Flow in axisymmetric expansion in a catalytic converter

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ABSTRACT

The flow in an axisymmetric expansion (circular diffusor) is used in many different engineering applications, such as heat exchangers, catalytic converters and filters. These applications require a relatively uniform flow at the inlet. To minimise the pressure loss, an ideal solution would be to use a quite long expansion, but this is often not possible due to space restrictions. Therefore a short expansion combined with e.g. guide vanes is often used. The present study will use a Selective Catalytic Reduction (SCR) system for large marine diesel engines as a case. The catalyst is designed for a specific local flow rate and a non-uniform inflow to the catalyst will severely reduce the efficiency of the process. Since each ship will have a unique design the flow system, it is desirable to be able to design the system using Computational Fluid Dynamics (CFD). However, CFD fails to predict flow separation in many cases and cannot be used as the only design tool [1]. Typically CFD has to be validated against experimental data from representative designs under varying conditions to find trustworthy turbulence modelling, sufficient grid resolution and suitable boundary conditions. Here Particle Image Velocimetry (PIV) is a unique method that resolve the entire cross flow. This type of flow is expected to have a fluctuating 'jet'-like structure from the smaller inlet pipe into the larger converter. The fluctuations of the jet are difficult, if not impossible, to capture with standard time averaged models, and more expensive methods like Large Eddy Simulation (LES) could be needed. Here PIV has an advantage compared with other measurement methods, because it captures instantaneous flow fields that are relevant for the catalyst efficiency and thus also for CFD validation.

The aim of the present study is to investigate flow phenomena in sudden pipe expansions similar to design used for catalytic converters with different upstream conditions and flow conditioning devices like guide vanes. This is done to provide a set of data that can be used to validate the use of CFD to such flows.

For the present study, a down-scaled model of the catalytic converter is constructed, see figure 1. The experiments are performed at laboratory conditions, with lower pressure, temperature and velocity than the full-scale catalytic converter. The Reynolds number based on the velocity in the inlet pipe and the diameter of the converter is Re = 200000. A preliminary study shows that this Reynolds number is high enough to ensure very small dependence of the Reynolds number. The inlet pipe has a diameter of D = 0.1 m. The catalytic container has a diameter of 2.8D and a length of 8D. The diffusor connecting the pipe and the converter container is expanding abruptly within a length of 0.5D. The inlet section has a length of 20D to give almost fully developed flow conditions before the expansion. Several inlet conditions will be investigated, including a straight pipe, one 90° bend and two out-of-plane bends. A catalyst dummy will also be mounted and tested. For the catalyst dummy different model factors will be tested to insure the corrected pressure resistance. The distanced from the expansion to the dummy will also be varied and tested. Then different guide vane configurations will be mounted to investigate the flow uniformity at the catalyst converter. The investigation is done with Stereoscopic Particle Image Velocimetry (PIV). The measuring plane, a cross plane through the converter pipe, will be transverse along the flow direction (z-axis at figure 1). The cross plane is created with a 200 mJ Nd:YAG double cavity laser. Two 16 MPixel cameras are placed in forward and backward scatter, respectively. Glycerine droplets with a diameter of about 2 µm, are used as tracer particles.

Example results are shown in Figure 2, where the cross plane is placed 5D downstream of the expansion. Here the mean velocity field of 500 snapshots from the empty converter with a straight inlet shows that the flow consist of a fast 'jet' in the middle and negative velocity at the walls. A snapshot been selected to represent a very common flow structure corresponding to the first mode found from a snapshot proper orthogonal decomposition (POD) analysis [2]. The white line indicate the change from positive to negative velocity. In the snapshot, the 'jet' has spread along a line through the center and is in contact with two opposite walls. At the rest of the walls, a recirculation zone is seen. As seen in Figure 2, the wall region is well resolved except at the bottom where velocity vectors are missing due to optical reflections.

