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Influence of Real Atmospheric Conditions on Free Propagation of Aircraft Noise

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Summary
The propagation of sound in the atmosphere is a complex process influenced by the atmospheric conditions and earth's surface. Thus a comprehensive numerical computation of the propagation of aircraft noise in the vicinity of an airport needs a detailed description of the atmosphere and ground in a range of about 20-40 km around the airport. These data are usually not available in practice – and are obviously not available for future scenarios. So the sound propagation models of common aircraft noise calculation tools, like the German AzBor the Integrated Noise Model from FAA, use standardised meteorological conditions. The main objective of this study is to quantify the noise level differences between calculations for these standardised meteorological conditions and calculations based on real weather conditions. Furthermore the study estimates the uncertainties of the sound levels resulting from the variation of atmospheric conditions. This information can be helpful to estimate the uncertainties of common aircraft noise source models in comparison to measured sound level distributions. The study concentrates on the sound propagation through the atmosphere from point sources at higher altitudes. Therefore ground effects and the effect of microphone height are not considered in this investigation. A ray-tracing algorithm is used to model the refraction of sound due to wind, wind gradients, and temperature gradients. The atmospheric absorption is calculated according to ISO 9613-1. Data on temperature, wind and relative humidity were collected over one year from radiosonde measurements at the meteorological observatory Lindenberg in Germany. The results show that the average sound pressure levels calculated for real atmospheric data over a period of one year and the levels calculated for standardised atmospheric conditions are similar in magnitude. Furthermore, common noise calculations result in slightly higher levels hence providing a conservative modelling of propagation effects.

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1. Introduction

This work was performed to compare common and more sophisticated propagation models and to investigate the accuracy of common aircraft noise models. The accuracy depends primarily on three influencing factors: the accuracy of the source description, the accuracy of source localisation and the accuracy of the transmission model. A direct quantification of the source accuracy is not yet possible, but it may be derived indirectly from sound level distributions measured under real conditions (e.g. by automatic aircraft noise monitoring systems), provided that the other two factors can be quantified. Information on the accuracy of source localisation can be derived from radar data. Hence the remaining task is the estimation of the uncertainty due to propagation effects. Common "best practice" aircraft noise calculation tools, like the German AzB [1] or the ECACDoc 29 [2] (implemented in the Integrated Noise Model [3]),are primarily developed to calculate cumulative aircraft noise over a longer time period in the past or in the future. These calculations have to cover large areas, for major airports up to some hundreds of square kilometres. Comprehensive meteorological data in suitable spatial and temporal resolution are usually not available.

The sound propagation calculation of these tools is thus based on standardised meteorological conditions, usually an isotropic atmosphere with 15 °C and 70% relative humidity. Since the aircraft is represented by a point source, this results in an attenuation due to spherical spreading of sound waves(i.e. a frequency-independent level decrease of 6 decibels per doubling of distance).The second attenuation effect affecting free sound propagation is the atmospheric attenuation. This effect describes the dissipation of the energy of a sound wave due to heat conduction and viscosity as well as energy transfer to a molecular level (excitation of rotational and vibrational modes of the molecules in the air). The atmospheric attenuation is well understood [4, 5, 6] and is usually modelled according to ISO standard 9613-1 [7].Effects induced by variable atmospheric conditions [8] like refraction or scattering are not

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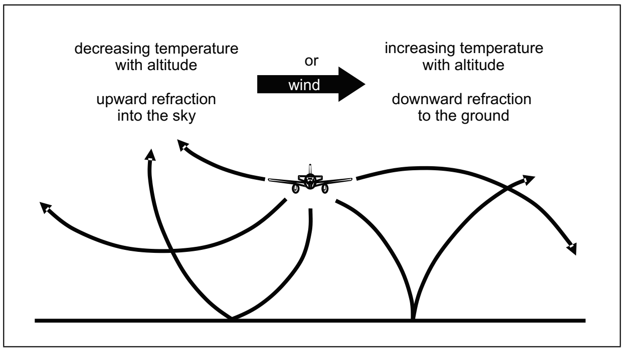

Figure 1. Influence of wind and temperature on sound propagation.

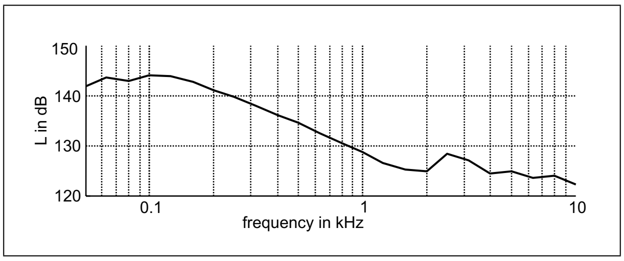

Figure 2. One-third-octave spectrum used for this investigation.The original spectrum was measured at a temperature of 3 °C, 78% relative humidity in a distance of 60 m under a radiation angle of 135 ° to flight direction. For this study it was normalized to a distance of 1 m.

taken into account by common aircraft noise models. The study concentrates on the sound propagation through the atmosphere. Therefore ground effects like ground reflection, small elevation angles or effect of microphone height and position are not considered in this investigation. For aircraft noise these effects areusually described by empirical or semi-empirical models [1, 9]. Additionally these effects were investigated within the DLR project “Quiet Air Traffic II” [10].

