Acoustic Projects

Andreas Holmberg[1] — *anholmbe@kth.se*

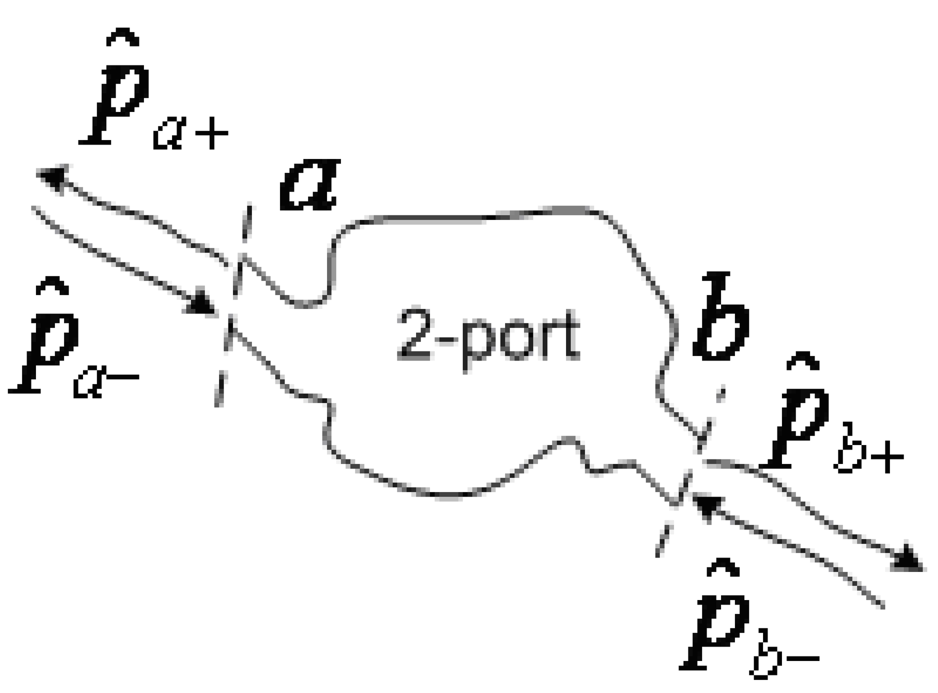
Karl Bolin[2] — *kbolin@kth.se*

Linné Flow Centre
The Marcus Wallenberg Laboratory

Characterization of flow generated sound in ducts[1]

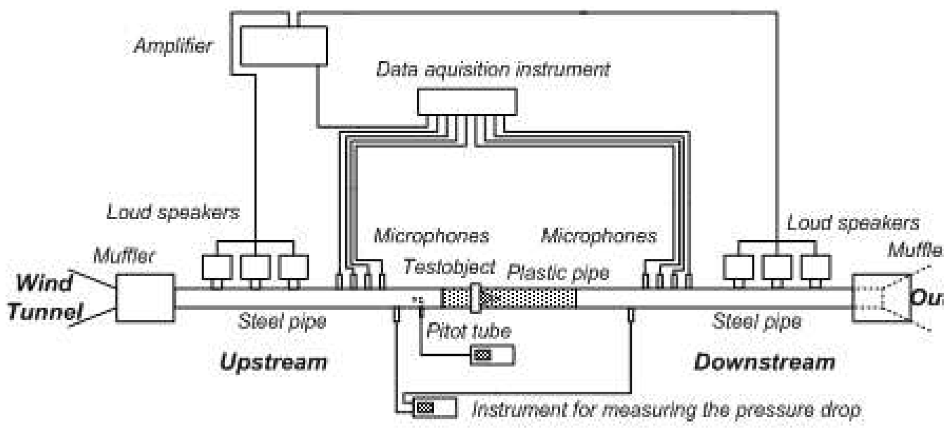
The focus of the project is to further develop the experimental methods of determining the characteristics of sound generation, propagation and dissipation in a flow. A generic problem of interest is the sound generation from localized flow separation, e.g. occurring when a triangular plate is placed in a flow. One application of such a plate is to function as a vortex mixer of gas particles during the purification process of diesel exhaust gases. Since it will be fitted in a vehicle, apart from the mixing properties, the effects on the sound field in the exhaust pipe are of importance.
For low Mach-number flows in a straight duct, it is often sufficient to consider the plane wave frequency region, i.e. frequencies below the cut-on of the first higher order mode of the duct cross section. The acoustic flow field will then be one-dimensional, and can be described as a superposition of two waves propagating in opposite directions. Complex geometry or different source mechanisms on the other hand are not one-dimensional. They can however be represented by an acoustic two-port element, where the incoming and outgoing pressure waves on both sides are all related by a scattering matrix plus a vector containing outgoing pressure waves generated inside the two-port element.

