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A REVIEW OF CURRENT PROCEDURES FOR NORMALIZING AIRCRAFT FLYOVER NOISE DATA TO REFERENCE METEOROLOGICAL CONDITIONS

Richard DeLoach

Langley Research Center
Hampton, Va. 23665

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A REVIEW OF CURRENT PROCEDURES FOR NORMALIZING AIRCRAFT FLYOVER NOISE DATA TO REFERENCE METEOROLOGICAL CONDITIONS

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SUMMARY

Procedures that are currently used to normalize raw aircraft noise data to reference weather conditions are reviewed. These procedures sometimes result in calculated values of molecular absorption which differ from measured values, especially at higher frequencies. An explanation is offered for this discrepancy, and its effect on normalized sound levels and on calculations of effective perceived noise level (EPNL) is examined.

INTRODUCTION

The atmosphere selectively absorbs acoustic energy by means of mechanisms that depend in a complicated way on temperature and humidity. Thus, raw field noise data must be normalized to reference weather conditions before one set of data can be compared with another.

In 1964, the Society of Automotive Engineers (SAE) published Aerospace Recommended Practice (ARP) 866 (ref. 1), a document providing standard values of atmospheric absorption coefficients for different temperatures and humidities. This document, which is based largely on the 1963 laboratory measurements of Harris (ref. 2) and the theoretical work of Kneser (ref. 3), constitutes a widely used standard for calculating the absorption coefficients needed to correct outdoor noise measurements to reference meteorological conditions.

When absorption coefficients calculated by the method of ARP 866 were originally compared by the SAE with absorption coefficients determined from aircraft flyover data (1/3-octave bands), the agreement was generally found to be quite good for band center frequencies below 4000 Hz. Above 4000 Hz, the ARP 866 calculation procedure originally overestimated measured losses somewhat, and the magnitude of this discrepancy increased with increasing frequency. Better agreement could be achieved above 4000 Hz if absorption calculations were based on the lower limiting frequency of each 1/3-octave band instead of the center frequency. A recommendation that this procedure be followed was incorporated into ARP 866, with similar guidelines for dealing with full-octave band data at the higher audio frequencies.

Since its publication in 1964, ARP 866 has been the subject of much discussion. Considerable data have been acquired in experimental studies, such as those conducted by Smith (ref. 4) and by Tanner (ref. 5), which indicate that absorption losses predicted by the method of ARP 866 agree well with measured losses for quite a wide range of meteorological conditions. Support for ARP 866 has not, however, been unanimous. Discrepancies have been reported between measured absorption losses and losses predicted from ARP 866, especially at the higher audio frequencies where the ARP 866 method sometimes overestimates measured losses. For example, Miller and Large (ref. 6) report discrepancies as great as 30 dB at 8 kHz for a 457-m (1500-ft) propagation path, and Franken and Bishop (ref. 7) report that the agreement between ARP 866 standard absorption values and measured absorption losses is improved at higher frequencies when the standard values are halved. Discrepancies have also been reported by McLeod (ref. 8), Robinson and Copeland (ref. 9), and other references cited in these papers.

It may be concluded from the literature that, although ARP 866 often works well for quite a wide range of conditions, there are apparently certain circumstances for which it fails to predict absorption losses accurately. In this report, an explanation is offered for those discrepancies which occasionally occur when calculations based on ARP 866 are compared with measured absorption losses.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

d	propagation path length
h	humidity
h_{max}	humidity of maximum absorption
m	absorption coefficient
m_{max}	absorption coefficient at humidity h_{max}
s	sound level

$\Delta m = m - m'$

$\Delta s = s - s'$

Subscripts:

r	reference-day conditions
t	test-day conditions

Abbreviations:

ARP	Aerospace Recommended Practice
EPNL	effective perceived noise level
SAE	Society of Automotive Engineers

A prime indicates values calculated from data in ARP 866.

DISCUSSION

Molecular absorption is a process in which acoustic energy is converted to the internal vibration energy of the constituent molecules in the propagation medium and ultimately into heat. This process, first described theoretically by Kneser (ref. 3), is responsible for much of the attenuation suffered by audio frequencies propagating in the atmosphere.

