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The Effect of Transfer Port Geometry on Scavenge Flow Velocities at High Engine Speed

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ABSTRACT

2-D LDV measurements were performed on two different cylinder designs in a fired two-stroke engine running with wide-open throttle at 9000 rpm. The cylinders examined were one with open transfer channels and one with cup handle transfer channels.

Optical access to the cylinder was achieved by removing the silencer and thereby gain optical access through the exhaust port. No addition of seeding was made, since the fuel droplets were not entirely vaporized as they entered the cylinder and thus served as seeding.

Results show that the loop-scavenging effect was poor with open transfer channels, but clearly detectable with cup handle channels. The RMS-value, "turbulence", was low close to the transfer ports in both cylinders, but increased rapidly in the middle of the cylinder. The seeding density was used to obtain information about the fuel concentration in the cylinder during scavenging.

INTRODUCTION

A major disadvantage with carburetted two-stroke engines is the leakage of fuel through the cylinder during the gas exchange. This leakage (short-circuiting) does not only reduce the efficiency, it also causes environmental deterioration, as the hydrocarbons emitted can react to form photochemical smog [1]. Hydrocarbons are also harmful to the health, even if they have not taken part in the photochemical smog reaction. Since many two-stroke engines today are used in hand-held tools such as lawnmowers, chain-saws, jack-hammers etc., this health damaging effect is not less severe than the smog build-up.

If the problems with short-circuiting of the fuel are to be solved, a better understanding of the flow behavior is necessary.

Reduction of the hydrocarbons emission can also be achieved by using an injection system [2, 3], but there is still problems to be solved before the injection

system can challenge the carburetor [4]. This is even more emphasized on small engines, that are supposed to be cheap.

Measurements of the flow velocities in two-stroke engines have earlier been performed by a number of scientists around the world, but the major part of these measurements has been made at low engine speed [5-7] and sometimes without combustion (motored engine) [8-10].

In small engines at high engine speed, the flow must be considered as compressible, and the compressible effects can not be investigated at low engine speed. Blowback is a phenomenon that occurs when the exhaust gases press the fresh fuel-air mixture down into the crankcase. Blowback phenomena can not be investigated in a motored engine.

This paper presents velocity measurements made on the flow of fresh fuel-air mixture from the transfer channels into the cylinder, when the engine is running at 9000 rpm with combustion. Two different transfer channel designs were examined; open transfer channels and cup handle transfer channels. Both cylinder designs are of the loop scavenged type [11].

EXPERIMENTAL APPARATUS

The engine: The measurements were made in the cylinder of a small handheld engine. It is a two-stroke crankcase compression SI engine with a displacement of 60 cc. Two cylinder designs were examined: One cylinder with open transfer channels and one with cup handle transfer channels. Schematics of the transfer channel designs are shown in Figures 1 and 2. Both types were, as mentioned, supposed to be loop-scavenged. They were very easy to remove and assemble on the same crankcase. The crankcase was mounted on a heavy block of steel in order to reduce the vibrations to a level where they did not affect neither the flow nor the measurement accuracy.

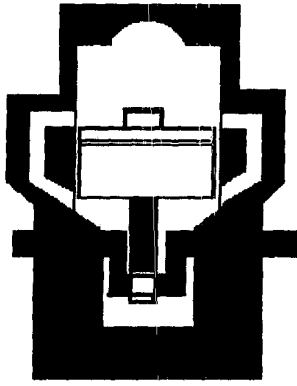


Figure 1. Schematic of engine with cup handle transfer channels.

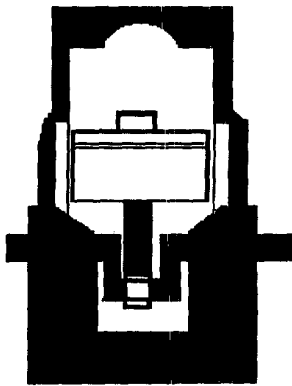


Figure 2. Schematic of engine with open transfer channels.

The engine with cup-handle transfer channels is better from all points of view, except from a higher price. It has higher power and lower HC emissions, due to higher trapping efficiency

The LDV-system: The velocity measurements were performed with a 2-component Dantec Fibre Flow system. This system consists of a 5 W Ar-ion laser, a bragg cell that shifts half of the beam 40 MHz and a transmitter that splits the light into the wavelengths 514.5 nm and 488 nm and leads the four resulting beams in optical fibres to a fibre optic probe which sends out the laser beams and collects the scattered light in backscatter mode. The collected light was transferred by an optical fibre to a color separator that separates the scattered light into the original wavelengths. Two photo multipliers convert the light to electrical signals and two signal processors (BSA Enhanced) perform a "real time" FFT to extract velocity information. The system was controlled by a standard 486/33 PC. The LDV system specifications are shown in Table, 1

Table 1: LDV system specifications

LDV system	Dantec fibre flow
Wavelength, vertical component	488 nm
Wavelength, horizontal component	514.5 nm
Beam spacing at front lens	14.25 mm
Front lens focal length	600 mm
Calibration Factor _{488nm}	20.549 (m/s)/MHz
Calibration Factor _{5145nm}	21.665 (m/s)/MHz
Diameter of measuring volume	0.09 mm
Length of measuring volume	~7.5 mm

To obtain scattered light it is usually necessary to seed the inlet air with some kind of particles that can scatter the light. In this case, it was not necessary, since the fuel and/or oil was not entirely vaporized as it entered the cylinder. The droplets served as seeding, and made further seeding unnecessary.

Optical access to the cylinder was achieved by removing the silencer and by this enable the laser beams to enter the cylinder through the exhaust port.

The LDV measurement volume location was moved by traversing the LDV-probe and by rotating the engine $\pm 25^\circ$ around the cylinder center.

The measurements were made along three lines; one from one transfer port to the other in the middle of the cylinder, one line 10 mm inside the centerline and one 10 mm outside. The location of the lines is shown in Figure 3. In order to reach the area close to the transfer ports, the engine was rotated 25° . The measurements were made four heights; 3, 5, 7 and 9 mm above the piston top at Bottom Dead Center, BDC.

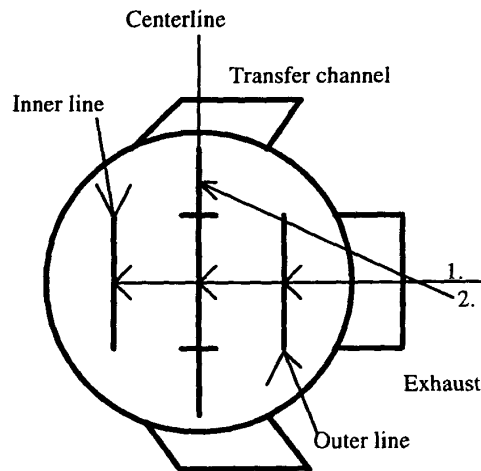


Figure 3. The cylinder seen from above with the lines measured shown; 1: The inner, mid and outer line measured with the LDV-beams entering the cylinder without being angled. 2: Close to the transfer ports, the engine was angled $\pm 25^\circ$ to enable optical access near the ports.

At each measuring point, 196588 velocity registrations were collected in each direction.

