Figure 4.- Layered weather profiles for atmospheric reference A and nonreference D conditions.

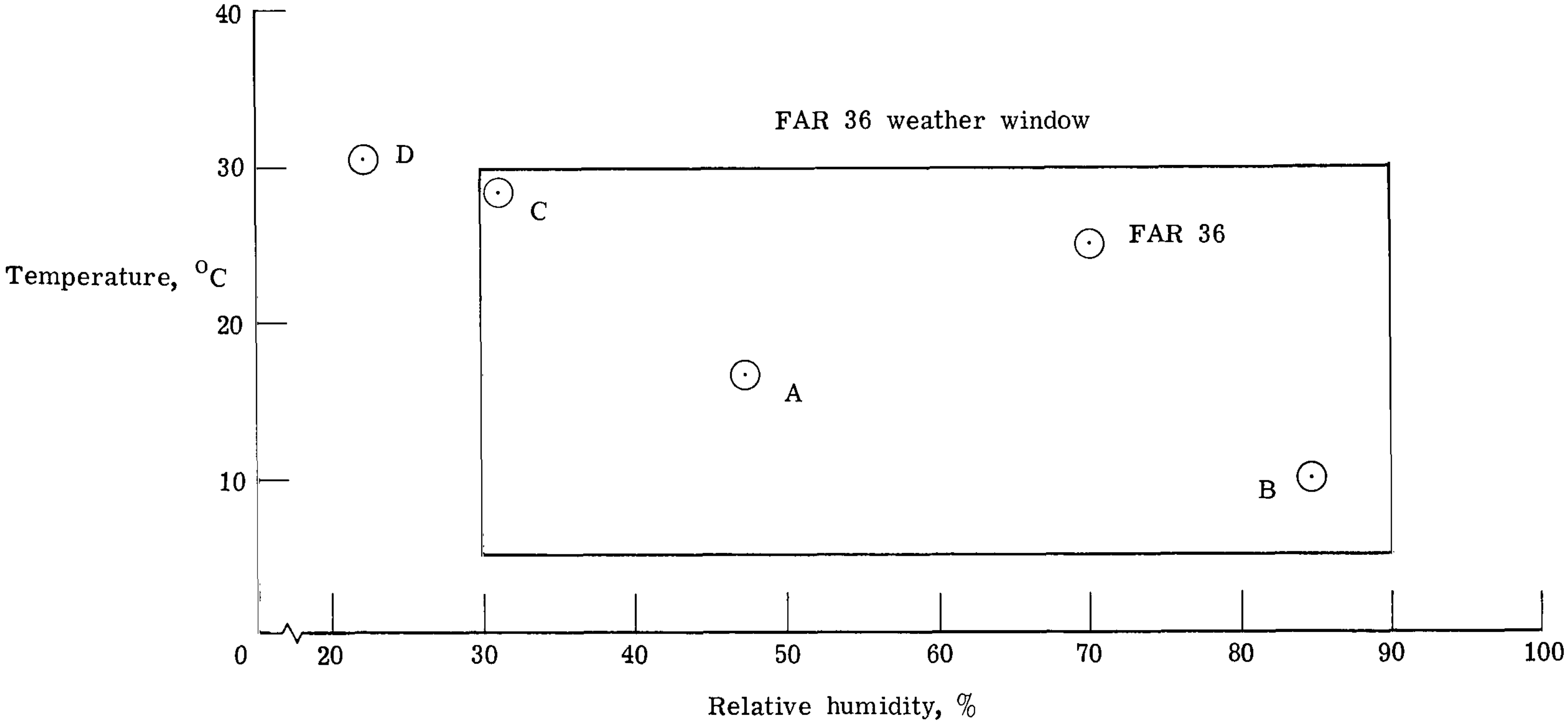

Figure 5.- Mean 10-m weather representation for atmospheric conditions A (reference) and B, C, and D (nonreference) compared with FAR 36 requirements.