There have been a significant number of investigations into the theory of sound propagation through the air and close to the ground [8, 11, 12, 13, 14, 15], but aircraft noise calculation, where more sophisticated sound propagation models are required, is only a limited field of application. Such tasks are usually related to exceptional local propagation situations (e.g. engine run-ups at night in the presence of temperature inversions). Current computational power offers the possibility to account for the influence of meteorological conditions on sound propagation in many ways – from simple approaches like the assumption of constant wind or constant gradient of sound speed up to the modelling of atmospheric turbulence. Obviously there are different modelling approaches, depending on the special field of application. Ray tracing algorithms [16, 17, 18] offer the possibility to calculate sound propagation in inhomogeneous moving media with a moderate computation effort. Another approach realised by the DLR IPA propagation model [19, 20, 21] uses the implementation of the Euler equations. The computational effort needed by this model is very high, but the consideration of turbulence, ground surface and obstacles is possible. However the practical use of such advanced models for aircraft noise calculation is generally limited by the availability of suitable data on real meteorological conditions as well as ground surface properties. The approach of this study is to calculate noise levels on the ground using a ray tracing algorithm and over one year measured data on the vertical structure of the atmosphere. These levels are compared with levels calculated by a common method based on standardised atmospheric conditions. The resulting differences are analysed with respect to two main mechanisms. The first mechanism is the atmospheric attenuation which depends on the vertical temperature and humidity profile. The analysis of the molecular processes determines the reliability of the approach of constant temperature and relative humidity. The second mechanism is the refraction of sound due to temperature gradients, wind and wind gradients: for a temperature inversion or downwind conditions the sound is refracted downward and in case of temperature lapse or headwind conditions it is refracted upward (cf. Figure 1). The analysis of this second mechanism is primarily an examination of the reliability of the concept of simple geometrical spreading of spherical sound waves that is used commonly (i.e. 6 dB per doubling of distance). Additionally the commonly-cited effect of displacement of sound rays due to constant wind will be analysed.

2. Study setup

The investigation assumes an omnidirectional static point source located at altitudes 2000 m and 10000 m above the ground. The emission characteristic of this source is expressed by a one-third octave sound pressure level spectrum. This spectrum is representative of the direction of maximum sound radiation of an Airbus A320 aircraft (cf. Figure 2). The results presented are expressed in terms of A-weighted sound pressure levels.

Source altitudes at 2000 m are discussed here, because they are characteristic for aircraft noise prediction in the vicinity of airports. In addition, source altitudes at 10000 m were analysed, since this is a typical cruising altitude – and sometimes people complain about noise from aircraft in cruising flight.

The levels on the ground plane are calculated considering variable meteorological parameters, i.e. temperature, relative humidity, wind velocity and wind direction. The influence of these parameters on atmospheric attenuation and geometrical spreading is investigated separately. Therefore the one-third octave sound pressure level $L_{p,n}$ in a distance s can be calculated from the emitted sound pressure level $L_{p,n}$ in a distance s_0 as

$$L_{p,n}(s) = L_{p,n}(s_0) - A_{\mathrm{div}}(s, s_0) - A_{\mathrm{atm},n}(s, s_0), \quad (1)$$

where A_{div} denotes the frequency-independent loss due to geometrical spreading and $A_{\mathrm{atm},n}$ denotes the atmospheric attenuation [22]. Other effects on sound propagation, e.g.

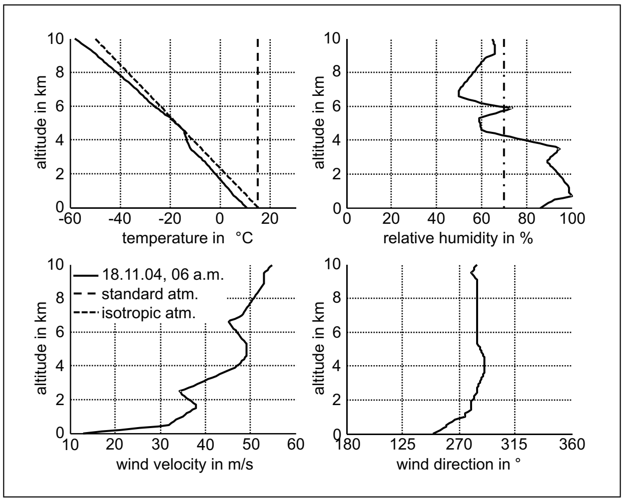

Figure 3. Vertical profiles of temperature, relative humidity, wind velocity and wind direction recorded at 18th of November 2004 at 6 a.m. compared to the standardised atmospheric conditions.

ground effects and screening are not addressed here because the study concentrates on the atmospheric influence on free sound propagation (cf. introduction). The use of a reference sound pressure level alternative to a sound power level is specific for the calculation of aircraft noise. Moreover this approach is more suitable when the geometrical spreading is described with reference to an emission plane as described in section 3.2.

