**Nationaal Lucht- en Ruimtevaartlaboratorium**

National Aerospace Laboratory NLR

## Executive summary

# Noise attenuation in varying atmospheric conditions

**Problem area**
To bridge the gap between measuring and calculating aircraft noise, variables like source variations and atmospheric propagation must be known accurately. Measured variations up to 12 dB occur for similar aircraft types flying the same procedure directly over the microphone. Standard noise calculations are not able to predict this variation since they are typically based on mean values. In this paper experimental results are presented to establish a first quantification of this variation in noise levels due to a varying atmosphere.

**Description of work**
An experiment was started in August 2010 to get a grip on the effect of the atmosphere on aircraft sound propagation directly under the flight path. Goal of this experiment is to see if correlations between atmospheric effects and noise levels could be derived which year average ($L_{DEN}$) noise levels could be corrected for. A known sound source is installed at 100 metres height in a weather-measurement-tower in the Netherlands. This setup provides the ability to simultaneously measure varying atmospheric conditions and their impact on sound attenuation. Preliminary results show complex correlations between weather parameters (i.e. humidity, wind speed, wind direction, turbulence) and attenuation. The experiment will continue in 2011, when results are collected to quantify the effects for the duration over one full year.

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Vliegtuiggeluidseffecten op de omgeving

**Descriptor(s)**
noise measurements
air-to-ground attenuation
atmospheric effect

This report is based on an invited presentation held at the Internoise, Osaka (Japan), September 4-7 (2011).

**Results and conclusions**
With a first look through the data until April 2011 the distribution of attenuation levels of 100 metres directly underneath the flight path are studied. No clear trends or correlations are found so far leaving a distribution of 2 dB(A) in noise levels a matter of attention for new research. To assess which effects contribute to the distribution, a more advanced statistical approach with different parameterisations is required.

**Applicability**
The results provide a quantification of the uncertainty of measurements due to weather influences. Although this quantification by this paper is slim, the completion of the data set, with the remaining data of the year, is expected to bring new insights and possible correlations. These new sights may for instance indicate whether atmospheric conditions, should be average per month or per year, when assessing aircraft noise.

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# Noise attenuation in varying atmospheric conditions

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# Noise attenuation in varying atmospheric conditions

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## ABSTRACT

To bridge the gap between measuring and calculating aircraft noise, variables like source variations and atmospheric propagation must be known accurately. Measured variations up to 12 dB occur for similar aircraft types flying the same procedure directly over the microphone. Standard noise calculations are not able to predict this variation since they are typically based on mean values. In this paper experimental results are presented to establish a first quantification of this variation in noise levels due to a varying atmosphere.

An experiment was started in 2010 to get a grip on the effect of the atmosphere on aircraft sound propagation directly under the flight path. Goal of this experiment is to see if correlations between atmospheric effects and noise levels could be derived which year average ($L_{DEN}$) noise levels could be corrected for. A known sound source is installed at 100 metres height in a weather-measurement-tower in the Netherlands. This setup provides the ability to simultaneously measure varying atmospheric conditions and their impact on sound attenuation. Preliminary results show complex correlations between weather parameters (i.e. humidity, wind speed, wind direction, turbulence) and attenuation. The experiment will continue in 2011, when results are collected to quantify the effects for the duration over one full year.

Keywords: noise measurements, air-to-ground attenuation, atmospheric effects

## 1. INTRODUCTION

In the Netherlands the aircraft noise impact on a community is calculated and regulated based on standardised aircraft flight performance, tabulated and categorised aircraft noise emission and basic sound propagation models. These calculated noise levels do often not agree with the actual measured noise levels. Figure 1 shows both $L_{Amax}$ and SEL levels of noise events with one aircraft type flying straight over the microphone while approaching the runway (see figure 2). The measured noise levels vary up to 12 dB(A) even though the events have similar distances (600 metres). Standard noise calculations are not able to predict this variation since they are typically based on mean values. Many factors related to the source, atmospheric attenuation and the receiver may influence the results and produce the distribution depicted in figure 1. In this paper, variation of noise attenuation directly under the flight path due to a variable atmosphere is studied.

