Turbocharger Compressor Response to Downstream Perturbations using Large Eddy Simulations

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Stringent regulations in terms of fuel consumption, pollutants, and noise associated with ICE applications, are calling for innovative turbocharging concepts. The design of an efficient centrifugal compressor with a broad operating range and improved noise signature constitutes a challenge. The operating range is limited at low mass flow rates by the emergence of flow instabilities known as stall and surge and at high-mass flow rates by choke conditions. The impact of the upstream and downstream perturbations (e.g. air temperature conditions, pressure pulses mimicking the effect of the intake valves, re-circulated flow from the EGR system) to the onset of instabilities, noise and system behaviour at off-design operating conditions is unknown and needs to be quantified. The knowledge built will allow an optimal component integration with a broad operating range and improved noise signature.

Introduction and Motivation:

The study targets to understand the mechanisms responsible for the onset of flow instabilities and noise generation in turbocharger compressors with installation effects and perturbations.

The research questions to be answered:

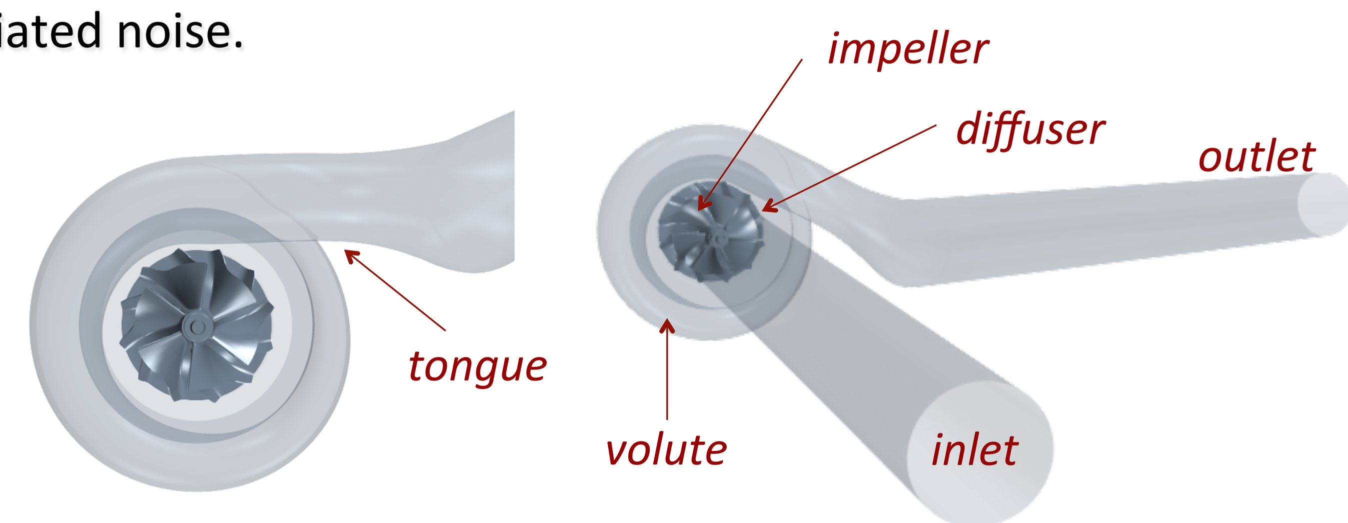
- Which are the mechanisms & key factors leading to stall onset in centrifugal compressors?
- Understand compressor system's components, their interactions, for an optimal boosting system
- Which are the mechanisms for the flow induced noise in compressor systems?

The strategy is to quantify and analyze flow instabilities using high fidelity CFD simulations and advanced post-processing techniques.

From a physics-based understanding build knowledge on off-design operating conditions in order to mitigate flow instabilities and associated noise.