The crank angle position was registered with an incremental encoder with the use of an external time base option in the LDV-system. The resolution was 360 pulses per revolution, that is one pulse per Crank Angle Degree (CAD).

OPERATING CONDITION

The engine was run on a gasoline made to be as harmless to the environment as possible. It was developed by Aspen Petroleum Inc., and examined by Ulf Östermark [12]. The only difference from the fuel examined in that report and the one used during the measurements in this report is the addition of 2% synthetic oil. The engine was run with wide-open throttle (WOT) and the engine speed was hold at 9000 rpm with a waterbrake modified to give precise adjustability even at high engine speed.

Many pairs of cylinders and pistons have been used during the initial measurements. Individual differences have been observed, but this paper only reports observations made on one pair of cylinder and piston of each design.

DATA PROCESSING

The output data from the LDV-system are the measured velocity and the CAD at which each individual velocity registration was performed. Due to high engine speed, it was not possible to cycle-to-cycle resolve the measurements.

The ensemble averaged mean velocity, \bar{U}_{EA} , and turbulence, u'_{EA} , for each CAD, θ , was calculated by

$$\bar{U}_{EA}(\theta) = \frac{1}{N_t} \sum_{i=1}^{N_t} U(\theta)$$

$$u'_{EA}(\theta) = \sqrt{\frac{1}{N_t} \sum_{i=1}^{N_t} [U(\theta)]^2}$$

where N_t is the number of velocity registrations for one CAD, U is the velocity registration and u is the fluctuating velocity component defined by

$$u(\theta) = U(\theta) - \bar{U}_{EA}(\theta).$$

This method gives good results if the mean flow does not change significantly from cycle to cycle [13]. The collection of data for each CAD can be performed for many cycles and even if the data rate is very low, acceptable accuracy of \bar{U}_{EA} and u'_{EA} can be achieved. The price that has to be paid is for this accuracy is the lack of information on the variation of mean velocity from cycle to cycle and hence the information on to what extent the ensemble averaged fluctuation u'_{EA} is affected by this cyclic variation.

RESULTS

Mean Velocity: Shown in Figures 4 to 9 is the mean velocity and its direction in the measurement plane for different crankangle positions. It can be noted that the first velocity measurements are captured at -30 CAD from the Bottom Dead Center (BDC). The thicker horizontal line shown in some of the figures is the position of the piston top at that current crank angle.

Turbulence: Figures 10 and 11 show the spread in velocity registrations as a function of horizontal position and crankangle for the four measuring heights. It can be noted that the RMS-value generally is higher in the middle of the cylinder where the two scavenging flows meet. If this is "true" turbulence or an artifact of bulk flow differences from cycle to cycle is hard to tell. Due to insufficient data rate it was impossible to cycle to cycle resolve the measurements.

Data rate: The data rate is a rough way to extract information about the concentration of seeding particles. Since, in this case, the seeding particles are fuel droplets, this gives some kind of information about fuel distribution in the cylinder. The data rate is very irregular as a function of CAD as seen in Figures 12 and 13. This must not necessarily be differences in the seeding concentration, it might as well be shock-wave phenomena. In a shock-wave front, the refractive index of the gas increases or decreases. The crossing of the LDV beams could be disturbed if the beams pass a shock-wave front, and the data rate would then decrease. A shock-wave phenomenon would explain the dip in data rate at -25 degrees from BDC.

Differences between the two cylinder designs: In the center of the cylinder with cup-handle transfer channels the velocities decrease, as shown in Figure 7. This is probably due to the transfer channel jets missing the measuring volume since they are directed towards the inner wall. Figure 4 shows the same effect in the center of the cylinder with open transfer channels. Here the velocities decrease as well but likely as a result of the two jets meeting in the center. Figures 4 and 7 show at the height 9 mm over the piston top at BDC that the velocity is lower in the cylinder with cup-handle transfer channels. Since the height of the transfer channels is lower than 9 mm on both cylinder types, the lower velocities measured in the cylinder with cup-handle channel at 9 mm height is probably due to better direction of the flow out from the transfer ports.

The RMS-value rise rapidly where the jets from the transfer ports meet. This is shown by the hill in the RMS landscapes. In Figure 10, showing the RMS-values for the cylinder with cup-handle transfer channels, the "hill" in the RMS-value turns to the right, which indicates that the left transfer channel jet is stronger than the other. A similar hill is found for the cylinder with open transfer channels, but here the RMS-value is higher close to the ports.

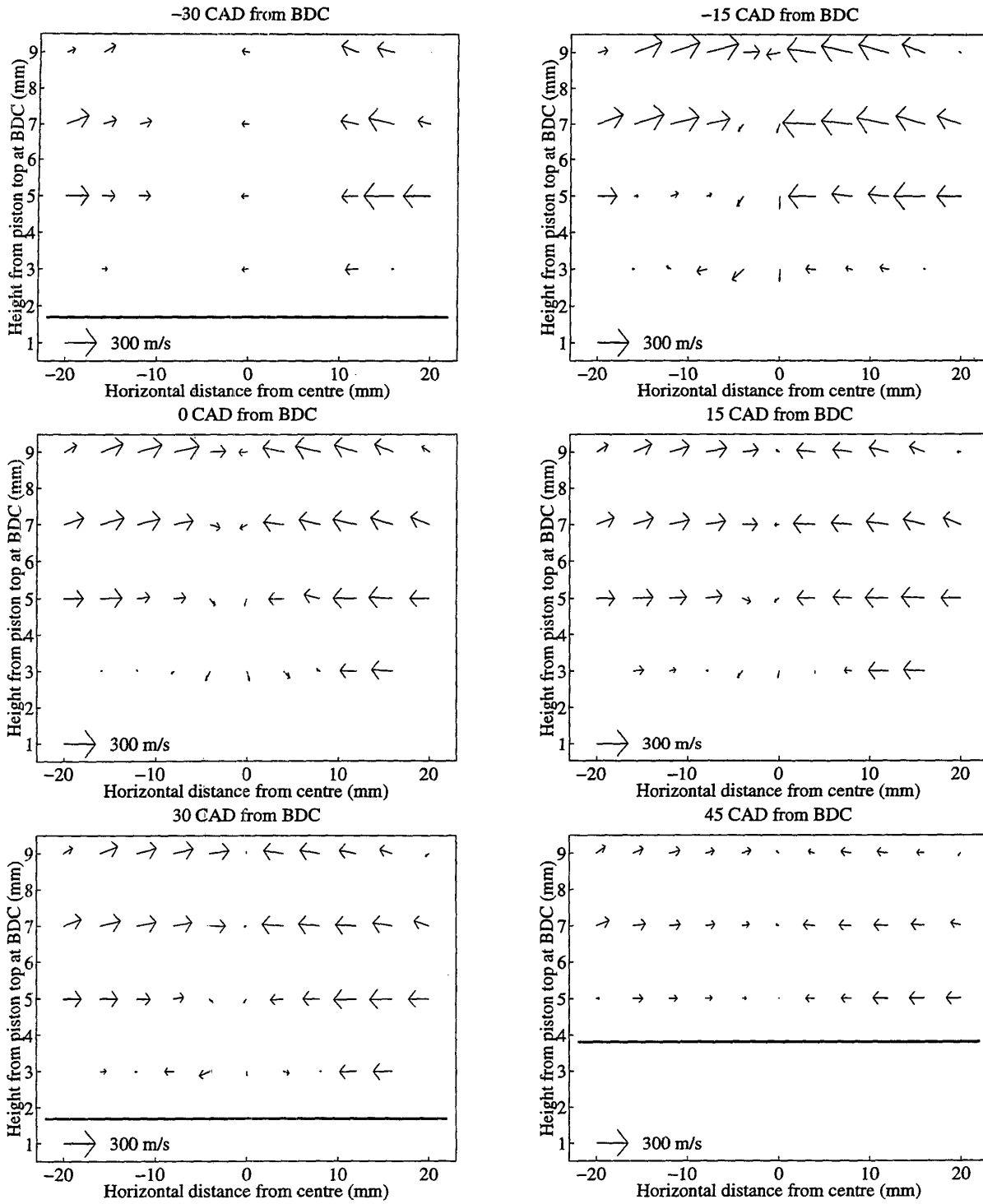


Figure 4: Open transfer channels. Mean velocity measured along the centerline of the cylinder.

