Helicopter detection: a fast computational method for long range sound propagation

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Introduction

A person can detect the presence of a nearby flying helicopter in various ways. One of these is aural detection. This paper presents an approach to assess the probability of detection in varying circumstances, such as the terrain and the meteorology. The main parameters are:

1. the helicopter noise source strength and directivity,
2. the long range sound propagation as a function of terrain and meteorology,
3. the presence of masking sound sources near the observer,
4. the probability of observer response to the exposed sound field.

The focus of this paper is on long range sound propagation. A computational method is presented that allows a quick assessment (within a few seconds) of the long range sound propagation (up to 20 km) around a source or a receiver. The method allows for arbitrary terrain altitudes, so that shielding by (multiple) hills and mountains is taken into account. Moreover, the effects of wind speed and temperature on sound ray curvature is included in a parametric way. Results of this fast computational method are compared with results from a numerical Parabolic Equation approach (PE). Finally, results of the full approach (all four steps) are illustrated. Figure 1 gives an example of the probability of detection around an observer for a given flight path.

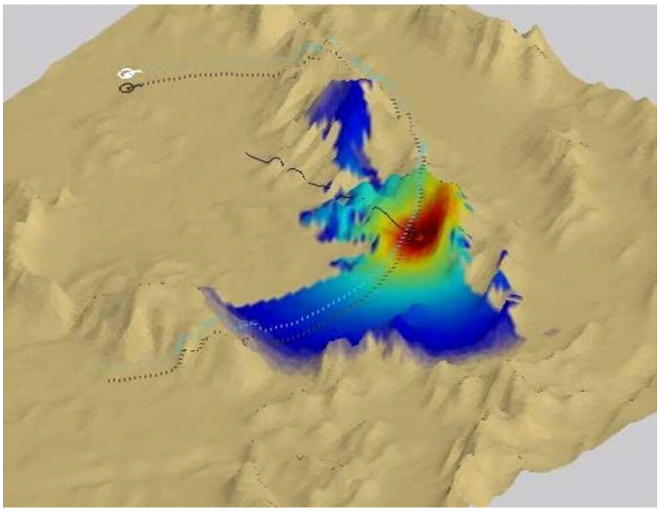

Figure 1. Example indicating the probabiltiy of detection around an observer for a given flight path.

1. Probability of detection

The probability of detection can be expressed in two ways:

- for a viewpoint from the helicopter: the probability of detection is calculated around the helicopter,
- for a viewpoint of an observer: the probability of detection is calculated around the observer.

The detection criterion is defined as: $C > 0$ means detection, and $C < 0$ means no detection. The value for C is calculated in dB. This values depends on the source strength Q, the sound propagation H, the masking sound level M, and the sound level difference Δ (between signal and background) for which a helicopter can be detected:

$$C = Q + H - M - \Delta \quad (dB)$$

Two values are taken into account: the expected value μ, and the uncertainty σ (for each Q, H, M, and Δ). The probability of detection is then defined as:

$$P(C > 0 \mid \mu, \sigma)$$

For example, if the calculated expected value μ is 0 dB, and the uncertainty σ is 5 dB, then there is a probability of detection of 50%. This is illustrated in Figure 2. Another example: if μ is -5 dB and σ is 5 dB, then the probability of detection is 16%.

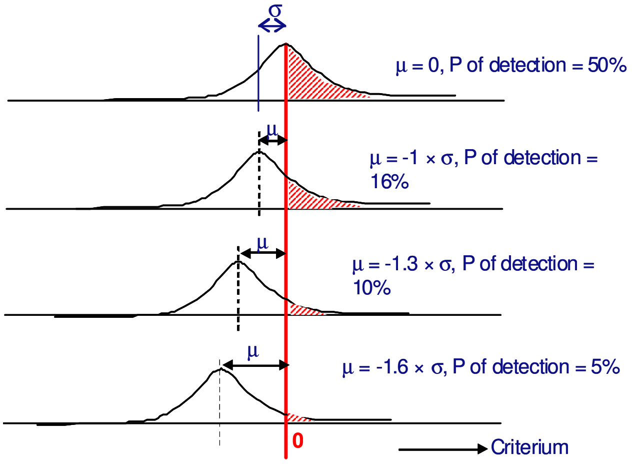

Figure 2. Four examples to demonstrate the probability of detection `P`.