The calculations for standardised atmospheric conditions were performed using two approaches. The first approach uses an isotropic atmosphere with constant temperature of 15 °C and pressure of 1013.25 hPa. The second approach uses the international standard atmosphere ISA [23] (i.e. a temperature of 15 °C and a pressure of 1013.25 hPa at sea level with a constant temperature decrease of 6.5 °C per km and a pressure decrease up to the tropopause). In both cases the relative humidity is assumed to be 70% over the whole range of the atmosphere and no wind is considered. The second type of standardised atmosphere is usually implemented in conventional aircraft noise prediction models.

The calculations for real propagation conditions are based on vertical profiles of meteorological parameters measured by radiosonde ascents. These measurements were performed at the meteorological observatory Lindenberg of the German weather service DWD in the year 2004. The year 2004 is chosen because the meteorological conditions were representative for Germany in the long-term [24, 25, 26]. The measurements include the vertical profiles of pressure, relative humidity, temperature, wind velocity and wind direction up to 30-50 km. The data contains measurements at standard altitudes (1000, 850, 700, 500, 400, 300, 250, 200, 150 und 100 hPa) and at every altitude where a parameter changes significantly. In Lindenberg the radiosonde measurements start every 6 hours (00, 06, 12 and 18 UTC). 2004 there were 14 ascents with no usable data and also a few with altitude dependent malfunctions of an instrument, e.g. a frozen sensor. In total the sound propagation calculations performed include more than 1200 vertical profiles of meteorological data.

Figure 3 shows an example of such a data set. It was recorded on the 18th of November 2004 at 6 a.m. This dataset shows the maximum average wind across the troposphere and a nearly constant wind direction of 270° (i.e. the westerly wind situation prevailing in Germany). The four diagrams show the measured vertical profiles of temperature, relative humidity, wind velocity and wind direction up to an altitude of 10 km as well as the corresponding profiles of temperature and humidity for a standard atmosphere and an isotropic atmosphere.

3. Geometrical spreading and atmospheric attenuation

3.1. Modeling of sound propagation paths

Common aircraft noise models assume that the sound is emitted from a point source and transported to the observer on spherical waves, i.e. along straight lines in a ray representation. When examining the effect of the real atmosphere on the transmission of sound the effect of refraction due to wind, wind gradients and temperature gradients must be taken into account. The consequence is a curvature of the sound rays due to gradients in sound speed or a displacement due to a constant wind speed. This studies sound propagation calculations are based on real atmospheric conditions and account for these propagation effects. The atmospheric variables, i.e. wind and temperature and hence the resulting speed of sound, mainly vary in the vertical direction. The horizontal deviations are usually more than an order of magnitude smaller and therefore negligible in a first approximation. Thus the atmosphere is assumed as vertically stratified medium with constant wind speed, wind direction and temperature on each layer boundary and therefore constant wind gradient, wind direction and temperature gradient in each layer.

Ray-tracing equations [16], as used in this study, are a valuable tool to calculate the sound propagation under such variable conditions. The sound propagation is described by trajectories, which are sound rays. Each trajectory begins at the location of the source. In a non-moving coordinate system the ray velocity,

$$\vec{v}_{\text{ray}} = \vec{v} + \vec{n} \cdot c, \tag{2}$$

is described by the wind $\vec{v}$ (the displacement due to the wind) and the sound speed c multiplied with the normal vector $\vec{n}$. The normal vector points in the direction of the ray trajectory (including refraction), i.e. it is perpendicular to the wave front.

3.2. Geometrical spreading

Assuming spherical wave propagation the loss due to geometrical spreading can be expressed as

$$A_{\text{div}}(s, s_0) = 20 \log \left(\frac{s}{s_0} \right). \tag{3a}$$

One goal of this investigation is to identify and to quantify deviations of geometrical spreading losses calculated under real atmospheric conditions from the assumption of a spherical propagation symmetry. Therefore it is more helpful to change to a planar geometry as shown in Figure 4. In this case the spreading loss for propagation of spherical waves can be expressed with respect to an "emission plane" parallel to the ground as

$$L_{p,n}(s) = L_{p,n}(s_1) - A_{\mathrm{div}}(s, s_1) - A_{\mathrm{atm},n}(s, s_1).$$

The distance s_1 is the distance between source and the intersection point of the sound ray with the emission plane. The reference sound pressure level on the emission plane is calculated with equation (1). For an omnidirectional source these levels are not constant. The geometrical spreading for spherical waves can then be expressed as

$$A_{\mathrm{div}}(s, s_1) = 20\log\left(\frac{s}{s_1}\right) = 20\log\left(\frac{h}{h_1}\right), \quad \text{with } h_1 = 1\,\mathrm{m}. \tag{4}$$

The advantage of this definition is that the spreading loss is constant over whole ground plane because it depends only on the distance $h - h_1$ to the emission plane.

A generalized formulation for the geometrical spreading must be able to account for arbitrarily shaped propagation paths. It should be based on an area comparison

$$A_{\mathrm{div}}(F, F_0) = 10\log\left(\frac{F}{F_0}\right), \tag{5}$$

where F_0 is the reference area the sound energy passes at the beginning of the propagation process. During the propagation this area changes to F. A straightforward approach is to define both areas by three adjacent sound rays forming triangles (cf. Figure 5). Ray tracing allows accounting for the refraction effects due to gradients in sound speed. 276 sound rays forming 500 triangles were analysed for this study. Figure 6 shows the intersection points of these rays with the emission plane with the dimension of 2×2 m. The intersection points are located on 10 concentric circles around the plane centre.