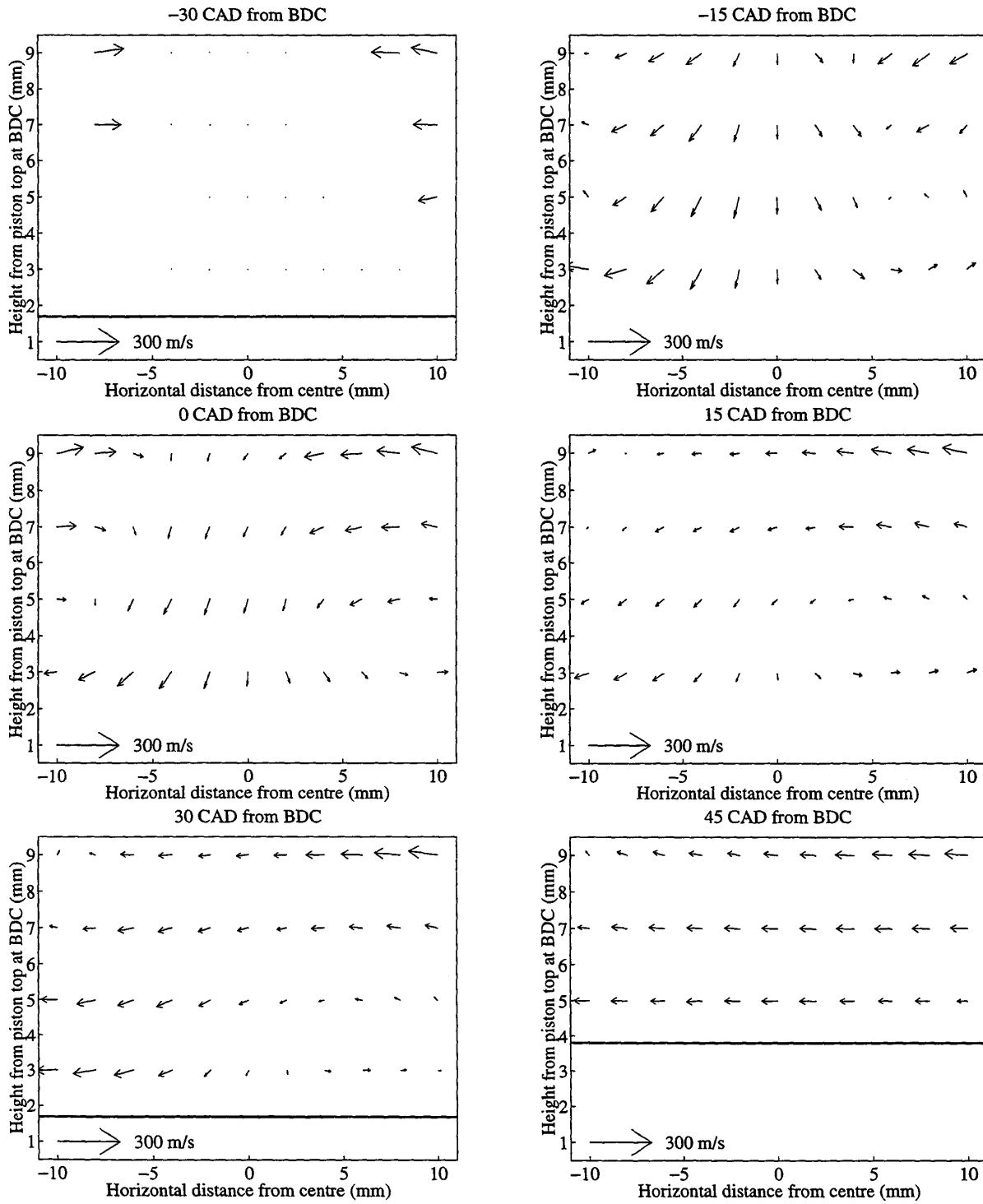


Figure 5: Open transfer channels. Mean velocity measured on the line 10 mm inside the centerline of the cylinder.

