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Executive summary

A long term low frequency noise outlook for aircraft during take-off

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Author(s)
H.W. Veerbeek
D.H.T. Bergmans

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When an aircraft starts to roll and executes its take-off, typical low frequency noise is generated. This typical noise decreases while the aircraft is accelerating on the runway. In 2003 at Amsterdam Airport Schiphol a new runway was brought into operation. After that, residences around the airport raised more and more complaints about typical low frequency noise. Because the noise energy is dominated in the low frequency domain, noise propagates easily over long distances. Hence, under some weather conditions the observed noise levels can even rise further.

Description of work
After the number of complaints raised, research has been started. First, indicative measurements were carried out, but only for short periods of time. This article exhibits the results of analyses of in-situ measurements obtained from a fixed noise monitoring terminal over the past couple of years. Analyses were focussed on the tendencies of the low frequency noise by aircraft that start to roll and execute take-off in relation with environmental factors.

Results and conclusions
The results show that only during a limited number of days throughout the year, in wintertime, observed low frequency noise will increase significantly.

This report is based on a presentation held at the INTER-NOISE 2009 Conference, Ottawa, Canada, 23-26 August, 2009.

Nationaal Lucht- en Ruimtevaartlaboratorium, National Aerospace Laboratory NLR

Anthony Fokkerweg 2, 1059 CM Amsterdam,
P.O. Box 90502, 1006 BM Amsterdam, The Netherlands
Telephone +31 20 511 31 13, Fax +31 20 511 32 10, Web site: www.nlr.nl

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A long term low frequency noise outlook for aircraft during take-off

Henk W. Veerbeek[a]
Dick H.T. Bergmans[b]
Air Transport Division
National Aerospace Laboratory (NLR)
Anthony Fokkerweg 2, 1059 CM Amsterdam, the Netherlands

ABSTRACT

When an aircraft starts to roll and executes its take-off, typical low frequency noise is generated. This typical noise decreases while the aircraft is accelerating on the runway. In 2003 at Amsterdam Airport Schiphol a new runway was brought into operation. After that, residents around the airport raised more and more complaints about typical low frequency noise. Because the noise energy is dominated in the low frequency domain, noise propagates easily over long distances. Hence, under some weather conditions the observed noise levels can even rise further.

After the number of complaints raised, research has been started. First, indicative measurements were carried out, but only for short periods of time. This article exhibits the results of analyses of in-situ measurements obtained from a fixed noise monitoring terminal over the past couple of years. Analyses were focussed on the tendencies of the low frequency noise by aircraft that start to roll and execute take-off in relation with environmental factors. The results show that only during a limited number of days throughout the year, in wintertime, observed low frequency noise increased significantly.

1. INTRODUCTION

In 2003 at Amsterdam Airport Schiphol a new runway *("Polderbaan")* was brought into operation. After that, residents around the airport raised more and more complaints about typical low frequency noise. In response, surveys started to study this typical low frequency noise. From this point on the typical low frequency noise generated by aircraft while the aircraft is accelerating on the runway is popularly termed *groundnoise*.

The first surveys done were indicative measurements able to relate noise measurements to aircraft departures. The noise monitoring network around Amsterdam Airport Schiphol producing A-weighted noise levels was used together with flight track information. Soon it was noticed that the detection of events while using A-weighted levels is poor. *Groundnoise* (its low frequency noise character) is not expressed well by A-weighted levels, because other noise sources easily influence the measurements. The threshold of the noise event detection based on A-weighted levels had to go up, which mend detecting rates went down. Therefore, for the further indicative measurements C-weighted levels were used instead. In this way the threshold corresponds with the character of the noise event.