Molecular absorption coefficients (dB loss per unit distance) depend on temperature, humidity, and frequency, but when absorption coefficients measured for different frequencies and weather conditions are plotted against humidity, the data collapse to a single curve when the humidity values and absorption coefficients are normalized by the quantities h_{max} and m_{max}, respectively. The quantity h_{max} is the humidity at which absorption is a maximum for a given frequency and temperature and m_{max} is the molecular absorption coefficient at h_{max}. Figure 1, obtained from data of reference 10, is an experimental curve, due to Harris, of normalized absorption as a function of normalized humidity. With the aid of a curve such as this, molecular absorption coefficients can be predicted for a wide range of frequencies and weather conditions when h_{max} and m_{max} are known.

Procedures outlined in ARP 866 for calculating molecular absorption coefficients are based on an experimental curve of normalized absorption as a function of normalized humidity as in figure 1, a curve of m_{max} as a function of frequency for several different temperatures, and a curve of h_{max} as a function of frequency for a single temperature. (When the quantity h_{max} is expressed in units of g/m^3, it displays only a mild temperature dependence. The temperature dependence of h_{max} is ignored in ref. 1.)

When ARP 866 was originally drafted, some corrections were applied to Harris' experimental curve of normalized absorption as a function of normalized humidity to account for the (small) effects of classical absorption. Adjustments were also made to theoretical curves of m_{max} as a function of frequency for various temperatures to bring them in line with Harris' experimental data, but Kneser's original curve of h_{max} as a function of frequency was incorporated into ARP 866 with no experimental adjustments. Measurements made since then, including Harris' comprehensive 1967 measurements (ref. 11), indicate that the Kneser curve of h_{max} as a function of frequency departs from the experimental data. This discrepancy can be seen in figure 2, where the curve labeled "Experimental" is a second-order polynomial of best fit to the experimental data of Harris and others presented in reference 11. This departure of the theoretical curve from the experimental data may be due to Kneser's assumption of a simple square-root dependence of h_{max} upon frequency, whereas more recent studies suggest that the frequency dependence is more complicated (refs. 12 and 13). In any case, compared with the experimental data in figure 2, h_{max} values adapted for the current standard are somewhat high, and the higher the frequency, the greater the discrepancy is between measured values of h_{max} and the h_{max} values employed in ARP 866. It will be shown that this h_{max} discrepancy may be responsible for the difficulties which are sometimes encountered when ARP 866 is applied at the higher frequencies.

Note in figure 1 that a higher value of h_{max} (and thus a lower value of h/h_{max}) results in a higher value for the absorption coefficient, if it is assumed that $h/h_{max} > 1$. (The quantity h/h_{max} is greater than 1 for temperature-humidity-frequency combinations occurring in most aircraft flyover noise measurements.) If the h_{max} values employed in the ARP 866 standard are somewhat high (and this is suggested by a comparison with experimental h_{max} values, as shown in fig. 2), then one would expect the absorption values predicted from ARP 866 to be higher than experimental values, at least under those conditions for which the absorption coefficients depend sensitively on h_{max}.

It should also be noted that for h/h_{max} values greater than about 4, the absorption coefficients depend only mildly on h_{max} (fig. 1). The fact that h/h_{max} is relatively large for a wide range of commonly occurring conditions may account for the generally good agreement which is often observed between measured absorption losses and losses predicted by the method of ARP 866, despite the h_{max} discrepancy illustrated in figure 2. Since h_{max} increases with frequency, the absorption coefficients depend more sensitively on h_{max} at higher frequencies than at lower frequencies. (The corresponding values of h/h_{max} are smaller. See fig. 1.) As mentioned in the Introduction, it is in fact at the higher frequencies that ARP 866 tends most to overestimate the absorption losses.

It is clear that the h_{max} discrepancy noted in figure 2 will have the greatest effect under conditions for which the absorption coefficients depend sensitively on h_{max}, and figure 1 indicates that there is a relatively strong h_{max} dependence when the normalized humidity h/h_{max} is small (e.g., less than about 4). The quantity h/h_{max} increases with humidity and decreases with frequency. For a constant relative humidity, h/h_{max} also decreases with temperature. Thus, one would expect better agreement between measured and predicted losses under relatively warm, humid conditions than under cold, dry conditions. One would also expect smaller discrepancies to occur at lower frequencies than at higher frequencies.

