Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Executive summary

Measuring environmental aircraft noise

Combining new technologies with old ideas

Problem area
For many countries only calculations are part of the process to uphold the law regarding environmental aircraft noise. People living in the vicinity of airports have more faith in measurements. The public feeling is that the noise measurements better represent nuisance. Hence, public pressure has risen to embed noise measurements into aircraft noise regulations. However, this incentive comes with legal, social and also technical challenges. One of these technical challenges is to minimize the measurement uncertainty. It is widely known that ground reflections influence measurement results. To minimize the measurement uncertainty, ground reflections can be eliminated while doing measurements. This idea is not new. Eliminating ground reflections in the past was done by measuring flush i.e. measuring with an inverted microphone. However the inverted microphone was not made robust and not suitable to monitor noise outdoors over longer periods of time

Description of work
New robust techniques are available to eliminate the ground reflections. In this paper, the inverted microphone is replaced by a flat microphone which has the size of a coin. In-situ measurements are done to validate measurement set-ups.

Results and conclusions
The new proposed set-up to measure environmental aircraft noise may help the process to incorporate noise measurement into noise regulations. The flat microphone on hard surface yields results that are similar to those of the inverted microphone. It creates opportunities to validate noise calculation results from different aerodromes in a better way, as typical local ground characteristics do not influence the results anymore.

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Combining new technologies with old ideas

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Measuring environmental aircraft noise: combining new technologies with old ideas

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ABSTRACT

For many countries only calculations are part of the process to uphold the law regarding environmental aircraft noise. People living in the vicinity of airports have more faith in measurements. The public feeling is that the noise measurements represent the nuisance in a better way. Hence, public pressure has risen to embed noise measurements into policy regulations. However, this incentive comes with, legal, social and also technical challenges. One of these technical challenges is to minimize the margin of the measurement uncertainty. It is widely known that ground reflections influence measurement results. To minimize the margin ground reflections can be eliminated while doing measurements. This idea is not new. Eliminating ground reflections in the past was done by measuring flush i.e. with an inverted microphone. However the inverted microphone was not made robust and not suitable to monitor noise outdoors over a long period of time.

New robust techniques are available to eliminate the ground reflections. In this paper, the inverted microphone is replaced by a flat microphone which has the size of a coin. In-situ measurements are done to validate measurement set-ups. The flat microphone on hard surface gives similar results as the inverted microphone.

1 INTRODUCTION

Different enforcement procedures of noise regulations exist for different environmental noise sources. For road, railway and industrial sources noise levels are measured on site, which may be part of the enforcement procedures. For aircraft noise, these procedures mostly do not include measurements, as they are based on calculations only. Public pressure is rising to embed measurements into aircraft noise regulations as well. Residents of airport surrounding areas have more faith in measurements, as they believe that noise measurements represent the nuisance better.

The reason that measurements are not yet widely incorporated in enforcement procedures of aircraft noise regulations is two-fold:

1. Measurements can not easily be repeated
2. Measurements results are not adequate predictable

Two aircraft flying the same procedure can produce very different measured noise levels on the ground, due to varying weather conditions, aircraft position, etc. This means that measurements can not be easily repeated, as the measurement results depend on many aspects

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that can not be controlled. Many airports are restricted by noise laws and therefore need the enforcement procedures to yield consistent results that can be controlled by operational or management decisions. Managing airports operations to adhere to noise laws by using noise measurements solely seems therefore at this moment impracticable. However public pressure is rising. The repeatability and prediction models need to be further improved.

This paper is about measuring environmental aircraft noise: combining new technologies with old ideas. New microphone techniques have become available to rally old measurement methods to measure and monitor aircraft noise, with unmanned measurement set-ups, over longer periods of time, while reducing the measurement uncertainty. The new technique increases the practicability and repeatability of the measurement system itself. To carefully incorporate noise measurements into noise enforcement procedures, many steps still need to taken and legal, social and technical issues need to be solved. This paper describes a small technical step on this road to incorporating noise measurements into aircraft noise regulations.