[a] Email address: veerbeek@nlr.nl
[b] Email address: bergmansd@nlr.nl

Between 2003 and 2006 several noise measurements were done, each over short periods of time (i.e. days)[1-2-3]. Summarizing the results of these studies it is noticed that:

- The heavier the aircraft (i.e. B747, A340) the higher the recorded noise levels are.
- Weather influenced results up to 4 dB(A).
- *Groundnoise* peaks around 31.5 Hz when the aircraft starts to roll. After that the aircraft is increasing speed and its low frequency component becomes less dominant.
- The highest C-weighted levels are recorded backwards 45 degrees from departure direction.

During the indicative measurement residents affected by *groundnoise* were simultaneously questioned. It was reported that not under all conditions the *groundnoise* led to nuisance. Results[4] demonstrate a relation between the nuisance reported and the measured C-weighted levels. To express the relation between *groundnoise* and (possible) nuisance, the hindrance curve given in[4-5] was developed.

For all the above measurements only short time periods are analysed. This paper exhibits the results of analyses of in-situ measurements obtained from a fixed noise monitoring terminal over the past couple of years. It focuses on the tendencies of the *groundnoise* in relation with environmental factors. In other words we know there is *groundnoise* and we know it is affected by environmental factors but how will *groundnoise* develop throughout the year? Under which circumstances and how many times will the environmental factors affect the *groundnoise* badly? Will it be just days where high C-weighted levels are measured or will it be weeks? This paper helps policy makers evaluate the dominancy of *groundnoise* throughout the year.

2. CONTEXT

One of the existing noise monitoring terminals at a location in the village of Hoofddorp, 2.3 km from start of roll (see figure 1), has been extended with C-weighted noise measurement and noise event detection. The noise events are detected using a fixed 70 dB(C) threshold and are available to the community in real-time via the Internet[6].

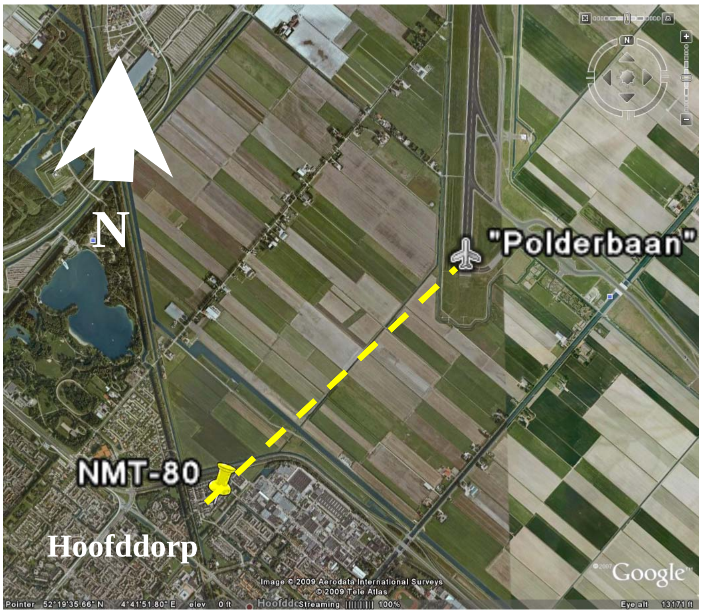

Figure 1: Map of the *"Polderbaan" – groundnoise* propagation path and noise monitoring location

For long term analyses noise events, together with a full set of noise and flight data, were collected for several periods in 2007 until 2009. The data is spread throughout the year, and combined to a fictitious year covering summer as well as winter conditions and thus a variety of meteorological conditions. Temperatures vary from -7 to 25 °C where wind blows from northwest (NW) to northeast (NE), corresponding with the northern departure direction of flights. The data cover 26000 departures, whereas during one year on average 55000 aircraft depart from the *“Polderbaan”* runway 36L.