SOME CALCULATIONS

To determine how sensitive molecular absorption coefficients are to h_{max}, calculations were performed for a variety of frequencies and weather conditions with the h_{max} values prescribed in reference 1. These same calculations were then repeated with the experimental h_{max} values from reference 11. A total of 1482 different combinations of frequencies between 1 kHz and 10 kHz in increments of 0.5 kHz, temperatures between 5° C and 30° C in increments of 5° C, and humidity between 30 and 90 percent in increments of 5 percent were considered. For each frequency-humidity-temperature combination, a quantity $\Delta m = m - m'$ was calculated, where m is the absorption coefficient based on experimental h_{max} data from reference 11 and m' is based on h_{max} values from reference 1. Figure 3 is a histogram of these Δm values.

It can be seen in figure 3 that almost all the Δm values that were computed (all but 16 of 1482) are negative; that is, for the weather conditions and frequencies described in the previous paragraph, absorption coefficients based on the h_{max} values prescribed in ARP 866 (ref. 1) are larger than absorption coefficients based on the experimental data of reference 11. Note also in figure 3 that the magnitudes of Δm can be quite large compared with the typical experimental error associated with a precision outdoor noise measurement. The Δm calculations are summarized as follows:

$\lvert\Delta m\rvert$, dB/304.8 m (dB/1000 ft)	Percent of 1482 combinations
>1	72.2
>5	29.4
>10	4.7

The largest discrepancies occurred at higher frequencies and cooler, drier weather conditions, as predicted. At lower frequencies, the discrepancies were generally smaller and were often well within the limits of typical experimental error.

NORMALIZED SOUND LEVELS

Noise data acquired under different weather conditions can be compared directly only if the data are normalized to the same reference weather conditions. The normalization procedure consists of adding the absorption losses calculated for test-day conditions to the measured sound levels and then subtracting the reference-day absorption losses. Obviously, any discrepancy in the absorption calculations will be reflected in the normalized sound levels.

Consider two sound levels, s and s', representing field data from the same noise source which have been normalized to the same reference conditions. Assume that experimental absorption values from reference 11 were used to determine s but that s' was determined from absorption coefficients calculated by the method of reference 1. The quantity $\Delta s = s - s'$ can be determined as follows:

$$\Delta s = (\Delta m_r - \Delta m_t)d \tag{1}$$

where Δm_t and Δm_r are discrepancies in the absorption coefficients for test-day and reference-day weather conditions, respectively, as defined in the previous section, and d is the propagation path length.

Calculations described in the previous section reveal that under reference-day conditions of 25° C and 70 percent relative humidity, $|\Delta m_r|$ is less than 1 dB/304.8 m (dB/1000 ft) for frequencies up to 10 kHz whereas, as the preceding table indicates, $|\Delta m_t|$ can be considerably larger than this for arbitrary test-day weather conditions. Since Δm_t is usually negative (fig. 3), it follows from equation (1) that Δs is usually positive. It is therefore concluded that s' is often greater than s, a result which, based on the previous discussion, suggests that data acquired under cool or dry conditions can lead to higher normalized sound levels than data acquired under warm or humid conditions. This result holds, even when both sets of data describe the same noise source and both sets are normalized to the same reference conditions by the method of reference 1. Such discrepancies are expected to be higher for high-frequency noise sources (a jet transport under approach power conditions, for example) than for lower frequency sources.

Aircraft effective perceived noise levels (EPNL) are generally based upon data which have been normalized to reference weather conditions. Calculations are now being made to determine how sensitive these EPNL values are to absorption corrections which are applied in normalizing the raw data to reference conditions. This investigation is not complete, but preliminary results indicate that when the procedures of reference 1 are used to normalize raw data to reference conditions, EPNL values can be higher than when experimental absorption data are used in the normalization procedures, especially when the raw data are acquired under relatively cool or dry conditions. Detailed results of this EPNL study are being compiled.