An example of ray intersection points with the ground plane is shown in Figure 7, for spherical propagation and for the real atmospheric conditions shown in Figure 3 and a source elevation of 10 km. As already mentioned above this dataset shows the maximum average wind across the troposphere and a wind direction of about 270°. The upward refraction due to the temperature gradient and the displacement due to the wind are obvious on this date. In comparison to the intersection points calculated based on an isotropic atmosphere (dots) the ones calculated based on the real data (squares) are wider spread and shifted eastward.

Figure 8 exemplifies the level reduction differences between the two ways of modelling the geometrical spreading losses, i.e. area enlargement (cf. equation 3c) based on real conditions and spherical propagation. For a source located at 10 km altitiude the spreading loss for spherical waves according to equation (3b) is 80 dB.

In this case the level reduction calculated by the area enlargement is greater than that calculated for spherical propagation. The difference goes up to about 1.5 dB for propagation distances of about 20 km. However for source-observer geometries relevant for aircraft noise propagation (i.e. source altitudes up to 2 km and propagation distances

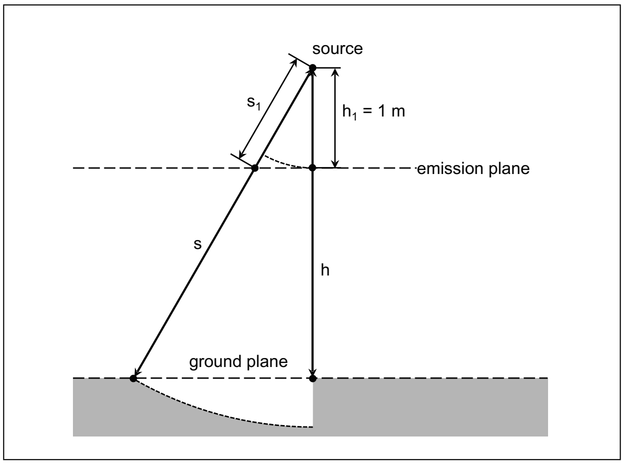

Figure 4. Definition of the emission plane. The sound pressure on this plane is not constant for a omnidirectional point source.

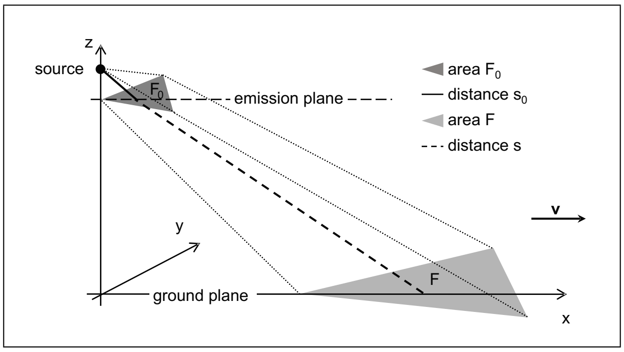

Figure 5. Sound propagation between emission and ground plane.

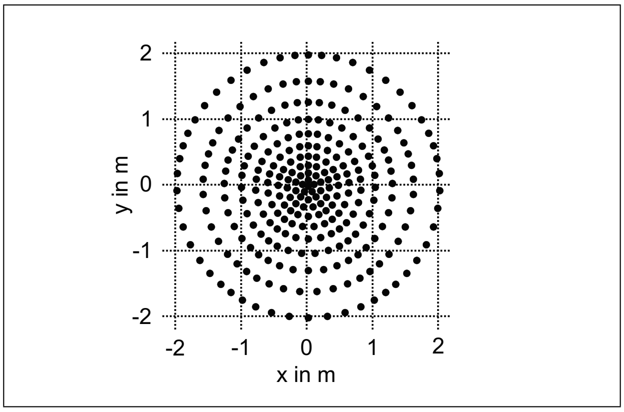

Figure 6. Intersection points of sound rays with the emission plane.

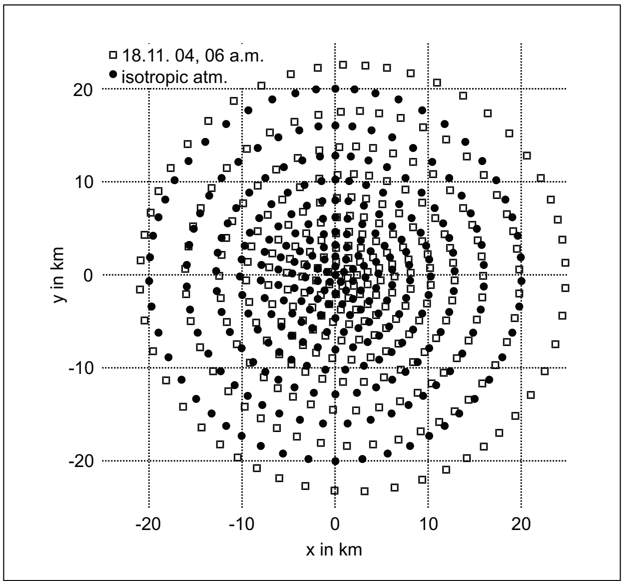

Figure 7. Intersection points with the ground plane for a source altitude of 10 km once based on an isotropic atmosphere and once based on the radiosonde data of the 18th of November 2004 at 6 a.m.