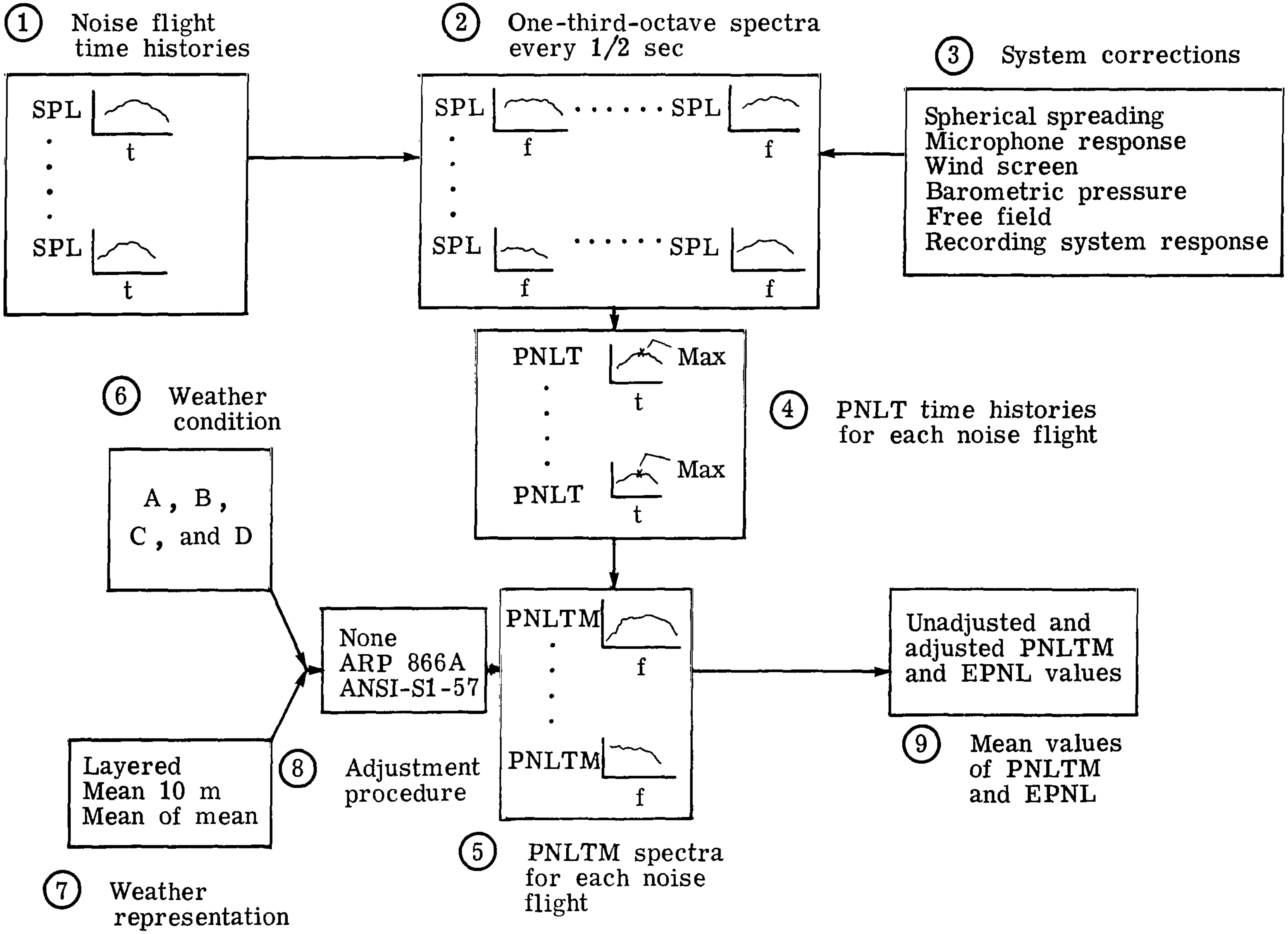

Figure 6.- Schematic representation of acoustic data reduction.