2 CONTEXT

Measurements of fly-overs done are often performed with the microphone mounted on a 1,2 metres pole, pointing towards the noise source. This means that sound arrives at the microphone perpendicular of its membrane – the angle for which the microphone is calibrated. This method suffers from ground reflection problems. Ground reflections result in additional variation of noise level which is considered unwanted.

Addressing the issue of the unwanted ground reflection when measuring aircraft noise is not new. In the seventies, the commercial airplane company Boeing has pointed out this problem in the article written by Merle B. MC Kaig [ref.3]. Under full-scale engine test conditions, a technique has been worked out at Boeing to avoid reflections, see figure 1.

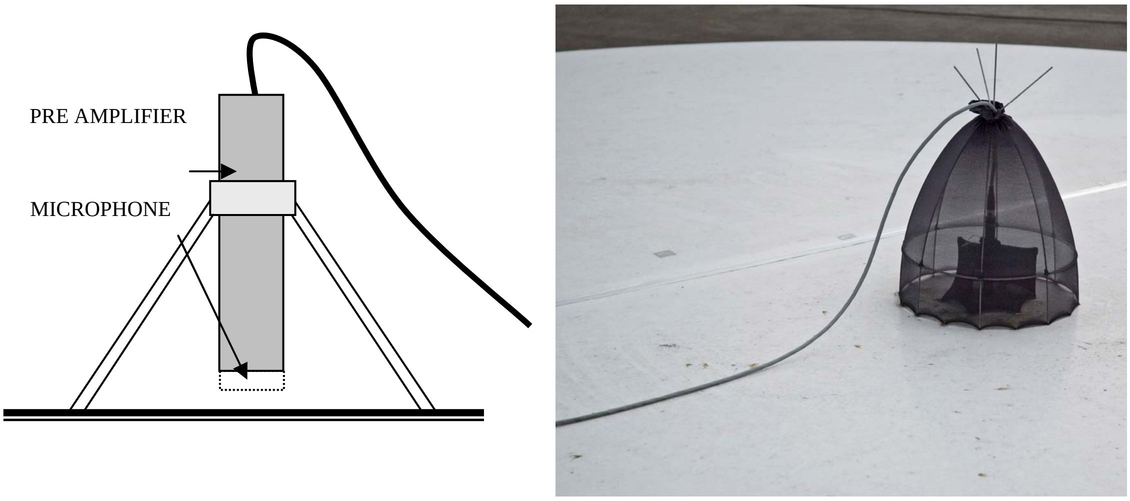


Figure 1 : typical example of an inverted microphone, schematic and photo

Briefly, the technique involves placing the receiver so close to the reflecting surface that the difference in path length of direct and reflected signals approaches zero. Under these conditions both the direct and the reflected waves for all frequencies of interest always arrive in phase and always in the same cycle. This means that the sound pressure level measured by the microphone is twice as high as the free-field situation. To calculate the free-field levels the constant amplification of the sound (pressure doubling) has to be subtracted for all frequencies of the measured levels. Because of the logarithmic conversion from sound pressure level to noise levels in decibel, this means that 6 dB has to be subtracted from noise levels of all frequencies. Knowing that free-field levels can be obtained by placing the microphone close to a reflected surface, 4 approaches are available:

1. Inverted microphone, see figure 1;
2. True flush, the microphone has been milled in the surface (e.g. plate or concrete), see figure 2;
3. Microphone mounted horizontal and directly to the surface [see ref.4], see figure 2;
4. True flush using a surface microphone, see figure 3.

The fourth approach is the ‘new’ approach, where new technologies are combined with old ideas.