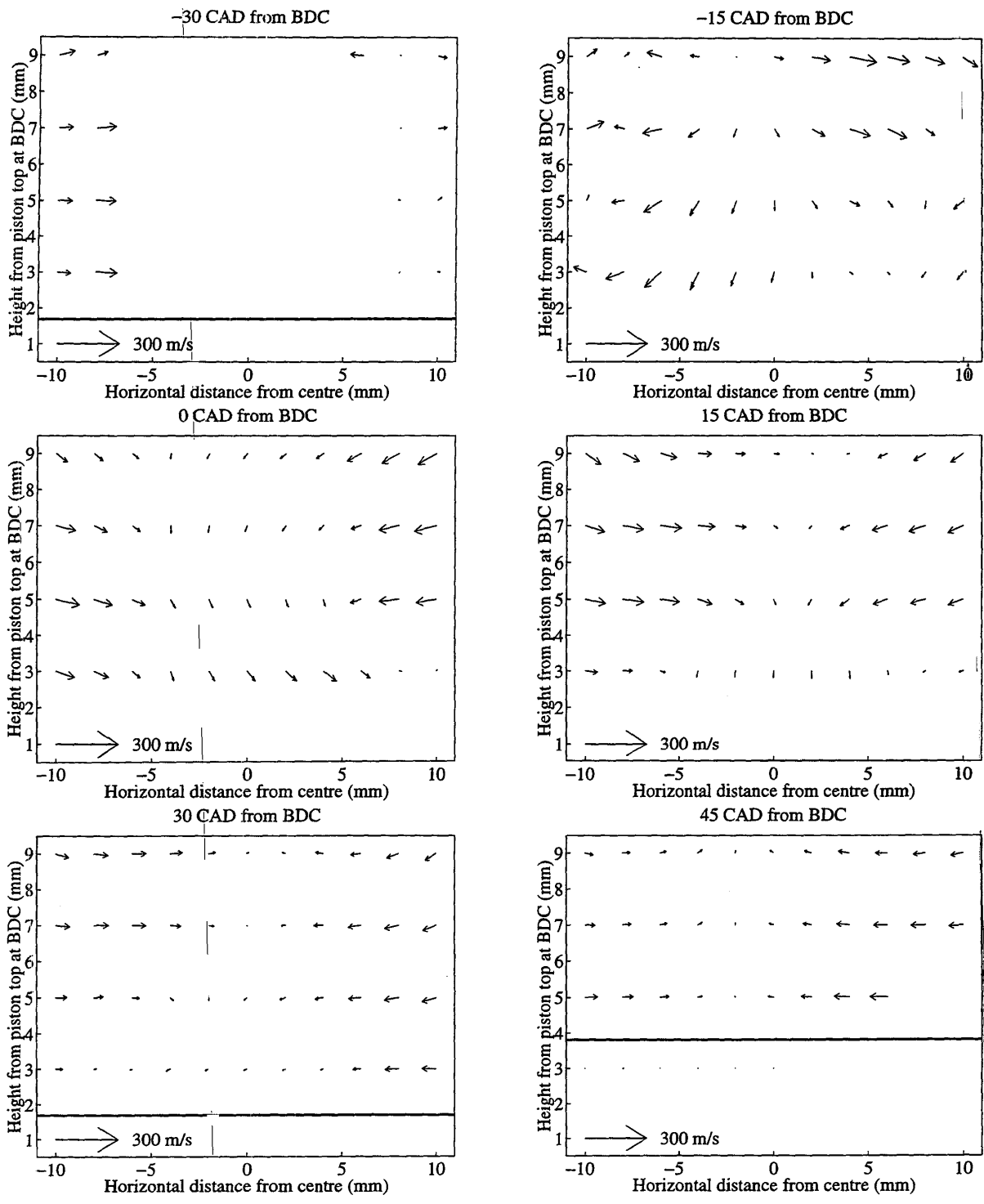


Figure 6: Open transfer channels. Mean velocity measured along a line 10 mm outside the centerline of the cylinder.

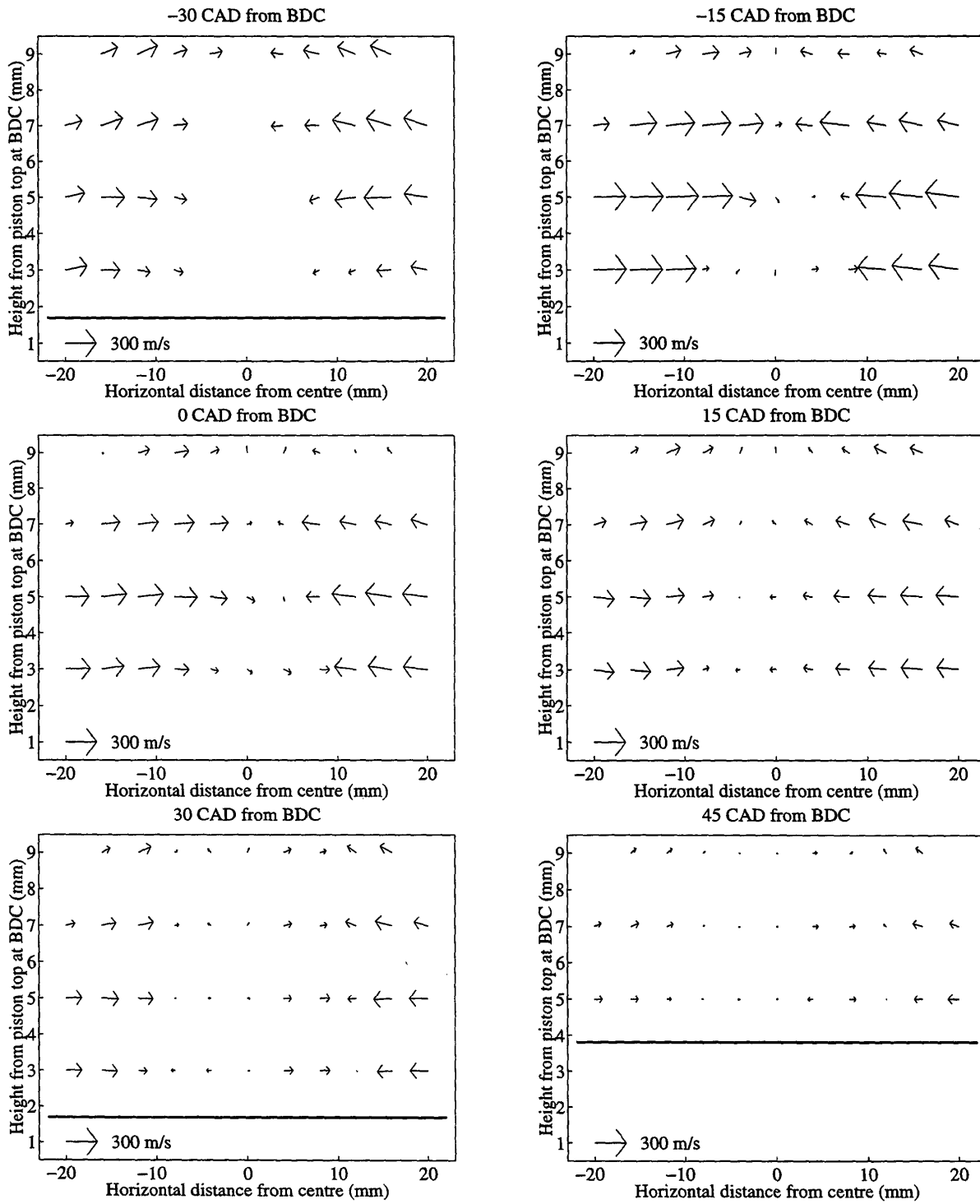


Figure 7: Cup handle transfer channels. Mean velocity measured on the centerline of the cylinder.

