GEORG-SIMON-OHM
HOCHSCHULE NÜRNBERG

Faculty of Applied Physics and Mathematics

(Fakultät AMP)

Effect of wind on propagation on sound wave in highway

Projectwork by:

Rohit Upreti

Matrikelnummer: 3556227

Submitted to:

Prof. Dr. Jan Lohbreier

CONTENTS

1. Introduction

The project “Effect of wind on propagation of sound wave in highway “is the continuation of the work by Christian Luger and Daniel Gundel under the title “ANALYSE DER SCHALLAUSBREITNG EINER AUTOBAHN MIT UND OHNE SCHALLSCHUTZWAND “.

Under my predecessors, the propagation of the sound wave was measured under different frequency spectrum (details under “Theory and Model Structure”) and the Sound Pressure Level (dB) were measured. Then, the propagated sound wave was subjected to a sound protective barrier (Schallschutzwand) with varying height and width and the Intensity of sound was measured at various point.

Under this continuation work, a new parameter is introduced “Wind” and the sound intensity relative to wind is studied. The simulating condition, initial parameters and initial domains form the original simulation are approximately same.

The main emphasis of this project is the tangible simulation of the propagation of the wave under the suitable turbulence model and most important, bringing the two COMSOL model together.

1.1. Theory and Model Structure.

Since the model uses multiple physics and multiple study. First let us define the domains that are being used in the simulation. The first physics used in this model is Acoustic pressure frequency domain and the second domain used is Turbulence model. The acpr domain is used here to calculate the sound pressure level before and after the turbulence used. And Turbulence model is used for simulating wind effects and eventually pressure change. Below is short description of the domains.

1.2 Acoustic pressure frequency domain:

Sound emitted from the highway consists of different frequencies spectrum. In general, this sound consists of frequencies in the range of 400 Hz to 1100 Hz. In some literature, the maximum frequency is stated as high as 1300 Hz as well. Here in this work, the range is in between 400 Hz – 1100 Hz.

Now that the frequency spectrum has been defined, next task is to define a source which emits these frequencies. In this simulation, a point source is defined with a power of 0.63096 W/m. The Impedance of the ground here is taken to be 7,000,000 $kg/m{\cdot}s^2$. The material used in the simulation is air with Density 1.25 kg/m^3 and the velocity of sound in air is taken to be 343 m/s.

With following expression defined in the acpr domain, we can need to define an expression for the sound pressure level. Taking the source (point) for the highway as a line source is much more feasible, since the sound source is being emitted from a particular length from the highway and thus a line source rather than a point source.

The expression for the Sound pressure level at a point from the source is given by [1]:

$$Lp = Lw - 10.log_{10}\left(\frac{r}{1m}\right) - 5 - 10.log_{10}\left(\frac{L}{1m}\right)\ dB$$

Where, Lp is the measured sound pressure level at L distance from source and

Lw is the power level of the source.

1.3 Turbulence Model:

Turbulence is a non-linear complex motion of fluid which usually involves of rotational, disordered and dissipative motion all at once. A direct simulation of turbulence is complicated because it involves dissipation and momentum exchanged by small-scale fluctuations. But at high Reynolds number (> 3500), the turbulent motion can be approximated.

Therefore, it can be said that turbulence is rather a local property of the fluid which is described by the eddy viscosity. The main equation while solving a turbulence problem involves solving the Navier-stokes equation. Based on the nature of turbulence problem, certain changes with only certain variables are made in the Navier-stokes equation. One of the reduced Navier-stokes equation is used in this simulation called K-epsilon (K-ε) model.

K-epsilon as a turbulence model: The K-epsilon model belongs to the member of the RANS. This is a two-equation model in which transport equations are solved for the turbulent kinetic energy (k) and its dissipation rate (ε) and hence the name K-epsilon model.

K-epsilon model is used for this simulation because of its small computational time, its convergence plot and its adverse pressure gradient. And most importantly, it's independence on the initial condition, which makes it an easier model to work with.

