Lateral Attenuation of Aircraft Noise

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Lateral attenuation of aircraft noise comprises all of the losses in addition to spherical spreading and atmospheric absorption. The phenomenon is primarily due to ground interference effects and is often regarded as a function of source-receiver distance and elevation angle. In this paper, theoretical predictions are made in order to examine the consistency of existing empirical data on lateral noise attenuation. The results indicate that the effects of source spectrum shape and meteorological conditions must also be considered in any model for predicting lateral noise attenuation.

Introduction

OF great importance to the control of community noise around airports is an accurate knowledge of the locations of equal noise load contours. In turn, the noise load at a given position is strongly dependent on the noise levels received from the individual aircraft at that place.

To obtain the noise levels at arbitrary positions, extrapolations are usually made from noise data measured beneath the flight path. Although the noise level decay rate with increasing distance from the source is due primarily to spherical spreading and atmospheric absorption, other phenomena also produce attenuations.

In particular, excess attenuations are caused by the effects of ground reflection. In addition, at low elevation angles, shielding effects of the aircraft on emitted noise might alter the observed noise levels. The latter influences give rise to the so-called lateral noise attenuation. By definition, this quantity is the difference in time-integrated or maximum noise levels during flyover between that received on the flight track and that received at a sideline position, at a distance from the aircraft equal to the distance to the position on the flight track.

The SAE-A21 Aircraft Noise Committee has developed an interim empirical prediction method for lateral attenuation of aircraft noise.[1] The method uses the effective perceived noise level as a measure of the noise. The recommended curves for predicting lateral noise attenuation (LNA) are given in Fig. 1. Shown in Fig. 2 is the geometrical model assumed in deriving the attenuation values. The amount of LNA in Fig. 1 is a function of elevation angle and distance to the side of the flight track. For a given distance, LNA decreases with increasing elevation angle; and the further the receiver is from the aircraft, the greater the attenuation for the same elevation angle. The distance dependence disappears for lateral distances larger than 914 m (3000 ft), and LNA becomes zero for an elevation angle equal to 60 deg.

The prediction method, in particular, seems adequate for aircraft powered by turbojet engines, since in the underlying data base, very few data are associated with modern turbofan engines. For example, one of the key sets of data is from an experiment using a military aircraft equipped with two rear-mounted turbojet engines.[2]

Recently, data from a ground effect experiment using a Boeing 747 aircraft became available.[3] Less LNA was measured for this wide-body aircraft powered by high-bypass ratio engines than for the turbojet-powered aircraft. As a consequence, an important conclusion drawn from the measurements was that the amount of LNA depends on the spectral contents of the noise source. This conclusion was supported by the fact that no definite shielding differences were apparent in the results of both experiments.

The observed significance of the type of noise source requires a consideration of the various factors which affect the spectral contents of the noise signal. Therefore, in this paper, the effects of source spectrum shape, atmospheric conditions (air temperature and humidity), and type of ground cover on LNA are quantified separately.

First, the empirical data given in Refs. 2 and 3 are summarized and a brief review of the procedure used for the prediction of ground effects is presented. The following calculation results indicate that a representation of LNA simply in terms of the two parameters, elevation angle and distance, may yield poor results.

Experimental Results

Long-range LNA expressed in effective perceived noise level (EPNL) units for the turbojet- and turbofan-powered aircraft is presented in Fig. 3. As depicted in Fig. 2, the elevation angle is the angle between receiver and source at the point of closest approach. The curves in Fig. 3 are least-square fits of acoustic data obtained by comparing data from a microphone close to the flight track with data from downrange microphones. The test matrices were such that, at small elevation angles, noise propagation out to ranges of more than 1000 m from the source was realized. The data were deduced from measurements over grassland with the microphones located at a height of 1.2 m. The meteorological conditions during the measurements were collected by weather station and balloon. The acoustic data were not corrected to reference weather conditions.

Also included in Fig. 3 is maximum LNA according to the prediction method reported in Ref. 1. Apparently, only the measurements of the turbojet-powered aircraft agree closely with the recommended attenuations.

The lesser attenuation for the B-747 aircraft was attributed to the presence of low-frequency noise in the source spectrum of turbofan engines. The spectral differences are illustrated by Fig. 4, where the 1-m free-field source spectra from the experiments in Refs. 2 and 3 are given. Each spectrum represents average characteristics abstracted from noise signals measured underneath the aircraft at an emission angle of 122.5 deg.