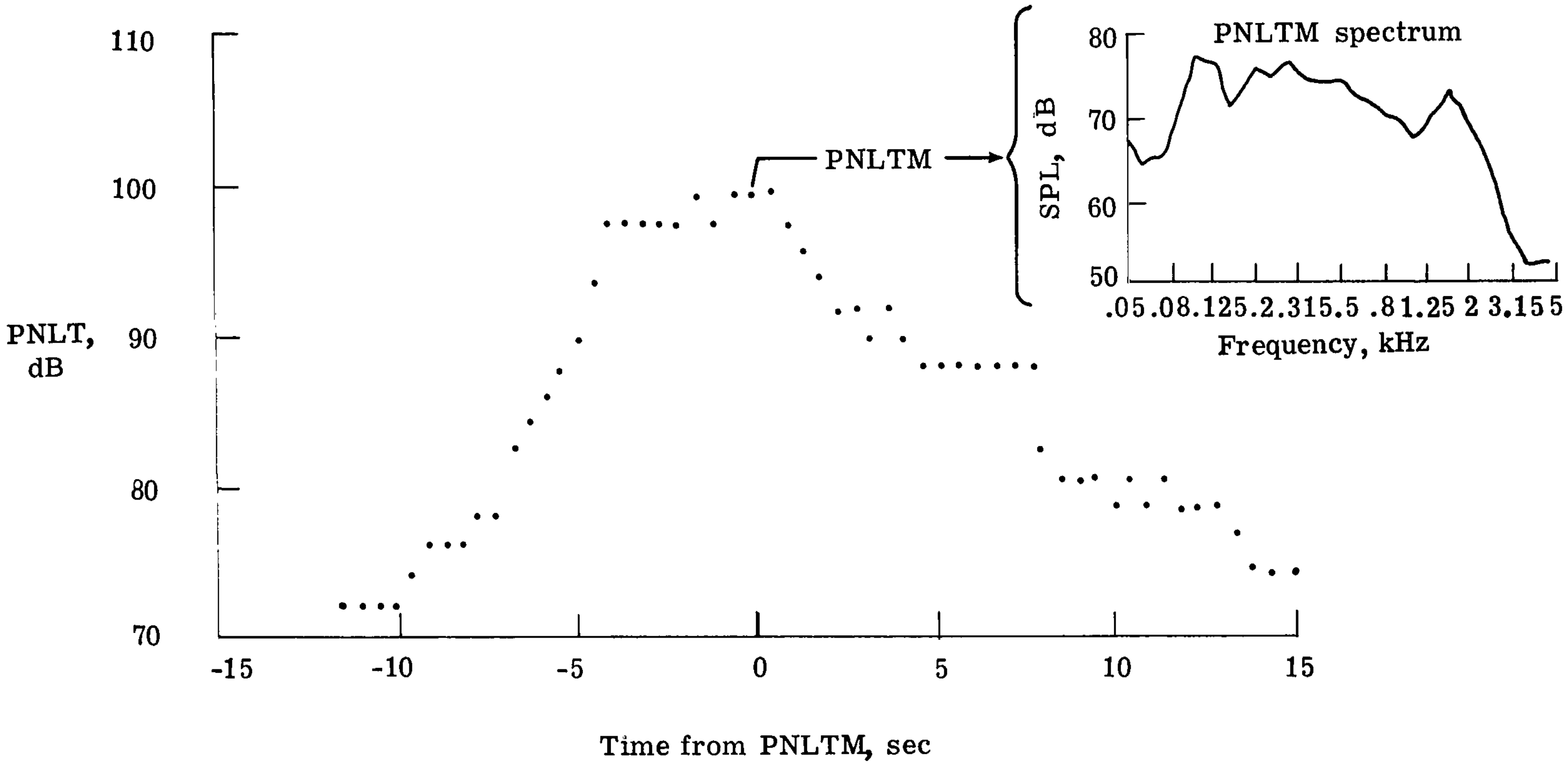

Figure 7.- Typical PNLT time history and PNLTM spectrum for 346-m overflight.