The sound path from "air-to-ground" is examined in this paper because the flight noise levels directly under the flight path are of prime importance when using the $L_{DEN}$ metric. EU Member States typically use the $L_{DEN}$ (or $L_{NIGHT}$) [1] to create noise maps showing the environmental noise impact around airports. The $L_{DEN}$ is expressed in decibels having the noise energy on a logarithmic scale, meaning the highest noise levels directly under the flight path contribute more than lower noise levels at lateral distances.

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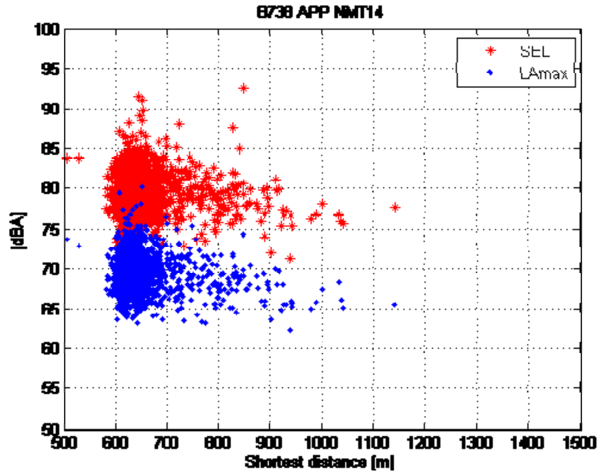


Figure 1: Noise results direct under the flight path of B737-800 approaches (noise monitoring terminal 14)

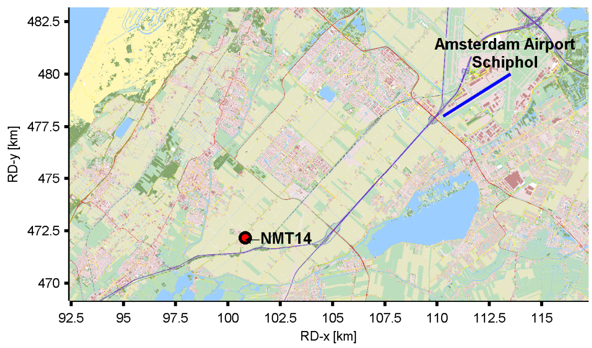


Figure 2: NMT 14 pointed out on the map

## 2. SET-UP

At the meteorological tower of the Royal Netherlands Meteorological Institute (KNMI) at Cabauw, a loudspeaker is positioned 100 metres above the ground and programmed to transmit the same predefined audio signal every hour.

The experiment aims to isolate the effect of the atmosphere on the sound propagation for vertical transmission and to assess the effect on the noise impact. The sound transmission to the ground is recorded with five microphones installed on the ground directly below the loudspeaker (see figures 3&4). The emitted sound is also recorded by a single microphone directly in front of the speaker. Simultaneously, the atmospheric parameters, like wind speed, wind direction, humidity, temperature, etc. are recorded. At the receiver side the emitted noise is measured with full ground reflections (i.e. measuring flush using a 40 centimetres metal plate described by ICAO Annex 16 [2]). To get the free-field levels the theoretical amplification of 6 dB is subtracted from the recorded levels at all frequencies.

Frequencies below 250 Hz are avoided to minimise the impact on surrounding premises. Accordingly, the audio signal is a random broad-band noise having a flat power spectral density between 250 Hz and 4 kHz. The emitted noise is not flat due to the specifications of the loudspeaker. The loudspeaker is designed as a public-addressing system and radiates best at speech frequencies around 500 Hz to 4kHz.