2. Computational method

2.1 Constraints

The computational method for the long range sound propagation has to be suitable for a rough terrain, with a size of e.g. 200 x 200 square km. Also, the effects of wind speed, wind direction and temperature have to be accounted for. Besides, the method needs to be fast; results are required within a few seconds.

As a result an engineering method has to be found or developed. The results of this method will be compared to results obtained with a reference PE model.

A new engineering method was developed, which is called the “substitute sources method”. The most significant differences with the Harmonoise model are: the screening effect, the ground effect, and a parametric model to estimate the curvature of sound rays due to the meteorology.

2.2 Substitute sources method

The sound propagation H is defined as:

$$H = A_{geo} + A_{air} + A_{screen} \quad (dB)$$

With A_{geo} the geometric spreading, A_{air} the air absorption, and A_{screen} the screening effect for a hill or mountain.

In Figure 3 the substitute sources method is explained. First, the attenuation from source Q_0 to receiver w_1 is calculated. Next, the substitute source Q_1 is determined such that the same sound levels for receiver w_1 result. Then the attenuation from source Q_1 to receiver w_2 is calculated. This can be repeated for multiple hills and mountains between a source and a receiver.

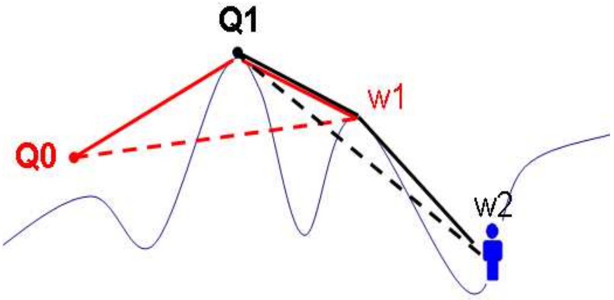

Figure 3. Schematic representation of the “substitute sources method“.

The substitute sources method is a two-dimensional method. By calculating several cross-sections a three-dimensional domain is covered, as shown in Figure 4.

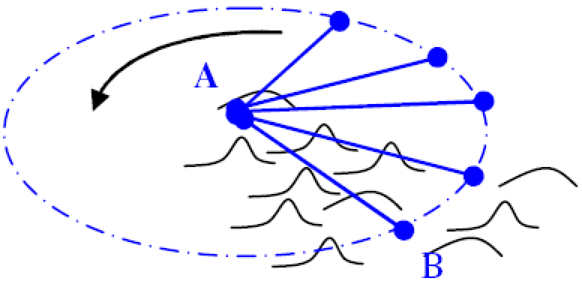

Figure 4. Rotating two-dimensional calculations to obtain results for a three dimensional domain.

2.3 Screening

The screening effect can be calculated with “Meakawa”. The path length difference (ε), between the direct sound ray and the screened sound ray, defines the screening effect in dB. We deal with relative smooth hills and mountains, and in general there are quite some “screens” between the source and a receiver. As a result, and by comparing with PE results, the screening effect A_{screen} is given as:

$$A_{screen} = 10 \log (40\ 2/c\ f\ \varepsilon + 3) - 2 \quad (dB)$$

With f the frequency and c the speed of sound. This formula differs from Meakawa: 10 log (20 2/$c\ f\ \varepsilon$ + 3) – 2. The factor “+3 dB” is for screening along the line of sight, and “–2 dB” is for a smooth top (compared to a sharp screen).

Further, the curvature of sound rays, due to the meteorology, is accounted for. Figure 5 shows that the path length difference decreases for a downward refracting sound ray.

This effect is accounted for by lowering the screen, in such a way that a straight sound ray is again obtained. This is indicated in Figure 6.

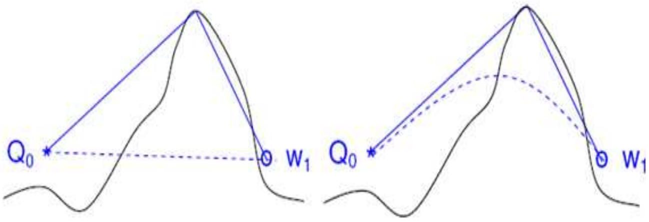

Figure 5. The screening effect is calculated via the path length difference between the direct and screened sound ray. Right figure: the meteorology causes refraction of sound rays.

