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Development of a rating procedure for low frequency noise: results of measurements near runways

Edwin Buikema[1], Martijn Vercammen[1], Fokke van der Ploeg[1], Jan Granneman[1], Joos Vos[2]

[1]Peutz bv, The Netherlands
{e.buikema@mook.peutz.nl; m.vercammen@mook.peutz.nl; f.vanderploeg@mook.peutz.nl; j.granneman@zoetermeer.peutz.nl}
[2]TNO Human Factors, Soesterberg, The Netherlands
{joos.vos@tno.nl}

Abstract
Recent issues concerning low frequency aircraft noise around airports (groundnoise) and a legal verdict about the application of low frequency noise criteria in the Netherlands have been the motivation to start a research commissioned by the Dutch Ministry of Housing, Spatial Planning and the Environment. One of the objectives is to investigate the possibilities of the development of a rating procedure for low frequency noise.
This paper gives an overview of the nature and impact of the low frequency groundnoise on the community, based on noise measurements and the experiences of residents around the airport.

Keywords: low frequency noise, rating procedure, airport groundnoise, noise measurements, annoyance

1 Introduction

The Dutch Ministry of Housing, Spatial Planning and the Environment has commissioned an investigation for the possibility of a rating procedure regarding low-frequency noise (lfn). One of the motivations to start the investigation are complaints about noise from aircraft taking off on runways near Schiphol Airport (groundnoise), especially in the northern part of the city of Hoofddorp. Eventually, the proposed methodology for lfn has to be compared with the actual situation around Schiphol.

In this article results of measurements on groundnoise are presented. The measurements are particularly targeted at the low frequency nature of the groundnoise and the impact on residential areas around Schiphol.

2 Groundnoise

In 2003 the 5th runway at Schiphol, the Polderbaan, was put into use. This has led to numerous complaints from residents in Hoofddorp. This was not foreseen in advance, because airplanes using the Polderbaan do not actually fly over Hoofddorp. However, it appeared that the starting procedure of aircraft causes a "roaring noise" in Hoofddorp. At Schiphol, this is called "ground noise" because it (mainly) occurs when the airplane is still on the ground during its take-off roll. Elevated noise levels can also occur due to landing aircraft applying reverse thrust.

Noise measurements were conducted in 2009. The purpose of the study was to gain a better understanding of the nature and extent of groundnoise around Schiphol. For instance, what exactly is groundnoise and what are the noise levels and frequencies concerning groundnoise?
The research was particularly focused on Hoofddorp, since most complaints were registered here. Hoofddorp is located at 2 to 3 km southwest of the Polderbaan. For departures, the Polderbaan is only in use from south to north. In principle, the planes take off against the wind. A limited amount of crosswind is also permitted. The Polderbaan can therefore be used for departures for about 25% of the year (generally with wind from northwest to northeast). Residents indicate that the nuisance particularly occurs during northeastern wind, so under "head on wind" conditions.

The noise of the engine of an aircraft, usually a turbofan, is direction dependent. During aircraft take-off, the highest noise levels are generated at an angle of approximately 135 degrees from the inlet of the turbofan. When planes depart from the Polderbaan, the highest noise levels thus can be expected in Hoofddorp (see Figure 1).

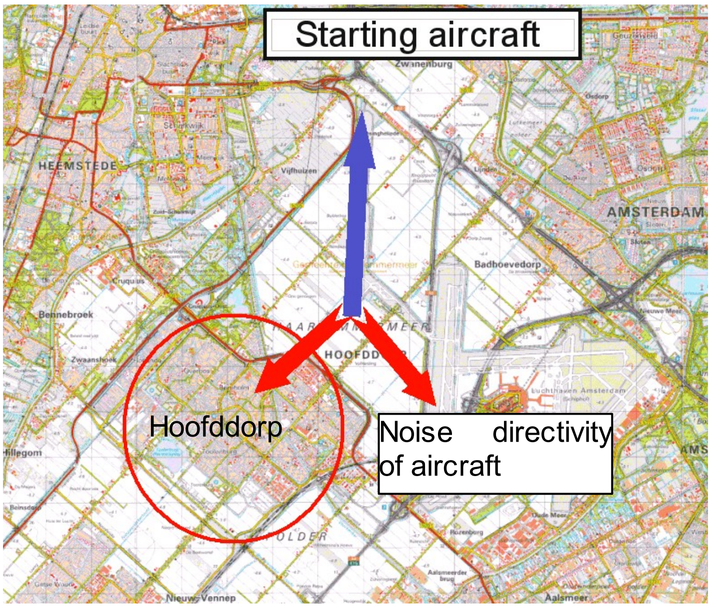


Figure 1 - Noise directivity of aircraft

The research is particularly targeted to determine the nature and extent of the groundnoise problem. Specific questions are:

1 What noise levels do occur and are there any decisive (low) frequencies?

2 Does nuisance only occur with large aircraft or do smaller aircraft also play a role? With a smaller (or medium) plane we mean a plane with turboprops or small turbofans (eg Fokker 70/100, Boeing 737 and Airbus 319). A larger aircraft means an aircraft with three or four larger turbofans (Boeing 747, Airbus 330 and MD 11).

3 What is the extent of the problem?

To answer these questions, noise measurements were done at various locations in Hoofddorp both outside and inside private homes. In addition, residents of several districts were asked to state the nuisance per type of aircraft. Using a specific questionnaire, the complaints about groundnoise were more clarified. In order to identify the extent of the problem, measurements on groundnoise of another runway, called the Kaagbaan, were also carried out in another city Badhoevedorp.

3 Results

3.1 Measured noise levels and spectra

The noise measurements were conducted at various locations around Schiphol during several days in February, March, June, July and September of 2009. Most measurements have been carried out at sites in Hoofddorp. During a day measurements were carried out, an average of approximately 100 to 150 aircraft departed from the Polderbaan. The measurements were carried out simultaneously at two or three locations in Hoofddorp. Not all measurement were useful due to background noise (eg passing cars or trucks). An overview of measurements sites in Hoofddorp is shown in Figure 2. At the runway, the type of aircraft departing was registred in order to establish a relation with the measured noise levels in Hoofddorp and the aircraft.

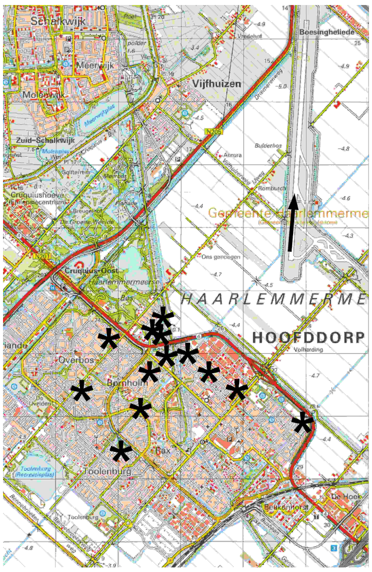


Figure 2 - Measurement positions in Hoofddorp

The purpose of these measurements was to determine the outside noise levels in residential areas on the outskirts of Hoofddorp and to determine whether the noise contains low frequencies. It also gives an impression of the impact of the groundnoise in Hoofddorp.
During a high use of the Polderbaan a plane can leave from the Polderbaan every 90 seconds. This results in relatively "loud noise moments" during a take off, alternating with relatively "quiet times" (the plane has already left). On the outskirts of Hoofddorp, the departure of an airplane from the Polderbaan can be measured over a period of approximately 30 seconds.

Figure 3 displays some noise spectra of three types of airplanes (B737, B747 and MD 11) measured at different positions on the outskirts of Hoofddorp. The B737 is a medium sized aircraft with two smaller turbofans. The B747 is a large plane with four large turbofans, suspended under the wings of the aircraft. The MD 11 is also a large plane with three turbofans, two under the wings and one in the tail of the aircraft.
The values in figure 3 relate to equivalent noise levels over the measurement period of approx. 30 seconds. The values are (linear) averaged over several planes, so outliers up (and down) are possible. The presented spectra were all measured on the same day in September 2009 under north eastern wind conditions. During other meteorological conditions (frost, temperature inversions), differences can arise.

