Ray-Tracing in a 3-D Wind Field for Prediction Purposes of Shooting Noise, Part I

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Introduction

For noise assessment of shooting sounds, specific prediction models are available that in particular consider the long-range propagation necessary to cover the whole range where shooting sounds are audible. They follow traditional concepts of noise prediction relying on long-term average levels, distinguishing only between downwind and up wind conditions. These models are sufficient to assess at large the shooting noise from shooting facilities, but they are less appropriate to support the daily noise management or to help planners to find a “low-noise” design for shooting ranges or for the configuration of facilities on larger training areas. For these tasks, models are needed that take into account the weather, i.e. the state of the atmosphere, in more detail than upwind or downwind. In addition to a traditional average level, the noise management also needs a measure for the variation of the average to estimate the probable excess levels of single events during the daily shooting.

Most of the current sound propagation models that consider atmospheric influences rely on approximations with respect to the atmosphere that are not applicable for shooting noise due to the large distances where shooting blasts can be significant for assessment (up to 20 km). For example, a horizontally homogeneous atmosphere cannot be supposed for such distances. For the same reason, a height independent wind direction does not apply because sound paths can reach higher layers of the atmosphere with different wind direction. An effective discussion of the current sound propagation models that consider atmospheric influences and their restrictions can be found in [1]. The present paper reports on the development of a 3D ray-tracing model that can handle a general atmosphere and that allows to investigate the variations of levels due to local changes of atmospheric conditions.

Aku-Ray model

General idea

In particular for large range propagation, the topography will determine the behaviour of the atmosphere that in turn acts on the sound propagation. Including this interaction is beyond the scope of this investigation. Instead, the model here separates the problems of predicting the atmospheric condition from the challenge to describe the sound propagation in a three-dimensional moving media. The following chapters describe the concept of this model. Part II will discuss the numerical procedures in more detail, [2].

The state of the atmosphere

The approach relies on the assumption that the parameters of the state of the atmosphere can be reduced for sound propagation purposes to (1) the vector field of the wind, the scalar fields of (2) temperature, (3) ambient pressure and (4) humidity defined in the 3D prediction domain around the source. All fields may vary with time. Hence, the challenge to compile these fields from weather models or measurements is a second step.

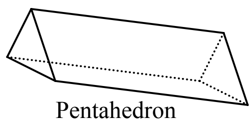
Predicted acoustical measure

It is a rather challenge to predict the sound at receiver sites in terms of the local sound pressure. Measurements of blast levels at large distances make clear that the local sound pressure is the result of often coherent superposition of sounds that travel along different paths from source to receiver, influenced by phase shifting ground reflections or cauterisation. As a consequence, the local sound pressure is strongly sensitive to small changes in receiver height, local ground properties, angle of incidence and so on. The sound energy at the receiver, instead, is not such sensitive to phase shifts and is a more appropriate measure for prediction. Therefore, the approach here focuses on the sound prediction at the receiver in terms of the sound energy or the so-called free field sound exposure that is derived from the acoustical energy, respectively.

Pentahedrons, the finite elements of propagation

In general, the model bases on the ray tracing procedure introduced by Pierce, [3]. This method calculates the propagation path of a single sound ray through an arbitrary atmosphere and is feasible to establish a numerical scheme for sound a 3D sound propagation model. Normally this ray-tracing model is used to set up a 2D particle model, describing the spreading of sound through a large number of sound particles that are released at the source and collected at the receiver sites. Part II shows that this method is not favourable for large distances in 3D. The model here uses the single rays to define finite elements to hold and propagate portions of the sound energy.

The finite element is chosen to be a pentahedron. Three adjacent sound rays constitute the edges of the pentahedron. The points of equal propagation time establish the vertices of the two triangles. The progression of the pentahedrons between the same three sound rays from the source to the receiver is called ‘aku-ray’. The basic idea of this model is that the energy in an aku-ray is conserved, only diminished by absorption in air or during ground reflection.



Pentahedron

Blast source

The blast source is supposed to be a sphere radiating sound at radial directions. To set up the starting conditions for the aku-rays, the surface of the sphere is evenly tessellated into triangles. The 3D directivity pattern of the source determines the portion of energy that is released through each triangle into the first pentahedron of the respective aku-ray.

Sound propagation

Applying the ray-tracing scheme, all aku-ray elements of the source are repeatedly propagated for appropriate time steps until they leave the given 3D domain of prediction. During propagation the triangular faces will expand reproducing the geometric spreading. In order to maintain accuracy, the aku-rays may split up into two new aku-rays if certain conditions are met.

Receiver site

A plane area of arbitrary shape and orientation defines the receiver site in this model. If an aku-ray penetrates this receiver area, a fraction of its energy, determined by the shared area of the aku-ray and the receiver area, adds up to the total sound exposure at the receiver. Due to the propagation through moving media the triangular face of the pentahedron represents to some extend the wave front, but the local energy still flows with the direction of the edges of the pentahedrons, the propagated sound rays. For each time step during the propagation procedure, the program runs a test whether or not an aku-ray element intersects with a receiver site. For a homogeneous atmosphere the model verifies the sound propagation in non-moving media.