The equation used for this model in the simulation are [2]:

1) For eddy viscosity: $\nu_t = \rho . c_{\mu} \frac{k^2}{\varepsilon}$

2) For Turbulent kinetic energy (k):

$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial x_j} = \frac{\mu_t}{\rho} s^2 - \epsilon + \frac{\partial}{\partial x_j} [\frac{1}{\rho} (\mu + \frac{\mu_t}{\sigma_k}) \frac{\partial k}{\partial xj}]$$

3) For dissipation rate (ε) :

$$\frac{\partial \epsilon}{\partial t} + U_j \frac{\partial \epsilon}{\partial x_j} = (C_1 \epsilon \frac{\mu_t}{\rho} s^2 - C_{2\epsilon}) + \frac{\partial}{\partial x_j} [\frac{1}{\rho} (\mu + \frac{\mu_t}{\sigma_\epsilon}) \frac{\partial \epsilon}{\partial xj}]$$

Where the empirical constants have following values:

$C\mu = 0.09$

$C_1 = 1.44$

$c_2 = 1.92$

Above mentioned formula is used in the simulation for the K-epsilon model.

1.4 Model structure:

Figure 1: Simulation area.

Here is the representation of the geometry used in the simulation. In order to recreate the highway condition, a rectangular box of length 50 m and width 16 m is taken. A point source of 0.63096 W/m is placed at 4 m from the wall. Within the acpr domain, Sound hard boundary wall is taken as the boundary condition and to attenuate the sound waves, perfectly matched layer is also taken as a boundary condition to attenuate the sound wave at boundries. The sound protective wall is here taken as 4 m high and 2m wide, it's wall is also taken as Sound hard boundary wall.

Since each domain uses the same geometry, no additional changes are needed in geometry. In the previous work "ANALYSE DER SCHALLAUSBREITNG EINER AUTOBAHN MIT UND OHNE SCHALLSCHUTZWAND ", the length of the simulation room was 150 m and width were 50 m. A parametric sweep of frequencies between 400 Hz to 1100 Hz was made so that the interference between the frequencies could be avoided, and the sound pressure level was measured at different points. Then, variables "Height of the wall" and "Width of the wall" were defined and with join function, then the variation between these variables and sound pressure level were measured. Free triangular mesh is used for the acpr domain, with maximum element size of 0.48/5 and minimum element size of 0.48/19. Meshing is of high importance when doing a simulation, the size of the model depends on the element size, degree of freedom etc. For the optimal mesh size, there is an option "Statistic" under the mesh tab, and it calculates the optimal mesh size for the model.

After the acpr domain, a new physics is added in the domain "K-epsilon as turbulence model". Physics controlled mesh for fluid dynamics is used for this domain and mesh size is taken as extra fine.

The first part of the simulation is to take the mean intensity of the frequencies. Here, frequencies between 400-1100 Hz are taken in 50 Hz interval. Then the frequencies are made to interfere at certain height from the ground and the mean intensities is taken. This measured intensity is the reference intensity which needs to be compared. The second and the most important part of the simulation is to couple the two domains together. While coupling the domains together, dependent variables needs to be taken into consideration. In this simulation, pressure appears in each domain. And thus, pressure is the dependent variable in this simulation. Now, the task is to link the pressure in a way so that there would be some intensity change after the wind simulation. Here, this is done in two study steps. First study step "Study 1" is turbulence model. The idea is to simulate the turbulence with some initial velocity so that it results some changes in the pressure. Then the changed pressure as dependent variable in linked in the acpr domain which is taken as "Study 2". Then the same frequencies are made to interfere at the same points and some changes is intensity is then expected.

2. Simulation and Results:

Ideally, both part of the simulation would yield better results with parametric sweep for frequencies 400 -1100 Hz. Then every frequency is overlapped and mean of the interfered region is yield. Because of high computational time and computational space, this interference is done manually. Below is an example of a simulation of 700 Hz frequency.