Earlier research[4-5] has shown that the propagation of low frequency noise is affected by:

1. Atmospheric temperature gradient.
2. Ground impedance.
3. Turbulence.
4. Wind (direction and speed).

It always will be a mix of the above influences that will result in increasing or decreasing *groundnoise* levels. However there might be tendencies found when propagation influences are viewed separately. Especially, if tendencies are found for the influence of ground impedance or wind mitigation steps can be taken. The ground impedance can be influenced by changing the ground surface. And for wind one could decide to change the runway utilisation depending on wind conditions. For instance: if during the day the wind blows from NW (perpendicular direction as propagation path) the “*Polderbaan*” could be used more often while during wind from NE (same direction as propagation path) the runway east of the “*Polderbaan*” could be used more often to reduce the hindrance due to groundnoise.

Because the availability of mitigation steps related to ground impedance and wind these influences are studied in more detail using in-situ meteorological measurements.

3. RESULTS

A. The influence of temperature

Previous research[4] and feedback from questioned residents in Hoofddorp showed that ground impedance may influence the recorded C-levels. As during winter the ground is harder (i.e. frozen or wet) and therefore less absorbing it is likely *groundnoise* levels are higher during winter conditions. First the relation between noise levels and temperature was therefore studied.

Measurements often come with practical downsides: a threshold is being built in the monitoring system[6] to determine the event as *groundnoise* automatically. While analysing the data statistically to understand the year’s development this must be taken into account. Presenting all recorded data may lead to wrong impressions since events below 70 dB(C) are neglected. However the detection rates itself may tell us something about the yearly development of ground impedance if they are related with the outside temperature.

Figure 2 shows all departures versus the detected *groundnoise* events. It gives an impression of the data used throughout the fictitious year. The number of departures (detected and real) can be read from the left axes. At the axes below it is considered that the samples between April and October represent the summer conditions and the samples between November and March represent winter conditions. Not for all departures a *groundnoise* event is detected especially during summer time.

Whereas, figure 2 gives the real and measured numbers of departures, detection rates can be determined. These detections rates are shown in figure 3 by the blue open dots with the left axes to read the value of the detection rate. The bars of figure 3 indicate the average temperature during the day for which at the right axes the value of the temperature can be read.

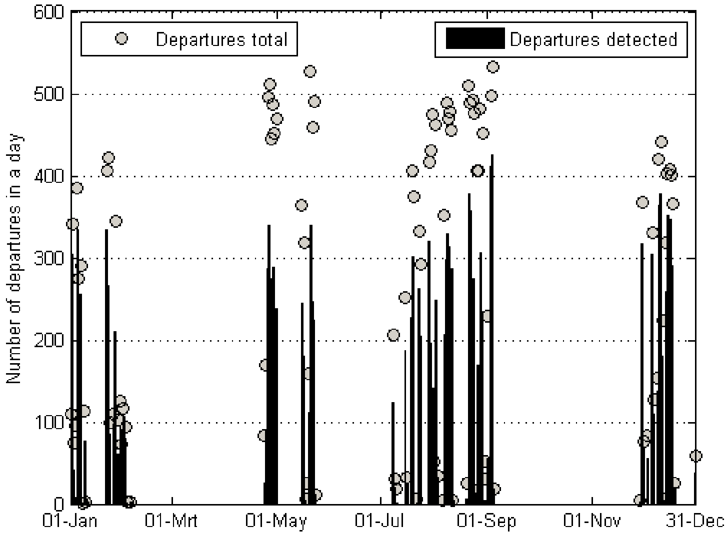

Figure 2: Number of departures in a day (total and detected as *groundnoise*) of fictitious year