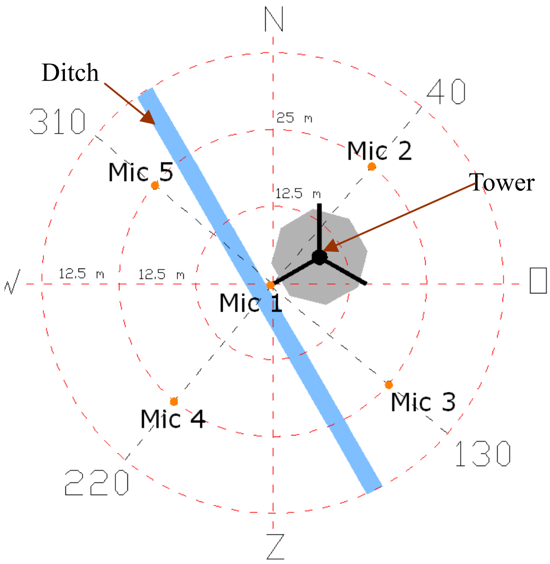


Figure 3: Measurement set-up (top view 2D)

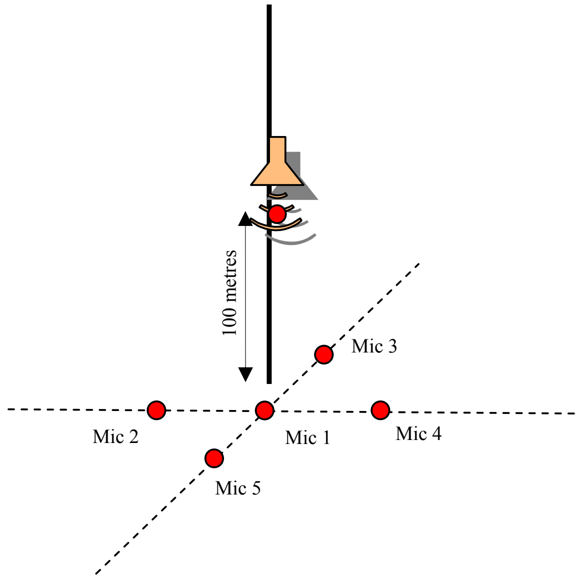


Figure 4: Measurement set-up (3D)

## 3. EFFECTS OF THE VARIABLE ATMOSPHERE

In order to establish a first quantification of the variation of the noise levels due to a variable atmosphere, different weather parameters are held against attenuation levels (R). The attenuation level is the subtraction of the noise level recorded by the microphone directly in front of the speaker by the noise level recorded on the ground. Both recordings for getting the attenuation levels are A-weighted average levels of 10 seconds normalised to 1 second.

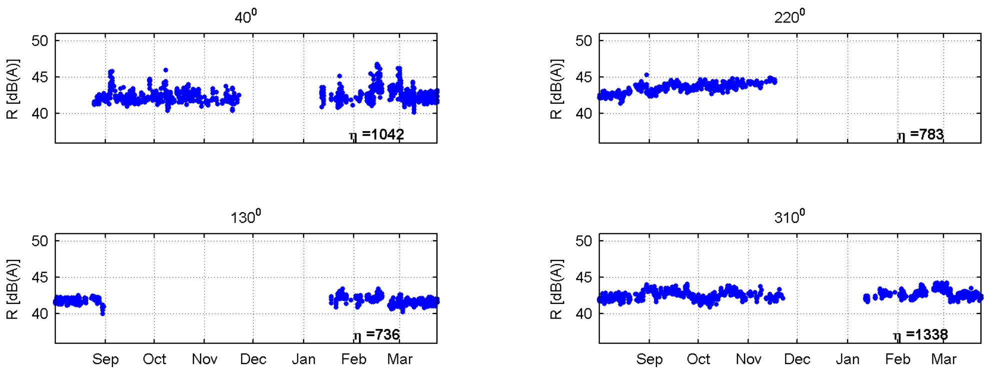


Figure 5: Results of the measurements from August 2010 until April 2011

The data in figure 5 forms the data measured from August 2010 until April 2011. The attenuation levels are held against the date of the noise event. Snow conditions are avoided, which is why gaps occur in the curves in December and January. Other gaps occur due to microphone failures. The sign η (eta) is the number of samples presented in the plot and is used as such throughout the paper.