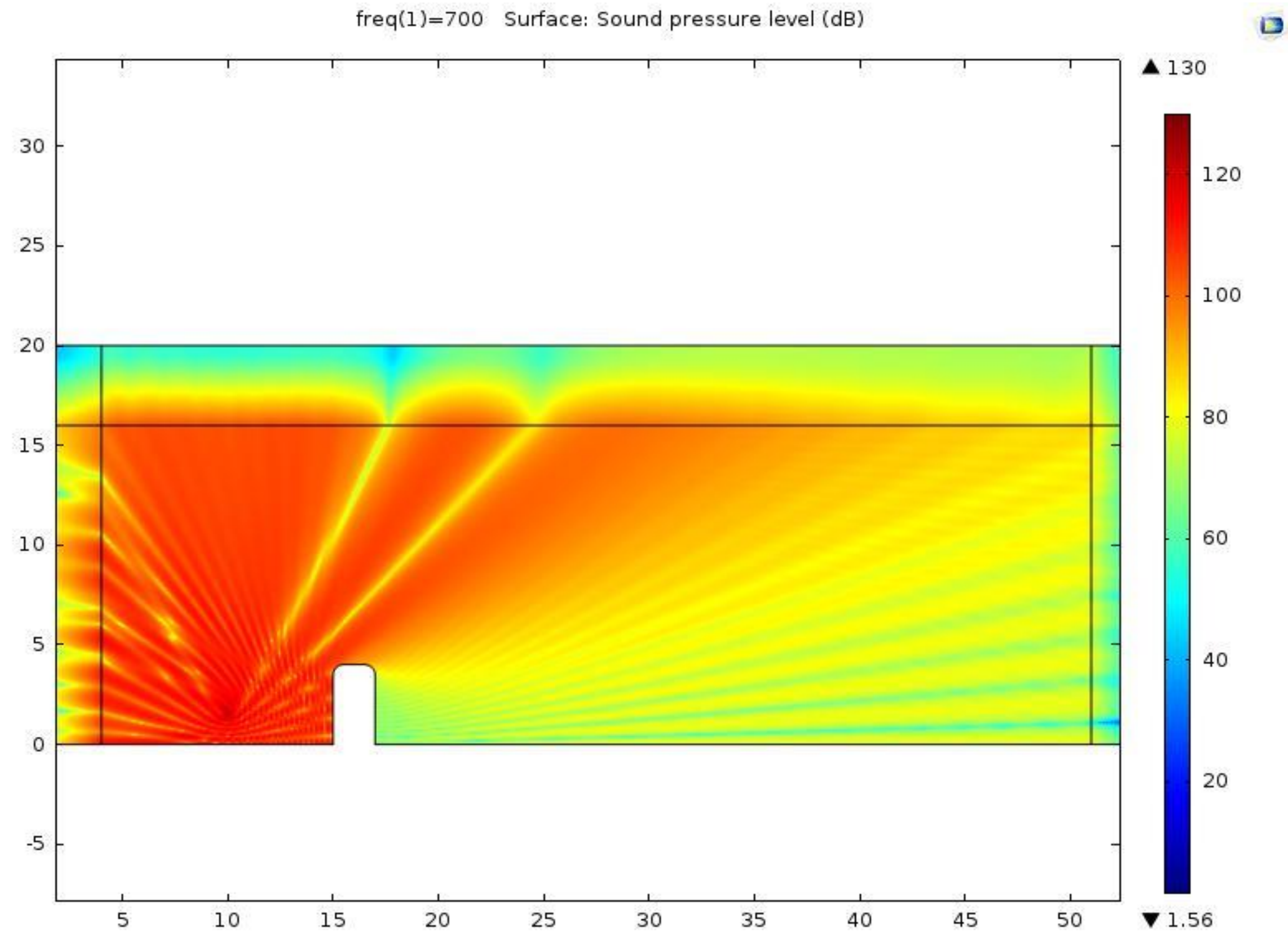


Figure 2: Frequency spectrum of 700 Hz.

Here in the figure, more of the intensity is reflected by the wall. As the distance increases along X-direction there are some interference pattern. In order to minimize this interference pattern, different frequencies are simulated, and the mean intensity is measured and plotted.

The simulation steps here is done in multiple steps:

1. In the first step of the simulation, frequencies between 400 – 1100 Hz in the interval of the 50 Hz is simulated. Then the sound pressure level at 2, 3, 5, 7 m from 40 m and 50 m is measured. Here, every frequency at the following points is interfered and the mean intensity is then measured.