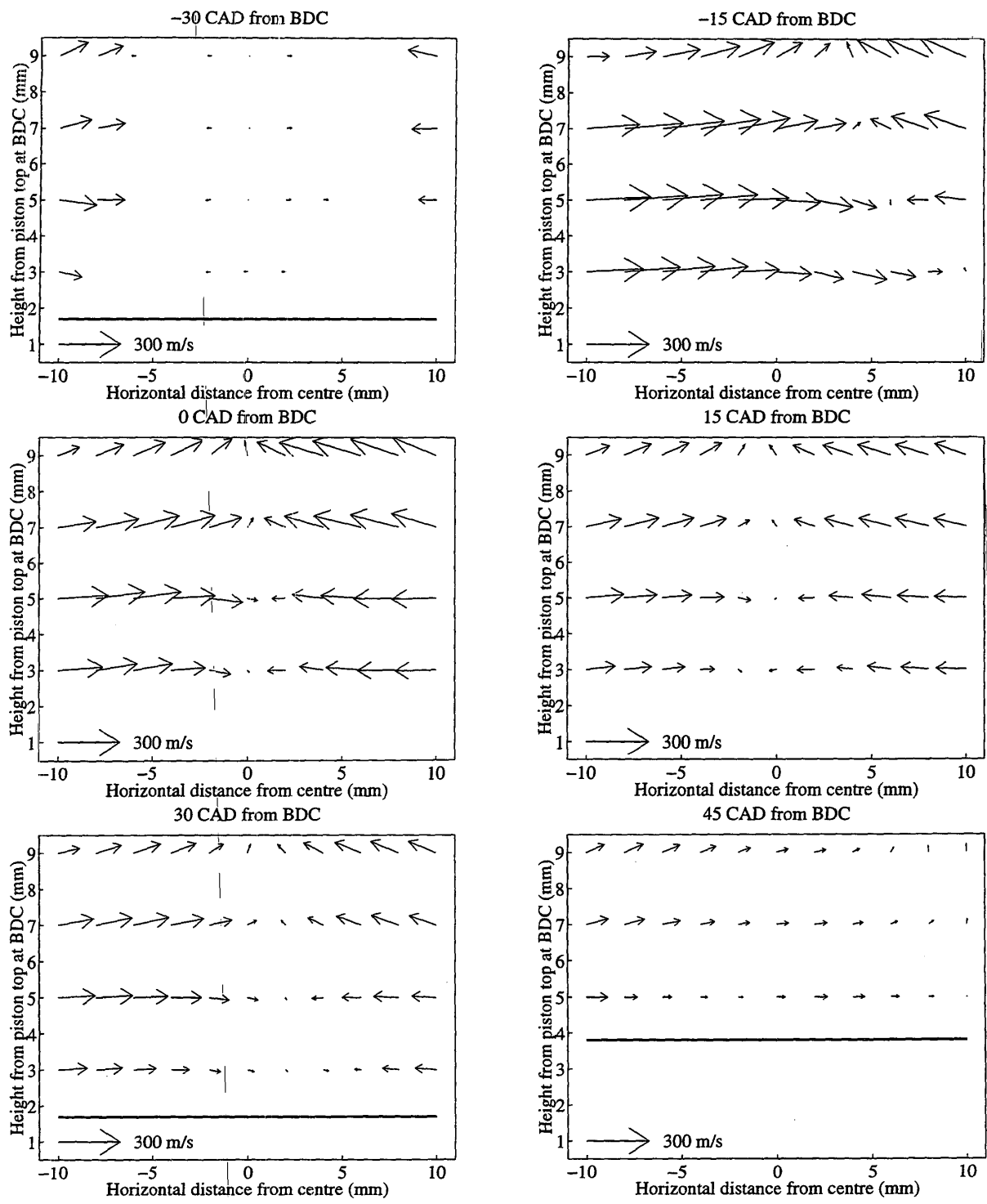


Figure 8: Cup handle transfer channels. Mean velocity on a line 10 mm inside the centerline of the cylinder.

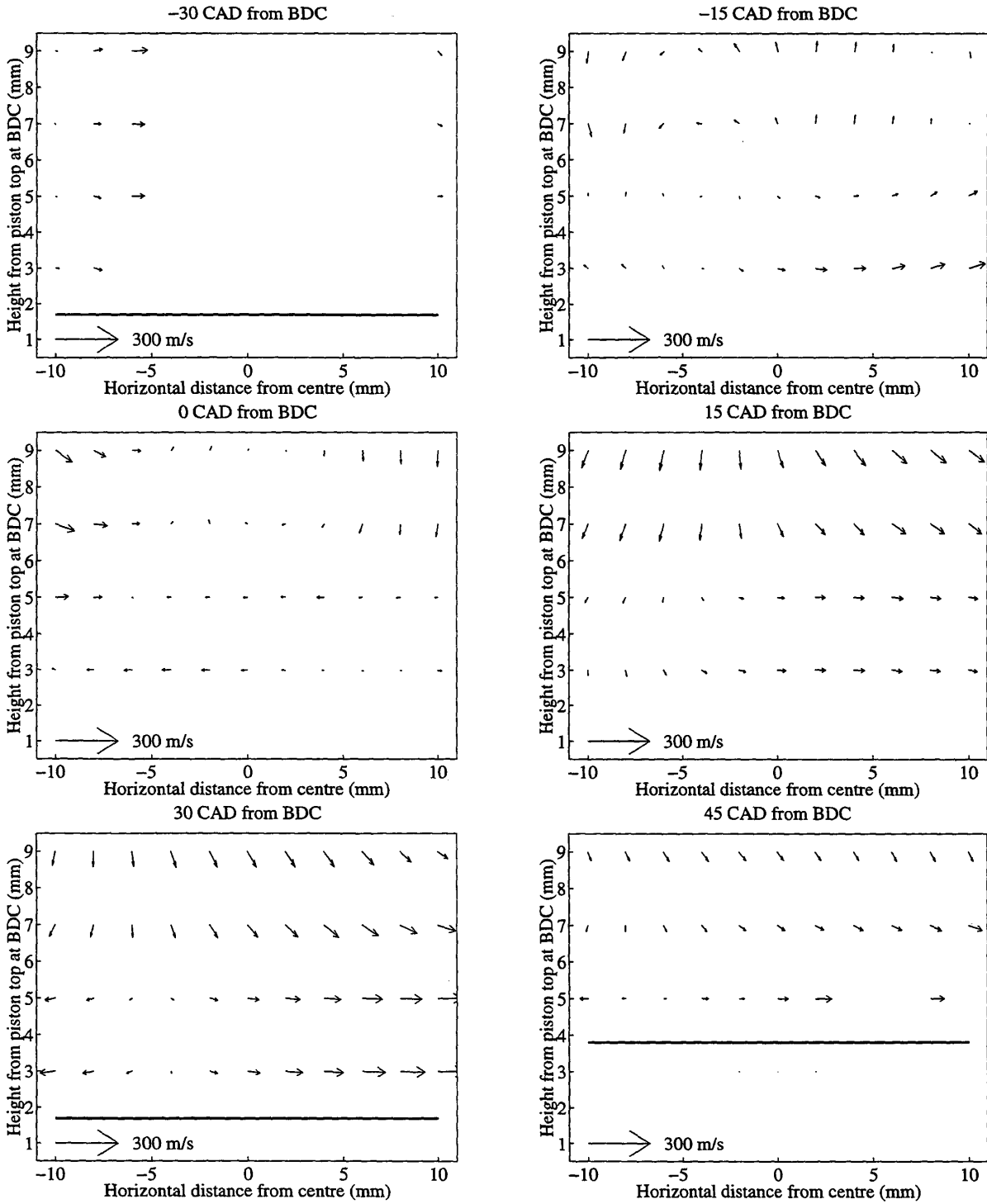
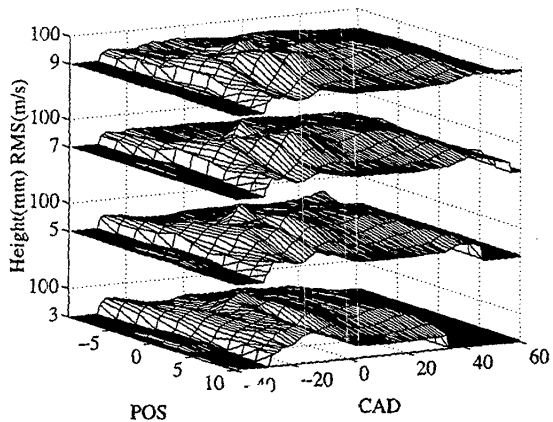
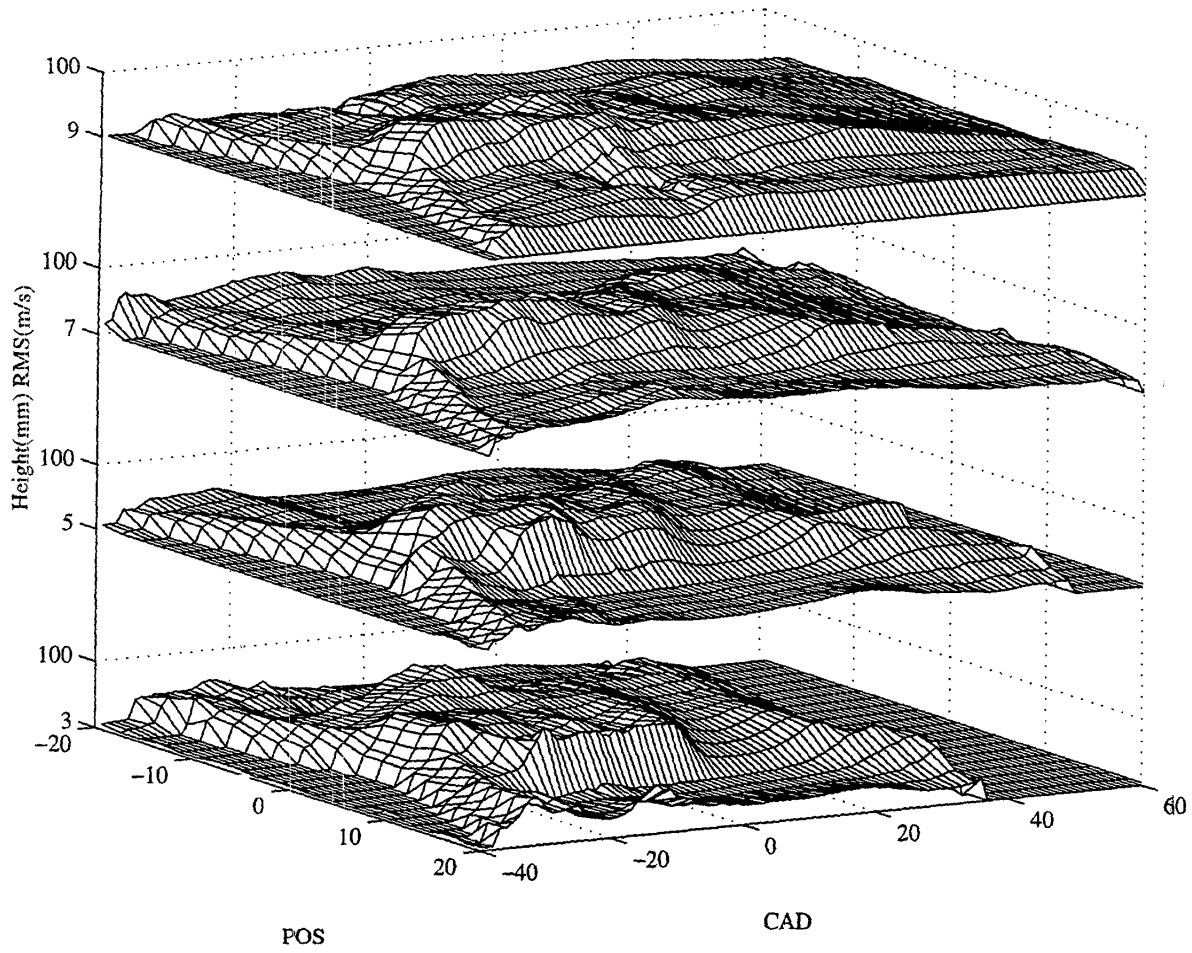
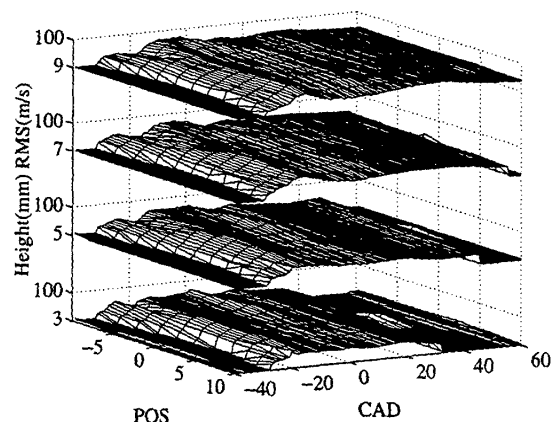


