LES of Flow Duct Acoustics

For Turbocharger Applications

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Abstract

Turbochargers are increasingly used in internal combustion engines and their acoustics is becoming an issue due to increased rotational speeds and improved noise control of other components. The objective with this project is to find CFD tools appropriate for the study of the acoustic properties of the turbocharger compressor. Both the reflection and transmission of incoming low frequency pulsations from the cylinders and the sound generation will be considered. To develop the methods, which are based on Large Eddy Simulation (LES), a simplified geometry consisting of a ducted orifice plate is used.

Background

Turbochargers are used in internal combustion engines to increase the power output at a given engine size and to improve the efficiency. They consist of a turbine and a compressor. The turbine, which is driven by the exhaust gases, drives the compressor that compresses the air going into the cylinders. Today turbochargers are used in most modern diesel engines and their use in gasoline engines is increasing. Due to this and the trend to make smaller turbochargers with higher rotational speeds their acoustics is becoming an issue.

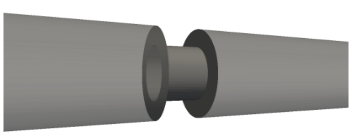
The acoustic properties of the turbocharger can be divided into one passive and one active part. The passive property is the damping effect the turbocharger has on incoming low frequency pulses, which are generated at the cylinders. The active property is the generation of high frequency noise.

To increase the understanding of the acoustics, with the aim of reducing the noise, it is desirable to couple the acoustics to a detailed study of the flow inside the machine. This area is difficult to access in an experiment, while computations can provide detailed information.

The objective is to find tools, based on Large Eddy Simulation (LES), which are appropriate for the study of the acoustic properties of a radial fluid machine. The aim is to be able to capture the flow inside the machine, how incoming pulses interact with this flow and the radiated noise and how it is correlated to sound generating mechanisms, i.e. specific flow phenomena.

Method

The study is carried out through compressible LES to fully capture the dynamics of the flow and its coupling to the acoustics simultaneously. To develop the method a simplified geometry, consisting of a ducted orifice plate, is used. The flow through this geometry is believed to have similar characteristics as that through a compressor, e.g. vortex generation, flow separation and shock waves at high Mach numbers.

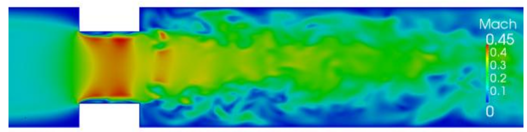


The orifice plate placed in a duct.

The project is divided into two parts. In the first part the passive properties are studied using an acoustic two-port model, which uses the acoustic pressure up- and downstream of the compressor to compute the reflection and transmission of incoming low frequency waves. Furthermore, the interaction between one wave, the plate and the flow will be studied in more detail. In the second part the active properties will be investigated by studying specific flow phenomena and their correlation to the radiated noise. The flow structures corresponding to specific sound generating frequencies are extracted with Dynamic Mode Decomposition (DMD).

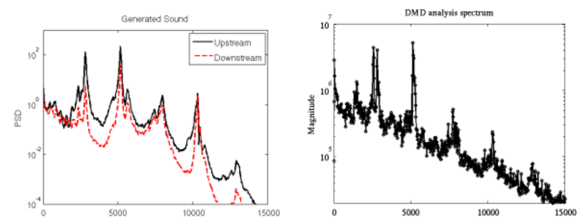
Results

Simulations have been performed for a 2 cm thick orifice plate, with an area contraction ratio of 0.36, placed in a square or a circular duct. Here, the flow filed in the circular ducts is shown for a mass flow of 50 g/s. It can be observed that as the air is forced through the orifice a jet is formed, creating a recirculation zone behind the plate, and vortex generation.

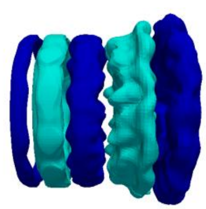


Flow through the orifice.

The sound generated by the flow above is shown below, together with a spectrum of the flow fluctuations in the orifice. Two distinct peaks can be observed in the generated sound, with corresponding peaks in the flow. The flow structures corresponding to these peaks are axisymmetric ring vortices and the structure at 5150 Hz is shown below. The flow spectrum also has a third peak. This is a non-axisymmetric flow structure, which does not generate sound.



Spectrum of generated sound (left) and of flow fluctuations (right)



Flow structure at 5150 Hz; iso-surfaces of positive and negative radial velocity

Conclusions

LES should be capable of resolving both the acoustics and the sound generating flow structures inside a rotating machine. The simplified geometry used has been shown to exhibit several of the flow characteristics seen in a compressor. Simulations of the sound generation show that high sound levels are generated at frequencies corresponding to axisymmetric flow structures.