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EXPLICA

Exhaust Pipe noise radiation Modelling by Innovative Computational Aeroacoustics

As outlined in the Strategy Paper Research for a Quieter Europe in 2020, significant research investments are needed to further reduce the road traffic noise in Europe. A major contributor to the noise, especially in urban environments, is the vehicle exhaust system. The radiation of the generated sound to the environment is mainly originating from the tailpipe end of the exhaust pipe. The exhaust jet flow has a temperature higher than the ambient temperature. The non-uniform mean flow and temperature of the exhaust jet as well as the surrounding geometry, i.e. ground surface and automotive body, influence the noise radiated to the environment, yet to what extent is so far an both open question as it has not systematically been studied by numerical methods.

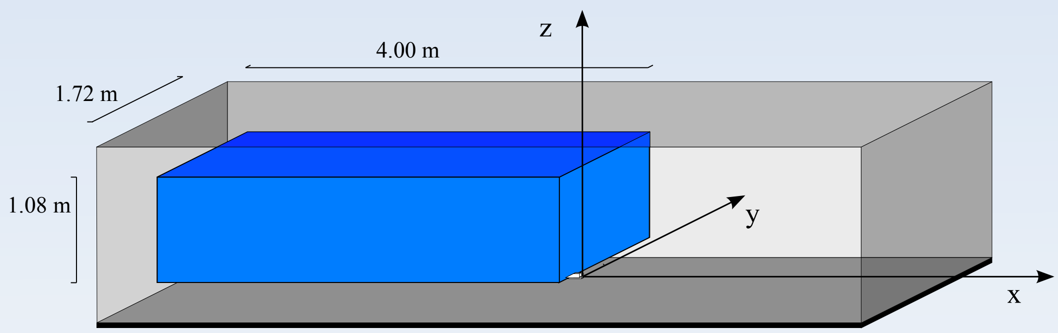


Figure 1. Configuration of an exhaust pipe (orifice located at the origin of the coordinate system) in the presence of a rigid ground surface and simplified automotive body. Computational boundaries are shown.

The EXPLICA project has two main objectives:
1. Development of a Fourier pseudospectral (FPS) numerical code to predict noise propagation in the exhaust pipe and radiation from its termination including the effects of exhaust jet flow and surrounding geometry, as illustrated in Figure 1. This method will reduce the computation times compared to the state-of-the-art methods.
2. Investigation of the effects of the non-uniform mean flow and temperature of the exhaust jet as well as the geometry surrounding the exhaust pipe on the radiated exhaust pipe noise.

The equations governing sound radiation from the exhaust pipe as in the configuration of Figure 1 are the linearized Euler equations (LEE). The non-uniform mean flow and temperature fields that arise in the LEE are solved separately by the Reynolds Averaged Navier-Stokes (RANS) equations prior to solving the LEE. The mean flow and temperature fields do refract the radiated sound waves. Also, acoustical energy is converted into vortices, which is also captured by the LEE.

The Discontinuous Galerkin (DG) method is a state-of-the-art method to solve the LEE developed at the host institute and has further been adapted in EXPLICA to solve the LEE for the problem of Figure 1. The method is time consuming and has been used for validation of the developed FPS method.

A previous FPS method has been further developed in EXPLICA and applied to solve the LEE for the problem of Figure 1. The FPS method has been validated for simpler cases by analytical results.

The capabilities of the FPS have been expanded by a multi-domain methodology, with a coarse grid covering the complete spatial domain and fine grids acting as a subgrid resolution of the coarse grid near local fine scale effect, see Figure 2. This multi-domain methodology does not introduce significant errors compared to the single-domain method and leads to a large speed-up compared to the single-domain methodology.

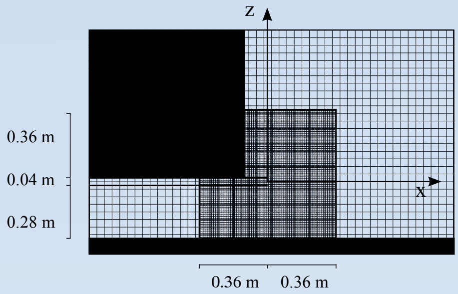
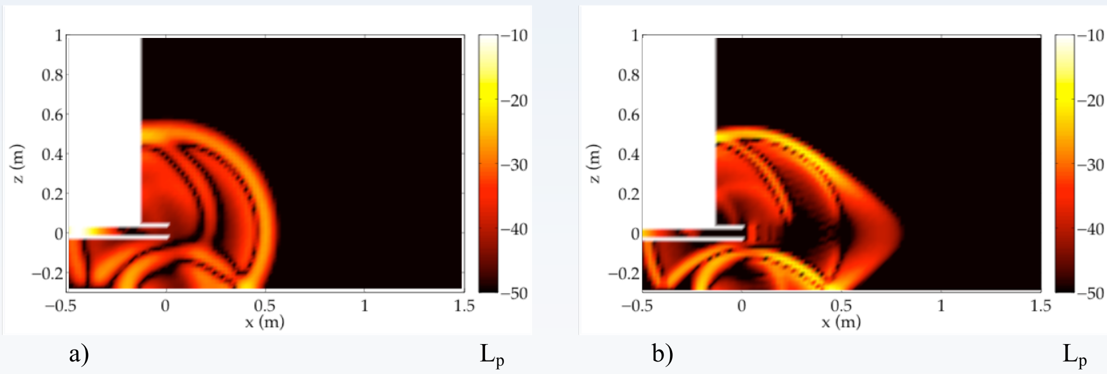


Figure 2. Cross section of Figure 1 at $y = 0$ discretized with coarse and fine grids according to the multi-domain FPS method.

The developed multi-domain FPS method has been applied to the geometry of Figure 1 to study the influence of surroundings and jet flow properties on the radiated sound field for 1/3-octave bands up to 2500 Hz. From the results it can be concluded that

- The presence of a rigid ground surface and simplified automotive body is shown to increase the radiated sound power by 6 dB for the lower frequency region compared to the exhaust pipe in free field;
- The automotive body causes a stronger shielding for the higher frequencies;
- Flow effects slightly increase the shielding effect of the body for all frequencies, but have a main impact behind the exhaust pipe, where low frequencies experience higher levels and a cone of low sound levels characterizes the high frequencies.

Figures 3 show a snapshot of the radiated sound in the absence and presence of a hot exhaust jet. It shows the refractive effects due to the jet and reflections from the surroundings. Figure 4 shows the directivity of the radiated noise projected on a hemisphere seen from a top view for 2000 Hz.



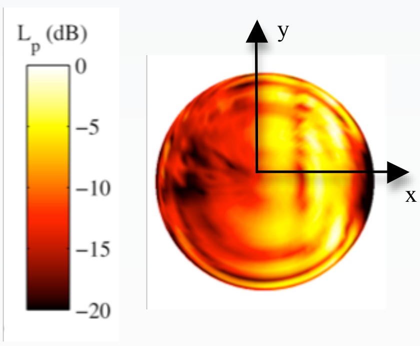


Figure 3. Snapshot of impulsive sound radiated from the tailpipe in the cross section of Figure 1 at $y = 0$. a) no jet, b) hot jet. L_p relative to maximum level.

Figure 4. Directionality of radiated sound for the configuration of Figure 1: top view of hemisphere with far field noise levels.