Discussion of first results

The current model only accounts for diffraction, absorption and ground reflection over flat terrain. Refraction, scattering and hilly terrain will be included in the next stages. The 'noise maps' in fig 1 indicate the free-field receiver levels at the ground. In terms of the model, the plane surface is made up by a mesh of evenly distributed rectangular receiver sites

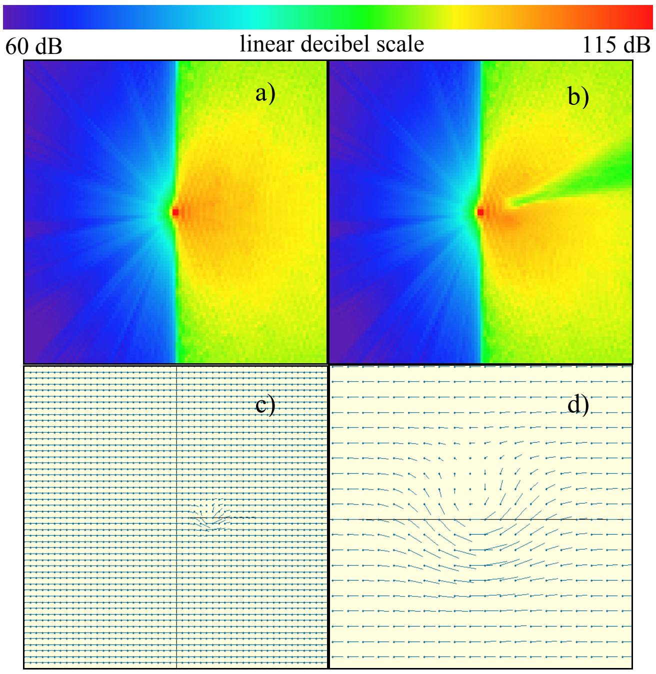


Fig. 1 Model results
resolution 100 x 100 m, area 10 km x 10 km
centred blast source, acoustical energy 10 kJ
a) Map of sound exposure level without and b) with eddy
c) Wind field with eddy, d) zoom of the wind field of c)

of 100 m x 100 m. The omni-directional blast source (10 kJ) radiates at (x = 0 m, y = 0 m, z = 3 m).
Fig. 1a shows the output in terms of the free field sound exposure level for a typical wind profile (horizontal homogeneous atmosphere). The wind blows at +x direction and increases with height according to a logarithmic approach. All y-components are set to 0. Close to the ground the wind dies out smoothly. Colours are indicating the exposure level (see scale at the top of fig. 1).
At downwind direction the map shows the expected result. Though the model uses a ray-tracing scheme, it predicts non-zero levels at upwind direction due to the finite element approach that focus on the energy between the sound rays. The prediction of the difference between upwind and downwind makes sense. The radial structure in the upwind region is a numerical artefact but the periodic structure in the downwind region is not. It depends on the height of the source above ground. This effect is also known in 2D ray tracing models.
Turbulence is not a feature in this model; however the atmosphere may have eddies. To discuss such an example, fig. 1b depicts the result for the same wind field as in fig. 1a but superimposed by an eddy at x = 1000 m, y = 0 m. The figures 1a) and 1b) show the wind field at 100 m height.
The eddy is simulated by a cylindrical air flow that is zero at the centre, increases to its maximum at a radius of 250 m and dies out again to greater radii following a Gaussian distribution. The effect of the eddy is rather impressive. The eddy generates a 'shadow zone' at a certain direction that is getting wider with distance.
During propagation the pentahedrons can change their shape dramatically. The diffraction causes cauterisation as shown in fig. 2. In 3D, this behaviour is no problem. However the various kinds of distortion needs a lot of numerical treatment and imagination to consider the geometry if this happens in conjunction with an area of a receiver site.

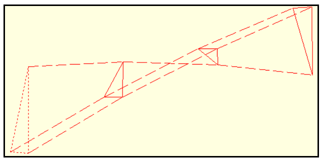


Fig. 2 Cauterisation with aku-rays

Conclusion and perspective

The presented sound propagation model at the current stage is rather promising. It predicts expected results but also yields surprising views on sound propagation in the presence of eddies. The validation of the model with respect to absolute levels will remain a challenge because the finding of realistic sets of atmospheric parameters will remain a challenge. An acoustical test campaign must focus on measuring the state of the atmosphere in a large volume around source receiver path.
However, the model allows to investigate the relative influence of many concrete aspects like the effect of eddies, of vertical wind components, of level distribution caused by randomized parameters and so on.
The next stage of the model will consider reflections at typical obstacles. In that stage the model would be applicable to some extend to the daily noise management on shooting facilities and help planners to find out a "low noise configuration" of facilities on larger training areas.

References

[1] Blumrich, R.; Heimann, D.: „Numerical estimation of atmospheric approximation effects in outdoor sound propagation modelling", Acta Acustica, 90(2004)24-37
[2] Zangers, J.; Hirsch, K.-W.: "Ray-Tracing in a 3-D Wind Field for Prediction Purposes of Shooting Noise, Part II", Fortschritte der Akustik, DAGA 04, Strasbourg
[3] Pierce, A. D., Acoustics: An Introduction to Its Physical Principles and Applications, Acoustical Society of America, Woodbury, New York, 1989, p. 371 ff.

Acknowledgement

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