Auralization of aircraft noise in an urban environment

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Summary

Aircraft noise can cause annoyance and sleep disturbance. In order to obtain a good impression of annoyance one should predict the audible aircraft sound and determine the impact of the sound on people.

The goal of this project is to develop a tool for the auralization of aircraft noise in an urban environment where reflections and shielding can play an important role.

The main research topic of the past project phase was to develop a filter to emulate the effects of atmospheric turbulence on sound propagation.

Introduction

Aircraft noise can cause annoyance and sleep disturbance. Currently, annoyance and sleep disturbance are predicted using indicators based on time-averaged sound pressure levels. To obtain a better representation of annoyance the audible aircraft sound should be predicted in order to determine the impact of the sound on people.

Figure 1: Aircraft taking off from Zurich airport.

Auralization is a technique to artificially create the aural aspects of an object or surrounding. Auralization can therefore be used to synthesize audible aircraft sounds that can be used in listening tests to determine the impact of aircraft noise on people.

Goal and methods

The goal of this project is to develop a tool for the auralization of aircraft noise in an urban environment. The tool should provide **plausible auralizations** of aircraft noise for typical urban situations where reflections and shielding can play an important role.

The project is divided into three parts:

1. Development of a sound generator to **synthesise aircraft noise** audio signals;
2. Design of a time-varying digital filter to **model sound propagation** in an urban environment for highly elevated and distant sources;
3. Development of an Ambisonics **sound reproduction** system suitable for aircraft noise.

The second part of the project is nearly finished. Work has recently begun on the first part and development of the third part will be done mostly in parallel.

Propagation model

The second part of the project deals with developing a model that describes the propagation of sound from source to receiver. The main research topic during this phase was to include the effects of atmospheric turbulence.

The propagation model currently supports:

- **spherical spreading** resulting in a decrease in sound pressure with increase in source-receiver distance;
- **Doppler shift** due to relative motion between the moving aircraft and the non-moving receiver;
- **atmospheric absorption** due to relaxation processes;
- **reflections** at the ground and façades due to a sudden change in impedance.
- **modulations and decorrelation** due to fluctuations in the effective soundspeed caused by atmospheric turbulence.

Atmospheric turbulence

When listening to aircraft fly-overs, fluctuations in the amplitude can be heard. The main cause of these fluctuations is atmospheric turbulence. Because these fluctuations or modulations can be clearly heard they have to be included in the auralizations.