CONCLUDING REMARKS

Standard procedures currently used to normalize raw aircraft noise data to reference weather conditions have been reviewed. For a wide range of commonly occurring conditions, these procedures can usually be depended upon to predict measured absorption losses quite accurately. However, there have been a sufficiently large number of discrepancies reported between predictions based on the current standard and measured absorption values to arouse the curiosity of the interested observer. Why does the current standard, which apparently predicts absorption losses quite well most of the time, occasionally overestimate absorption losses, especially at the higher audio frequencies, and under what conditions is this discrepancy more (or less) likely to occur? In this report, an attempt has been made to answer this question in terms of a discrepancy noted between values of one of the absorption parameters used in the current standard and experimental values of that parameter. The parameter in question is h_{max}, the humidity of maximum absorption for a given temperature and frequency. The h_{max} values used in the current standard come from a theoretical curve of h_{max} as a function of frequency generated in 1933 by Kneser (The Journal of the Acoustical Society of America, October 1933). These h_{max} values are larger than the experimental h_{max} values presented by Harris in NASA CR-647, which were reported after the current absorption standard was adopted.

It has been shown that for a wide range of commonly occurring conditions, absorption coefficients depend only mildly on h_{max} and thus the h_{max} discrepancy is expected to have little effect on standard absorption calculations for those conditions. There are conditions, however, for which the absorption coefficients depend more or less critically on h_{max}; it is under these conditions that one would expect the largest discrepancies to occur between measured losses and losses predicted by the method of the current standard. Absorption coefficients can depend strongly on h_{max} at higher frequencies and for cool, dry weather conditions. Thus, one should expect better results when the current standard is applied under relatively warm, humid conditions and better agreement is expected at lower frequencies than at higher frequencies.

It is concluded that since current standard procedures for calculating molecular absorption losses rely on h_{max} values which are not supported experimentally, losses predicted by this standard may not be accurate under those conditions for which the h_{max}

dependence is strong. Special care should be exercised in using the current standard on data which have been acquired under relatively cool or dry test-day conditions, especially for higher frequency noise sources.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
March 17, 1977

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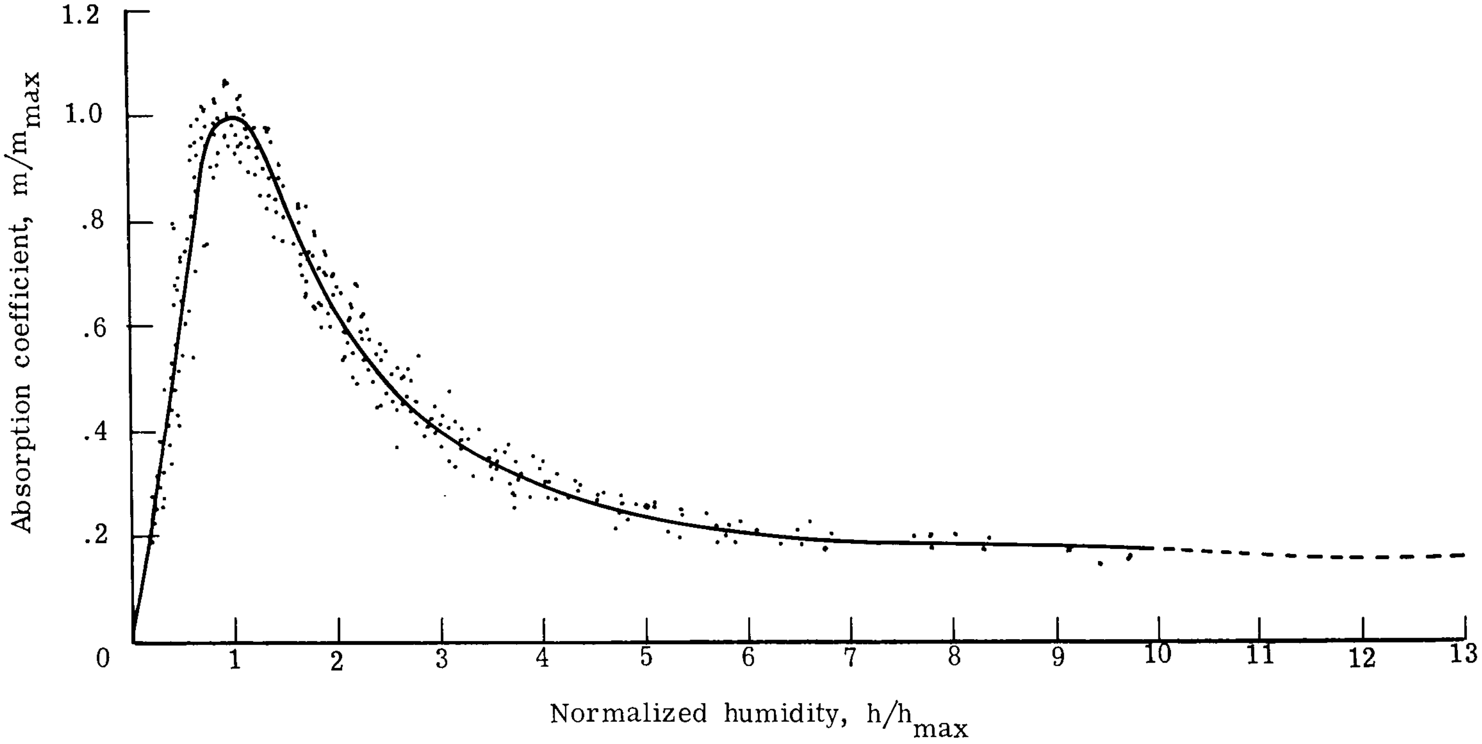