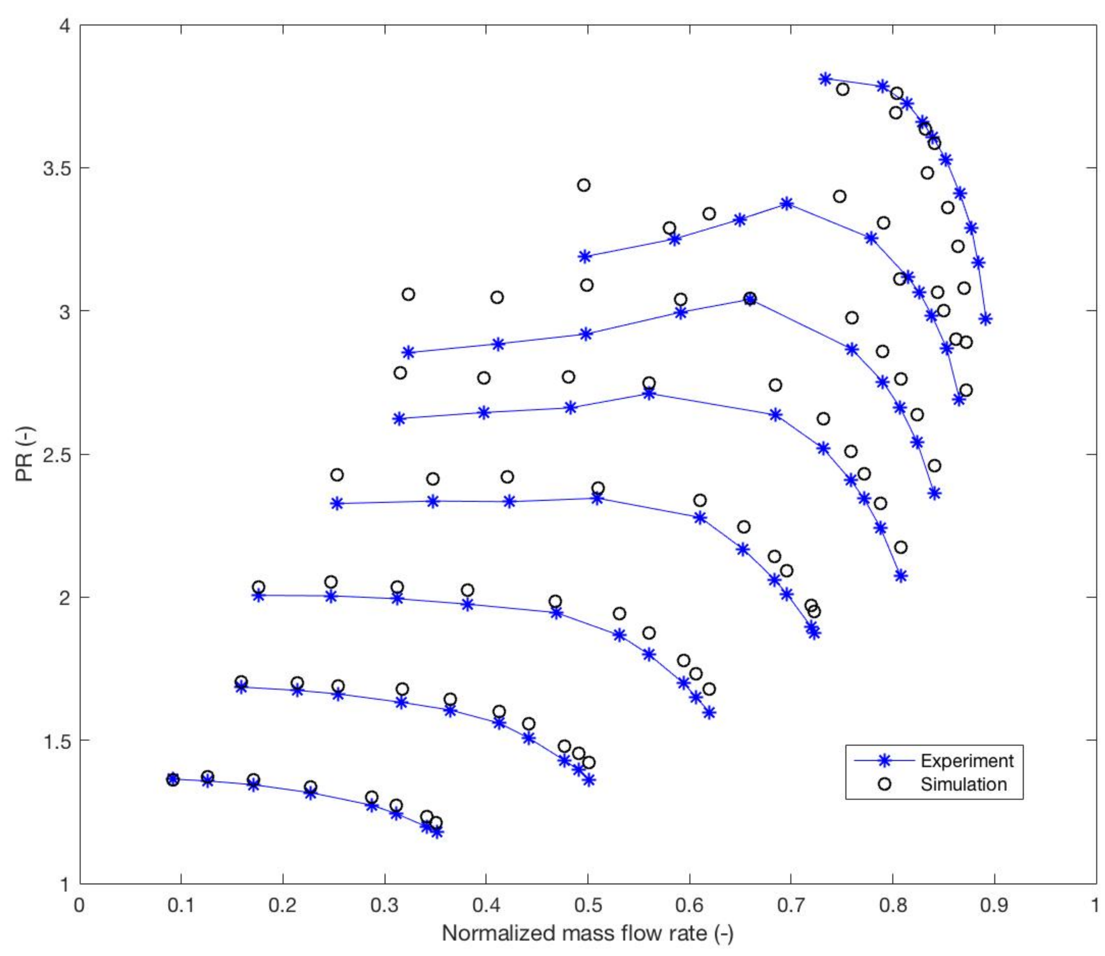
Setup:

A turbocharger compressor is used for the numerical analysis. The CAD geometry is shown in the Figure below. The flow enters the inlet pipe. The flow turns radially in the impeller region through the action of a centrifugal force into the high pressure volute region. The flow is then discharged in the outlet pipe. For the numerical analysis the commercial software Star-CCM+ is used. Steady-state RANS simulations are used to simulate an entire compressor map. The solution is later on used to initialization of the unsteady LES simulations. Unsteady LES is used to capture flow instabilities and associated noise.