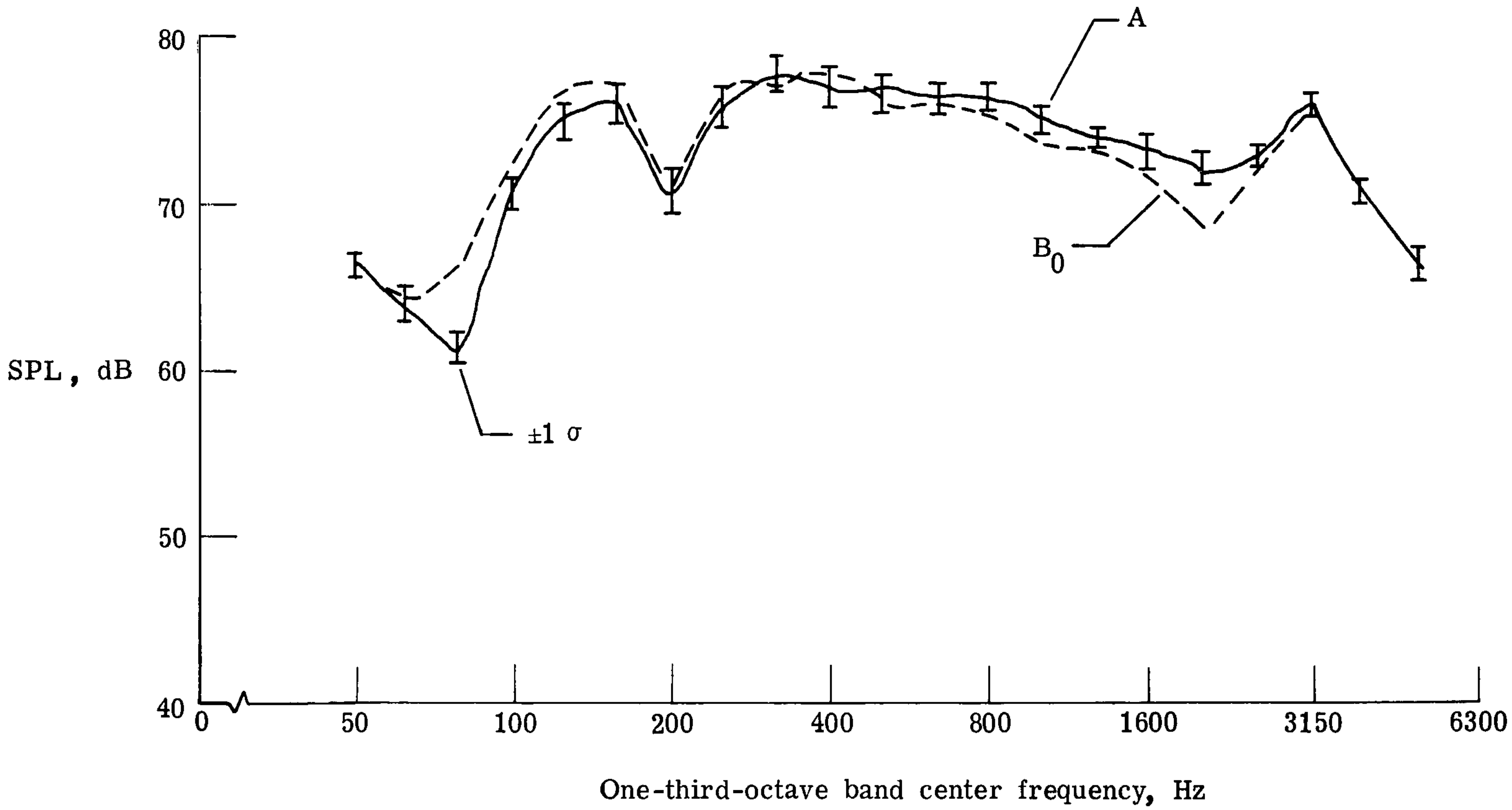

Figure 8.- Mean reference spectrum A and unadjusted nonreference weather condition spectrum B_0.