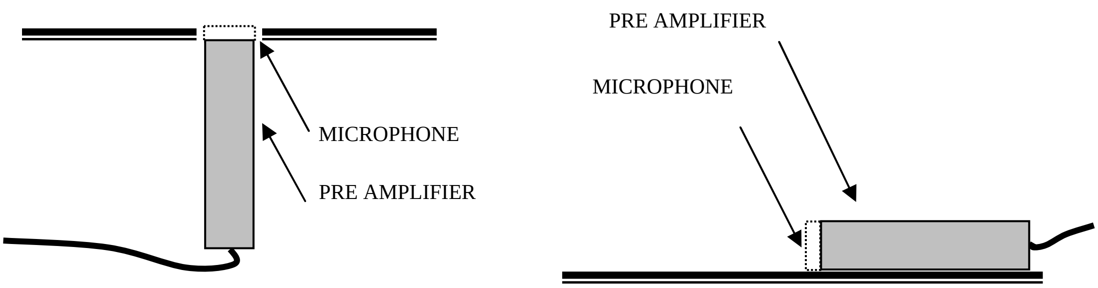


Figure 2: schematic figures – left: true flush – right: horizontal mounted

For the embedding of measurements into aircraft noise regulations, standards and guidelines need to be used, to guarantee the ‘high’ quality of the measurements. At least two accepted international guidelines are available:

- Annex 16 [ref.1]

  Annex 16 is the international Standard and recommended practices to the Convention on International Civil Aviation. It mainly focuses on measurement methods to gain certified noise levels for aircrafts and helicopters. The appendices of this document contain guidelines to monitor aircraft noise on and in the vicinity of aerodromes.

- ISO 1996-2 [ref.2]

  The ISO 1996-2 standard gives guidance to determine the environmental noise levels caused by traffic, railway, industrial and aircraft noise. This document is typically used by consultants to assess the noise in residential areas.

Both guidelines describe flush and pole-mounted microphone set-ups. Besides the aim for ‘high’ quality measurements an acoustician is also keen to use an easy and robust set-up. It should be robust enough to stay operational during extreme weather conditions (like rain), especially when noise is measured over a long period of time. For the pole-mounted microphone robust set-ups are widely available. Using the ‘new’ approach (i.e. with the surface microphone) a robust and easy to use set-up also becomes available while doing flush measurements.

3 THE EXPERIMENT

The main interest of this experiment is to find the best available technique to eliminate the unwanted ground reflections, by measuring flush. For environmental noise monitoring according to Annex 16 the height of the tripod depends on the obstructions surrounding the measurement location. The microphone position should be selected in such a way that no obstruction influences the sound field produced by the aircraft to be measured. This may lead to different tripod heights (depending on the different environmental ‘obstructions’), which means different ‘ground’ reflections and therefore different results. These different results, between the different tripod heights are not the main interest of this paper and only mentioned here. It is assumed this difference due to different tripod heights is adding an extra measurement uncertainty. In our experiment the tripod has been fixed at 1.2 metres at all time.

The key element in the experiment is the replacement of the inverted microphone with the true flush surface microphone, see figure 3. Hereby the standards as mentioned in paragraph 2 are used as reference to design the different measurement set-ups. In-situ simultaneous measurements are done using the following set-ups:

1. a microphone on a 1,2m tripod (channel 0,(ch0))
2. a flush B&K 4949 microphone on a 3.0m diameter dense plywood ground plate (ch1)
3. a inverted microphone on a 3.0 m diameter dense plywood ground plate (ch 2)
4. a flush B&K 4949 microphone on a 0.4m diameter metal ground plate (ch 3)

