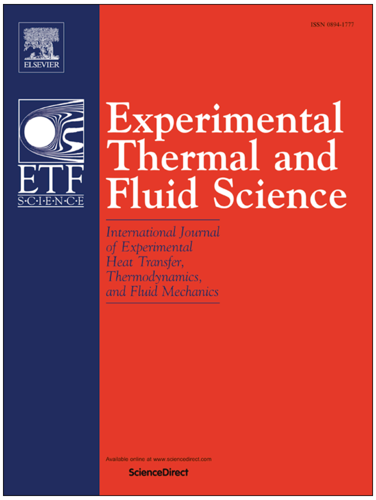

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Measuring turbocharger compressor inlet backflow through particle image velocimetry

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Abstract

An experimental measurement campaign is presented where particle image velocimetry (PIV) was used in an effort to characterize the velocity field in a turbocharger compressor when unstable operating conditions lead to flow reversing from the diffuser into the inlet pipe. Previous studies have successfully used this and similar techniques, but the most relevant results have been obtained in an open compressor where the backflow can diffuse into the ambient. In this work a glass pipe long enough to confine the full extent of the backflow has been used. Advantage was taken from the fact that this backflow is at higher temperature due to the compression process, enabling a preliminary work where a thermocouple array was used to estimate its maximum length across the compressor map. Using these results as a reference both axial and transversal velocity fields were measured. Issues associated with each one are described, along with relevant results that show how the technique correctly identifies the reversed flow, a conclusion that is supported by the comparison of the velocity average and standard deviation profiles with those of measured temperature.

Keywords: Turbomachinery, Flow visualization, NVH, Automotive, Surge, Stall

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1. Introduction

Given the sustained push for the automotive industry to achieve greater efficiency and further emission reductions, thermal engines of passenger vehicles continue to undergo a transformation towards reduced engine displacement [1].

While these engines bring many advantages, they are not without issues. In order to meet power targets equivalent to those of their larger predecessors, the supercharging strategy of the downsized engine has become a cornerstone of its design and development [2]. On pair with engines, automotive turbocharger compressors have become smaller and, more importantly, are expected to provide higher levels of boosting pressures even at reduced air flow conditions [3].

As air mass flow is reduced at higher pressure ratios the compressor flow becomes unstable, ceasing to be evenly distributed. The impeller blades start stalling as flow detaches from their outer edges. This unstable operating regime impacts the efficiency of the compressor [4] and if mass flow rate is reduced too much or if changes in the operating point occur, as it is often the case with the sudden acceleration or deceleration of passenger vehicles, the compressor can go into deep surge.

A known issue since the early days of large steam-powered turbomachinery [5], deep surge occurs when the flow completely detaches from the impeller blades and, free of opposition, the compressed flow reverses direction and surges upstream the impeller and into the inlet duct until the momentum of the incoming air forces air back into the compressor, starting a new surging cycle.

This hazardous phenomenon does not, however, appear spontaneously. It was promptly observed [6] that surge only happens after the slope of characteristic curve (this is, the curve drawn by the pressure ratio as air mass changes at a given constant shaft speed) reaches a maximum and changes direction, the pressure ratio decreasing instead of increasing as flow is further reduced.

Sometimes called mild surge conditions [7], this change in slope is produced by blades partially stalling and hot compressed flow reversing along the periphery of the impeller and then reintegrating into the core flow as the central part of the impeller still keeps operating.

Unstable operation conditions where these complex backflows are present in the inlet zone have also been linked to an increase in the unpleasant noise emitted by the compressor [8, 9], a concerning issue for automotive manufacturers as public demand for quieter vehicles rises.

The accurate characterization and modelling of these unstable flow conditions is thus necessary to successfully tackle these issues and design corrective measures. Proposals include different geometries in the final part of the inlet such as elbows [10], tapered ducts [11] or volumes, boosting the flow swirl with the use of vanes [12] pre-rotation devices [13], or different ported shrouds [14] to guide and contain the backflow.

In parallel to these experimental strategies numerical models have been developed to simulate the operation of the compressor at these unstable conditions and the flow detachment, reversal and reintegration process [15, 16]. However, it is necessary for both CFD simulations and experimental modifications to be validated regarding how their setup affects the onset and the evolution of the backflow [17]. Gathering experimental data to support such validation is thus one of the primary

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