A-weighted noise level (LA), perceived noise level (PNL), and EPNL average measurement results are plotted in Fig. 5 as a function of elevation angle for the turbojet- and turbofan-powered aircraft. The curves demonstrate a slight effect of noise unit on LNA values for the turbojet engines. On the contrary, for the turbofan engines, a dramatic decrease of LNA occurs if measures other than effective perceived noise level are used.

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Summary of Theory

The radiation geometry of the problem is also outlined in Fig. 2. The aircraft is assumed to generate sound as a point source, and the sound waves are assumed to travel rectilinearly through the atmosphere. Then, at a given frequency, the sound pressure received above a partly reflecting ground surface can be represented by the sum of the direct sound pressure and the sound pressure from an image source, the latter multiplied by a reflection coefficient

$$p=(p_1/R_1)\{\exp[i(kR_1-wt)]+Q\exp[i(kR_2-wt)]\} \quad (1)$$

where p_1 is the amplitude of the sound pressure at a reference distance from the source; $Q=|Q|e^{i\varphi}$ is the complex reflection coefficient; and $k=2\pi f/c$ is the propagation constant in air (f is the frequency and c the speed of sound).

The reflection coefficient for spherical wave propagation reflected by a flat plane on which a normal impedance boundary is prescribed can be expressed as[4]

$$Q=Q_p+(1-Q_p)F(p) \quad (2)$$

In this equation, Q_p is the familiar plane wave reflection coefficient, which is given by

$$Q_p=(Z\sin\psi-1)/(Z\sin\psi+1) \quad (3)$$

where ψ is the angle of incidence (see Fig. 2), and Z is the normalized acoustic impedance of the ground surface.

To describe the acoustic properties of the ground surface, it is convenient to use the empirical formula of the form[5]

$$Z=1+9.08(f/\sigma)^{-0.75}+i11.9(f/\sigma)^{-0.73} \quad (4)$$

The values of the input parameter σ pertaining to grass and concrete may be 62.5 and 750, respectively.[2]

The function $F(p)$ in Eq. (2) describes the interaction of a curved wave front with the flat surface:

$$F(p)=1-\sqrt{\pi}pe^{p^2}\,\mathrm{erfc}(p) \quad (5)$$

where

$$p=-i(\sqrt{ikR_2/2})(\sin\psi+1/Z) \quad (6)$$

where $\Delta R=R_2-R_1$.

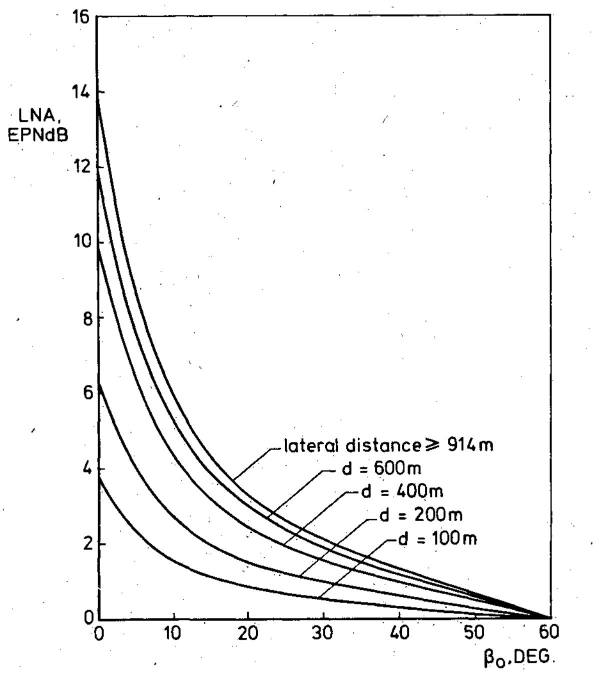

Fig. 1 Prediction curves for lateral noise attenuation (Ref. 1).

The corresponding sound pressure level difference over a one-third octave band is obtained from an integration of the mean-square pressures. On the assumption that white noise Adequate expansions of the function $F(p)$ into series are given in Ref. 6.