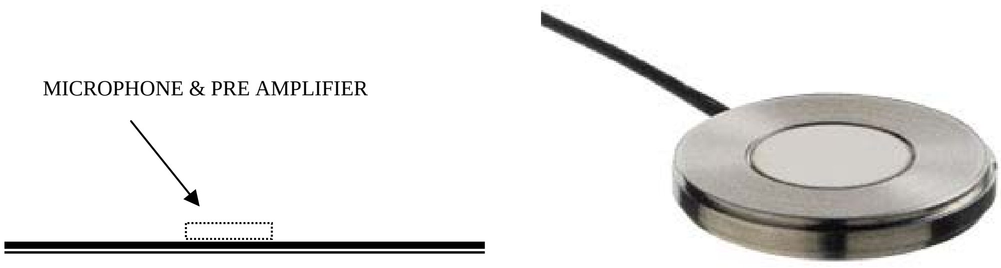


Figure 3: example of a surface microphone, schematic and photo

These set-ups are installed on top of one of the NLR buildings in Amsterdam. NLR lays under the Amsterdam Airport Schiphol routes for approaching the 'Oostbaan' runway and departing from the 'Buitenveldert' runway. Figure 4 shows these routes and the measuring site. The measurements done were unmanned and all equipment has been installed without replacing it for a period of three months.

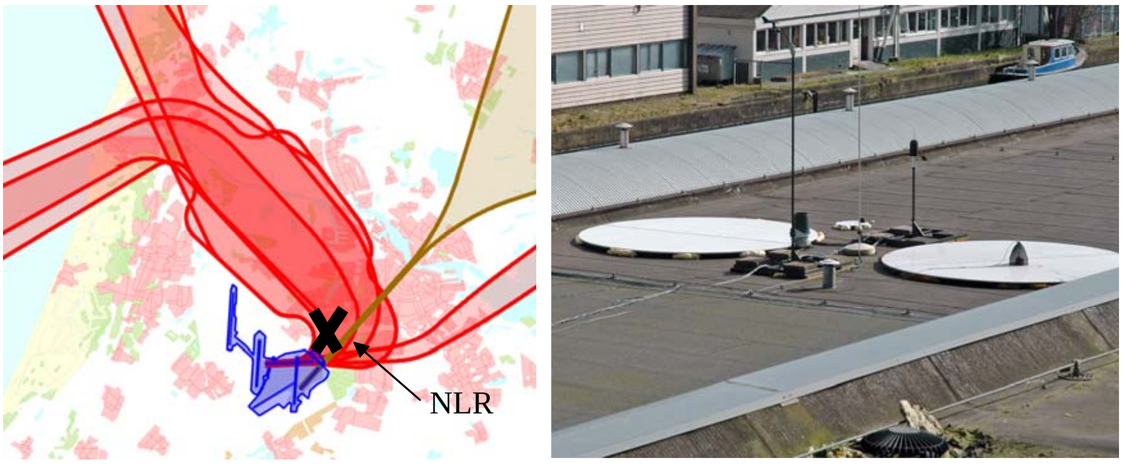


Figure 4: Schiphol routes going over NLR Amsterdam – photo measuring site

The Surface Microphone used in the experiments for this paper was the Brüel & Kjær type 4949. The Surface microphone was originally developed upon request of Airbus that was looking for an easy to use and robust, low profile transducer to measure sound pressure on the skin of an airplane. This resulted in the type 4948 Aerospace Surface Microphone which is now very often used in the aerospace industry.

It was realized that there would be a market for a transducer with the same dimensions as the aerospace Surface Microphone but a lower price and a different dynamic range. This eventually resulted in the 4949, the so called Automotive Surface Microphone – used regularly in wind tunnel testing all over the world. With its height of only 2.5 mm including the built-in Constant Current Line Drive (DeltaTron type), amplifier and optionally even CIC (Charge Injection Calibration) for in situ verification, the Surface Microphones have opened a whole new application area. The ease of use and long cable drive capability are the two most obvious benefits. Principally being a condenser microphone and building on the calibration heritage from the world of acoustics, the Surface Microphones offer a new dimension of accuracy for measurement of acoustic signals as well as dynamic pressure fluctuations.

