Large Eddy Simulations of Compressor Flows at Low Mass Flow Rates

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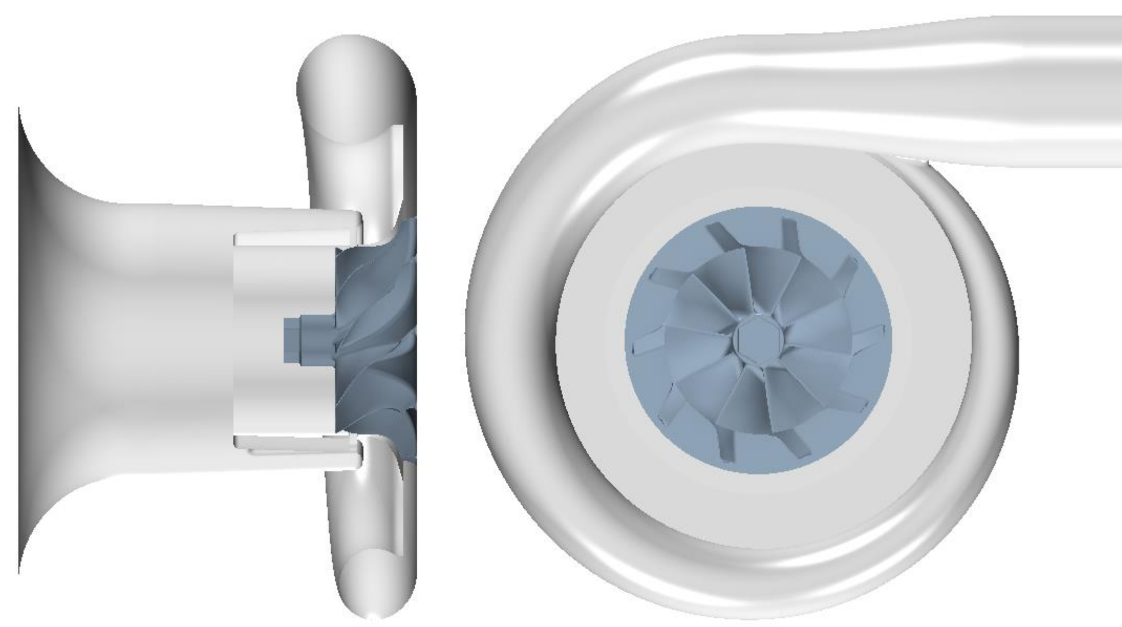
Rotating Stall and Surge are flow instabilities that limit the operating range of centrifugal compressors at low mass-flow rates. Under such conditions amplified sound is generated, resulting in a notable discomfort. The project aim is to predict and characterize their generation mechanisms using the Large Eddy Simulation approach. Flow features are quantified by means of Flow Decomposition techniques. The modal flow decomposition elucidates a mode occurring at the surge frequency. The mode explains the oscillating pumping effect occurring during surge. It also shows a connection where sound waves propagate upstream at the speed of sound. The surface spectra contour reveal the shape of the pressure pulsation during surge and support that a pressure gradient occurs with the oscillating modes found with the modal decomposition.

Introduction and Motivation:

There are several different acoustic noise generation mechanisms that are being provoked in a turbocharger compressor, which can be categorized according to their different acoustic and appearance characteristics; monopoles, dipoles and quadruples. The assessment of the flow inside the centrifugal compressor that generates sound is a challenging task when experimental methods are considered. The confinement of the geometry complicates flow visualization measurements and sophisticated setups are required to deliver high quality images. The aim of the present study is to elucidate the differences and the occurrences of acoustic noise sources triggered by the unsteady flow phenomena inside the centrifugal compressor towards off-design operating conditions. In order to visualize the flow features in the confined compressor geometry, detailed Large Eddy Simulations are performed enabling the analysis of the spectral properties.