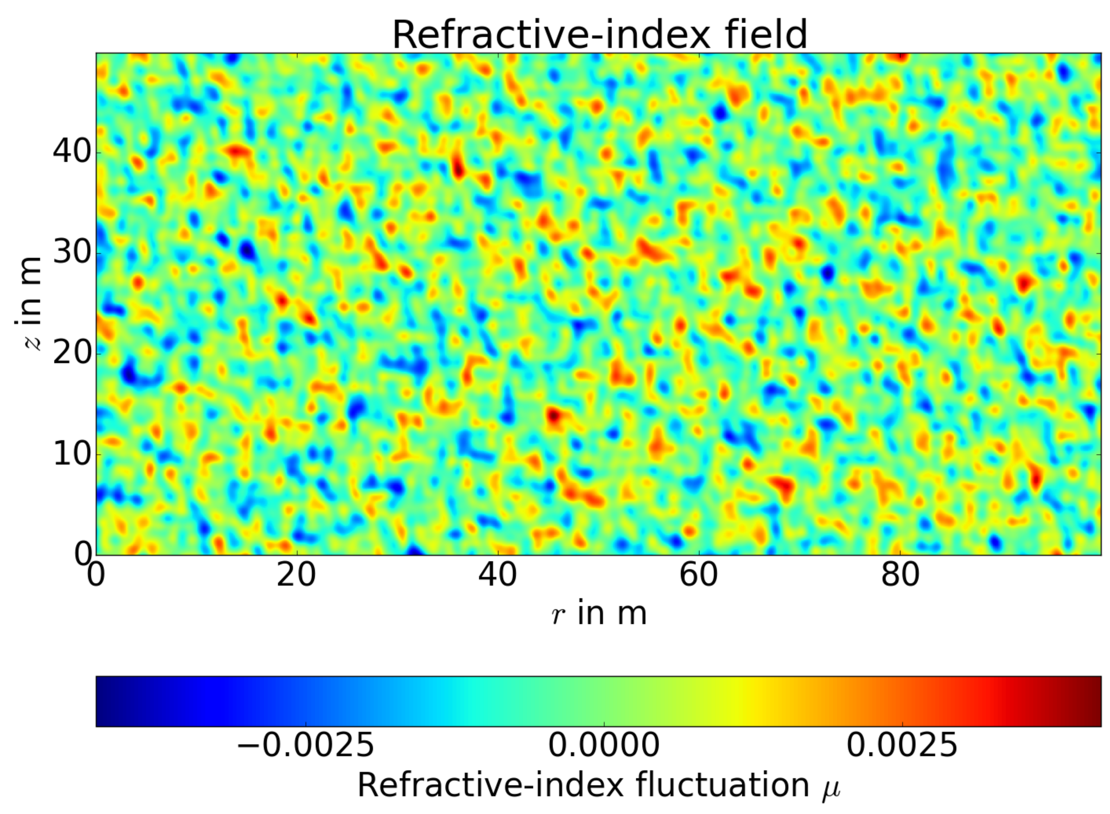

Figure 2: The refractive-index as function of position. This field is generated using a statistical description of atmospheric turbulence.

The theory of turbulence is a statistical theory. In models of atmospheric sound propagation, the turbulent atmosphere is usually described as a medium with a randomly fluctuating effective sound speed or refractive-index as illustrated in figure 2.

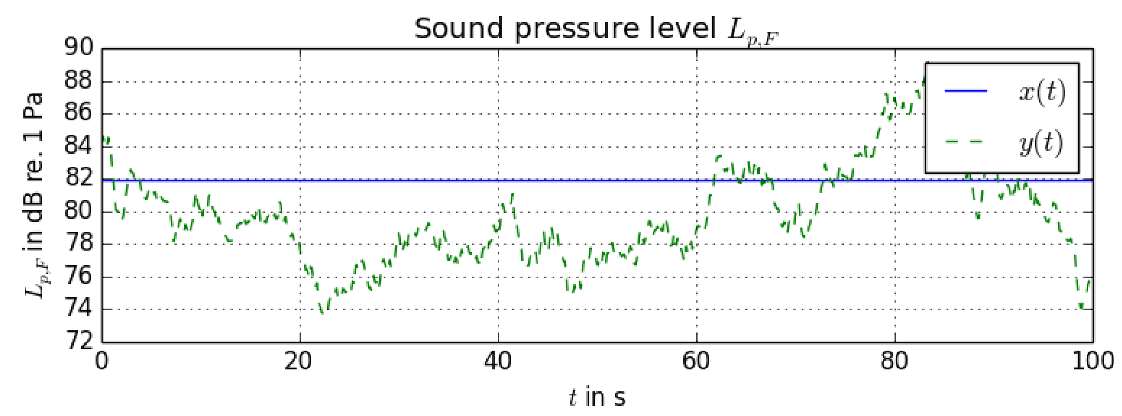

Figure 3: Signal with and without modulations.

Turbulence causes besides the clearly audible amplitude modulations also phase modulations. While we're not sensitive enough to hear these phase modulations directly, the fluctuations cause decorrelation between direct and reflected sound resulting in a less pronounced interference pattern which is audible.

Model and results

A new method was developed that allows including frequency-dependent amplitude and phase fluctuations or modulations by calculating time series of each.

Central to the method is the covariance function which is related to the mutual coherence function. The covariance function and autospectrum are Fourier transform pairs. Therefore, by calculating the covariance a spatial impulse response can be obtained. The convolution of the impulse response with series of random numbers results in time series of fluctuations.

Figure 3 shows an example of modulations applied to a single tone. Fast and slow fluctuations can be seen.