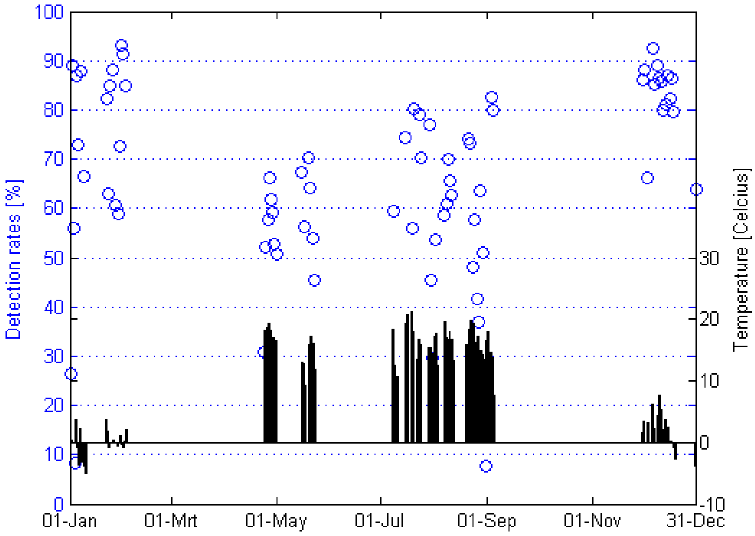

Figure 3: Detection rates of *groundnoise* – and temperature of the fictitious year

It is noticed that during wintertime detection rates are likely to be higher than 80% while summertime shows rates below 80%. Knowing there is a cut-off at 70 dB(C), departures (of less noisy aircraft) in summertime generate more events below the 70 dB(C) than during wintertime. This means that *groundnoise* levels in wintertime are expected to be higher. The assumption that this is also caused by the influence of the change of ground impedance (absorption), is supported by the difference in temperature. In wintertime the temperature sometimes drops below freezing point. In these circumstances the ground will be harder (so less absorbing) than during summertime. Also due to the low temperatures one may assume that the land will not dry up easily and is therefore wetter during wintertime i.e. acoustically harder.

B. The influences of wind

In this paragraph the fictitious year is presented from the wind perspective. First the data is presented for different wind directions divided by winter and summer condition. Second an extra step is taken to study the influence of wind speed.

Due to the threshold of 70 dB(C) decreasing detection rates during summer conditions were shown in the previous paragraph. To study the tendencies of wind this threshold used in the automatically detection may trouble the results. Therefore out of the fictitious year the four heavy aircraft (1. B747-400; 2. MD-11; 3. A330-200 and 4. A330-300) are selected to study the wind influences throughout the year. These four heavy aircraft all have high detection rates (above the 90%) as well under winter as summer conditions; therefore the threshold of the noise event detection does not affect the statistic analyses.

Table 1: Wind direction and number of samples

Wind directions	Specification in degrees	Number of samples winter	Number of samples summer
WNW	281.25°-303.75°	35	87
NW	303.75-326.25°	80	260
NNW	326.25-348.75°	93	259
N	348.75-11.25°	13	106
NNE	11.25-33.75°	32	158
NE	33.75°-56.25°	95	258
ENE	56.25°-78.75°	225	198

The *groundnoise* observed at the microphone is caused by aircraft departing from the *"Polderbaan"* in the northern direction (i.e. 360°). To study the influence during propagation the wind direction is divided in several intervals.

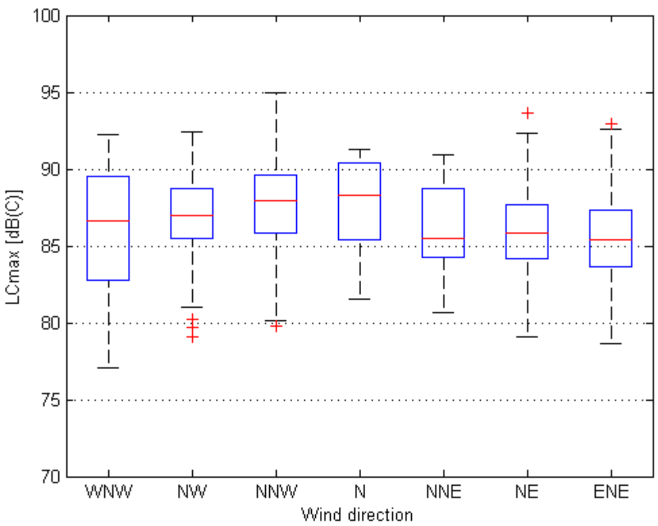

Figure 4: Winter conditions: distribution of 1.B747-400 2.MD-11 3.A330-200 4.A330-300 $L_{C.max}$ per wind direction