From Eq. (1) follows that the difference between the sound pressure level received in the presence of a ground surface and the free-field sound pressure level, is given by

$$\Delta L=10\log_{10}[1+|Q|^2+2|Q|\cos(2\pi f\Delta R/c+\varphi)] \quad (7)$$

emission across each band occurs, Eq. (7) changes to[7]

$$\Delta L=10\log_{10}[1+|Q_c|^2+2|Q_c|\cos(\beta+\varphi)] \quad (8)$$

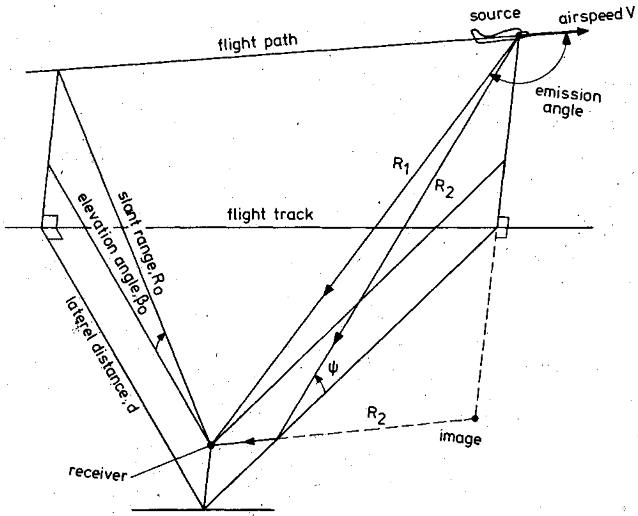

Fig. 2 Geometrical model.

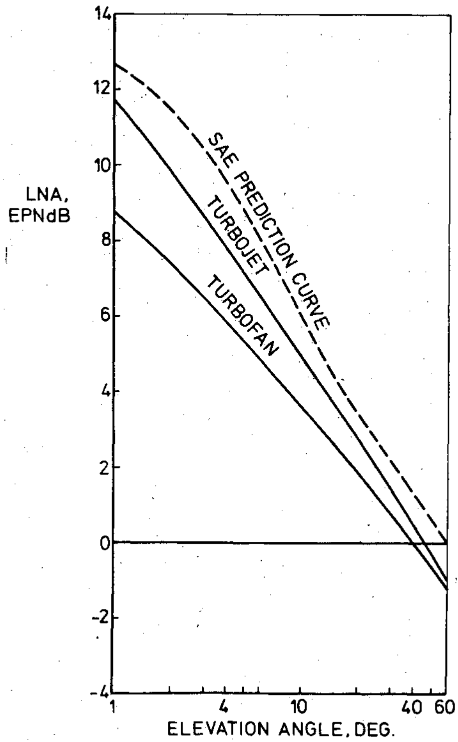

Fig. 3 Measured long-range lateral noise attenuation (Ref. 3).

where the quantities α and β are given by

$$\alpha = 0.2316\pi f_c \Delta R / c \qquad (9)$$

$$\beta = 2.0134\pi f_c \Delta R / c \qquad (10)$$

The subscript c in Eq. (8) indicates that the reflection coefficient is evaluated at the center frequencies of the tertsbands.

Lateral Noise Attenuation Prediction

The general characteristics of lateral noise attenuation may be studied by particular examples. Consider the case of an elevation angle $\beta_0 = 1$ deg and a slant range $R_0 = 1000$ m (see Fig. 2). To also make the calculation results in a quantitative sense to be compared with the empirical data, the situation is considered that both the receiver under the flight path and the lateral receiver are positioned at a height of 1.2 m above grassland. Furthermore, for the predictions, the reference one-third octave band spectra in Fig. 4 are used.

For EPNL analysis, a level flyover and an airspeed $V = 100$ m/s are considered. At each half-second of the flyover the free-field spectra at the proper slant ranges are determined, assuming that the source spectra in Fig. 4 are not dependent on emission angle. The conversions are made using the standard values of atmospheric absorption given in Ref. 8. Next, the spectra beneath the aircraft and at the sideline position are corrected for ground reflection effects. From these, the PNL time histories are evaluated. To obtain the EPNL values, both time histories are integrated antilogarithmically over the time interval during which the instantaneous value of PNL is within 10 PNdB of the maximum value. Subtraction of the lateral result from the value on the flight track yields LNA.

For LA and PNL analysis, lateral noise attenuation is taken equal to the noise level difference at an emission angle of 90 deg.

Computed values of LNA due to the presence of the ground as a function of relative humidity are plotted in Fig. 6 for three air temperatures. The main properties of these curves can be summarized as follows:

1) Less attenuation is found for the turbofan-powered aircraft than for the turbojet-powered aircraft.

2) The greatest attenuations occur if EPNL units are used.

3) Lateral noise attenuation values in LA and PNL have approximately the same order of magnitude.

4) Especially for the turbofan-powered aircraft, values of LNA exhibit a strong dependence on atmospheric conditions.