Figure 9: Cup handle transfer channels. Mean velocity on the line positioned 10 mm outside the centerline of the cylinder.

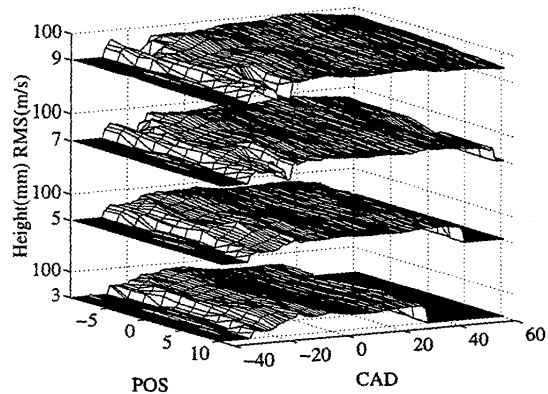
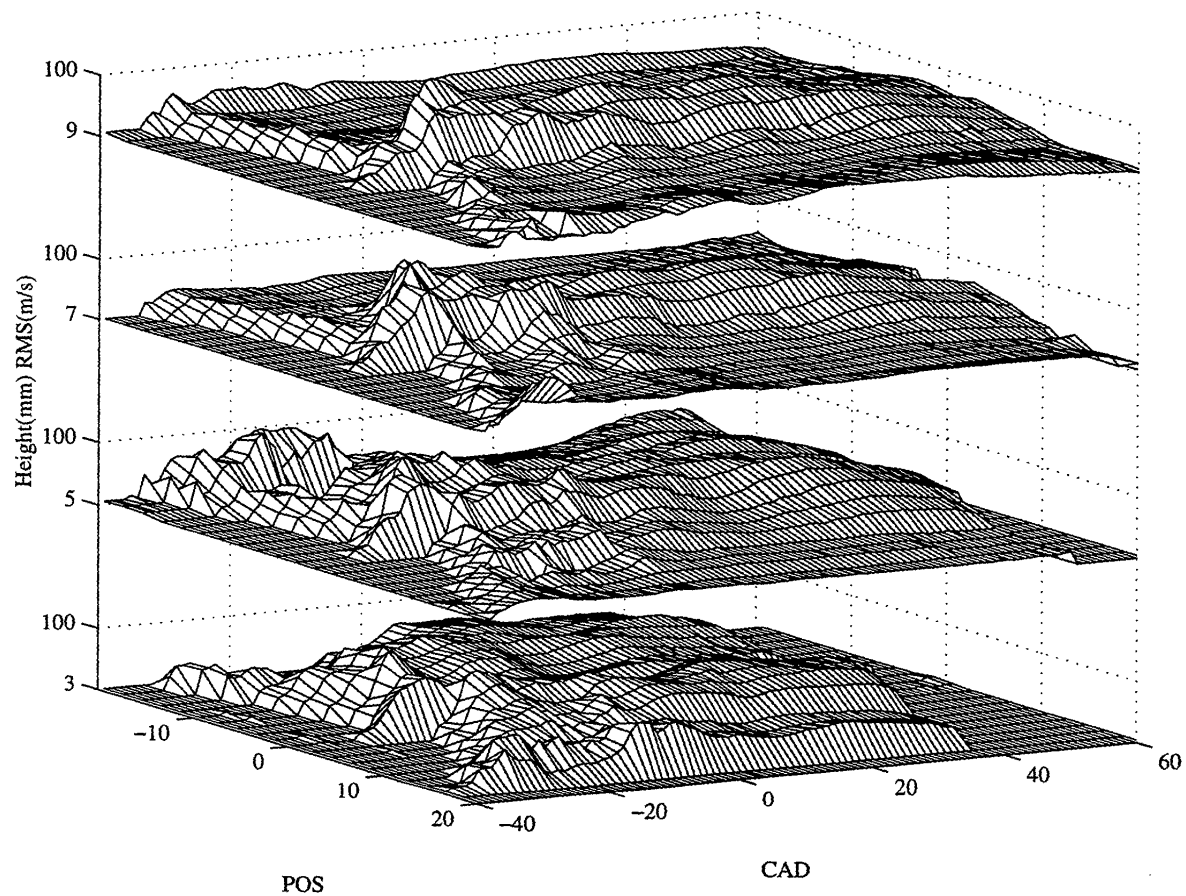