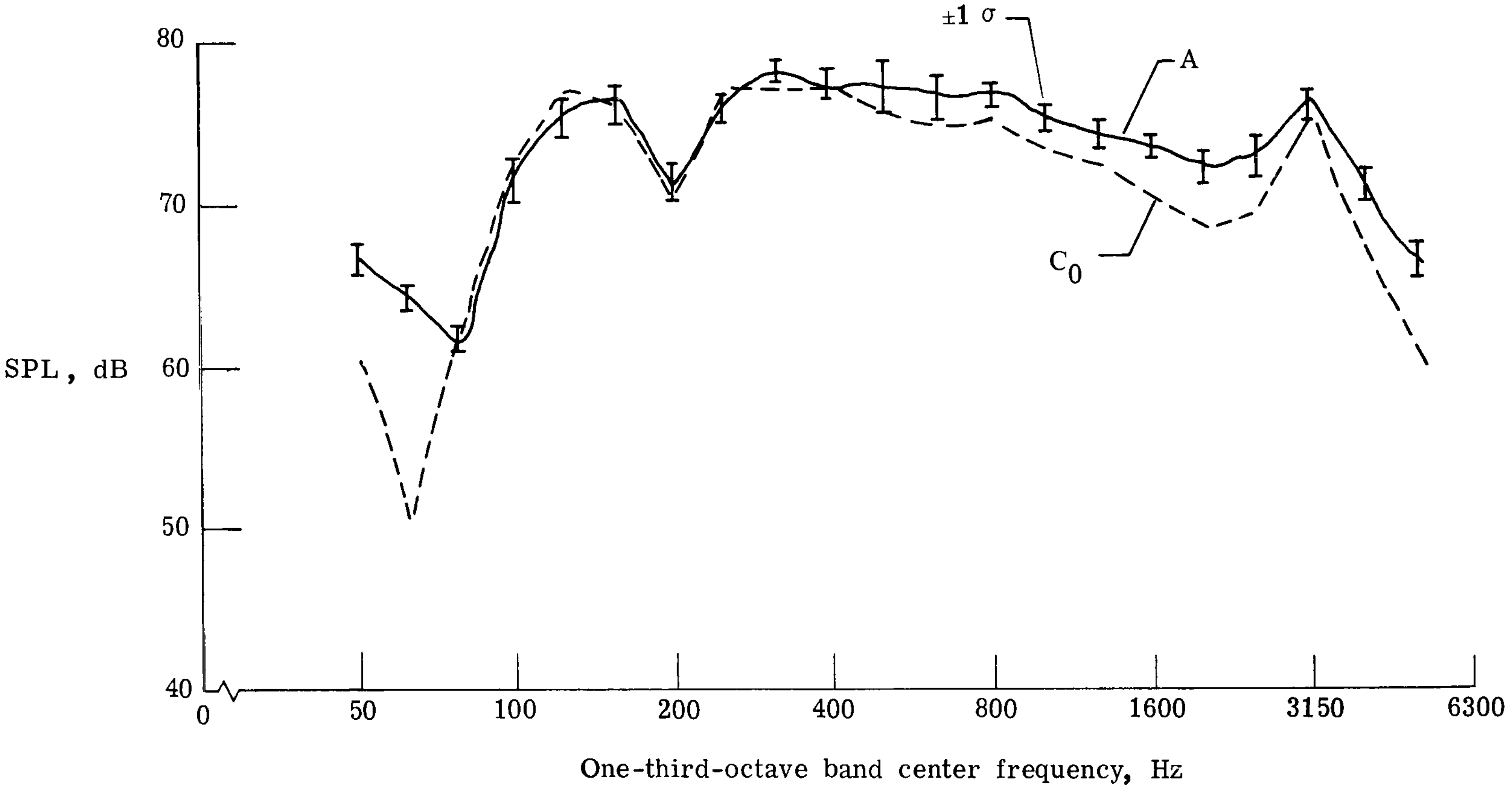

Figure 9.- Mean reference spectrum A and unadjusted nonreference weather condition spectrum C_0.