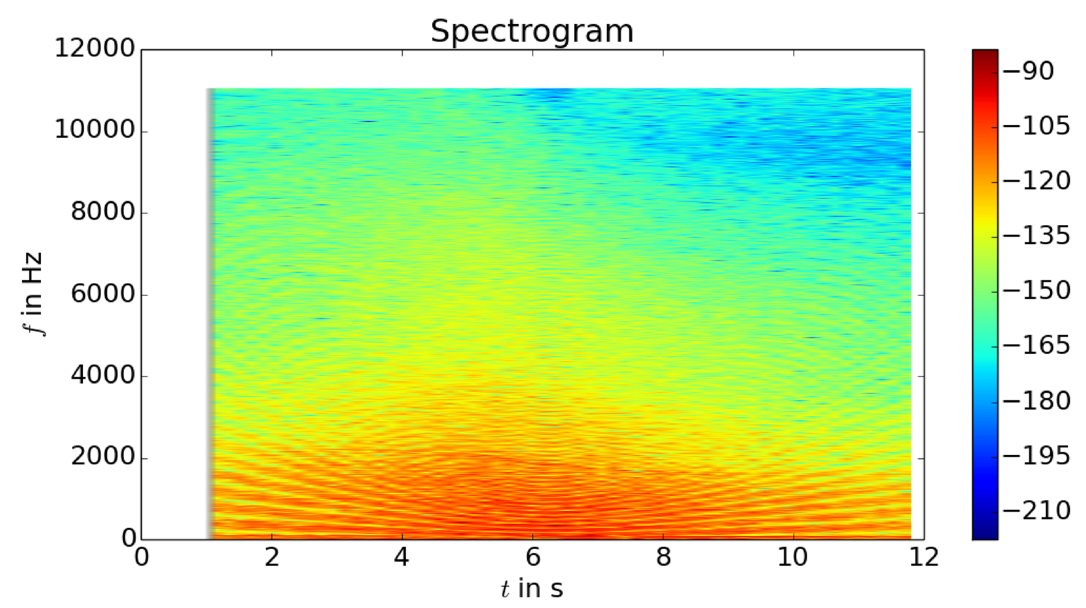

Figure 4: Spectrogram of aircraft auralization showing time on horizontal scale and frequency on vertical scale. The color represents the sound pressure level.

The model was developed in order to add the fluctuations to aircraft auralizations. Figure 4 shows an auralization of a fly-over without fluctuations. The Doppler shift and mirror effect are clearly visible. In figure 5 amplitude and phase modulations were added.

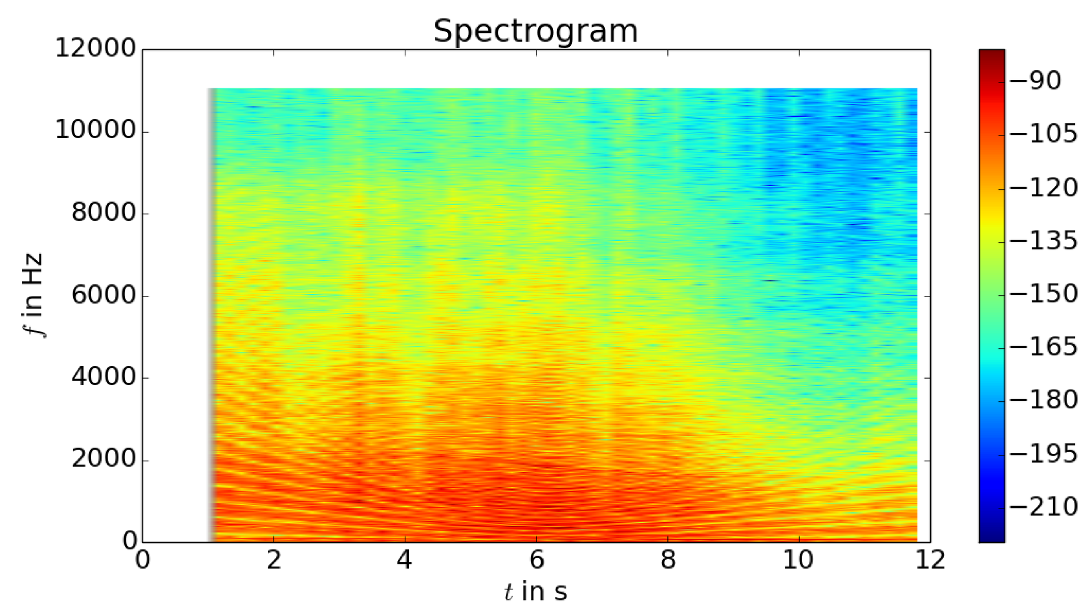

Figure 5: Another spectrogram but now including the effects of turbulence.

In the near future the model will be validated by comparing the level fluctuations with those from recordings.

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