RMS values 10 mm inside the centerline.

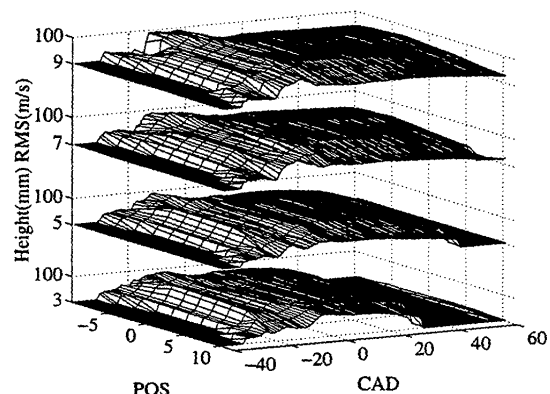


RMS values 10 mm outside the centerline

Figure 10: Cup handle transfer channels. RMS-value (m/s) for the four measuring heights 3, 5, 7 and 9 mm as a function of crank angle position and horizontal measurement position. The largest figure at the top shows the RMS value for the centerline.

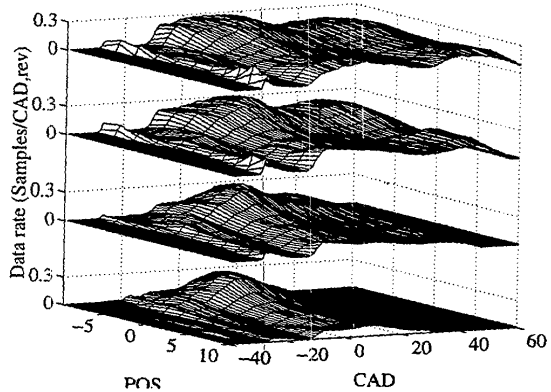
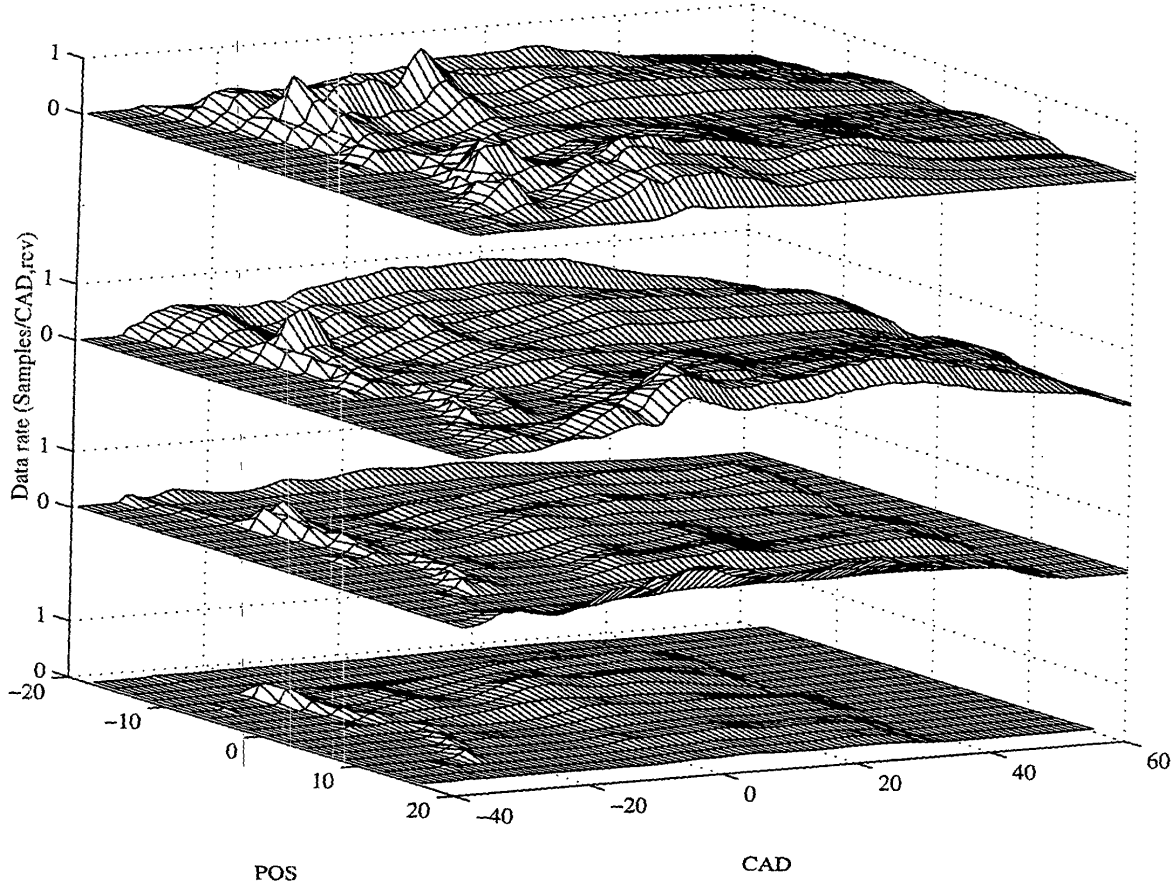


RMS values 10 mm inside the centerline.

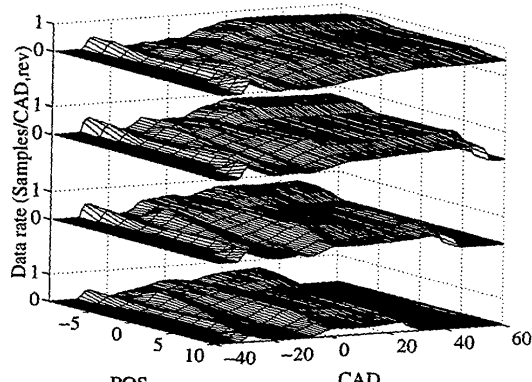


RMS values 10 mm outside the centerline.