5) Under standard day weather conditions (relative humidity 70%, temperature 15°C), the attenuations reach certain minimum values.

Unmistakably, the first three properties listed above agree with the major details of the experimental results in Fig. 5.

The predicted dependence of LNA on source spectrum shape and atmospheric conditions may be explained by the spectra in Fig. 7. For two combinations of air temperature and relative humidity, the A-weighted tertsband noise levels under the flight path and at the sideline position are shown. Apparently, the very low attenuations under standard day

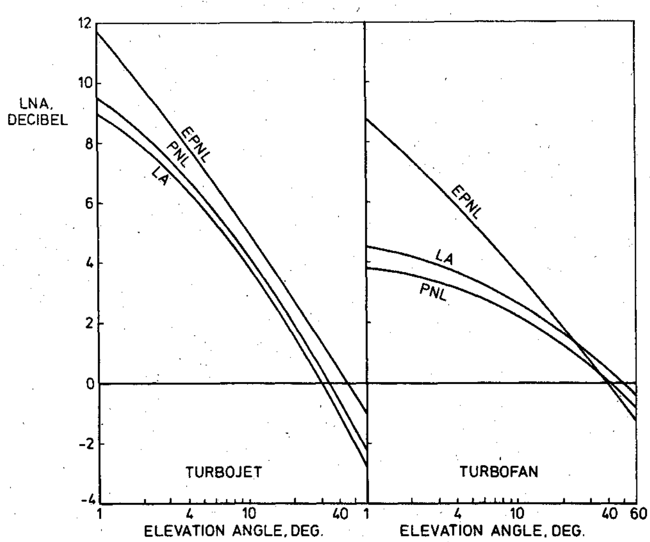

Fig. 5 Effect of noise unit on long-range lateral noise attenuation.

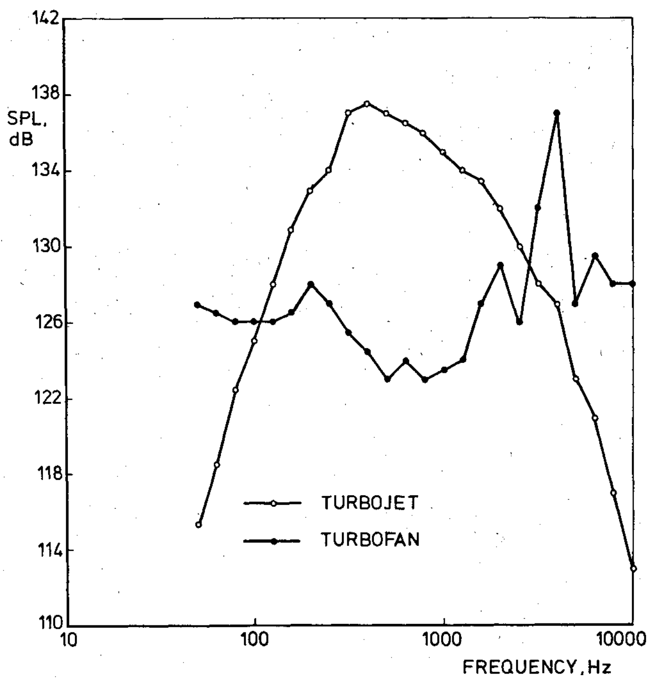

Fig. 4 Typical 1-m free-field spectra (from Ref. 3).

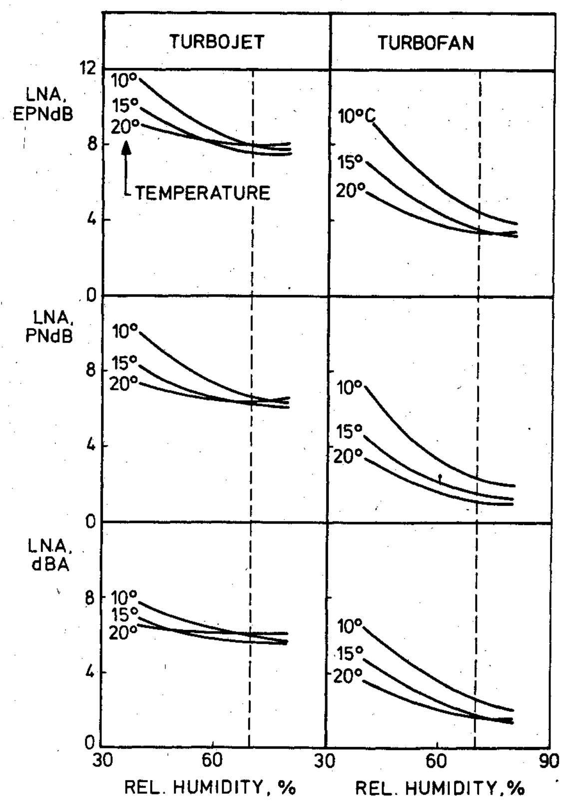

Fig. 6 Predicted effect of atmospheric conditions.

