MULTI-PLANAR STEREOSCOPIC PIV MEASUREMENTS IN A COMBUSTION ENGINE

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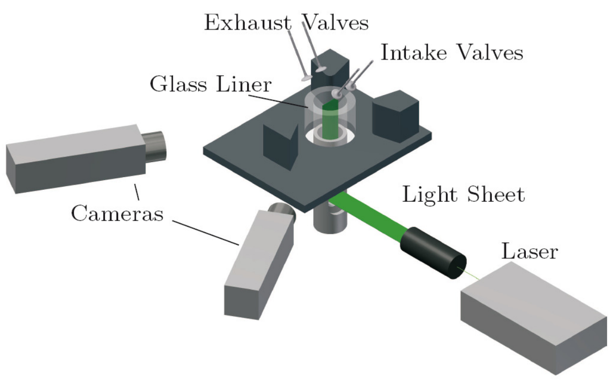
Summary The flow field inside an internal combustion engine has a strong impact on the mixing of fuel and air and the combustion. It is influenced by the moving valves and the piston and it is highly three-dimensional and unsteady. The present study visualizes the evolution of the flow structures by vorticity contours and streamlines. The data were acquired using multi-planar stereoscopic particle-image velocimetry (PIV). The results show the time-dependent development and merging of different vortex structures.

EXPERIMENTAL WORK

The measurement principle of stereoscopic PIV is non-intrusive, such that the flow is virtually not disturbed. The flow is seeded with small oil droplets and illuminated with a laser light sheet. The particle images are recorded by two cameras simultaneously from two different viewing angles, Figure 1 a. From these two projections, the three components of the velocity field in a plane are reconstructed. The investigated combustion engine is equipped with a quartz glass cylinder and quartz glass piston crown to enable optical access. In a set of 14 axial planes, Figure 1 b, 70 samples are taken at each position at defined crank angle positions (40 to 320 crank angle degree (CAD) after top dead center). The engine runs at 1500 rpm. More details of the experimental setup and the investigated engine can be found in [1]. To reconstruct the volumetric flow field, the measurement planes were interpolated onto a Cartesian grid at a resolution of (x,y,z) = (1,1,1) mm. The vortices were identified using the Γ_1-criterion of [2], modified for three-dimensional data. This criterion does not use derivatives and therefore it is well suited for PIV data. For planar data, the criterion ranges from -1 to 1, such that it indicates the intensity and direction of rotation. For three-dimensional data the absolute value is used. The contours shown in Figure 2 have a value of Γ_1=0.8.



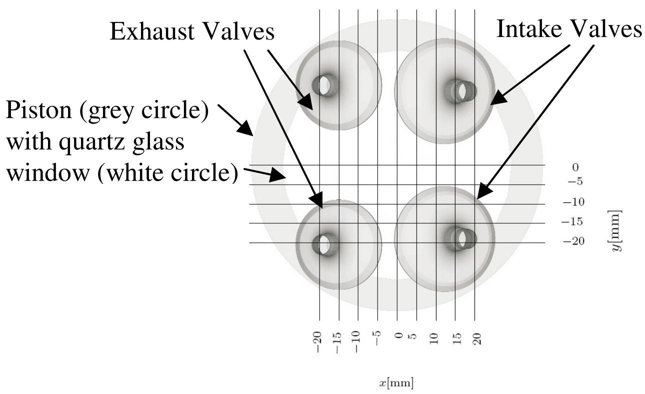


Figure 1 a) Experimental setup b) Measurement planes

RESULTS

Two main kinds of vortices evolve during the intake and compression phases. An intake air jet separates from each of the two inlet valves and forms a ring vortex. Due to the geometric constraints the two ring vortices are not circular but strongly distorted. Furthermore, a "tumble vortex" is formed, which rotates about an ideally horizontal axis in the combustion chamber, triggered by specially designed intake ports. The results show that the intake (0-180 CAD) and compression (180-360 CAD) phases can be divided into 4 main stages regarding the vortex evolution.

- (I) 40-60 CAD: The ring vortices develop, especially the inner halves between the valves, Figure 2 a.
- (II) 80-180 CAD: The curved tumble vortex is formed, Figure 2 b. The shape of the tumble is imposed by the following air inflow which makes the tumble center move downwards at either side of the valves, but not underneath the valves. The outer halves of the ring vortices outgrow the inner halves. The flow pattern is stretched and dispersed due to the expansion. The intake valves close at 196 CAD.
- (III) 200-220 CAD: The weak inner ring vortex halves disappear due to the closed valves and are displaced by the growing outer ring vortex halves, Figure 2 c. The outer ring vortex halves merge with the tumble vortex since they have the same direction of rotation, Figure 2 d.

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(IV) 240-300 CAD: The final tumble vortex stabilizes, rotating around a straight, horizontal axis, Figures 2 e and f.

After being chaotic during the intake phase due to the superposition of the ring vortices and the tumble, the flow pattern becomes very structured after bottom dead center due to the closing of the valves and the compression. The analysis of the turbulent kinetic energy reveals that the fluctuations introduced during the intake continuously decrease until a minimum at 260 CAD is reached after which a slight increase is detected, which may be attributed to the disruption of the compressed vortex [3].