Figure 11: Open transfer channels. RMS-value (m/s) for the four measuring heights 3, 5, 7 and 9 mm as a function of crank angle position and horizontal measurement position. The largest figure at the top shows the RMS value for the centerline.



Data rate 10 mm inside the centerline.



Data rate 10 mm outside the centerline.

Figure 12: Open transfer channels. The three figures show the number of velocity registrations divided by the number of revolutions the engine proceeded during the measurement. The largest figure on the top shows the data rate for the centerline. The four planes in each figure represent the four heights the four heights 3, 5, 7, and 9 mm on which the measurement were made.

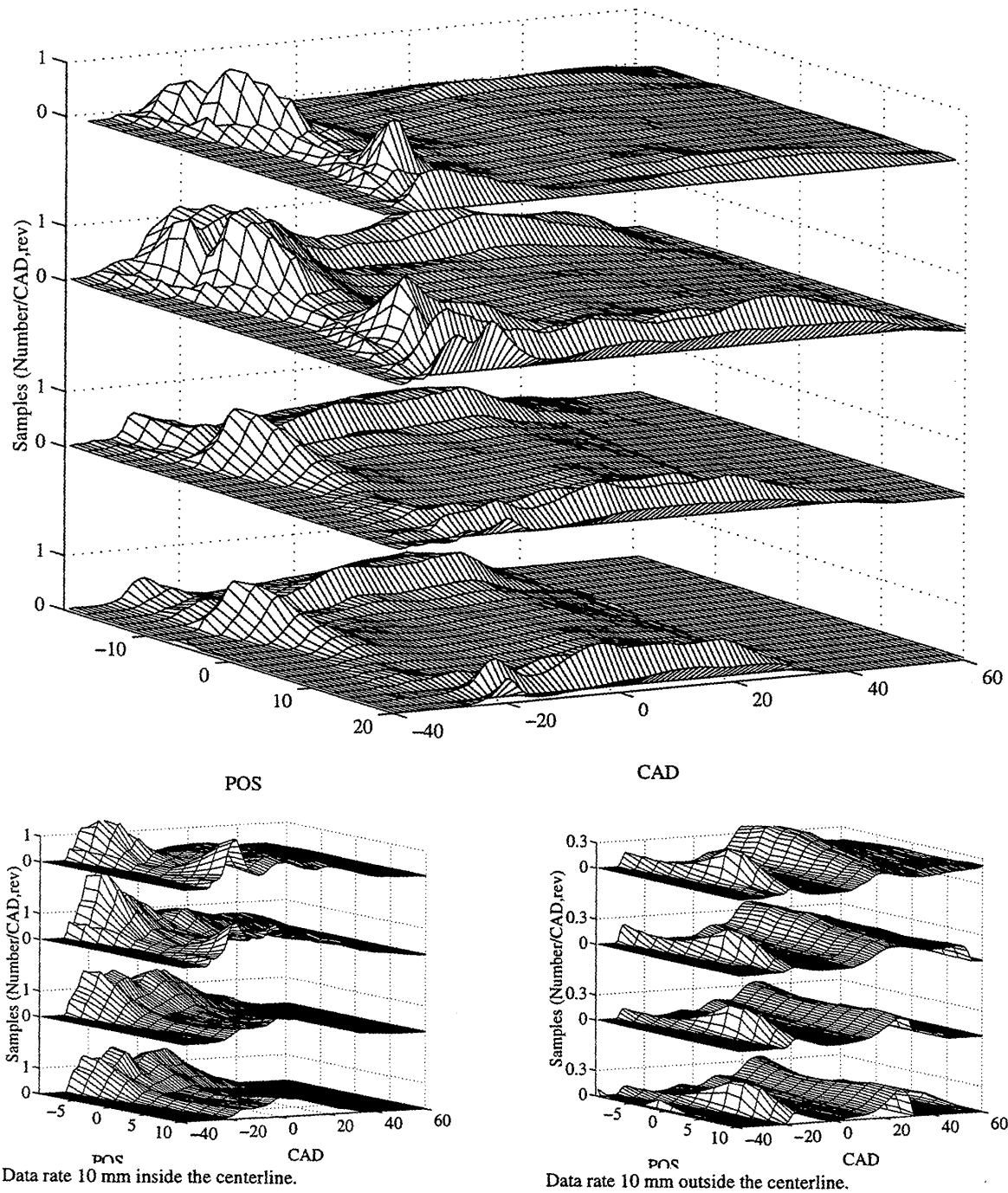


Figure 13: Cup handle transfer channels. The three figures show the number of velocity registrations divided by the number of revolutions the engine proceeded during the measurement. The largest figure on the top shows the data rate for the centerline. The four planes in each figure represent the four heights the four heights 3, 5, 7, and 9 mm on which the measurement were made.

The cylinder with open transfer channels gives higher data rate when measured along the outer line, as can be seen in Figure 12. The cylinder with cup handle transfer channels gives the highest data rate along the inner line, shown in Figure 13. In a loop-scavenged cylinder, the concentration of fuel and air is supposed to be high close to the wall opposite from the exhaust port.

In the cylinder with open transfer channels, the data rate is very low at the height 3 mm above the piston top at BDC, shown in Figure 12, compared to the cylinder with cup-handle transfer channels, shown in Figure 13. This is probably because the flow is more parallel to the piston top in the cylinder with cup-handle transfer channels.

The data rate is generally higher close to the left transfer port on both cylinder types. This emphasizes the theory of the two transfer channels jets having unequal magnitude.

As seen in Figure 5, the velocity along the inner line in the cylinder with open transfer channels are generally pointing downwards during the whole scavenging phase. In Figure 8, the cylinder with cup-handle transfer channels shows the opposite flow direction. The flow direction is supposed to be upwards along a line close to the back wall of the cylinder, if loop scavenging is desired. This is the case in the cylinder with cup handle transfer channels.

Along the outer line the cylinder with cup handle transfer channels shows unorganized velocities in the beginning of the scavenging phase, as shown in Figure 9. In the late part of the scavenging, an organized flow downwards of large magnitude commences. In the same plane for the cylinder with open transfer channels, shown in Figure 6, high velocity flow from the transfer ports in the beginning of the scavenging phase occur. The fact that the cylinder with cup-handle transfer channels does not show such velocities leads us to the conclusion that the flow is more directed towards the back wall.

Individual differences. Several piston-cylinder pairs have been examined prior to the ones presented in this paper. The cylinders then examined were of the same type as the ones presented here, but the flow showed differences that could not be explained by a visual examination of the cylinder individuals. For example, the lack of symmetry in bulk motion that was detected in the open channeled cylinder in this paper, did not occur on an other individual of the same design. Neither did the large difference in data rate from one side to the other in the cylinder with cup handle transfer channels occur when measuring on an other cylinder-individual of the same design. This shows that there are differences in the flow behavior from cylinder to cylinder, even if they are of the same design. These differences are probably due to manufacturing imperfections. It can be mentioned, that all cylinders were taken from the manufacturing line, and that no further machining was made to reduce the spread.

CONCLUSIONS

1. The loop scavenging effect is poor in the cylinder with open transfer channels.
2. The RMS-values are low close to the transfer ports, but increases in the center of the cylinder.
3. The fuel droplet concentration is ununiform, especially as a function of CAD.
4. There are big differences from cylinder to cylinder even if the cylinders have the same design.

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