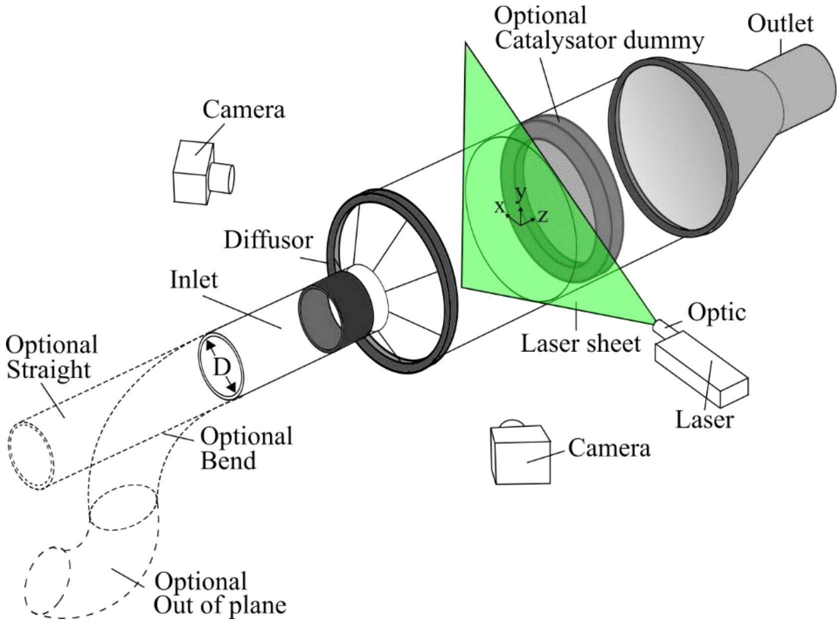

Figure 1 A sketch of the experimental setup, where the three different inlet conditions are shown. A movable catalysator dummy, to introduce a pressure resistance are shown behind the laser sheet. The diffusor is formed as a Klöpper head.

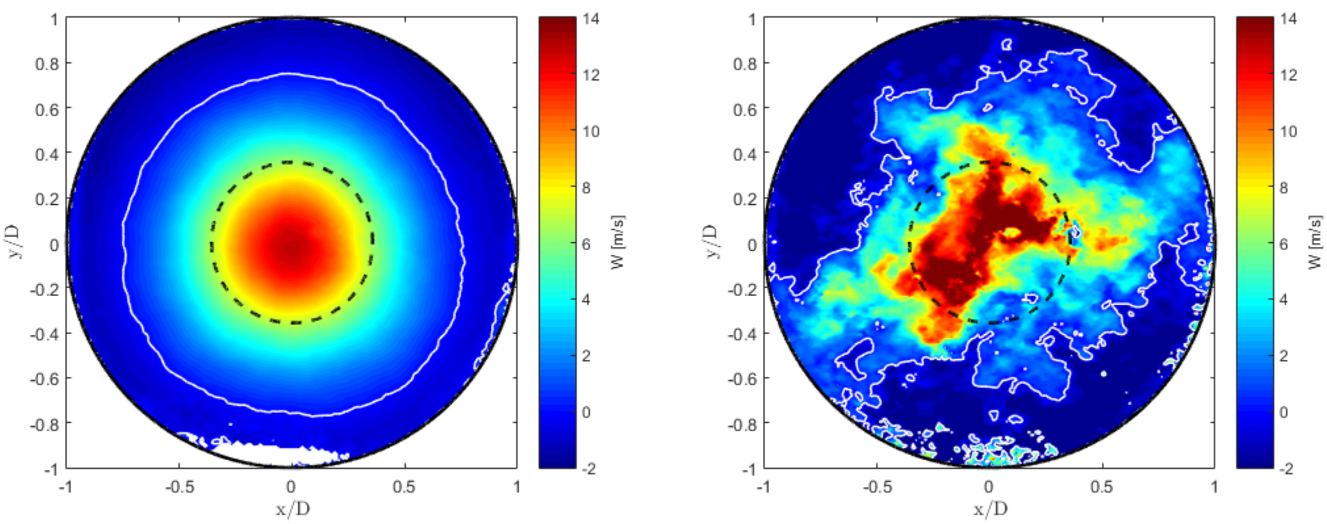

Figure 2 The measured velocity field at z = 0, 5D downstream the inlet, for a straight inlet where the Reynolds number are set to 200.000. On the left picture the mean velocity field with no catalysator dummy and on the right one of the single measurement. Colors show out-of-plane velocity W and the white line indicate W = 0 m/s. The solid line are the converter and the dotted line the size of the inlet pipe.

REFERENCES

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