Figure 1.- Normalized molecular absorption coefficient as a function of normalized humidity. (After Harris (ref. 10).)

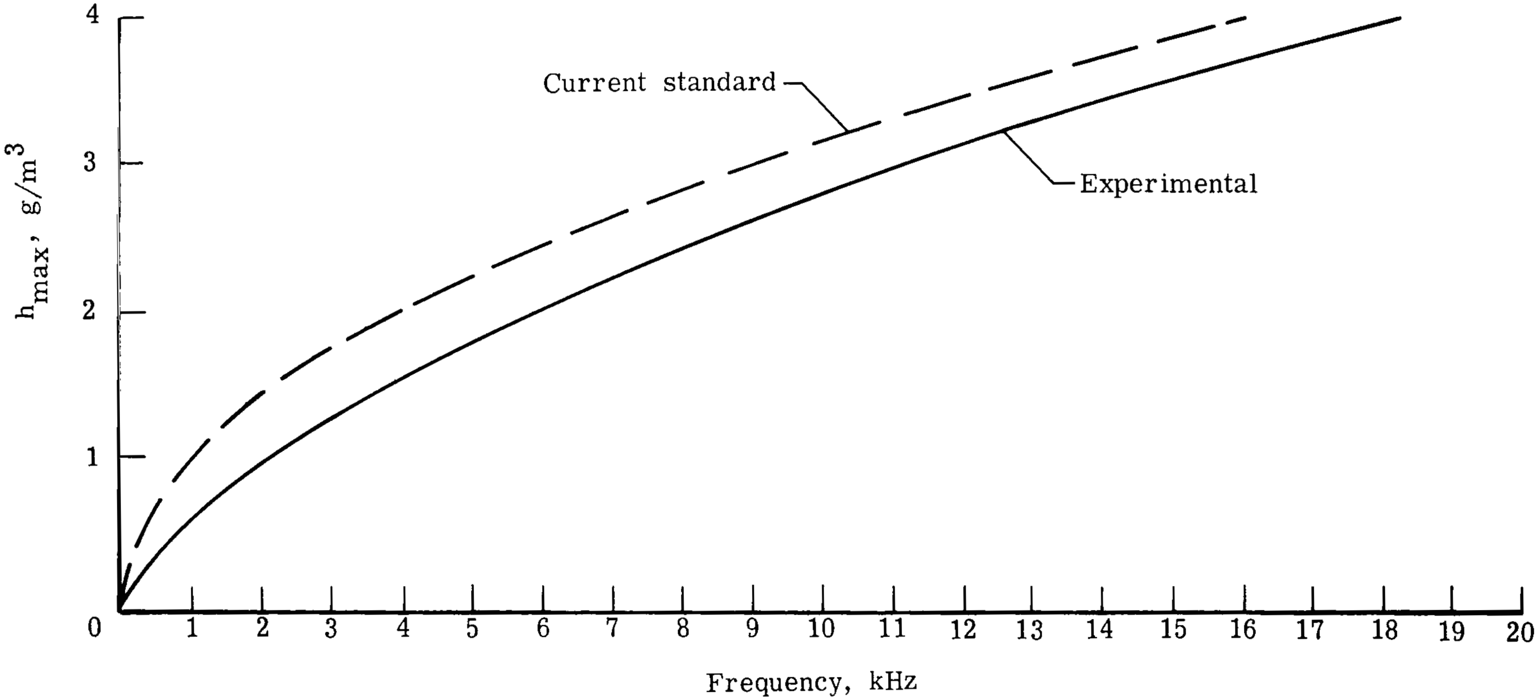

Figure 2.- Relaxation frequency as function of concentration of water vapor in air expressed in g/m^3. (After Harris (ref. 11).)