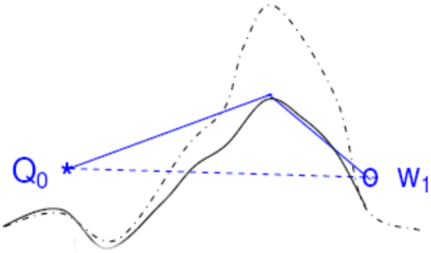

Figure 6. By lowering the screen (mountain), the curved sound ray is again a straight line.

The curvature of the sound rays depends on the speed of sound, which is a function of height. Two types of profiles for the speed of sound have been chosen: a logarithmic one and a logarithmic-linear one. The wind speed determines the scaling of these profiles. One can see the logarithmic profile as being representative for the day time, and the other for the night time. As a first step the curvature of the sound rays is fitted with polynomial functions. In Figure 7 an example of curved sound rays for a log-lin profile is give. The red broken line indicates the fit. Also, the difference in height is indicated with M. As a second step these differences in height can be fitted with a polynomial function. In this way a fast technique is obtained to determine the curvature of sound rays for different wind speeds and for two different sound speed profiles.

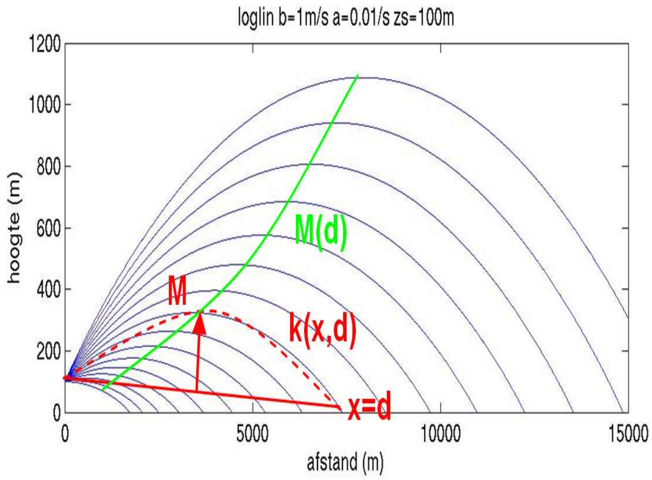

Figure 7. Fitting the curvature of sound rays (in red), and fitting the difference in height (in green).

2.4 Ground effect

Next, the ground effect is investigated. For a downward refracting atmosphere multiple sound rays can reach a receiver (see Figure 8). In general the ground has a certain absorption, as well as some scattering due to roughness. By comparing PE results for different grounds, it was found that only a small amount of absorption is sufficient to consider only the direct sound path. Therefore, the substitute sources method considers only the direct sound path.

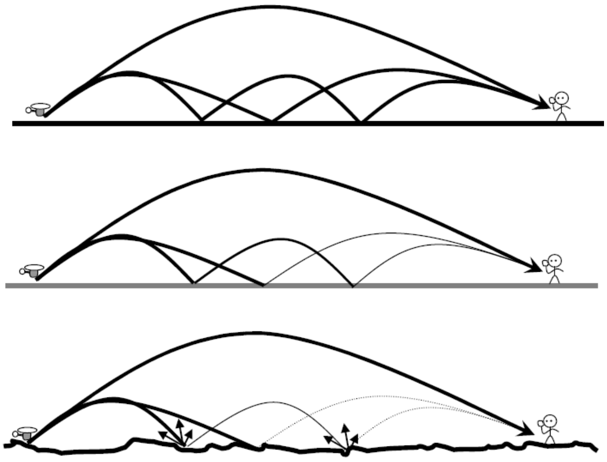

Figure 8. Ground reflection of sound rays for a downward refracting atmosphere. Top: reflecting ground. Middle: absorbing ground. Bottom: scattering ground.

3. Comparison with PE results

In the previous sections the PE method has already been mentioned. The PE method applied here is the so-called general terrain PE method (GTPE), which has terrain following coordinates (see Figure 9 and [1]).

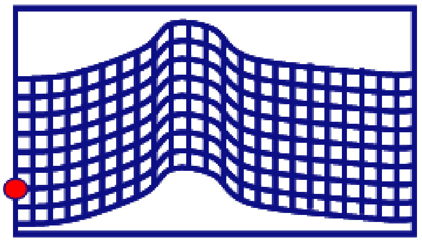

Figure 9. Terrain following coordinates for the PE method (GTPE).

The GTPE method can handle a relatively smooth terrain, so the actual terrain requires a certain smoothing. For the comparison with the substitute sources method four representative cross-sections were chosen. These cross-sections for the ground were then smoothed, as shown in Figure 10.