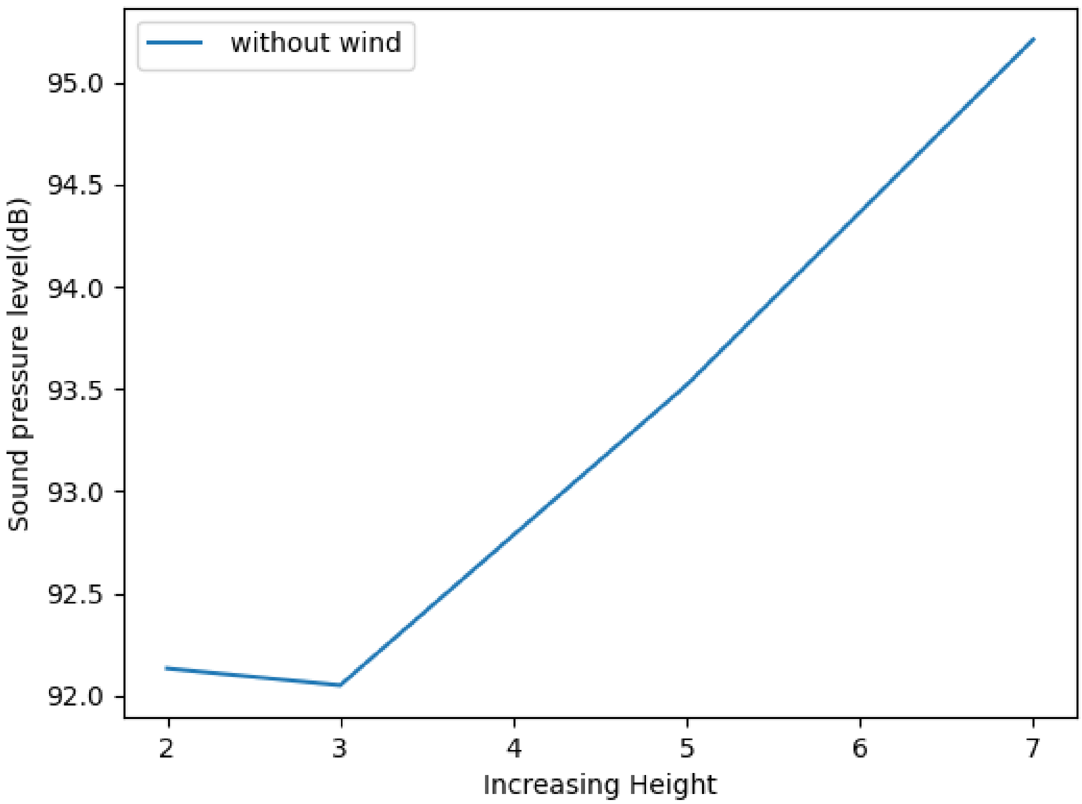


Fig 3: Mean sound intensity between 400 Hz -1100 Hz at 40 m.