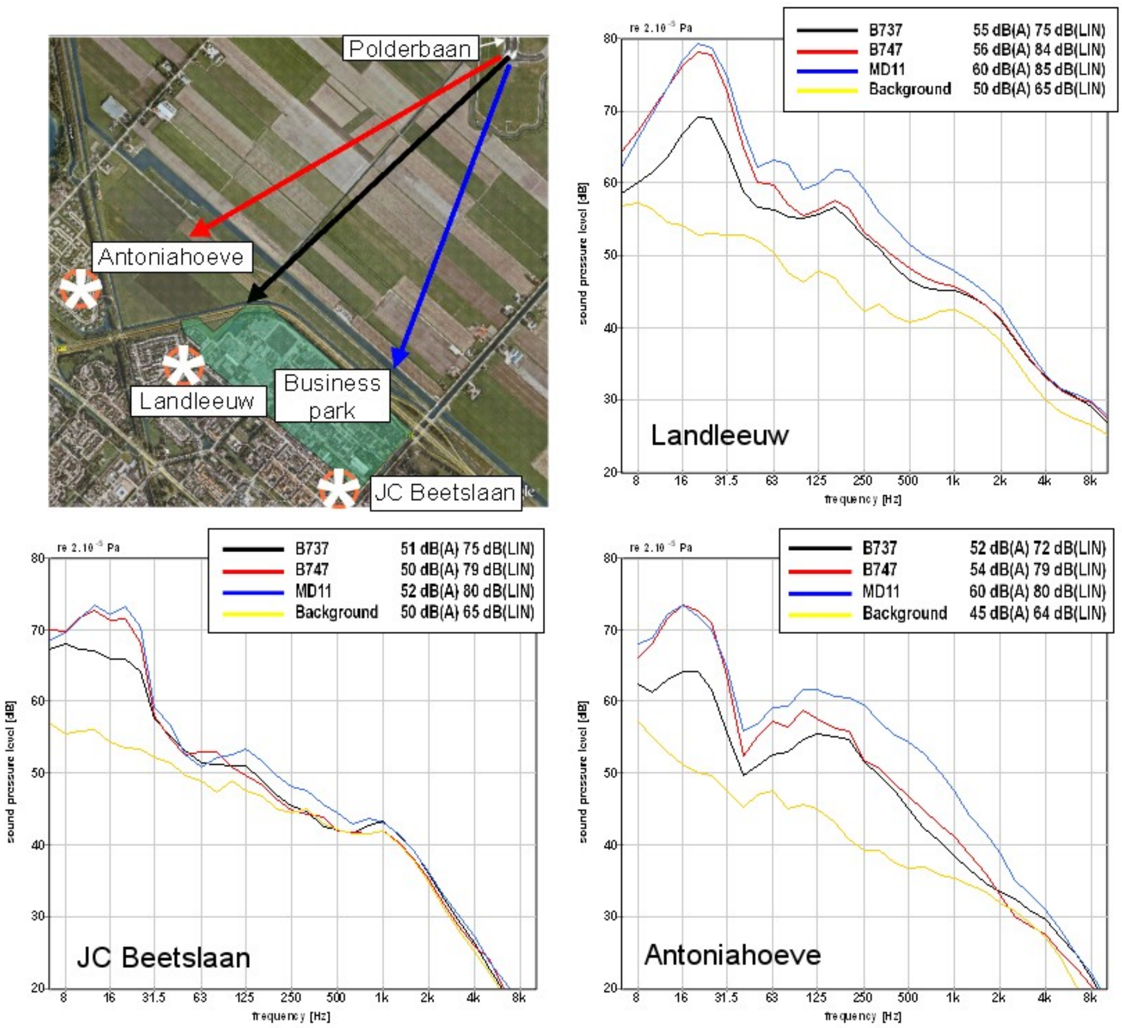


Figure 3 - Results of measurements in different position in Hoofddorp - levels averaged over 30 seconds - 1/3-octave band values

The positions (Landleeuw, Antoniahoeve and JC Beetslaan) are all located under a different orientation relative to the Polderbaan. In addition, there are little to no buildings situated between the measurement positions Landleeuw/Antoniahoeve and the Polderbaan, while a business park is located between position JC Beetslaan and the Polderbaan.