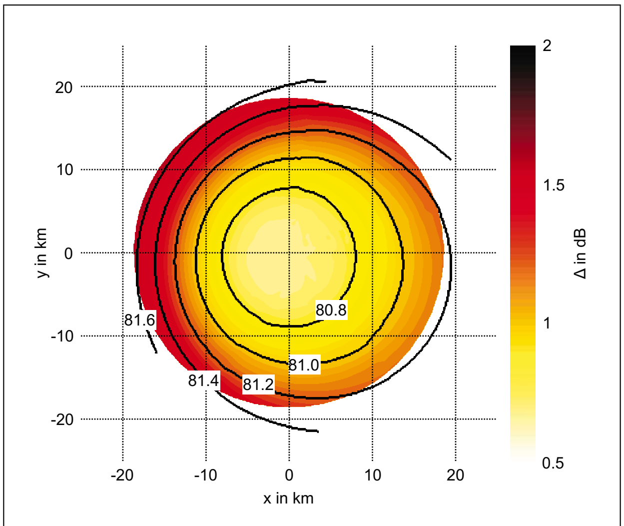

Figure 8. Level reduction in dB due to geometrical spreading for a source at 10 km altitude for the atmospheric data of the 18th of November 2004 at 6 a.m. The spreading loss for spherical propagation is 80 dB. The black contours are calculated by the area enlargement. The coloured background shows the difference to spherical sound propagation calculation.

up to about 4 km) the differences are substantially lower than 0.5 dB (cf. Table I) and hence not of practical importance.

3.3. Atmospheric attenuation

The atmospheric attenuation,

$$A_{\mathrm{atm},n}(s, s_0) = \alpha_n \cdot s_{\mathrm{eff}}(s, s_0), \tag{6}$$

describes the molecular air absorption [7]. It depends on the frequency-dependent absorption coefficient, α_n,

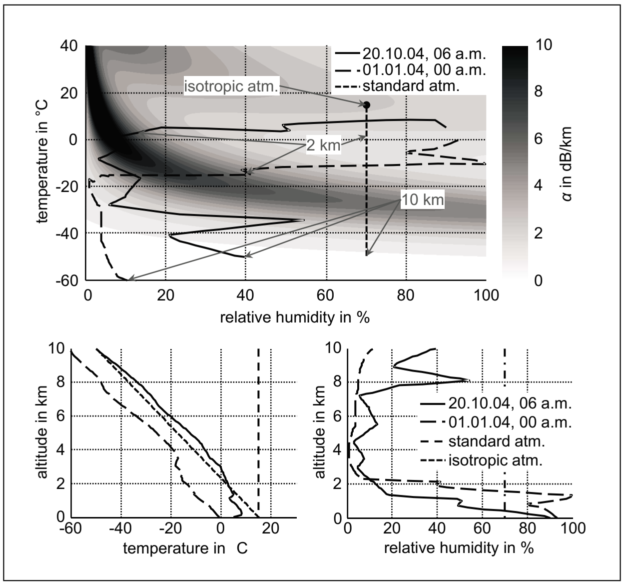

Figure 9. Absorption coefficient α according to ISO 9613-1 for afrequency of 250 Hz at standard atmospheric pressure. The lines represent the conditions from radiosonde measurements as well as for the standard atmosphere. The isotropic atmosphere is represented by a point. The lower diagrams show the corresponding vertical shapes of temperature and relative humidity.

and on the effective distance s_{eff} the sound travels between source and observer. The atmospheric attenuation increases rapidly with increasing frequency [14]. It is mainly influenced by temperature and humidity. The influence of pressure variations in the atmosphere is negligible under normal atmospheric conditions [27]. Figure 9 shows the absorption coefficient of the 250 Hz frequency band as function of relative humidity and temperature at standard atmospheric pressure. These absorption coefficients are calculated for the full range of relative humidity (0–100%) and temperatures between −60 °C and +40 °C according to ISO 9613-1. This covers the range of both parameters in the troposphere at mid-latitudes. Also included are the distributions of temperature and relative humidity up to 10 km for two days, one with high and one with low atmospheric attenuation as well as for the standard atmosphere. The isotropic atmosphere is also represented by a point.

The effective distance s_{eff} (cf. equation 4) equals the shortest distance $s - s_0$ between the corresponding points on emission and ground plane only in the absence of refraction and wind. Otherwise it has to be calculated along the sound ray hence being greater than the closest distance.

The choice of the reference system is important in calculating the atmospheric attenuation. The sound rays computed by the ray-tracing process incorporate not only curvatures caused by wind gradients and temperature gradients, but also the shift of the air in the wind direction. This can be illustrated regarding a small air package moving with the wind $\vec{v}$ (cf. Figure 10). Inside this package – i.e. in the moving reference system – the sound is propagating along an effective path of length s_{eff}. For an observer in the

Table I. Geometrical spreading losses A_{div} based on the isotropic and on the standard atmosphere, as well as the averaged losses for real atmospheric data measured in 2004.