Recordings with high background levels before and after the recording are removed. The results of microphone 2 (position 40º) have a rare pattern compared to the others. This is explained by the fact that position 40º lies close to the entrance of the site and may therefore have short disruptions due to cars, smashing doors, etc.

### 3.1 Effects of wind speed, direction, temperature and humidity

In general the attenuation levels fluctuate between 41 and 45 dB(A) and no clear correlation is shown by figures 6 up to and including 9. The weather specifications (wind velocity, wind direction,

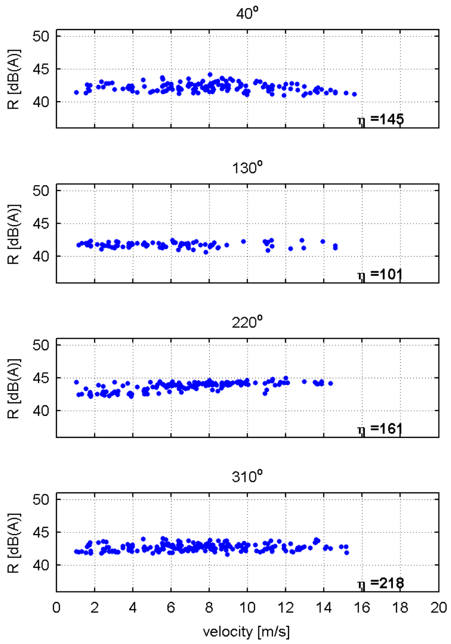


Figure 6: Wind Speed from South-West

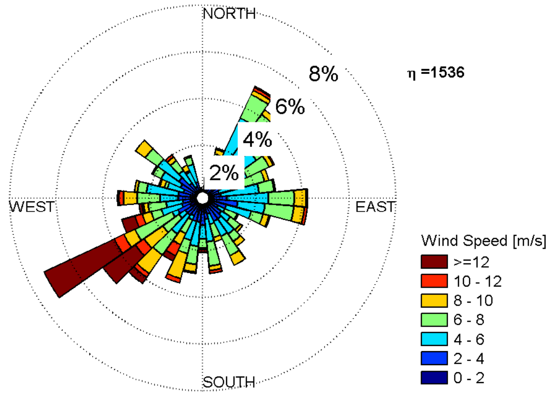


Figure 7: Wind direction

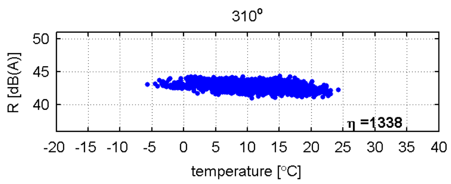


Figure 8: Temperature

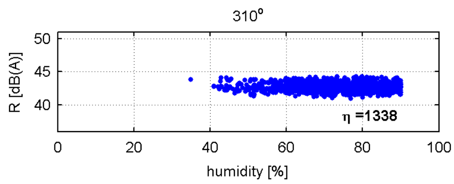


Figure 9: Humidity

temperature and humidity) in these figures are the general Cabauw values extracted from the national measurement-weather-network at a height of 10 metres.

Figure 6 and 7 may give an indication of the refraction effect due to the wind. Whilst the wind speed increases the attenuation levels at position 220º increase in contradiction with the levels of position 40º. Statistically this trend is considered very poor. The number of events is low and this trend could not be recognised at other wind directions. Whether this is a trend or not might become clearer, when the data set for a full year becomes available.

### 3.2 Effect of turbulence

The atmosphere is constantly varying and described by fluctuating parameters like wind speed and temperature. The mean and variation of the parameters during the noise measurement interval is derived. This decomposition allows the study of the mean and variable characteristics of the atmosphere separately. The deviation of the mean characteristics is better known as turbulence. Turbulence is an atmospheric instability that is typified by randomly moving air volumes. Two main mechanisms are described in literature [3] as the cause of turbulence. The first mechanism is shear of the air volumes due to velocity differences. The second is buoyancy differences, which is caused by heating of the sun. This is a thermal instability. Consequently, the effect of turbulence on sound is frequently parameterised as a function of temperature ($\sigma_T$) and wind speed ($\sigma_{WV}$) fluctuations. Parameterisations are commonly expressed in an equation similar to equation 1.