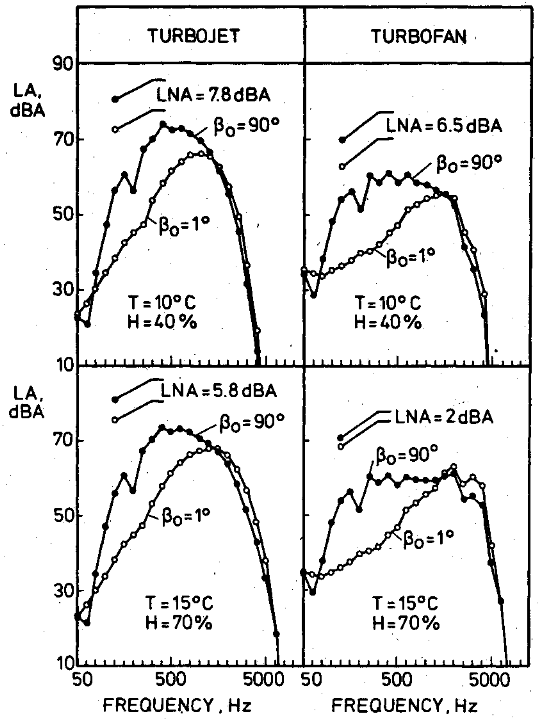

Fig. 7 Noise spectra.

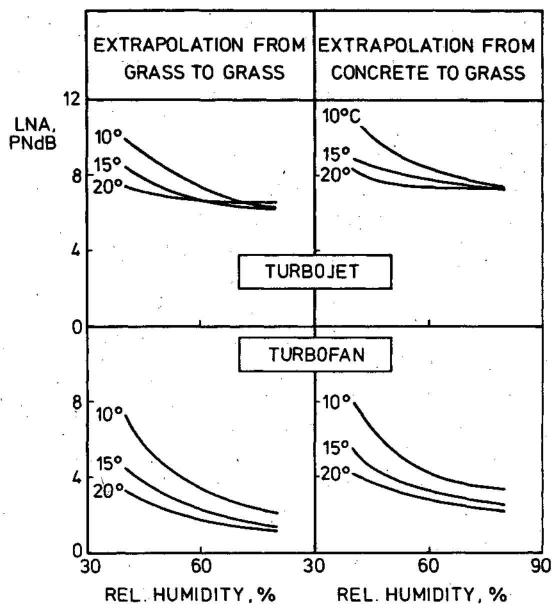

Fig. 8 Effect of ground cover.

weather conditions, as predicted for the turbofan-powered aircraft, occur because the dominant frequency bands are near 2000 Hz, where the ground effects at the two positions are virtually the same. At the different atmospheric condition, just as in the case of propulsion by turbojet engines, the maximum acoustic energy is located near 400 Hz. As a result, larger values of LNA are obtained because ground effects greatly reduce the overall noise level at the sideline position.

The effect of the hardness of the ground surface is shown in Fig. 8, where LNA is expressed in PNL. Again lateral propagation over grassland is considered. For the type of terrain under the flight path the presence of a grass-covered surface and concrete is distinguished. Figure 8 indicates that the use of concrete instead of the grassland for the execution of the initial measurements causes a slight increment of LNA of about 1 PNdB.

Concluding Remarks

The predictions reported in this paper show that lateral noise attenuation is a very sensitive function of the nature of the noise source, the atmospheric conditions, and the quantity used to express the attenuations. Three points should be remarked as a consequence of these observations.

First, it is clear that in addition to elevation angle and lateral distance, the above-mentioned variables must be considered in the extrapolation of noise levels from overhead measurements to sideline positions.

Second, the suggestion that, under standard day weather conditions, LNA plays a very unimportant role warrants continued research. Experiments performed for a range of definite atmospheric conditions (inclusive refractive conditions due to vertical wind and temperature gradients) may also provide a decisive answer concerning the validity of the current scheme for predicting LNA.

Third, from the observation that the amount of LNA is dependent on the noise unit, it is only logical that EPNL values cannot be applied to calculation methods which make use of maximum noise levels.

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