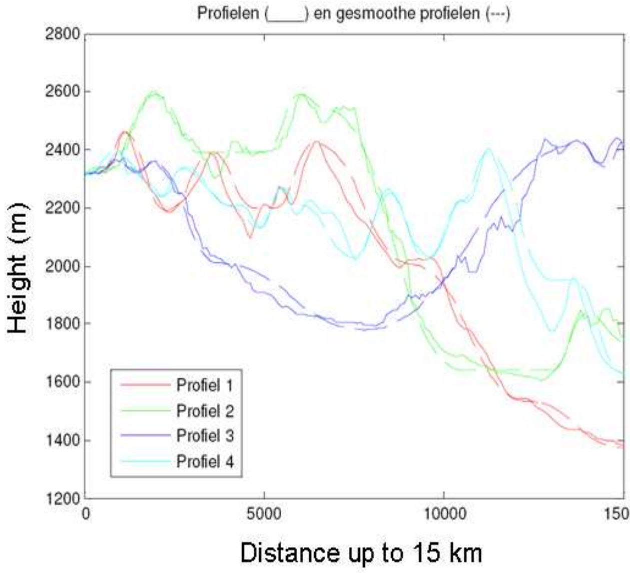

Figure 10. A selection of 4 ground profiles: original and smoothed (for the GTPE and substitute sources method).

The results for A_{screen} for one of these ground profiles is shown in Figure 11, both for the GTPE results as for the substitute sources method. The top figure shows the smoothed ground profile. The bottom figure the results for A_{screen}. In red the GTPE results are show, in blue the substitute sources method (Qsub) results. Also, results are presented for three different speed of sound profiles. The highest values are obtained with the logarithmic-linear profile. The lowest results are for a neutral atmospheric situation, i.e. there is no refraction of sound rays.

The comparison between both methods is rather good, and the effect of the mountains can be clearly seen. These results are shown for the 250 Hz octave band.

The comparison between GTPE and the Qsub method has been done for several ground profiles, several speed of sound profiles (i.e. for several wind speeds), and for nine third-octave bands. More than 5000 sound propagation results haven been evaluated. Figure 12 shows a histogram with the differences between both methods. The mean difference is 0 dB (which is logical, given the information in Chapter 2). The standard deviation is 8 dB. This seems a high value. However, by taking into account the uncertainties for the source strength Q, the masking sound level M, and the sound level difference Δ (between signal and background), the uncertainty for the sound propagation H is not the limiting factor. Ultimately, by reducing the uncertainty for the long range sound propagation, the probability of detection computation cannot be improved significantly. Therefore, it is concluded that the developed substitute sources method is a suitable model to calculating the probability of detection.

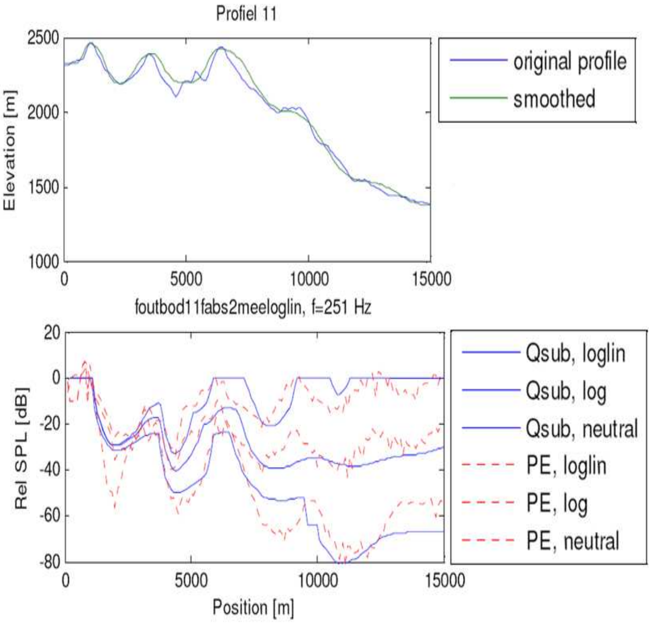

Figure 11. Top: smoothed ground profile for the GTPE and Qsub calculations. Bottom: GTPE results (in red) for A_{screen} and for the substitute sources method (Qsub, in blue) for three meteorological situations (a log-lin profile, a log profile, and neutral). The log-lin results give the highest values for A_{screen}.