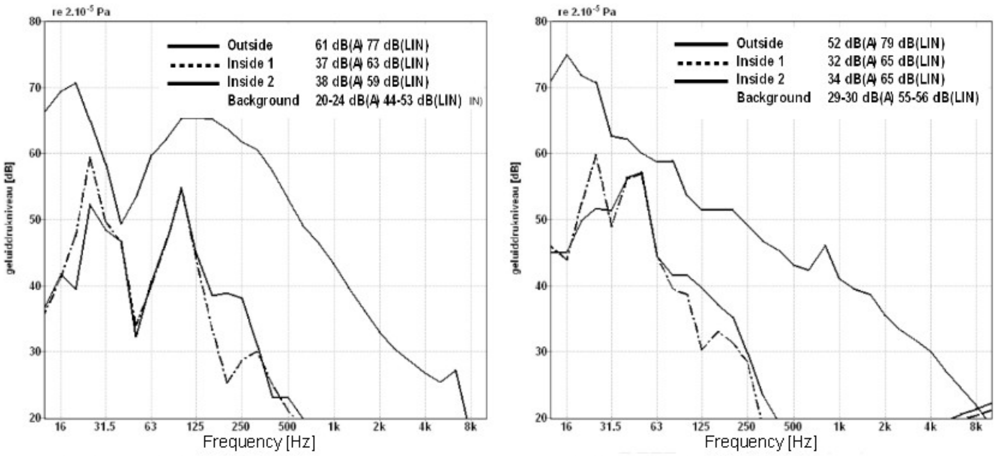
From Figure 3 it can be seen that the highest noise levels at low frequencies occur at the position Landleeuw (concentration at 25 Hz). For larger aircraft like the B747 and MD11, the average noise levels are approximately 84 to 85 dB at 25 Hz (unweighted equivalent noise level over 30 seconds). For smaller aircraft (such as the B737) the linear averaged noise level at 25 Hz is approximately 9 to 10 dB lower. The silent moments between the two starts are excluded here.

The measured spectra and levels appear to vary by location. For example, at the positions Antoniahoeve and JC Beetslaan the noise levels are lower and seem to move towards lower frequencies. The unweighted noise level for an MD11 at these positions is approximately 80 dB (5 dB lower compared to position Landleeuw). At position Antoniahoeve, increased noise levels also appear at 125 Hz and 250 Hz, while for the position JC Beetslaan there is no concentration of sound near these frequencies. Because of this concentration at 125/250 Hz the A-weighted sound level for an MD11 at this position is similar to position Landleeuw.

On the outskirts of Hoofddorp, it can be seen that at different positions also differences in levels and nature (concentrations in other frequencies) are measured.

As the assessment of low-frequency noise often occurs inside houses [1,2,3,4], measurements were made within four houses in Hoofddorp. For each house, measurements were performed in two rooms, the living room and one bedroom. In each room, measurements were carried out in two corners (a lower and upper corner, located diagonally opposite each other). For each airplane, an analysis of this event was made. The average time of analysis is approximately 30 seconds. Quiet moments between two take-offs have not been accounted for.

Figure 4 presents two results of measurements in two rooms in different houses. The figure also includes the outside noise level, as measured next to the facade of the house (thus excluding reflections from the building).



A321 – Antoniahoeve B777 – Louisahoeve

Figure 4 - Results of measurements inside homes - levels averaged over 30 seconds - 1/3-octave bands values

The figures show noise spectra for the take-off of an Airbus 321 and a Boeing 777, both departed from the Polderbaan. It can be seen that in different houses differences in spectra occur. Although the spectrum outside has no apparant tones, the spectrum inside becomes tonal in character. For example, in the house Antoniahoeve peaks occur at 25 Hz and 100 Hz and in the house Louisahoeve peaks occur at 25 Hz and 40/50 Hz. In the house Antoniahoeve the peak at 100 Hz determines the A-weighted sound level. Inside the house Louisahoeve, the peak at 50 Hz also has influence on the A-weighted sound level. Based just on the spectrum measured outside, these peaks inside can not be predicted.

The tonal character can both be explained by the large wavelength at low frequencies, creating a "standing" wave inside a room. On the other hand, resonances of panels / parts of the facade play a role in the low frequency region. For this resonance frequency, the sound reduction is very low.
The noise levels are both dependent on the sound spectrum outside and the sound reduction of the facade and the dimensions of the room behind the facade. Therefore, no specific frequency can be designated which can predict the annoyance for all the residents.

3.2 Type of airplane versus annoyance

A research was conducted with six residents, where these residents have classified there nuisance per airplane for several periods of a day ("no nuisance" to "very annoying"). The homes of these residents are all located on the north side of Hoofddorp. For half of these houses (front row), there are little to no barriers between the house and the Polderbaan. Concerning the other half, there are at least two rows / blocks of houses or other buildings located between the house and the Polderbaan. By residents of the front row, 90% to 100% of the "big" aircraft were observed and 50% to 70% of the "small" aircraft were observed. "Observed" here means that the aircraft can be heard inside the house, which does not automatically mean that this results in nuisance. The residents behind the front row only observed 0% to 15% of small and larger aircraft.