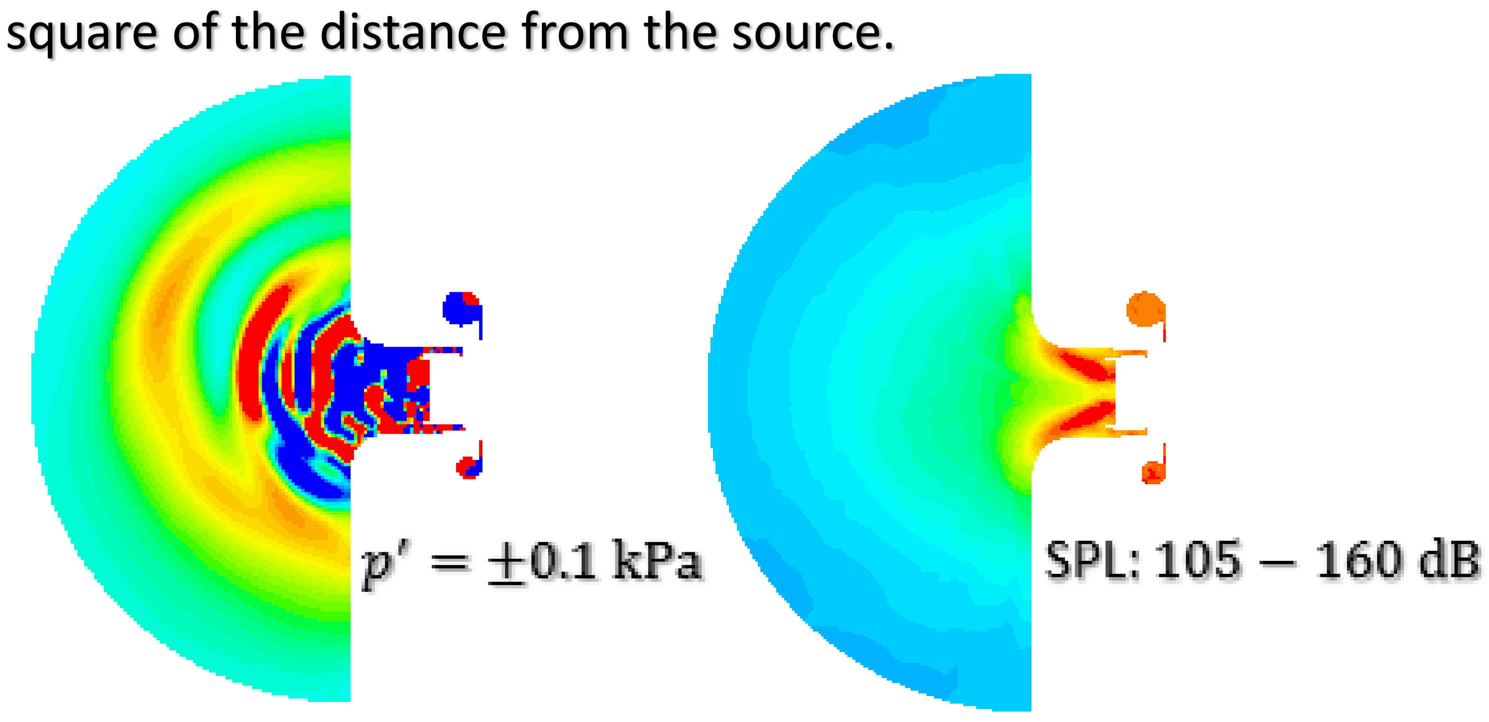
Setup:

A production turbocharger compressor with a ported shroud is used in the numerical analysis. The figure shows side and front views of the CAD geometry. The flow enters from a hemispherical domain via the bell mouth inlet. The flow turns radially in the impeller region by the action of a centrifugal force into the larger volute volume to high pressures and is eventually discharged in the volute exit pipe.