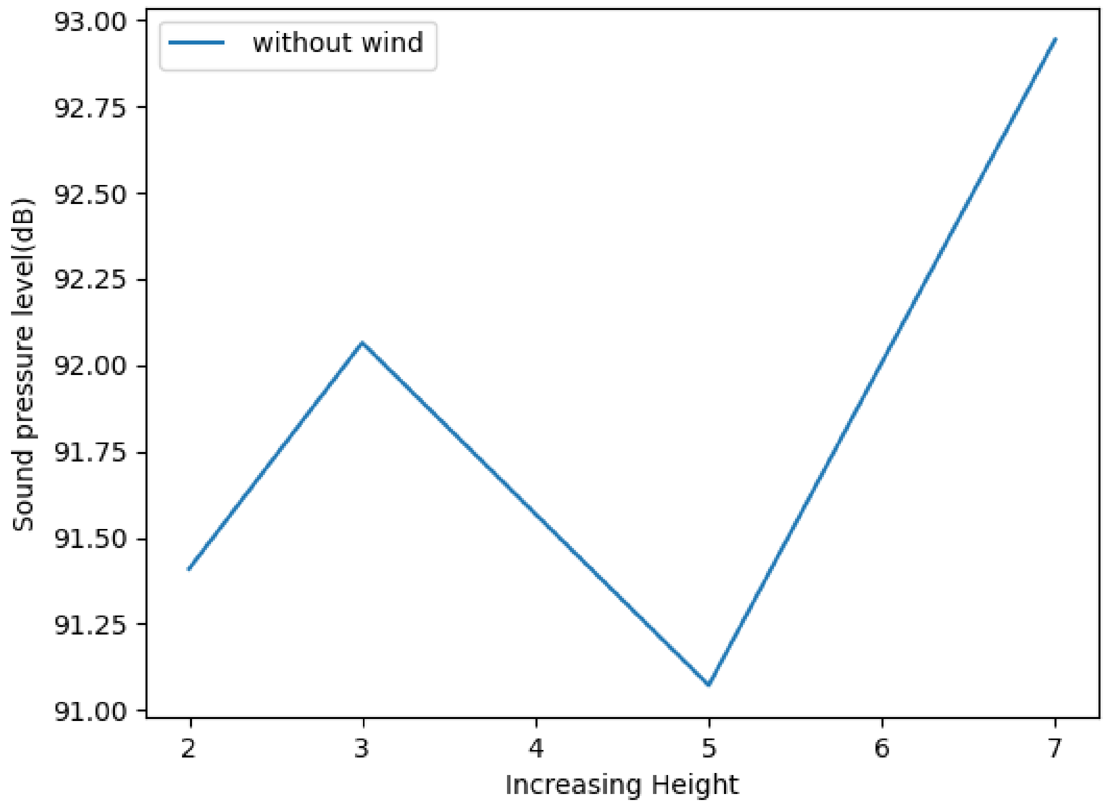


Figure 4: Mean intensity between 400 Hz – 1100 Hz from 50 m

2. The second part of the simulation is done after coupling the two model together. This is the most crucial and important part of the simulation as expected change depends on this simulation and the velocity needs to be changed at every step and the pressure contour needs to be examined. Then observed intensity is then compared with the intensity without wind. There, was so significant change in intensity when the wind is blowing normally, neither at low velocity nor high.

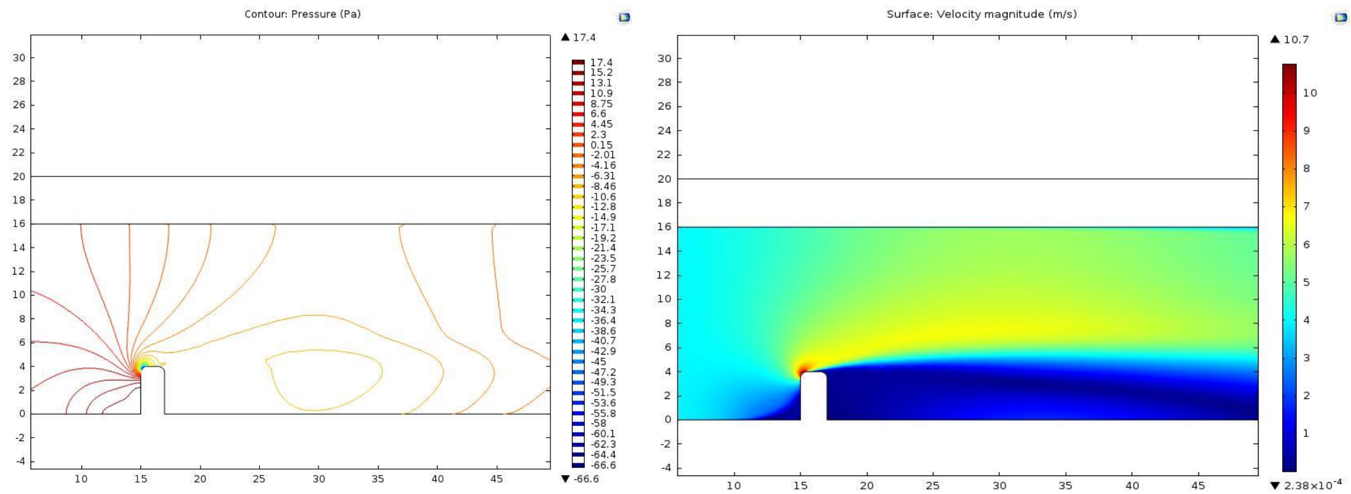


Figure 5: Pressure contour and normal velocity profile at 4 m/s.

Change in intensity is directly proportional to the pressure change, and in the pressure contour for 4 m/s and higher, there was no significant intensity change observed. However, upon changing the angle there was some intensity change observed. There were some noteworthy intensities change at an angle of 8.08˚ and 12.04˚ at 7.07 m/s and 8.18 m/s respectively.