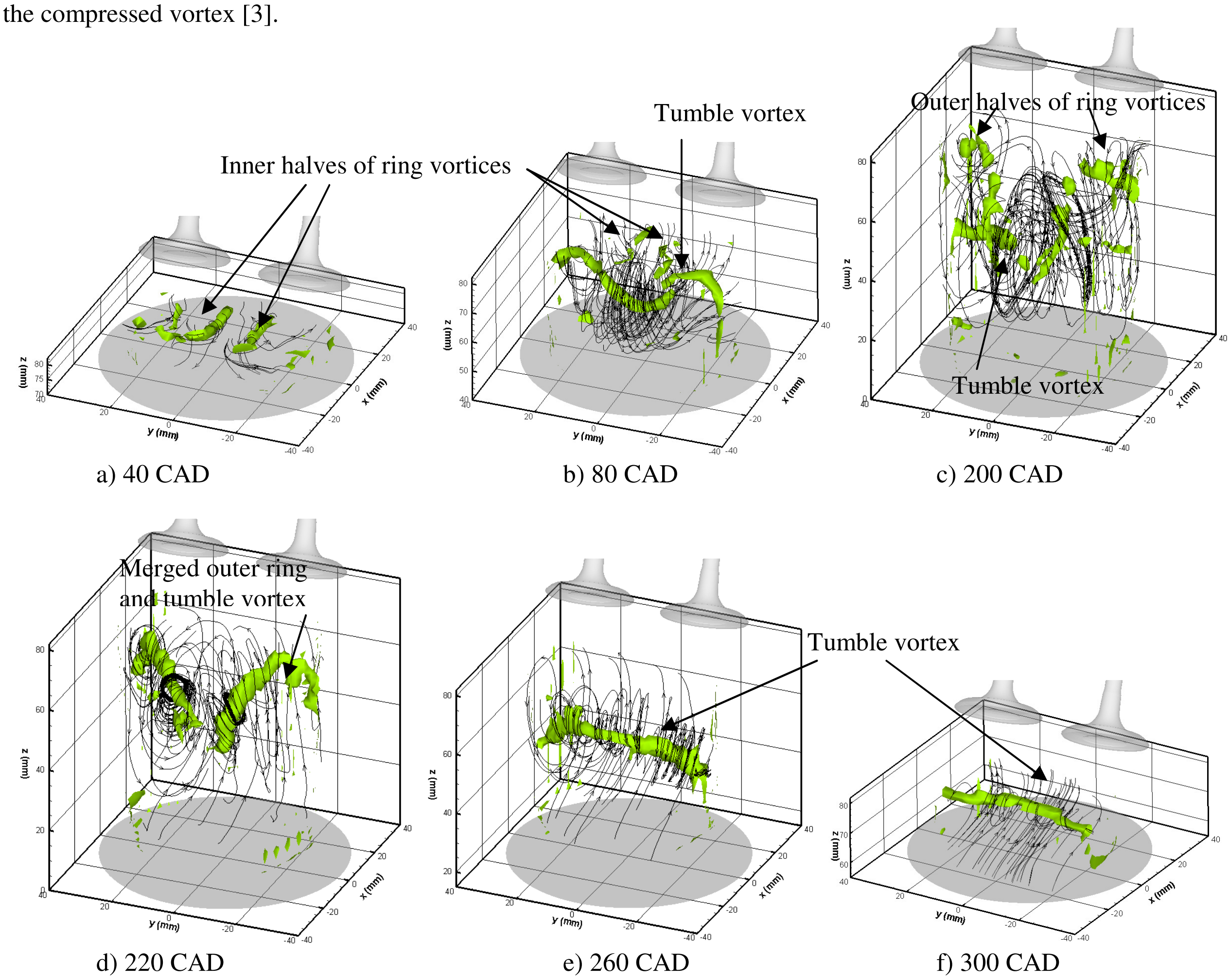

Figure 2 Isosurfaces of $\Gamma_1 = 0.8$ (min = 0, max = 1), at different crank angles after top dead center (CAD). Black lines: stream lines. Grey circle: piston. Valves: Intake valves.

CONCLUSIONS

The results describe the temporal evolution of the in-cylinder flow structures of an IC engine at the turning points of the vortex evolution using multi-planar stereoscopic PIV data. The results can help to better understand planar, single-plane flow measurements (such as high-speed, instantaneous PIV, or single-point techniques, such as Laser Doppler Anemometry (LDA)). Furthermore, the findings will help to validate instantaneous 3D-measurements, such as holographic (analogue) PIV, where the acquisition of many samples is time consuming. When applying holographic (analogue) PIV to this engine in the future, it is recommended to start measuring the flow structures at late crank angles where the fluctuation level is low, since a reduced number of samples is then needed to reach reliable ensemble averages. The results will be helpful for estimating the fuel/air interaction (mixing) and flame propagation as well as validating numerical and tomographic data.

References

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