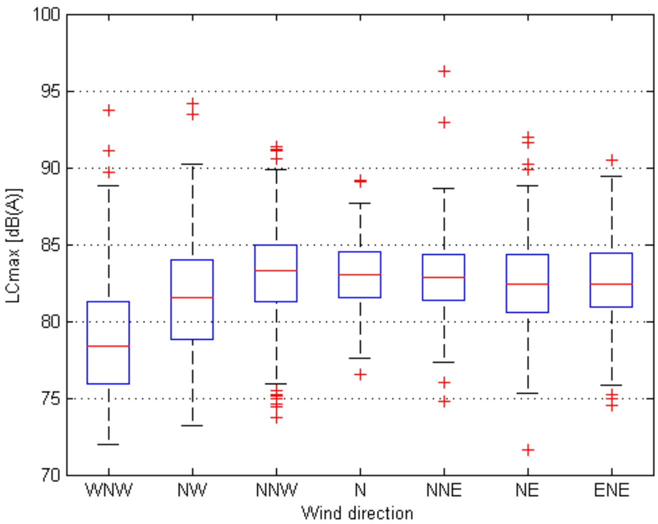

Figure 5: Summer conditions: distribution of 1.B747-400 2.MD-11 3.A330-200 4.A330-300 $L_{C.max}$ per wind direction

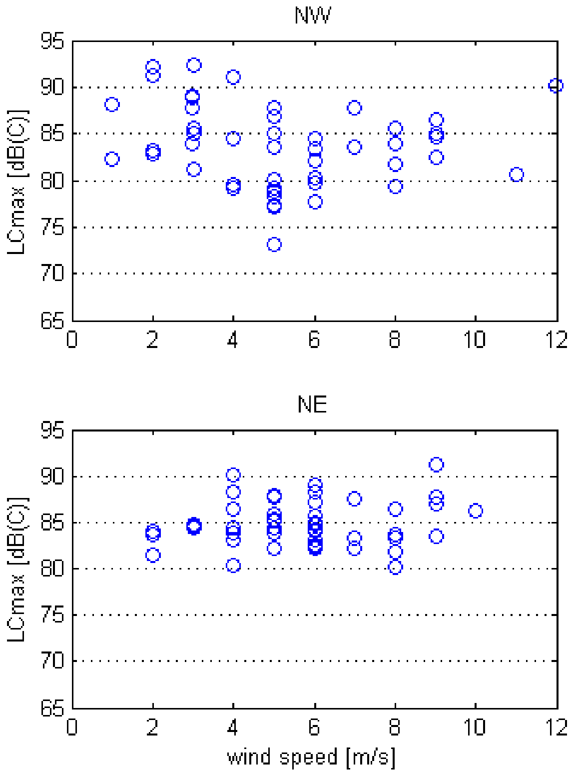

Figure 6: B747-400 L_{Cmax} noise levels during the winter conditions per wind direction at different wind speed