$$\langle \mu^2 \rangle = a \cdot \left( \frac{\sigma_{wv}}{c_0} \right)^2 + b \cdot \left( \frac{\sigma_T}{T_0} \right)^2 \qquad (1)$$

In equation 1, $c_0$ is ambient speed of sound and $T_0$ the temperature at zero height. The velocity and temperature deviations are added to describe a turbulent index ($\mu$) in a specific propagation direction. In which the values for *a* and *b* are considered scaling constants. Typical values for this index, in case of both constants being one, are in the order of $10^{-5}$ to $10^{-7}$ for turbulence ranging from severe to minimal. Turbulence has an influence on sound propagation and is known to scatter sound waves. Therefore a relationship between the turbulent index and the attenuation is sought after. In figure 10, the normalised turbulent index is plotted against the attenuation measurement minus the theoretical prediction of spherical spreading and atmospheric absorption [4]. This leaves the undetermined attenuation due to turbulence.

From the data depicted in figure 10, it is hard to correlate turbulence and attenuation. Several variations for the *a* and *b* constants in equation 1 were assessed, but no clear correlation emerged.

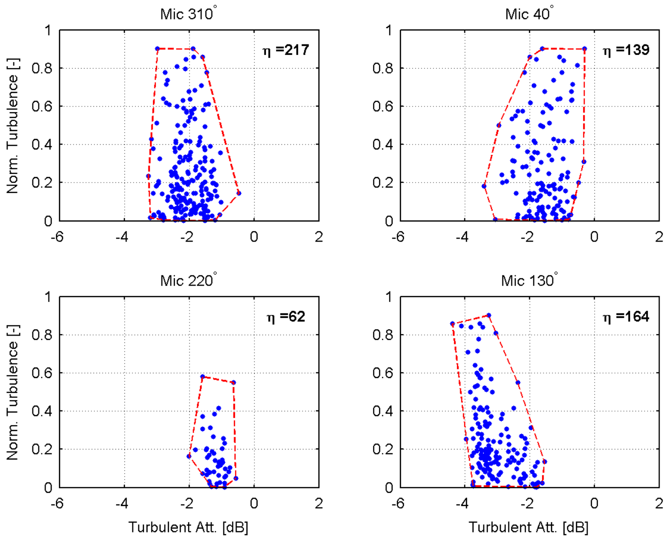


Figure 10: Normalised turbulence vs. attenuation with South West-wind conditions

(the red dashed line represents the boundary of the extreme points)

### 3.3 Intermediate conclusions

When trying to explain the distribution range up to 4 dB(A) at 100 metres distance, two options can be formulated: it might be that the influences of different weather parameters are balancing each other or that other influences are dominating.

To assess the biggest attributer to the variation in measured noise levels, an advanced statistical approach with different parameterisations is required. The completion of the data set, with the remaining data of the year, also will possibly result in new insight and correlations.

## 4. APPLICATION OF THE EFFECTS DIRECTLY UNDER THE FLIGHT PATH

To get a first grip on the effect of the atmosphere on aircraft sound propagation directly under the flight path, noise variation between predicted and measured attenuation levels of 100 metres height differences are illustrated by figure 11. First the theoretical predicted attenuations are calculated based on spherical spreading and atmospheric absorption. The absorption correction applied is based on local temperature and local humidity. Secondly the measured attenuation is subtracted form the predicted attenuation and depicted by the blue dots. The red line represents the predicted reference attenuation and the dashed magenta line the mean of all blue dots depicted.

Remarkably in figure 11 there is an overestimation of the attenuation mean of more than 2 dB(A). The authors believe this difference is mainly due to the 6 dB(A) subtraction to get the free-field levels while measuring flush. A full pressure doubling at all frequencies will in reality not occur. Also remarkable is that the blue dots are not equally distributed around its mean. Clouds with blue dots suddenly mirror in the measured mean. This sudden change may be explained by the grass-cutting times and is to be analysed in our future examinations. The flush measuring technique may influence the results, making the variations of a changing atmosphere 2 dB(A) according figure 11.