If for each resident the most annoying moments are considered, it appears that on average 43% of these moments are caused by small aircraft and 57% are caused by large aircraft. Therefore most nuisance is caused by larger aircraft. That 43% of these moments are still caused by small aircraft is partly due to the fact that proportionally there are more departures of small aircraft. Therefore, larger aircraft generate more nuisance than smaller aircraft. However, among the smaller aircraft outliers scored as much annoyance in comparison to the "large" aircraft.

Additionally, the reported moments of annoyance were compared with the measured indoor noise levels. Comparisons were made with the equivalent A-weighted and C-weighted noise levels. The C-weighted noise levels also were considered because in some literature [5,6], C-weighting for low frequency noise is proposed. It should be noted that the noise measurements and the nuisance investigation were not performed simultaneously, so the outcome has its limitations.

The indoor measurements were performed in four houses, two rooms for each house. If the noise levels per room are ordered based on A-weighted sound levels, it appears that 42% of the highest A-weighted values are caused by small aircraft and 58% by larger aircraft (highest noise levels, top 3 per room). If ranked based on highest C-weighted noise levels, it appears that 12% of the highest C-weighted values are caused by small planes and 88% by larger aircraft. The ranking based on A-weighted noise levels appear to agree better with the annoyance reported by the residents. The A-weighted sound levels inside are mostly determined by the octave bands of 63, 125 and 250 Hz.

3.3 Extent of the problem

In order to determine the impact of groundnoise in Hoofddorp, the noise levels on the outskirts of Hoofddorp are compared to levels towards the town center. Figure 2 indicates the measurements positions. A comparison between simultaneously conducted measurements of groundnoise in positions on the outskirts of Hoofddorp and other positions closer to the center of Hoofddorp shows that the noise levels flatten fairly quickly. Measured reductions of 15 dB at low frequencies are no exception.
In figure 5 some examples of noise measurements are presented. The figure shows the measured maximum noise levels, as in positions towards the center of Hoofddorp the noise is (much) less measurable in relation to the background noise level than on the outskirts of Hoofddorp. Also, here the smaller type of aircraft are virtually undetectable / measurable.

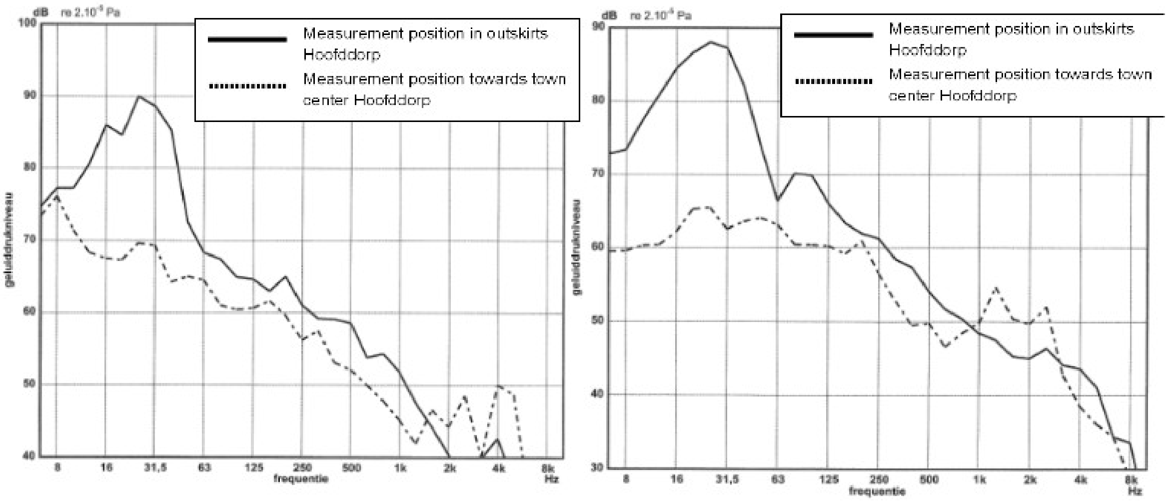


Figure 5 - Comparison noise levels outskirts versus position towards town center - maximum 1/3 octave band levels

This was confirmed by the nuisance investigation (see 3.2), whereby residents of the front row observed relatively more planes in comparison to residents of houses behind the front row.

In addition, the measurements of the noise levels in Hoofddorp were compared with measurements elsewhere around Schiphol. These comparative measurements provide insight into the extent to which the problems are (very) specific in Hoofddorp. As mentioned before, the highest noise levels encounter at an angle of approximately 135 degrees from the front of the plane. Figure 5 shows that a similar situation arises in the southern part of Badhoevedorp due to aircraft taking off from the Kaagbaan. Therefore, measurements were conducted on the outskirts of Badhoevedorp.