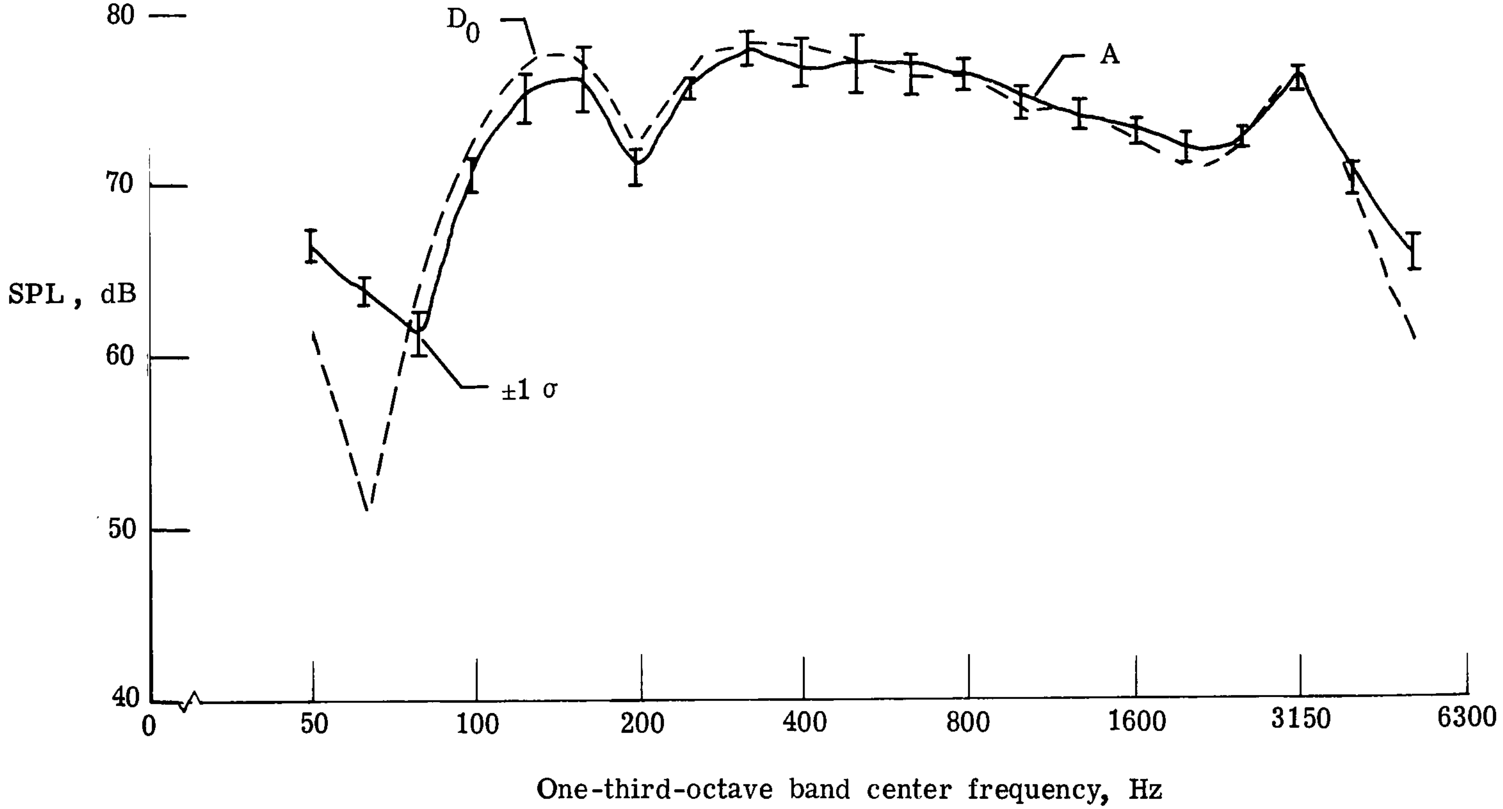

Figure 10.- Mean reference spectrum A and unadjusted nonreference weather condition spectrum D_0.

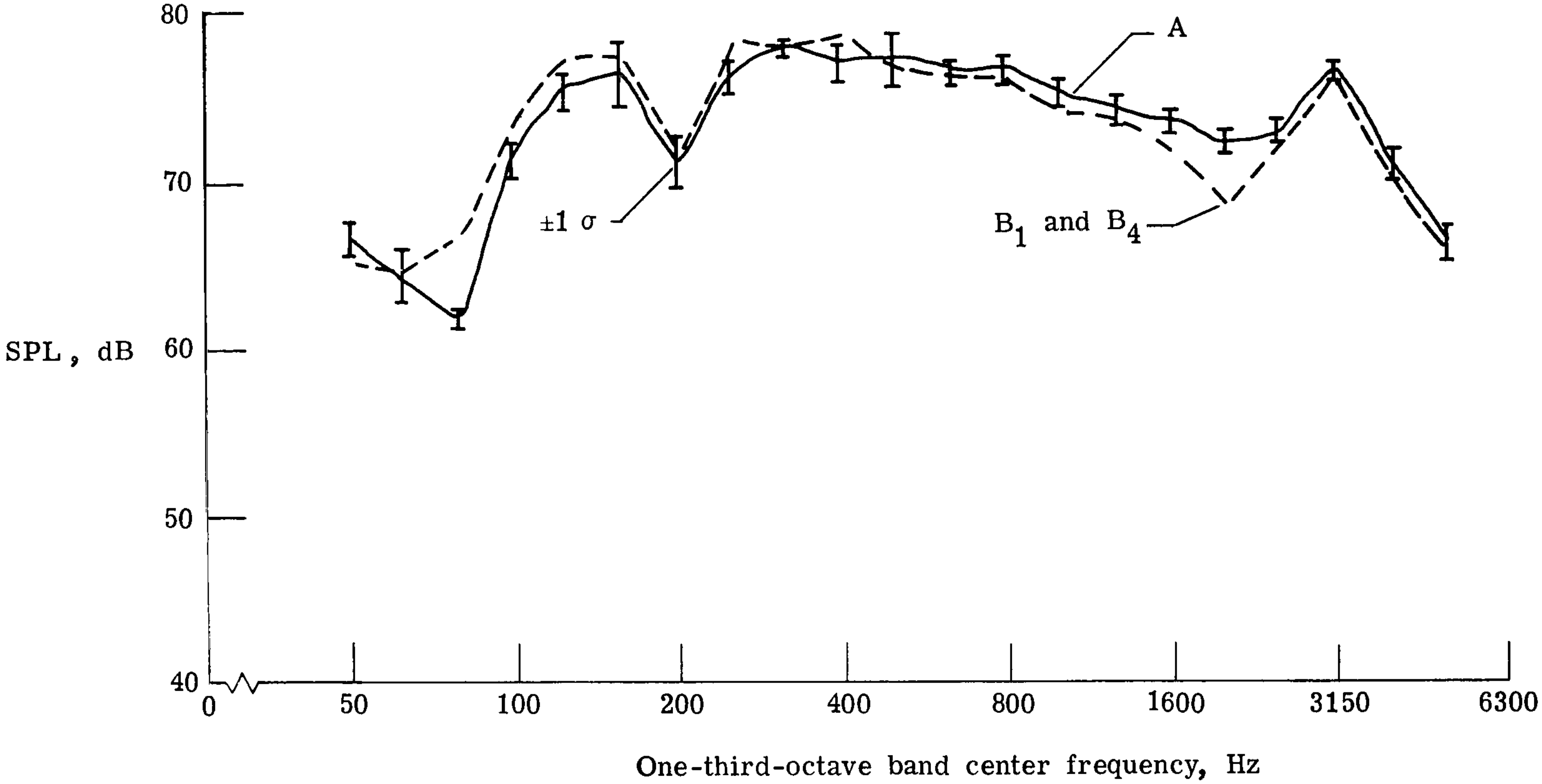

Figure 11.- Mean reference A and weather condition B adjusted spectra obtained by using layered meteorology.