$$\begin{pmatrix} \hat{p_{a+}} \\ \hat{p_{b+}} \end{pmatrix} = \begin{bmatrix} \rho_a & \tau_{ba} \\ \tau_{ab} & \rho_b \end{bmatrix} \cdot \begin{pmatrix} \hat{p_{a-}} \\ \hat{p_{b-}} \end{pmatrix} + \begin{pmatrix} \hat{p_a^s} \\ \hat{p_b^s} \end{pmatrix}$$



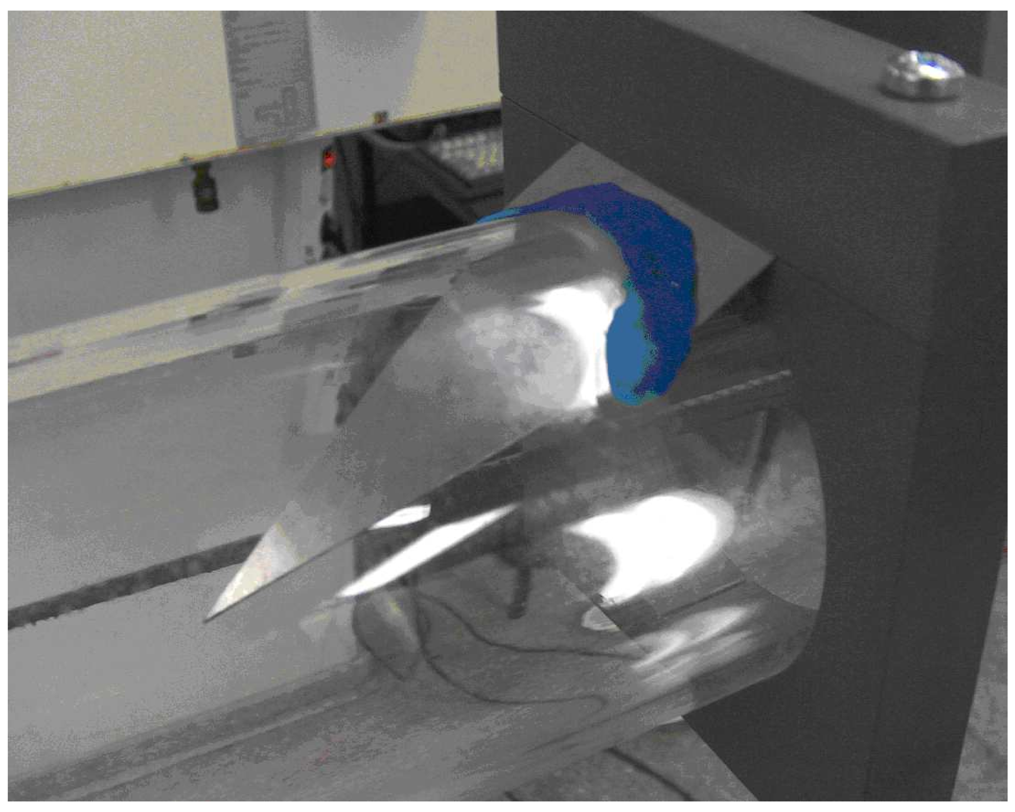
Experimental methods[1]

The measurements are carried out in two steps: first the scattering matrix is measured by calculating the transmission and reflection of sound generated by loud speakers, mounted in the duct. Since the input signal to the loud speakers is known, the measured sound can be separated from any flow noise not correlated with this signal. The pressure amplitudes of the propagating waves in the up- and downstream direction can be resolved from measured pressures at two different cross sections, using the theory of wave decomposition. If more than two different microphones are used at each side of the two-port element, an over determined system of equations is obtained, from which the pressure amplitudes and the wave numbers can be determined. Second the sound in the duct is measured without any loud speakers, and using the now determined scattering matrix the effects of reflection and transmission can be accounted for. In order to suppress turbulence flow noise at the microphones, the fact that the turbulent flow field is uncorrelated at two different cross sections is used.



Experimental setup[1]

The test rig is connected to the subsonic wind tunnel at The Marcus Wallenberg Laboratory. The duct consists of two circular steel pipes connected with the measurement section, which is constructed by a plastic transparent pipe, allowing for optical measurement methods, e.g. the PIV laser method.
The measurement section can be interchanged by using an empty pipe for reference measurements, or by using a pipe with a slit in it enabling the mounting of the test plate.