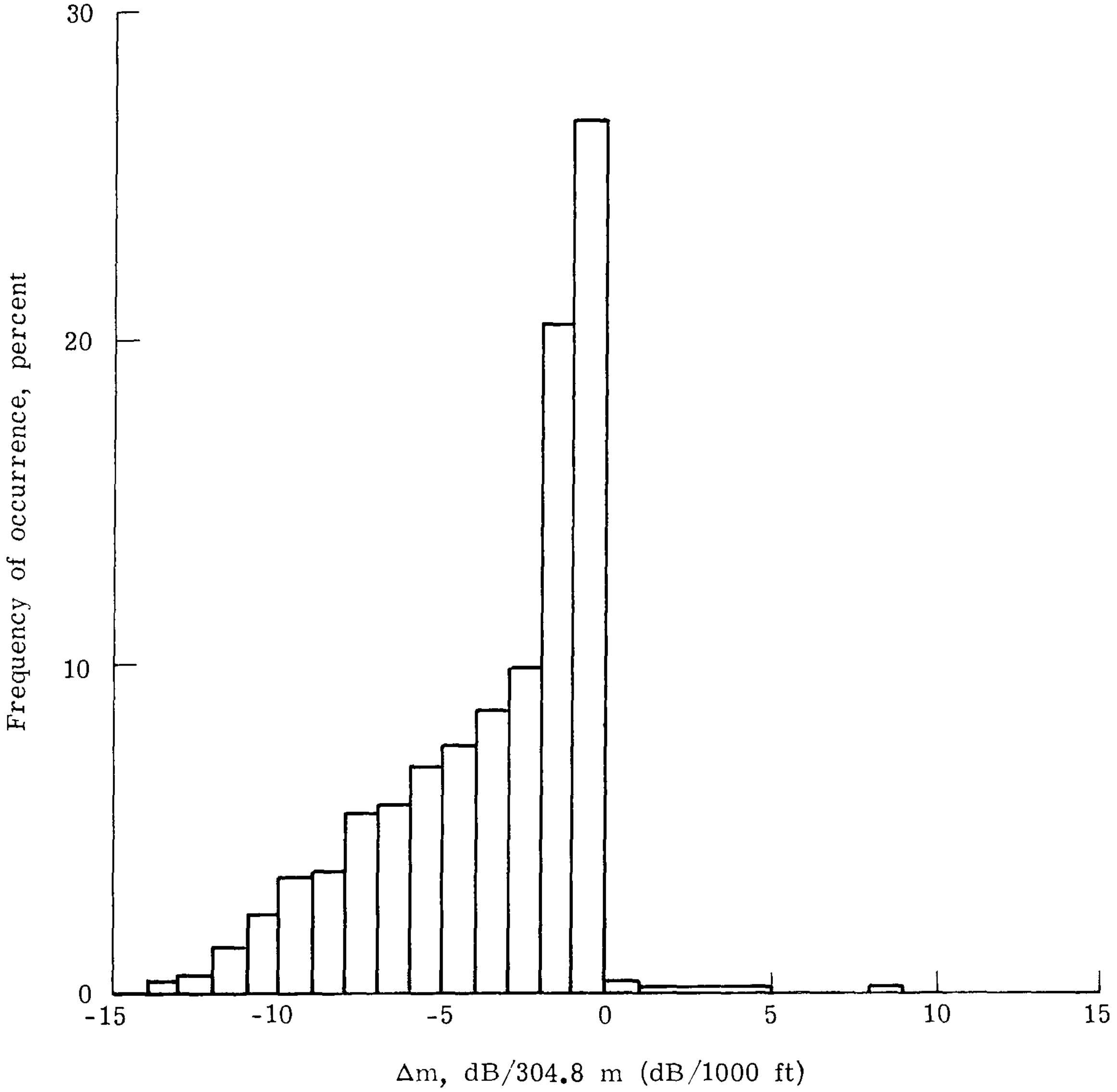

Figure 3.- Histogram of Δm values.

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