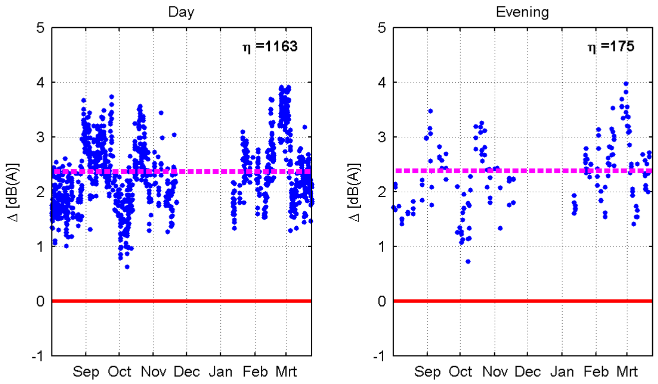


Figure 11: Differences between theoretical values vs. measured distribution at position 310 º

(solid red line represents the predicted reference; dashed magenta line represents the measured mean)

Figure 1 and figure 11 both show the distribution of measured noise from "air-to-ground". The distinction is its distance and its noise source. A variation up to 2 dB(A) may be explained by turbulence and or refraction in figure 1, but as the distance increases it is most likely that the distribution diverges. As most atmospheric variations occur in the first 100 metres it is not expected that the next 100 metres (up to 200 metres) will add an extra 2 dB(A) and so on. The authors are still convinced that, besides the varying atmosphere, the aircraft configuration settings are a big contributor to the 12 dB(A) distribution of figure 1.

Aircraft noise directly underneath the flight path is typically derived from the so-called noise power distance tables (NPD). No corrections apply as lateral attenuation starts to play a role at an angle of (ground) incidence from 60º or lower. More mean values (like power settings, ground dispersion, etc.) are used while doing contour calculations [5] in the vicinity of airports. It is well known that by best practice (i.e. an engineering method) two errors may result in the correct (measured) answer. By means of a casus and based on the results illustrated in figure 11 the measured results are put in the perspective of an $L_{DEN}$ calculation in the text box on this page.

**To put things in perspective** the impact towards the $L_{DEN}$ is calculated. A simple casus is elaborated having the following assumptions:

- 12 aircraft per hour pass during the day and evening (not during the night);
- all aircraft pass at 100 metres directly over the receiver point;
- all aircraft have a SEL of 75 dB(A);
- all aircraft have the same emitted spectrum as the loudspeaker;
- directivity is ignored due to the high elevation angles.

The casus aims to quantify the shortcomings while doing contour calculations. The casus is heavily simplified.

The casus above based on **theoretical predictions** results in a $L_{DEN}$ of **50,3 dB(A).** Taking the mean (dashed magenta line in figure 11) of the **measured attenuation** for day and evening the $L_{DEN}$ shifts to **48,0 dB(A)**. Hereby it is assumed that the changing variable atmosphere during the measurements period represents the weather throughout the year.

## 5. CONCLUSIONS

With a first look through the data until April 2011 the distribution of attenuation levels of 100 metres directly underneath the flight path are studied. No clear trends or correlations are found so far leaving the distribution of 2 dB(A) in noise levels a matter of attention for new research. To assess which effects contribute to the distribution, a more advanced statistical approach with different parameterisations is required. The completion of the data set, with the remaining data of the year, is expected to bring new insights and possible correlations.

## 6. RECOMMENDATIONS

The experiment will continue in 2011, in which results are collected to quantify the effects for the duration over one full year. The first look through the data upon April 2011 has given new sights to improve our research, like:

- the use of the advanced statistical approach 'principal component analysis' detailed in [6] to withdraw independent atmospheric influences.
- to alter the source from 100 metres height to 200 metres height, which may lead to better understanding of the distributions at higher altitudes;
- to change the ground plates with a plates having a larger diameter to eliminate influences of the surrounding grass and to get a full (a better) ground reflection.

## ACKNOWLEDGEMENTS

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