Source altitude	2 km, vertical	2 km, west 43.5°	2 km, east 43.5°	10 km, vertical
Isotropic atm. in dB	66.02	66.02	66.02	80.00
Standard atm. in dB	66.12	66.15	66.15	80.58
2004				
Mean in dB	66.11	66.14	66.13	80.58
Median in dB	66.11	66.15	66.12	80.62
Standard deviation	0.034	0.104	0.103	0.093

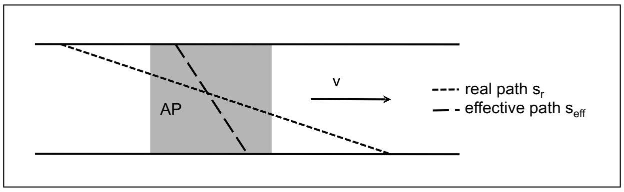

Figure 10. Sound propagation paths through the atmosphere under tailwind conditions in a stationary reference system (real path s_r) and within an air package AP moved with wind velocity v (effective path s_{eff}).

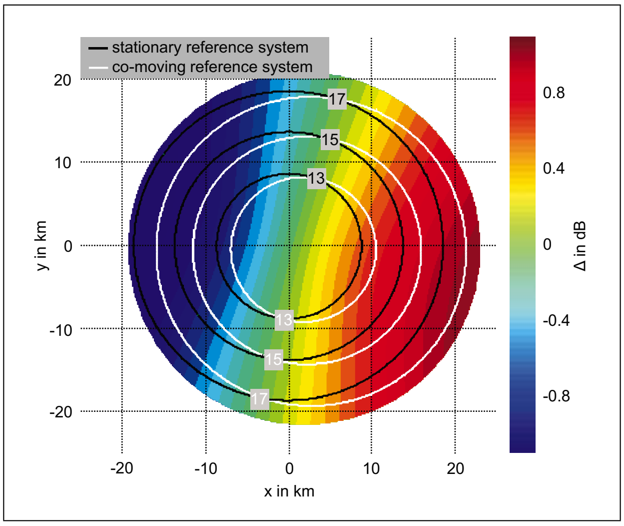

Figure 11. Level reduction due to atmospheric attenuation for a source at 10 km altitude in dB for the atmospheric conditions of the 18th of November 2004 at 6 a.m. calculated once for the stationary and once for the co-moving reference system with the wind. The coloured background shows the difference between the two level reductions.

"real" stationary reference system the sound is travelling along the real path of length s_r. However the molecular processes determining the atmospheric attenuation have an effect only along the effective path which consequently has to be estimated. To achieve this the distance travelled by the sound due to the pure displacement by wind is calculated and subtracted from the real path. These calculations are based on a runtime estimation of the sound rays.

Figure 11 shows the level reductions due to atmospheric attenuation computed for a source at 10 km altitude. The black contours are for a stationary reference system, i.e. calculated along the real path s_r. The white contours are for a reference system moving with the wind; they are calculated along the effective path s_{eff}. The background colour indicates that the difference between both cases can reach up to 1 dB for large propagation distances due to the wind displacement.

4. Atmospheric influences on long-term noise immission

4.1. Sound ray displacement due to wind

The analysis of the displacement of sound rays is important insofar as this effect is often discussed with respect to the design of weather-optimised noise abatement departure flight routes. The current investigation provides quantitative information on this effect – it simply requires an analysis of the sound ray emitted vertically.

These rays are calculated for each meteorological profile recorded by the Lindenberg radiosonde in 2004. Figure 12 shows the corresponding distribution of the intersection points of these rays with the ground for source altitudes of 2 and 10 km. The background indicates the frequency of these intersection points. The distribution scatter due to wind is scattered about ±150 m with an eastward shift of about 50 m – a result that reflects the dominance of westerly winds in Germany. The corresponding results for an altitude of 10 km show a distribution with a scatter of about 1000 m.

A scatter of about 100 m indicates that there is no practical relevance to optimise departure flight tracks with respect to a prevailing wind direction because it is one magnitude less than the dimensions of the lateral flight path spreading observed in practice.

4.2. Geometrical spreading

The analysis of the geometrical spreading under real atmospheric conditions for source altitudes of 2 km and 10 km is summarised in Table I. The table shows mean and median values of the geometrical spreading losses calculated from the real atmospheric data measured in Lindenberg in 2004 compared with the losses for the isotropic and the standard atmosphere. The results are shown for a vertically emitted sound ray (source altitudes of 2 km and 10 km) and for the rays radiated with angles of 43.5° westward