Surface Microphones are “all Titanium”. This characteristic has the additional benefit of extremely high corrosion resistance. In this experiment the Surface Microphone was left outside experiencing varying Dutch meteorological conditions during a period of 3 months without any visible signs of beginning corrosion. Finally, with an upper frequency of 20 kHz and a dynamic range from 30 to 140 dB the Automotive Surface Microphone has specifications which perfectly meet the requirements for environmental aircraft noise measurements.

4 RESULTS

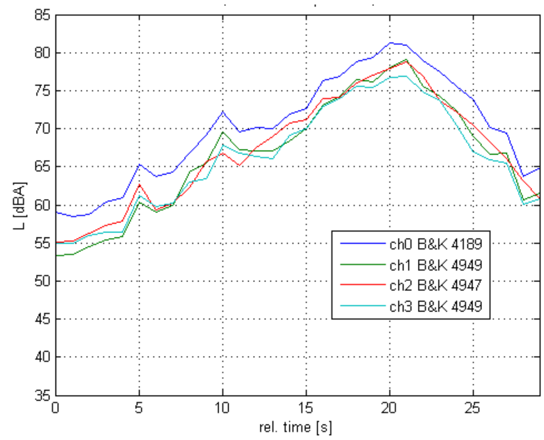
In figure 5.1 results are presented for an Airbus A320 that flies over the measuring set-ups on June 13, 2007. This event is considered representative. More events were obtained over a period of three months showing similar results.

The figures 5.1.1 & 5.1.3 until 5.1.6 have an equal time axis. Measurements were done simultaneously; therefore the time lines are equal. The spectrograms (figures 5.1.3 until 5.1.6) shown are the noise energy difference per third octave band for two different measurements set-ups. Recorded noise energy levels per third octave band of both set-ups are subtracted. Figure 5.1.2 shows the recorded signals transformed to the frequency domain. Figure 5.1.2 shows sound pressure levels (non-weighted) and figure 5.1.1 shows A-weighted noise levels.

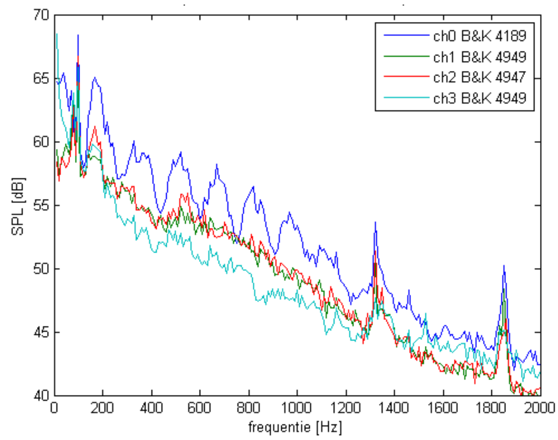
Showing figure 5.1 with this layout the overall A-weighted noise levels can easily be analysed. A-weighted noise levels are normally used for the enforcement of aircraft noise regulations – therefore these levels have been used as a starting point.

Figure 5.1.2 shows that the A-weighted noise levels for the microphone on a tripod are higher than the results of the other set-ups. With the other set-ups a correction has been done for the ground reflection, while the results for the microphone on the tripod still contain the ground reflections. The influence of the ground reflection becomes visible in 5.1.2., where in the FFT plot up to 1200 Hz shows sinusoidal behaviour. In 5.1.1 the differences between the microphone on a tripod and the other set-ups are in the order of 5 dB(A). This value is typically location bound as the ground specifications influence the ground refection. The ground reflection is also visible in the figures 5.1.3 and 5.1.4.: the yellow squares form a convex parabola. As the angle of incidence changes over time (the aircraft is a moving source) the most dominant ground wave frequency also changes.