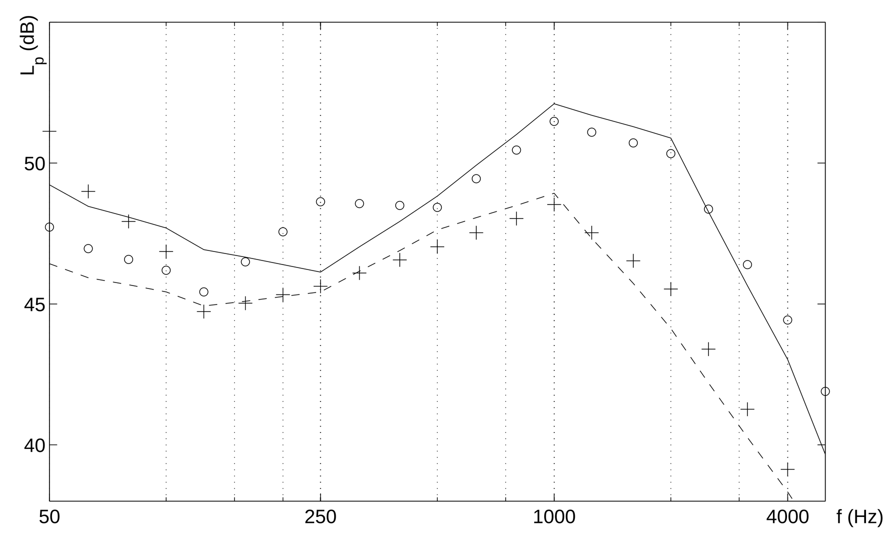


Masking of wind turbine noise[2]

In the light of global warming and the increased need for renewable power sources Sweden's installed wind turbine capacity will be increased from today's 1 TWh annually to 20 TWh annually by 2020. This is equal to 16% of Sweden's electrical energy consumption in 2004. Although emissions of greenhouse gases from wind turbines are lower compared to other power sources wind turbines are disturbing to nearby residents, for instance, emitting noise and disrupting the view. Wind turbines are situated mainly in rural and recreational areas where benign soundscapes are a key aspect of a good living environment. The introduction of large scale wind turbine farms into these locations could lead to deteriorating living conditions for nearby residents. However, noise from wind turbines can be made inaudible by other sound sources, this phenomena is called masking. Presently the Swedish Environmental Impact Assessments do not take this into account when analyzing noise disturbance from wind turbines. The main sources of natural background noise in rural and recreational areas arise from wind blowing through the vegetation and sound from the sea in coastal areas. Consequently, sound from vegetation and the sea should be modeled and the effect of these sources on wind turbine noise should be evaluated to better estimate the annoyance of wind turbines on nearby residents.

Ambient noise models[2]

The increased hub heights of wind turbines have resulted in an interest to develop wind farms in forested areas. The rustling of the leaves and the swooshing of coniferous trees are, as wind turbine noise, depending on the wind velocity. Earlier work at KTH has produced a semi-empiric vegetation noise model. This has now been coupled to turbulent wind field simulations and consequently fluctuations of vegetation noise can be estimated. These variations are vital for the masking issue as at periods with low background sound level the wind turbine could be audible.
Sound from breaking waves are among the most calming and gentle known to mankind. This natural sound source could mask wind turbine noise from off-shore wind turbines and wind turbines in coastal areas. The sound level from the shoreline is depending on the wave height and consequently has lower correlation to wind turbine sound level than sound from vegetation. However the high sound levels from the sea should mask wind turbine noise in many circumstances. Measurements on several locations along the Swedish coastline have been performed. These show that the sound pressure is proportional to the wave's energy. A model for sea wave noise is currently developed at MWL.
The figure below shows measurements and predictions of coniferous tree sound at two different wind speeds. As can be seen the spectrum changes with wind speed, this is due to flow separation around the needles producing aeroacoustic dipole sources.



Audibility and Annoyance[2]

When examining the impact of wind turbine noise on nearby residents. Two main questions should be asked: Firstly, when is wind turbine noise audible and secondly when is it annoying. These two questions are not necessarily the same. The audibility is depending on the auditory system of the subject but the annoyance is coupled to several psychological parameters such as noise sensitivity, tiredness, mood etc. and therefore not as easily quantified as the audibility.
The hearing threshold of wind turbine noise in several different background noise environments have been determined in psychoacoustical experiments and compared to different loudness models. The tests are performed inside the anechoic room at MWL using a 2AFC procedure in order to reduce anticipation and habituation biases. Test results show higher S/N-ratios than expected from the models. These deviations are probably due to additional informational masking.
Psychoacoustic annoyance tests of wind turbine noise are relatively difficult to perform due to two parameters; firstly the annoyance is mainly caused by long time exposure not easily reproduced in a controlled acoustic environment. Secondly the sound levels of wind turbine noise are generally low compared to other noise sources and therefore large variations between different subjects are common. The most appropriate method for annoyance tests are magnitude estimation tests. These can also investigate the connection between loudness and annoyance.

Acknowledgments

The financial support from the Swedish Research Council via Linné Flow Centre[1] and the Swedish Energy Agency[2] are gratefully acknowledged.