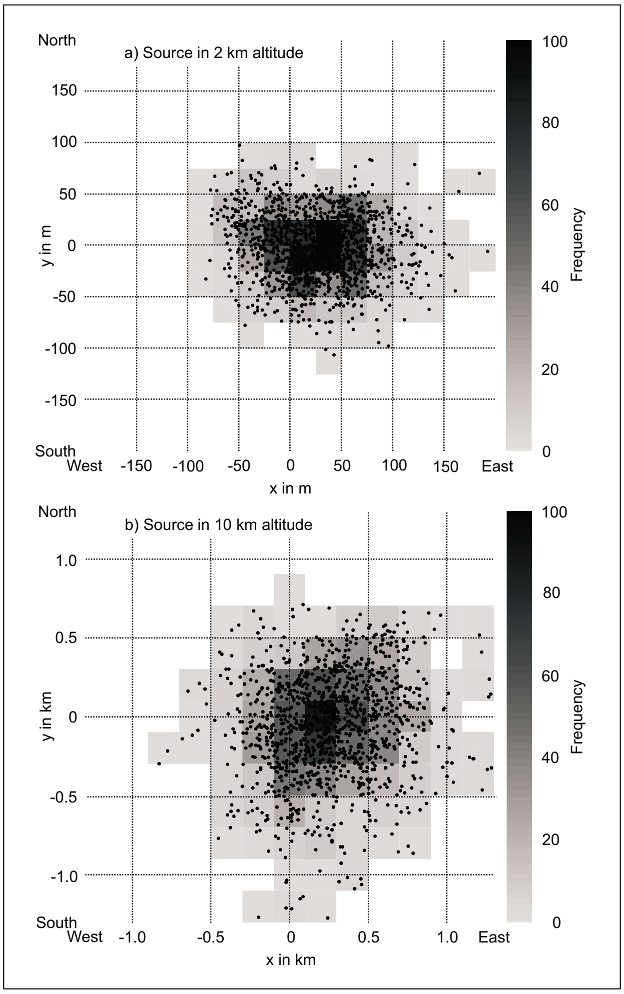

Figure 12. Distribution of the intersection points with the ground plane calculated for the vertically emitted rays for the atmospheric conditions in Lindenberg measured in 2004.

and eastward (only 2 km altitude). These rays intersect the ground plane at a distance of about 2 km from its centre.

The differences between the particular cases are negligible for the source at 2 km altitude. The losses for the isotropic atmosphere are about 0.1 dB lower than for the other cases. The similarity of the results for the real atmosphere and the standard atmosphere is an indicator that the temperature gradient for the standard atmosphere is quite a good description of the average gradient in the real atmosphere.

If the source is positioned at an altitude of 10 km the influence of variability of the atmospheric parameters increases. For the vertically emitted rays the losses for the real atmosphere and standard atmosphere are again comparable, but the assumption of an isotropic atmosphere with no wind underpredicts the losses due to spherical spreading by about 0.6 dB.

The atmospheric induced variations of the geometrical spreading losses are, however, very small. The standard deviations increase with increasing source altitude and increasing radiation angle. The reason is the longer propagation path where temperature gradients, wind speed, and

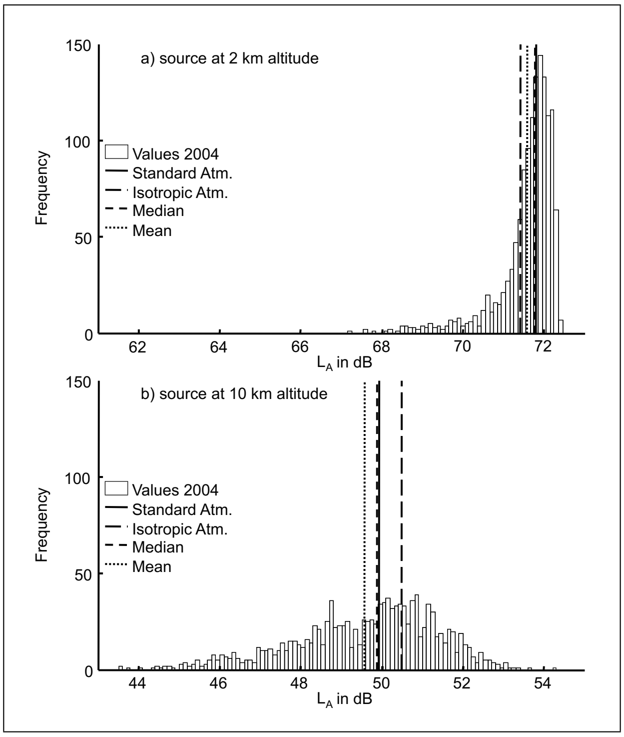

Figure 13. Frequency distribution (cf. Table II) of the A-weighted sound levels on the ground due to atmospheric attenuation calculated for the measured relative humidity and temperature in Lindenberg in 2004. Only the vertically emitted sound ray is analysed and geometrical spreading for spherical waves is assumed.

wind gradient have a stronger influence on the sound propagation. Generally the atmospherically induced variations of the geometrical spreading losses are only in the order of 0.1 dB and less.

4.3. Atmospheric attenuation

The result of the analysis of the atmospheric attenuation is shown in Figure 13 and summarized in Table II. The figure shows the distributions of the A-weighted sound pressure levels on the ground. As for the geometrical spreading these levels are calculated for the vertical profiles of relative humidity and temperature recorded in Lindenberg in 2004 and compared to the levels on the ground plane resulting from the assumption of the isotropic and the standard atmosphere respectively. Generally the level deviations due to the atmospheric attenuation are one order of magnitude higher than those due to the geometrical spreading. Therefore it is possible to calculate the geometrical spreading for spherical propagation in a windless atmosphere.

