Unconventional Volute-Diffuser Assembly for Extended Compressor Range

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Centrifugal compressor range is highly dependent on installation effects, which for turbochargers , means that volute geometries sometimes sacrifice stability in favor of space/weight. Herein we investigate the concept of a non-axisymmetric vaneless diffuser (VLD) in a typical turbocharger test case. The concept is compared against classical VLD treatments, i.e. pinching and shelving. In terms of stability there are clear advantages to the technique, especially on the peak efficiency speedline, however it is also apparent that the scroll section shape and area distribution also need to be redesigned in order to avoid high pressure losses. Counter intuitively, the key of the method appears to be the uneven pressure distribution induced by the trimmed VLD which dominates over any parasitic scroll induced diffusion at low flow conditions.

Introduction and Motivation:

Automotive turbochargers are subject to tight packaging restrictions, hence compressor volutes often have to be designed with certain aerodynamic compromises. Since range and stability are important factors for automotive manufacturers, any range-efficiency trade-offs have to be carefully managed.

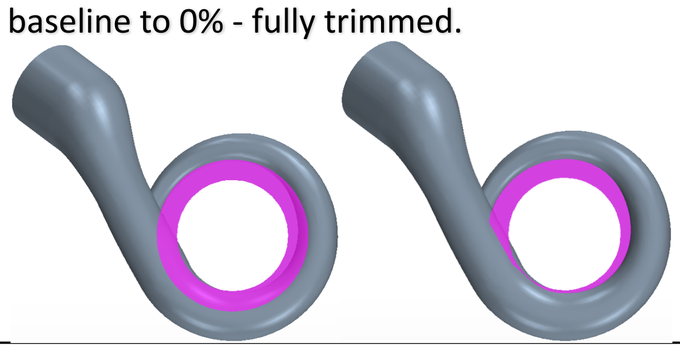
Existing literature suggests that a trimmed vaneless diffuser (VLD) internal volute can provide stability extension for centrifugal blowers with little efficiency penalties. The purpose of this research is to investigate the applicability of this concept to a compressor stage relevant to the automotive industry.

Questions regarding the actual cause of the increased stability as well as the universal character of the method will be addressed.

Understanding the root causes of both the stability increase and pressure losses will pave the way for optimal implementation of this method and ultimately to better overall fuel efficiency of automotive powerplants.

Setup:

Thus far, RANS methods were employed to assess the various configurations. Both the k-ω SST (RC) and the SA (RC) models were tested against the baseline experimental data with comparable accuracy. The SARC model was ultimately chosen owing its computational speed and proven accuracy. Convergence was assessed using both the conventional monitors (i.e. residuals, mass flow imbalance, efficiency, PR) but also tailored parameters such as individual torque distribution on the blade passages, radial force magnitude and direction. The geometric variations considered were proportionately cutback diffusers, ranging from 100% - baseline to 0% - fully trimmed.

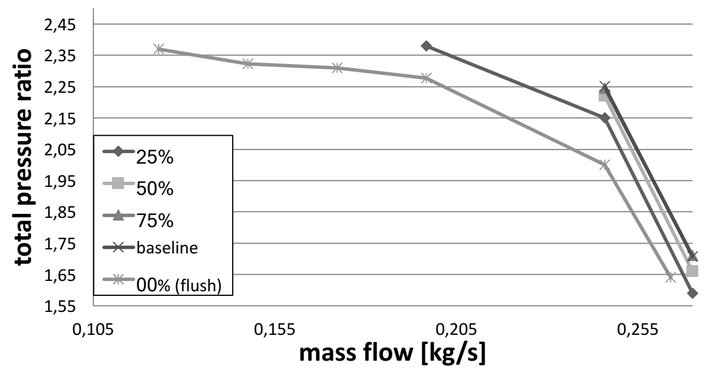


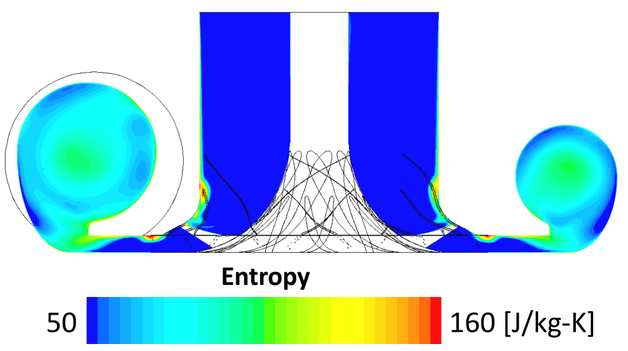
The baseline volute (right) is modified by trimming the protruding part of the VLD by various percentage. The flush volute (left) has the VLD fully trimmed.

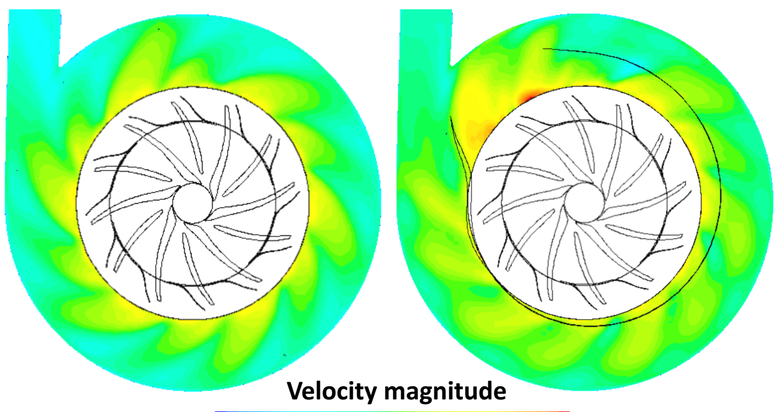
Results:

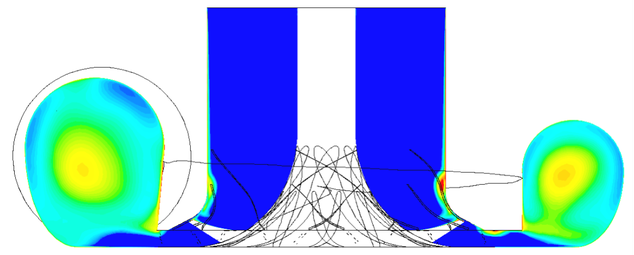
One trimmed variation with significantly increased stability has been identified, although having – in the current, raw form- high efficiency penalties. The variation is characterized by an overall increase in throughflow velocity as well a strong pressure distortion across the circumference. Losses are attributed to the now inadequate aria distribution of the scroll and can be addressed through a future optimization study. Since the modified volute has a greater volume than the original, it would be expected that the diffusion would be higher. Instead this cannot be observed, pointing towards a clear less-than-optimal shape and aria distribution.

It is worth mentioning that the variation in question outperforms the classical pinching of the VLD in terms of range extension while matching its efficiency.









The flush volute has been proven to stabilize the compressor stage across the peak efficiency speed line (top). However, due to the lower diffusion (bottom), flow velocity inside the scroll leads to greater entropy being generated across the volute (right), making the compressor less efficient.

Summary and Conclusion:

The fully cutback VLD resulted stable operation across the speedline, but at ~7% efficiency penalties. Trimming led to a steady increase in the radial velocity component, mismatching the volute aria distribution and also limiting the choke margin. A redesign of the volute scroll is in order, for achieving the full potential of the method. A strong circumferential pressure distortion was observed in the trimmed case, potentially linking stability to mass flow distribution on the impeller passages. URANS simulations have been started and will be analyzed in the future to observe the behaviour as a function of the stage's Greizer-Moore constant B.

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