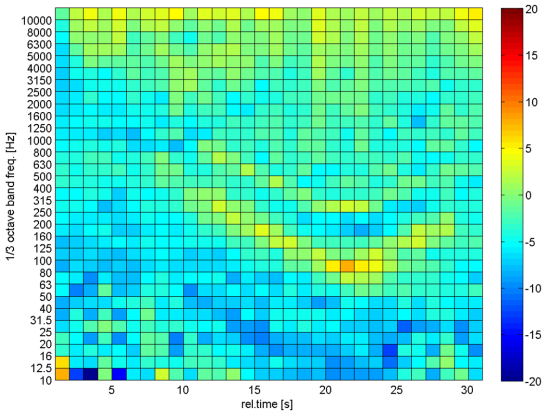
In the time domain the difference in A-weighted noise level per measured second between using an inverted microphone (old idea) and the flat microphone (new technology) is minimum, up to 2 dB(A). The lines of ch1 and ch2 in figure 5.1.1 show the same trend, except around 11 seconds. When ch1 and ch2 are compared in figure 5.1.2 the curves are



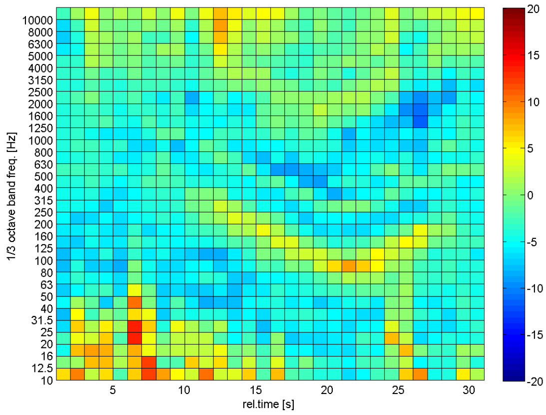
5.1.1: Overall dBA level of an A320 passing



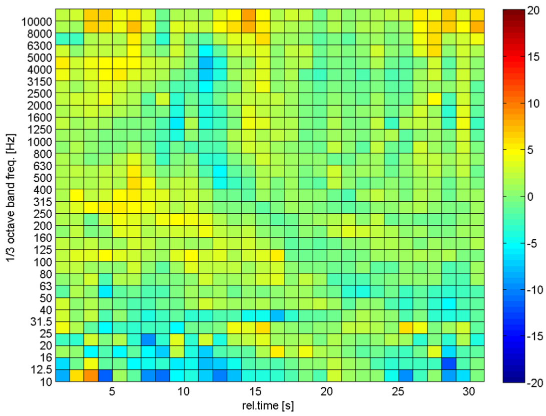
5.1.2: FFT of an A320 passing



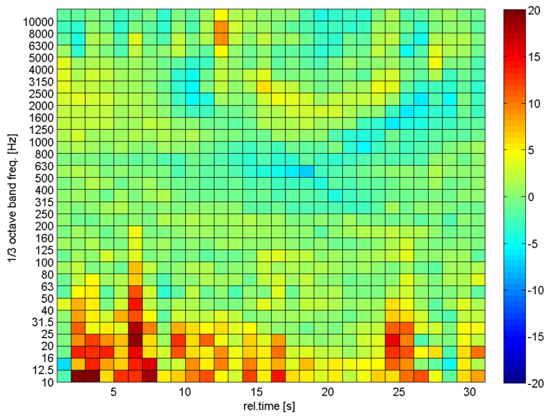
5.1.3: spectrogram, difference ch1 – ch0 [dB]



5.1.4: spectrogram, difference ch3 – ch0 [dB]



5.1.5: spectrogram, difference ch2 – ch1 [dB]