Figure 13a shows the results for a source at 2 km altitude. The frequency distribution of the levels on the groundcovers a range of 5.2 dB. The annual averages (mean and median) differ within a maximum range of 0.4 dB from the levels estimated for the standard and isotropic atmospheres. The distribution is asymmetric with a steep decay at higher levels and a pronounced tail to lower levels. The level range of ±1 dB around the mean

Table II. A-weighted sound levels on the ground plane for the vertical emitted ray due to atmospheric attenuation for the isotropic and the standard atmosphere, as well as the averaged level reductions for 2004 and their percentage distribution around the arithmetic mean; geometrical spreading for spherical waves is assumed.

Source altitude	2 km (Figure 7a)	10 km (Figure 7b)
Isotropic atmosphere – Level in dB	71.40	50.49
Standard atmosphere – Level in dB	71.80	49.93
2004		
Mean – Level in dB	71.58	49.56
Median – Level in dB	71.78	49.88
Standard deviation	0.73	1.81
Number of values ±0.5 dB around the mean	890 (65.5%)	241 (19.0%)
Number of values ±1 dB around the mean	1274 (91.8%)	527 (41.5%)
Number of values ±2 dB around the mean	1311 (96.5%)	945 (74.5%)

level already includes 92% of all calculated values. The standard deviation is about 0.7 dB.

The variations in ground level for the source at 10 km altitude are shown in Figure 13b. Because of the greater variety of the atmospheric parameters, the distribution is much wider and more symmetric than in Figure 13a. The distribution covers a range of 10.7 dB with a standard deviation of about 1.8 dB. The comparison of the averages with the values for the standard and isotropic atmospheres is quite good with a range smaller than 1 dB.

Figure 9 shows two examples of atmospheric conditions. These conditions and a source at 10 km altitude lead to opposed extreme atmospheric attenuations (tails of the distribution shown in Figure 13b). The measurement on the 1st of January shows very low temperatures and a low relative humidity. A low atmospheric attenuation results for this combination. The measurement on the 20th of October leads to a high atmospheric attenuation, mainly because the temperature is higher than the standard atmosphere and the relative humidity above 2 km is low.

5. Summary and conclusion

Current "best practice" aircraft noise calculation tools usually assume an isotropic atmosphere with no wind to model the sound propagation for standard situations. This simplified approach is sometimes criticized. The goal of this study was to quantify the errors of A-weighted sound levels on the ground introduced by the assumption of an isotropic atmosphere. The study focuses on the analysis of the losses due to geometrical spreading as well as the atmospheric attenuation. Therefore ground effects are not considered.

The analysis was performed using a ray tracing algorithm for two static point sources with a typical aircraft noise spectrum located 2 and 10 km above ground. The atmospheric data were derived from meteorological measurements by radiosondes at the observatory Lindenberg in Germany during 2004. This year was representative for a climatologically relevant long-term period for Germany. About 1200 vertical profiles of temperature and relative humidity, as well as wind velocity and direction were processed.

The analysis of the geometrical spreading under real atmospheric conditions shows that the assumption of spherical spreading introduces very small errors. The predicted sound levels on the ground are only about 0.1 dB higher for a source altitude of 2 km, or 0.6 dB higher for a source altitude of 10 km, with a maximum standard deviation of 0.1 dB.

The variations of A-weighted sound levels on the ground due to the atmospheric attenuation (depending on relative humidity and temperature) are significantly higher. The ground levels cover a range of 5 dB to 11 dB for source altitudes between 2 km and 10 km. The corresponding standard deviations are 0.7 dB and 1.8 dB respectively. However the agreement of average levels with those derived for an isotropic atmosphere is good. Differences are about 0.2 dB and 1 dB for the source altitudes 2 km and 10 km respectively.

Due to the assumption of a stationary source the results are at first relevant only for the estimation of maximum sound levels rather than of exposure levels. However the propagation times estimated for the two approaches to model geometrical spreading are comparable for a source altitude of 2 km. This indicates, that for relevant propagation situations the influence on level-time-history is small and hence the differences in sound exposure level will be of the same order as the level differences estimated for the stationary source.

The distributions of maximum as well as exposure sound levels measured for particular aircraft types by noise monitoring sites around civil airports show standard deviations of the order of 2–3 dB. The standard deviations found for the two propagation effects investigated are much smaller. This is an indicator that other effects (especially variations in engine power and aircraft position) dominate the long-term distribution of the sound levels on the ground under real weather conditions.

So the results of this investigation support the assumption that an isotropic atmosphere is a good approach to calculate aircraft noise over long-time periods (like equivalent sound levels). Standard conditions of 15 °C and 70% relative humidity are suitable at least for Germany. If type-specific distributions of emission levels are implemented in aircraft noise tools (e.g. [1]), the long-term distribution of sound levels resulting from a calculation will be comparable to the measured distribution, although only an isotropic atmosphere is used for sound propagation.

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