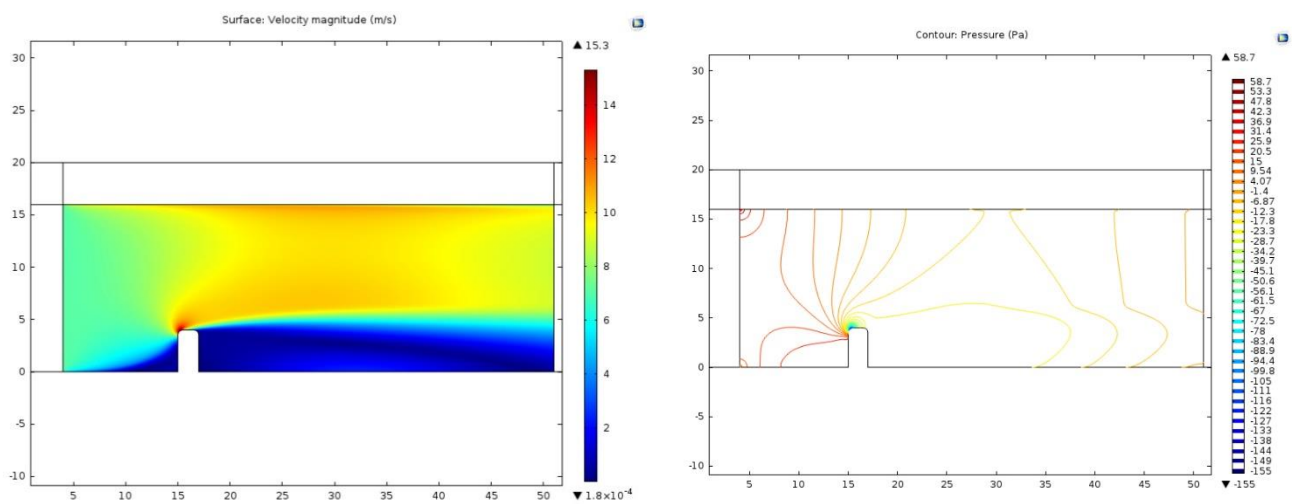
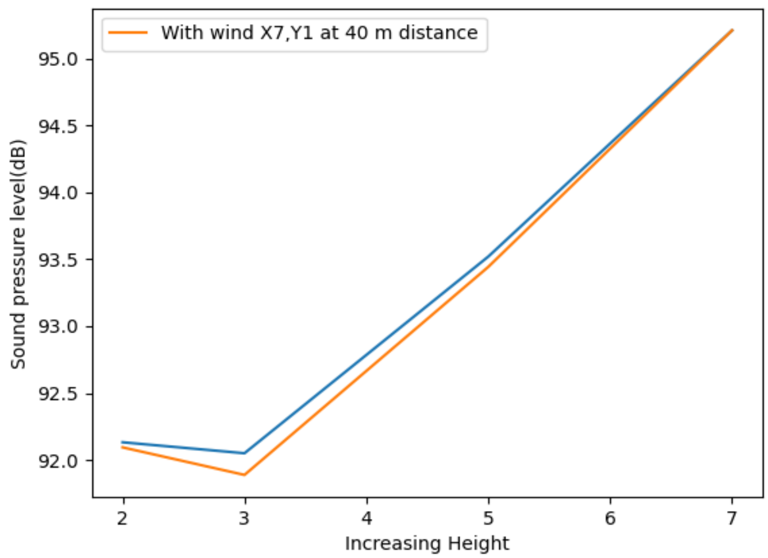


Figure 6: Velocity and pressure contour for 7.07 m/s at 8.08˚ angle.

In the pressure contour there is a significant pressure change at ca 2-3 m from ground. So, some intensity change is ought to be expected in this region at 40 m and 50 m.



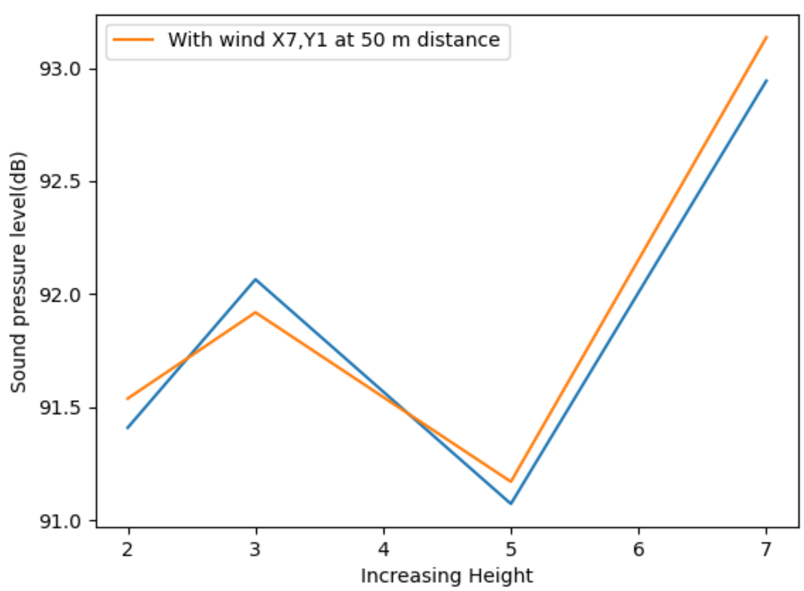


Figure 7: change in intensity at 40 m and 50 m at increasing height from ground.

Similarly, another change in intensity in was is observed in 8.18 m/s at 12.04˚.