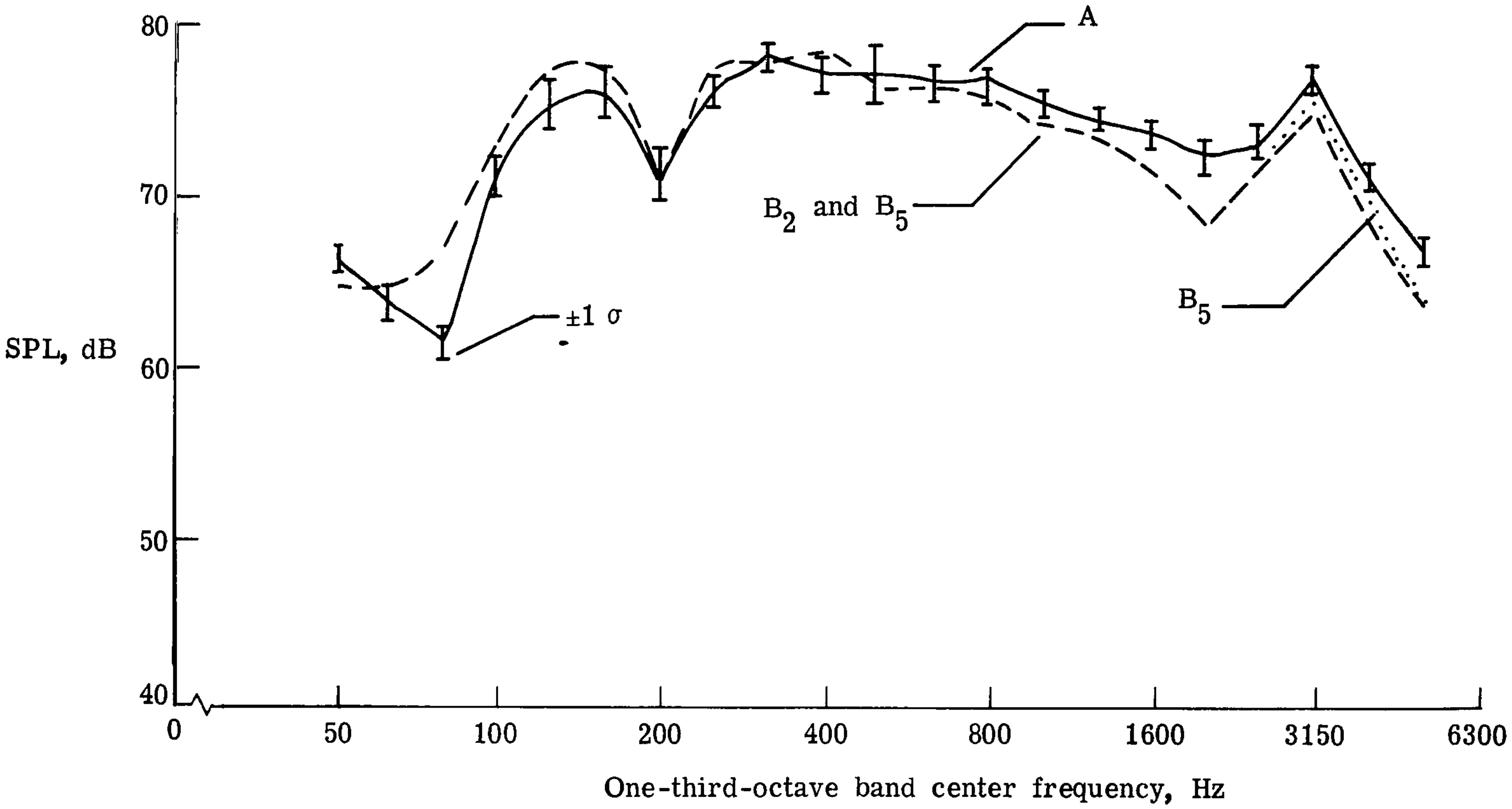

Figure 12.- Mean reference A and weather condition B adjusted spectra obtained by using mean 10-m homogeneous meteorology.