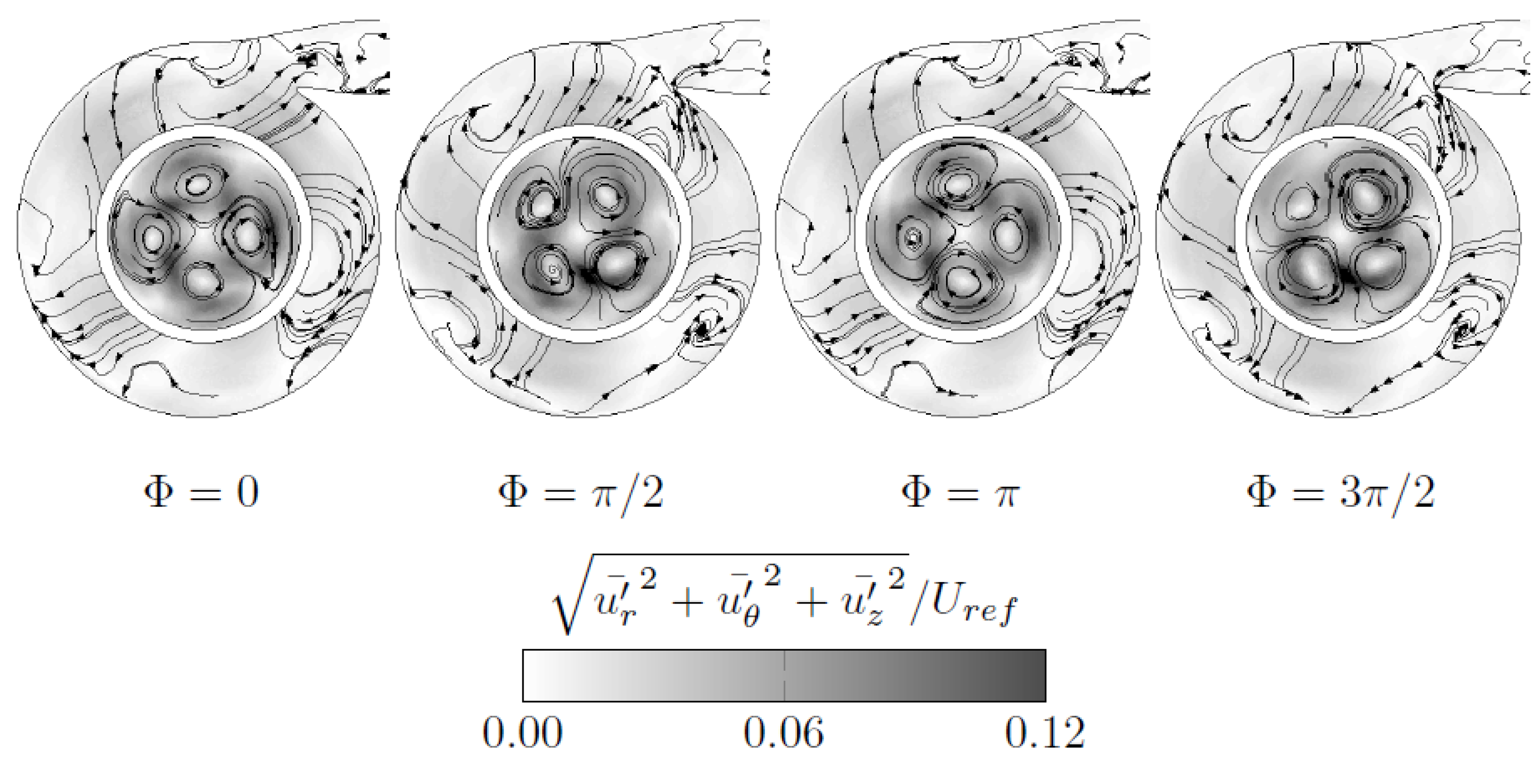


Results:

Turbulent fluctuations are dominant in the vicinity of the impeller whereas the acoustical pressure fluctuations, are more dominant in the hemispherical domain upstream of the bell mouth. There sound waves at different wave lengths are seen to propagate upstream at the speed of sound. At distances exceeding a wavelength the pressure falls of like the inverse square of the distance from the source.



Phase angle evolution of the flow perturbation at off-design operating condition. The figure shows circulating vortical structures upstream and downstream of the impeller, which have been identified as rotating stall. This is observed as a high amplitude noise source.



Summary and Conclusion:

Because the instantaneous velocity and pressure fields, respectively, are rather complex to quantify over time we make use of diverse post-processing methods to enhance the understanding of the large flow structures occurring in the compressor flow during off design operating conditions. With flow mode decomposition, characteristic modes corresponding to rotating stall and surge have been found. Surge describes a system oscillation with compete flow reversal. Rotating stall have been identified as circulating vortical structures both upstream and downstream of the impeller region. These flow instabilities are observed to radiate sound waves to the acoustic far-field.

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