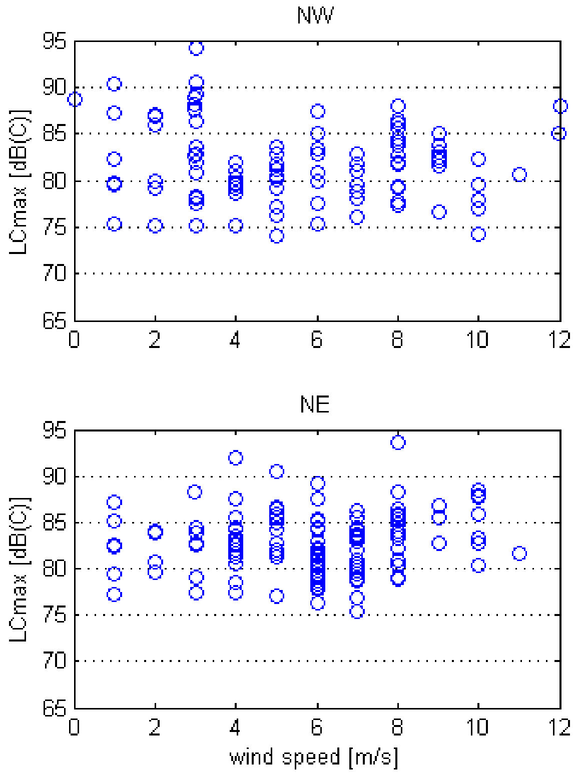

Figure 7: B747-400 L_{Cmax} noise levels during the summer conditions per wind direction at different wind speed

Table 1 gives the specification in degrees of these boundaries, see second column. It also gives the number of samples in which *groundnoise* has been recorded by specified wind direction for summer and winter conditions.

All these measurement samples have individual recorded overall C-levels. For both winter and summer conditions the data is presented in a boxplot by the figures 4 and 5. In descriptive statistics[7], a boxplot is a convenient way of graphically depicting groups of numerical data through their five-number summaries: 1. the smallest observation (sample minimum); 2. lower quartile; 3. median; 4. upper quartile; and 5. largest observation (sample maximum). A boxplot also indicates which observations (if any) might be considered as outliers. Boxplots can be useful to display differences between populations without making any assumptions of the underlying statistical distribution: they are non-parametric. The spacing between the different parts of the box helps to indicate the degree of dispersion (spread) and skewness in the data, and identify outliers.

In paragraph A it was found based on detection levels that noise levels during winter in general are higher than during the summer. Viewing the blue boxes (50% of the samples are inside these boxes) support this tendency further. For every wind direction the blue box is significant lower for summer conditions than for winter conditions. However a tendency for the different wind directions is not noticed as the level of the boxes changes just a bit with varying wind direction. The noise levels related to the wind direction NE (i.e. in line with the propagation path towards the measurement location) and NW (i.e. perpendicular to this propagation path) are overlapping each other and do not show differences. In figure 5 for summer conditions it is noticed that the box is moving downwards (headwind), but for winter conditions this is not noticed. In other words: wind direction does not shift the yearly results.

It is known that different wind directions do influence the noise propagation. As this effect was not shown in the overall wind direction analyses, the data of the fictitious year is presented in more detail including wind speed. For all detected noise events of the B747-400 for summer and winter conditions the $L_{C.max}$ is set out against the wind speed for the wind directions NE and NW in figure 6 and 7. It is believed the number of samples while getting into more detail (only the B747-400) is still enough samples to determine a statistic tendency, if any.

As well as for the wind direction no clear tendency (line) can be determined from figure 6 and 7. From this data it can not be said that an increase in wind speed having wind direction NE raises the $L_{C.max}$. Most likely the influence of wind falls in the margin of other environmental influences affecting noise propagation throughout the year.

C. Overall view – high levels?

The observations so far show *groundnoise* level variations depending on aircraft types and meteorological conditions (i.e. mainly temperature thus the ground impedance). The variations in noise levels cause *groundnoise* to be experienced as either annoying or just as detectable during days with different conditions.

The last step in the study aims to determine how many times during a year high/annoying *groundnoise* levels occur. Therefore the noise levels are combined with the hindrance curve mentioned[4-5] before. First this curve is explained by presenting data of one individual aircraft departing at different times in the fictitious year.