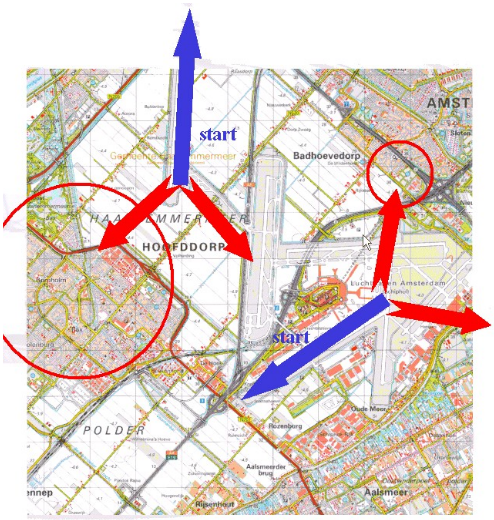


Figure 6 - Possible effect groundnoise on another location

The (averaged) measurements of the take off of an Airbus 330 are presented in Figure 6. For comparison reasons, measurement results of the take off of an Airbus 330, as measured in Hoofddorp (Landleeuw), are also included. The figure shows that the noise levels at frequencies around 25 Hz are lower in Badhoevedorp in comparison with Hoofddorp (position Landleeuw), but the levels at 125 Hz are higher. The same effect was also seen at other measurement sites in Hoofddorp (Antoniahoeve), both in terms of spectrum and noise level, where the sound levels near Antoniahoeve have resulted in many complaints.

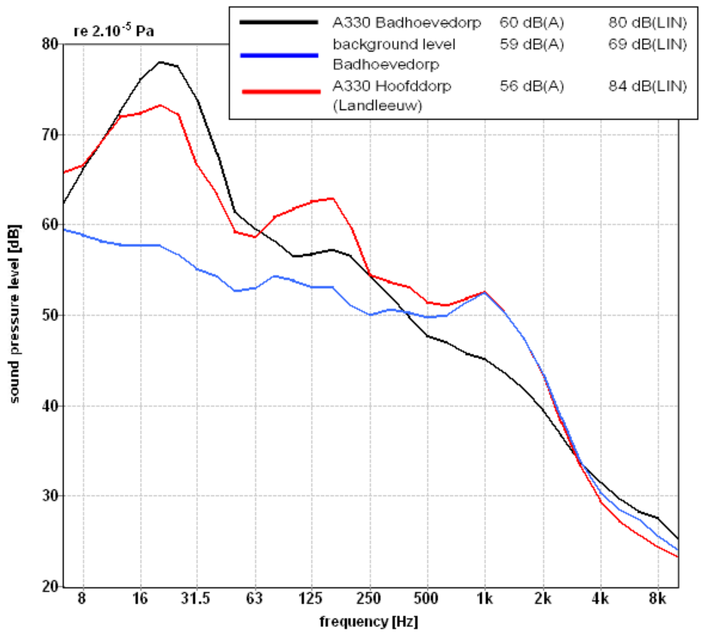


Figure 7 - Results of measurements in Badhoevedorp - levels averaged over 30 seconds - 1/3-octave band levels

4 Conclusions

As part of the investigation for the development of a rating procedure for low frequency noise, measurements have been performed to give more insight into the nature and impact of one of the motivation to start the research, namely the (low frequency) groundnoise around Schiphol.

Especially on the outskirts of Hoofddorp, the noise measurements have shown that the levels and spectrum depend on the relative orientation to the Polderbaan. For groundnoise, no frequency can be regarded as decisive for the annoyance.

Large planes cause most moments of nuisance, but there are outliers among the small planes which can cause as much nuisance. The moments of nuisance might best be predicted by A-weighted values.

In order to identify the extent of the problem, it was shown that the highest levels and most moments of nuisance especially occur on the outskirts of Hoofddorp. In addition, it was shown that groundnoise is not only observable in Hoofddorp due to the Polderbaan. In Badhoevedorp, another city around Schiphol, same levels of groundnoise can be measured due to aircraft departing from the Kaagbaan.

The above results are important in the next phase for the development of a possible rating procedure for low frequency noise. Eventually, the proposed methodology for lfn has to be compared with the actual situation around Schiphol.

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