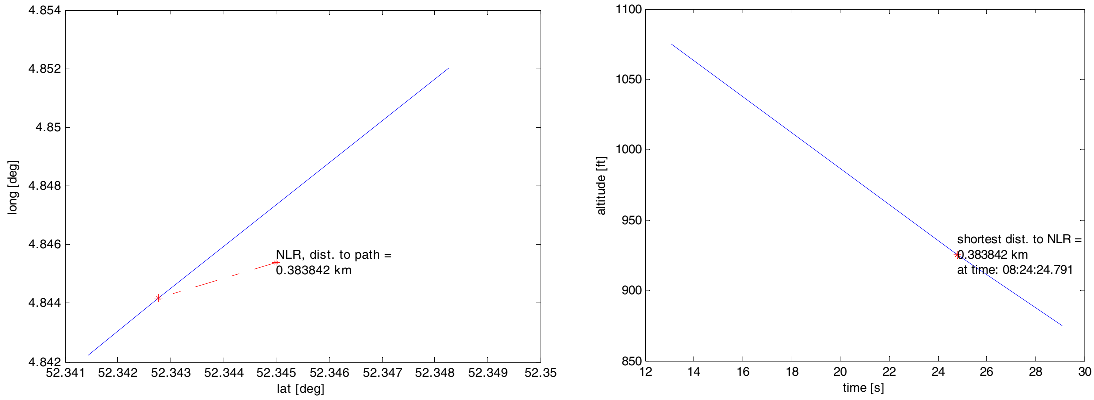


5.1.6: spectrogram, difference ch3 – ch1 [dB]

Figure 5: Results of an A320 passing the measuring set-ups at 13-06-2007, 8:24 pm

almost equal. The maximum difference in A320 noise levels (ch2 – ch1) occurs after about 25 seconds. At this moment in time the squares of the spectrogram in figure 5.1. are close to green (0 dB) by every frequency band.

For completeness the Airbus 320 flight path is displayed in figure 5.2. Figure 5.2.1 indicates the path flown in latitude and longitude coordinates, together with the closest point of approach between of the aircraft towards the set-up location. Figure 5.2.2 shows the time versus the altitude together with the time of shortest distance between the set-ups and the Airbus 320.



5.2.1 Latitude, longitude & closest point

5.2.2 Altitude flight & closest point

Figure 5.2: The A320 flight path at 13-06-2007, 8:24 pm

In figure 5.1.2 the set-up with the small diameter ground plate (0.4 metres) records significant lower sound pressure levels for the frequency range under 800 Hz. From this frequency (800Hz and below) the wave length becomes larger than the plate itself. The reflection of noise waves of a frequency lower than 800 Hz does not cause an optimal pressure doubling and therefore subtracting 6 dB is too much. The wave can not fully reflect in each cycle. This might also be an explanation for why the differences in the low frequencies of figure 5.1.6 are bigger than in figure 5.1.5.

Besides this reflection that does not lead to full pressure doubling, other practical downsides in our set-up may have influenced the results. The plates on the roof could not be attached without a cavity beneath the plates (thus not in line with the guidance of Annex 16). The cavity may act like a spring causing extra damping. Hereby, the radiated energy of the plate may bounce back by the roof, causing an increase in the recorded level. To reduce these influences of the cavity absorbing material has been installed between the roof and plate.

Small differences also may occur due to the different set-ups positions. The maximum distance between the set-ups is 6 metres, therefore a small time shift may occur and local side reflections may differ. However we believed these differences are not significant.

5 CONCLUSION & DISCUSSION

The new proposed set-up to measure environmental aircraft noise may help the process to incorporate noise measurement procedures into noise regulations. With the flat microphone on a large ground plate similar results are measured as with the inverted microphone. Knowing its robustness (in our case a measurement period of three months), it has been proven that measuring and monitoring environmental aircraft noise without ground reflections over a long period of time is possible.

This measurement method also creates opportunities to validate noise calculation results from different aerodromes in a better way, as typical local ground characteristics do not influence the results anymore.

The ground plate should be large enough in a way that the reflected wave in each cycle can reflect optimal. However, doing measurements always comes with practical downsides. Using the surface microphone is easy and robust, but installing a dense plywood ground plate with a 3 metres diameter is not an easy (and quick) way to build-up the set-up. Instead (as

ISO 1996-2 states) a concrete surface may be used. By doing this, you should realise results under low elevation angles may be influenced by temperature differences above the surface. That's why in our experiment the plates have been painted white to reduce this influence.

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