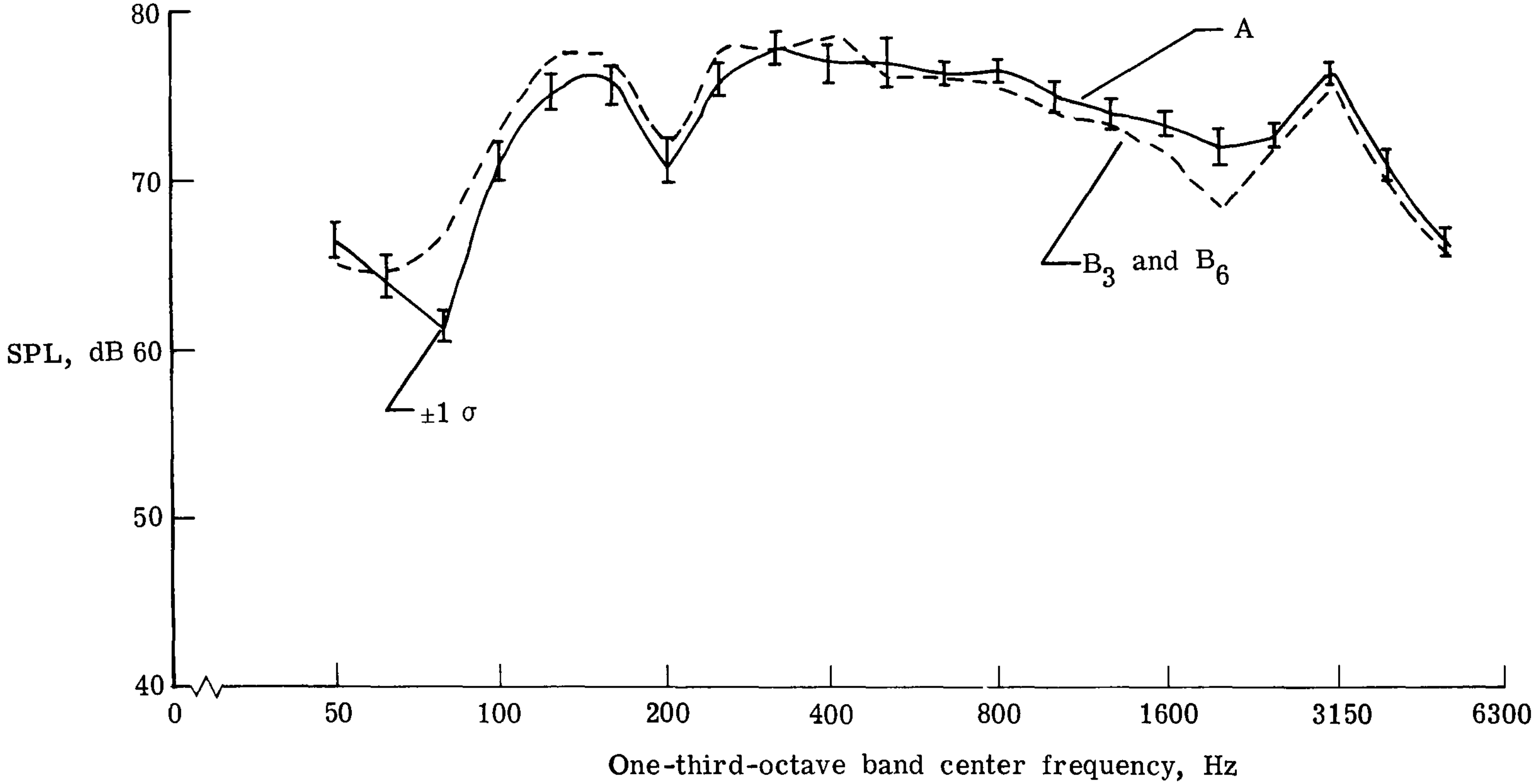

Figure 13.- Mean reference A and weather condition B adjusted spectra obtained by using the mean of mean 10-m and aircraft altitude meteorology.

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16. Abstract

Measured aircraft flyover noise spectra and effective perceived noise level (EPNL) values obtained under widely different weather conditions have been adjusted according to a proposed national standard recommended by Working Group S1-57 of the American Standards Institute. The results were statistically compared with the same measured spectra adjusted according to an alternate procedure presented in the Society of Automotive Engineers Aerospace Recommended Practice 866A and with reference spectra and EPNL values obtained under almost ideal weather conditions (isothermal profile and no wind). Three different ways to represent the weather condition through which the sound propagated were also evaluated.

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