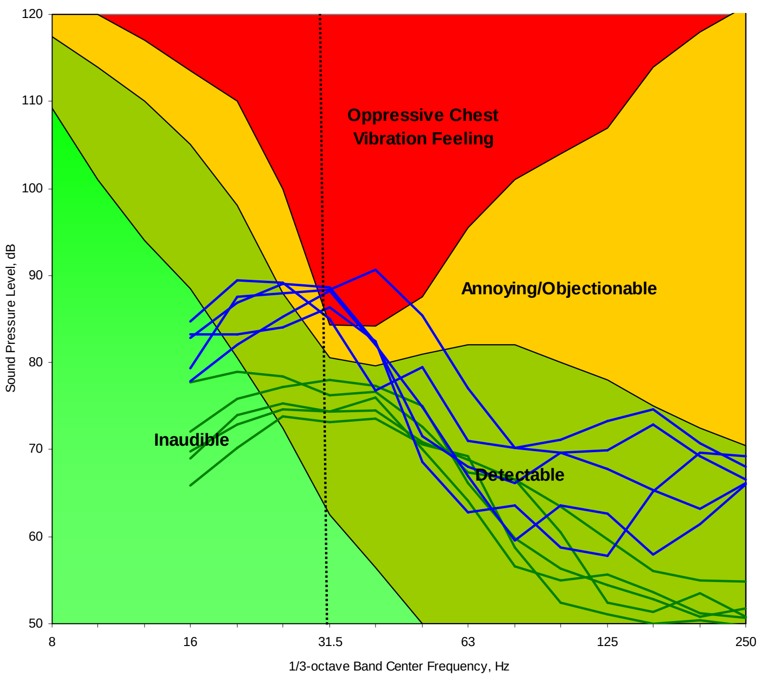

Figure 8: MD11 noise levels per 1/3-octave band with low frequency noise criteria
– blue lines: measurements under low temperature and NE wind conditions
– green lines: measurements under high temperature and NW wind conditions

Secondly all measurements of the fictitious year are hold against this hindrance curve. This gives an overview of the overall *groundnoise* development throughout the year.

As an example of noise level variations which might or might not lead to annoyance, the levels of one MD11 (having a unique tail number) have been studied. The aircraft (type) characteristics are thus excluded as a variable. Two sets of five flights each have been selected for this aircraft to illustrate the difference between good (i.e. lower temperatures, NE-wind) and bad noise propagation conditions towards the measurement location (i.e. higher temperatures, NW-wind). The difference in measured *groundnoise* levels is clearly shown in figure 8. The increase of about 10 dB in the range of 25 to 40 Hz causes flights to be classified as annoying.

When combining the hindrance curve criteria with measurement of all individual flights an indication can be found on the occurrence of annoying flights throughout the year. The results as derived from the measurement data are shown in table 2. The days included in this analysis each have at least 50 departures from the "*Polderbaan*".

Table 2: Number of days (> 50 flights per days) showing annoying flights

Percentage of flights classified annoying	Number of days with measurements in winter period	Number of days with measurements in summer period
0 to 5 %	6	17
5 to 10 %	7	15
10 to 15 %	8	10
15 to 20 %	8	
20 to 25 %	5	
total	34	42

The overall average shows that 6.7% of the departures are classified as annoying on a summer day. Under winter conditions this percentage increases up to 14.4%. Given an average of 300 departures per day this results in 20 respectively 43 departures which might be experienced as annoying.

4. CONCLUSIONS & RECOMMENDATIONS

The results show that only during a limited number of days throughout the year, i.e. mainly in wintertime, low frequency noise will increase significantly. This finding does confirm the observations made during studies/measurements for limited periods of time.

For individual aircraft a relation between temperature, wind (speed and direction) and the observed noise levels has been found. However, when looking at the overall relation between meteorological conditions and noise levels only a temperature related effect was found. It is assumed that this effect is related to ground impedance (hard surface thus the ground impedance). The relation found can help policy makers to judge the usefulness of measures to be implemented.

The value of a long-term dataset has been proven. The available dataset can serve as a reference set for future verification of the effectiveness of *groundnoise* reduction measures.

It is recommended to further extend and revise this dataset. The extension with data of a second measurement location in the area will help to even further enlarge the value of the analyses.

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