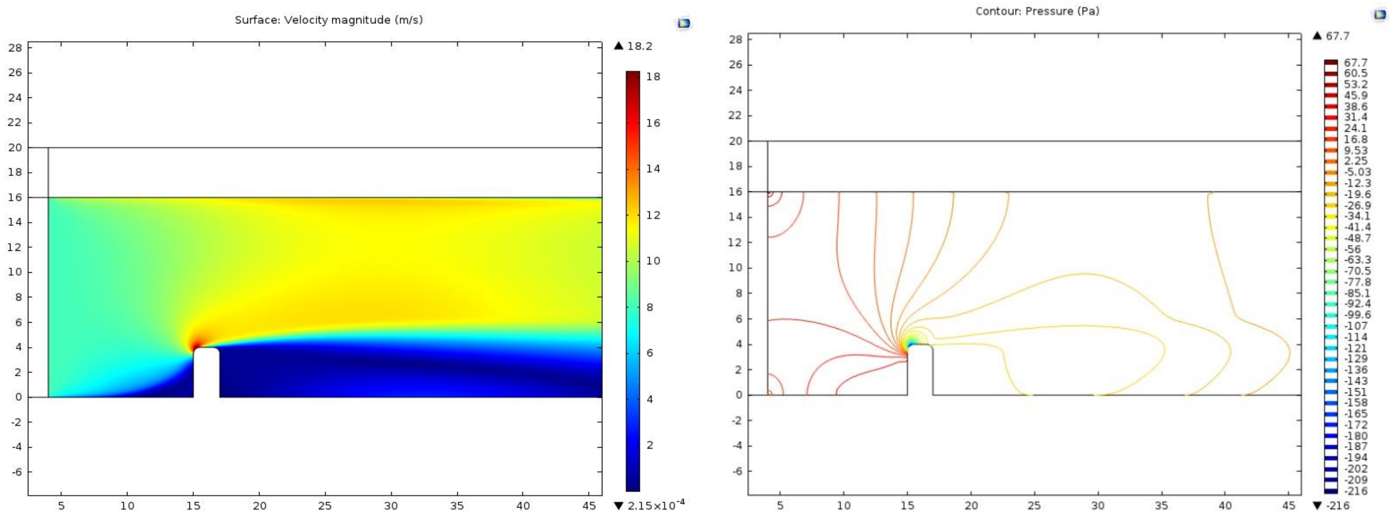
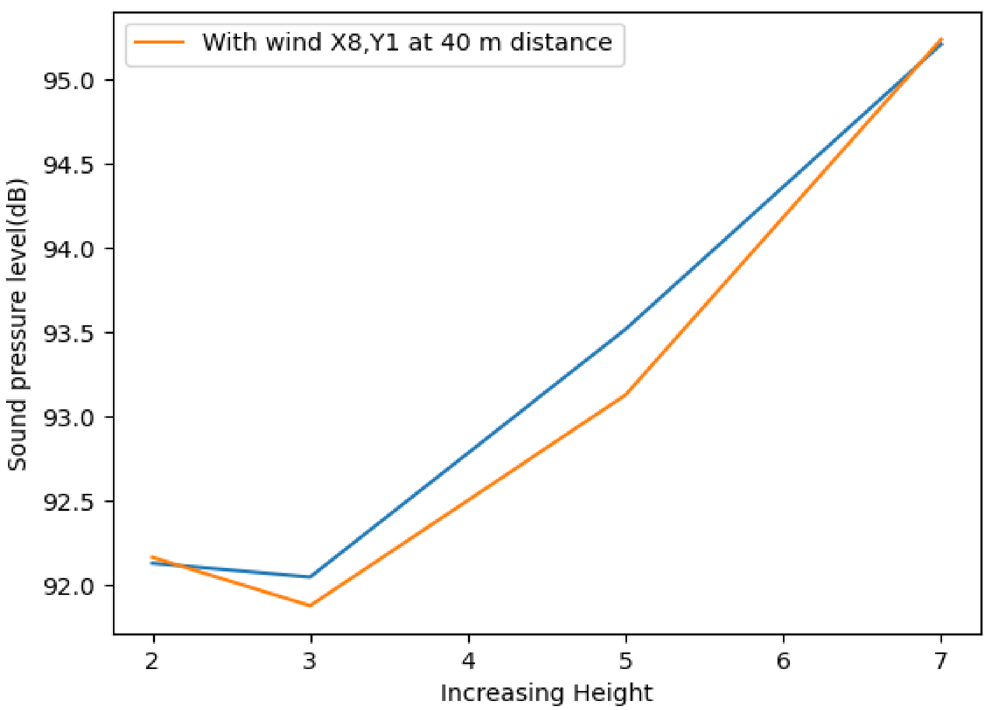


Figure 8: velocity and pressure contour for 8.18 m/s at 12.04˚.