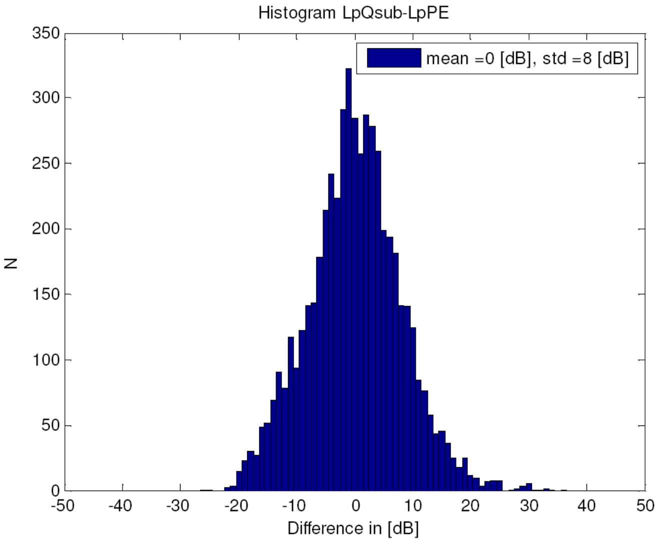

Figure 12. Histogram of more than 5000 comparisons between GTPE results and Qsub results.

4. Example

In Figure 13 and Figure 14 a simple example of the terrain and the calculated probability of detection is shown, respectively. In the centre of the terrain a helicopter is present. The result in Figure 14 depends on the height and flying direction of the helicopter, the wind speed and direction, the masking level and sound level difference (which depends on the wind speed and the possible number of observers), and the time of the day (day or night). The results in Figure 14 were calculated in two seconds on a standard computer.

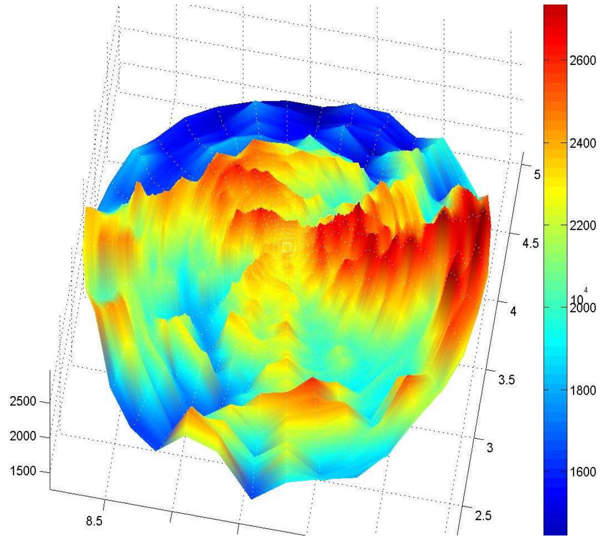

Figure 13. Height of the terrain in meters centered around the helicopter.

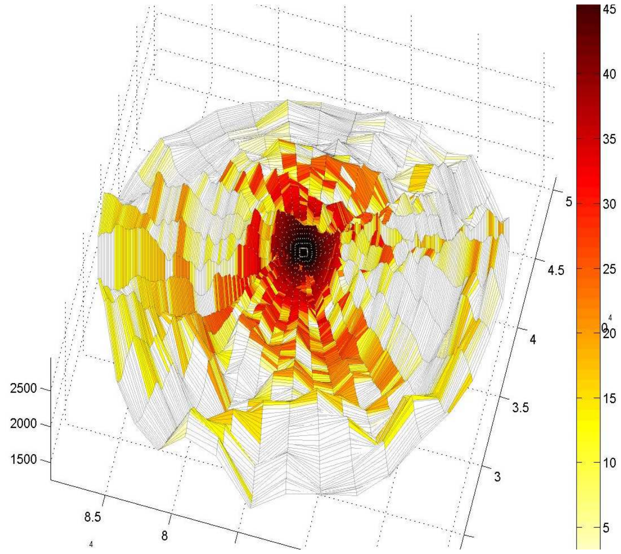

Figure 14. Example of the calculated probability of detection, corresponding to the terrain ans shown in Figure 13. White: detection < 10%. Red: detection > 50%.

References

[1] Computational atmospheric acoustics, Erik M. Salomons, Kluwer, Dordrecht, The Netherlands, 2001