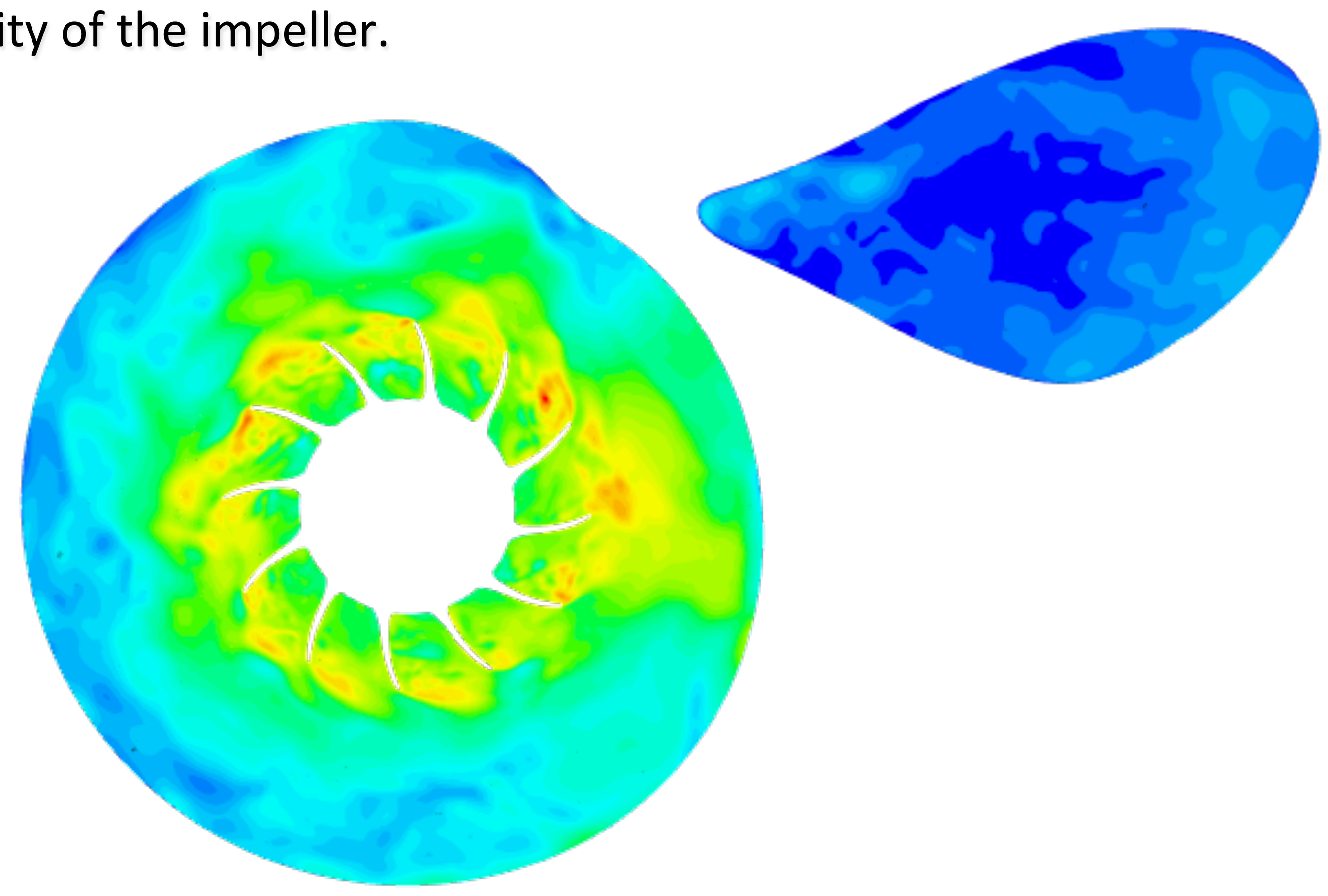


Results:

An entire compressor map was simulated using a steady RANS based formulation.



Targeting the generation mechanism for flow instabilities at low mass flow rates and the impact of pressure pulsations the use of unsteady methods are necessary. Turbulent fluctuations are captured in the vicinity of the impeller.



Summary and Conclusion:

Based on RANS simulations deviations from measurements were observed at high PR and at low mass flow rates. This indicate that the steady simulation was not able to capture the impact of flow instabilities in the system. Baseline LES without installation effects have been performed. The knowledge built will be used to study the effect of pulsations. Pulsations mimicking the effect of the intake valves will be placed at the outlet boundary of the compressor. The target is to understand the impact of unsteadiness to the onset of flow instabilities.

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