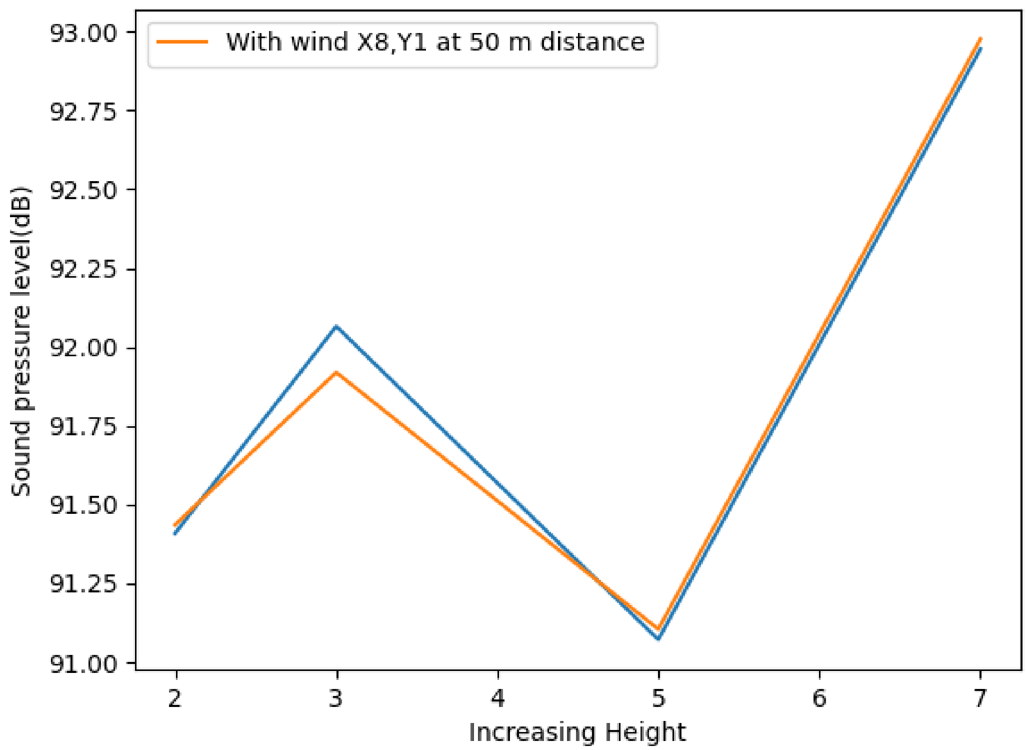


Figure 9: change in intensity at 8.18 m/s at 12.04˚.

3. Summary

Underthis simulation work, a relationship between wave propagation and wind is established. This is done by using multiple physics from COMSOL Multiphysics simulation software. Multiple physics are used in this simulation “Acoustic pressure frequency domain” and “Turbulence Model”. Under Turbulence model, K-epsilon model is selected. Because of the convergence, small model size and advert pressure gradient, this model is selected.

After defining the geometry, material and sound source the simulation is done. Avoiding parametric sweep, first step of the simulation is done. First frequencies are made to interfere at certain points and average intensity at this point are taken. These average intensities are then taken as reference point after the wind simulation.

In the second step of the simulation, the two model are combined. Which is the main objective of the simulation. This is done by taking dependent variable from one model to another model. Then the second step of the simulation is done. Here wind of different velocities and at different angles are simulated and the mean intensities and some changes in the intensities were observed. It is seen that normal wind flow doesn’t have a significant intensity change but depends on the angle of flow. In this simulation it is observed around 8˚ to 12˚.The intensities decreased at the region where the pressure change is appeared to be low after turbulence. However, at the long distance the sound intensities increase because of the multiple refraction with the ground [3].

In the summary, it is observed that in the short distance, the intensity decreased and especially around 2-3 m from the ground and it remains unchanged above 5m. Wind certainly have an impact on the wave propagation. It is also observed that low frequencies interact more and loses energy and higher energies frequency can travel farther and interfere again resulting in little louder sound than before.

References.

[1] Sound pressure level expression from the previous project work Christian luger and Daniel gundel.

[2] https://web.stanford.edu/class/me469b/handouts/turbulence.pdf

[3] https://www.sciencedirect.com/science/article/pii/S0360132318307327