EXPERIMENTAL INVESTIGATION OF CHARACTERISTICS TURBULENCE USING AERONAUTICAL INTERNAL COMBUSTION ENGINE

Adriana Aparecida dos Santos Costa, est-at@ipev.cta.br
Instituto Pesquisa e Ensaios em Voo
Endereço: Praça Marechal Eduardo Gomes, 50 - Vila das Acácias
CEP.: 12.228-904 - São José dos Campos – SP – Brasil

Cristiane Aparecida Martins, cmartins@ita.br
Instituto Tecnológico de Aeronáutica
Endereço: Praça Marechal Eduardo Gomes, 50 - Vila das Acácias
CEP.: 12.228-900 - São José dos Campos – SP – Brasil

José Luz Silveira, joseluz@feg.unesp.br
Universidade Estadual Paulista – UNESP – Campus de Guaratinguetá
Endereço: Av. Ariberto Pereira da Cunha, 333 – Pedregulho
CEP.: 12.516-410 - Guaratinguetá – SP - Brasil

Abstract. *This work presents a proposal of experimental investigation turbulence characteristics inside IO-540-K1D5 engine using particle image velocimetry. The turbulence inside combustion chamber is critical in combustion process because it needs to have high energetic efficiency and control particulate material emissions. Controlling correctly responsible parameters for performance is an effective way to obtain high energetic efficiency and a clean combustion. Basically, there are two kinds of diagnostics techniques when it is necessary experimental studies. They are intrusive and non-intrusive diagnostics techniques. In general, intrusive are cheaper and does not demand much expertise regarding non-intrusive techniques. Meanwhile it presents minor temporal and spatial resolution. Non-intrusive techniques have several advantages, but they depend on largely of the quality of the DOE (Design of Experiment), the precise knowledge and control of boundary conditions as well as the physical process to be monitored (particle sizing, velocimetry, mixture process or combustion). It needs much more financial resources and researchers with a lot of experience. It is an unquestionable fact that non- intrusive diagnostics techniques are powerful tools to analysis combustion process. In particular, engine stroke process presents a great challenge. There are several simultaneous phenomena which occur in critical conditions. Here are showed one non-intrusive method to analyze the characteristics of flow aspirated into the combustion chamber and how these characteristics can affect the combustion process. This technique is Particle Image Velocimetry (PIV). In this work used Particle Image Velocimetry measure the velocity field of particles in a plane of the flow, swirl and tumble. A good swirl and tumble promotes fast combustion, improves the process efficiency of the engine and reduces pollutant emissions. Therefore, this work may subsidize new projects aero improving performance and reducing emissions to the environment.*

Keywords*: particle image velocimetry, swirl, tumble, combustion.*

1. INTRODUCTION

PIV is used in measuring the velocity field of particles in a plane of the flow. A pulsed laser and suited optics are used to create a planar laser sheet through the flow. The seeded flow particles are then illuminated by the high energy laser pulse and a high-speed camera records their position at that time. After a selected amount of time, another laser sheet is produced by a second pulse and the particle's positions are once again recorded by the camera. This allows one to determine the distance and direction that each particle traveled during the time between pulses. In this work has been used a stereoscopic PIV (3D PIV) and it allowed to measure 3 true displacements (d_x, d_y, d_z), three true velocities, swirl, tumble e cross-tumble number.

Swirl and tumble motion are two important parameter for computational fluid dynamics (CFD) simulations of engines. Swirl is used to describe circulation about the cylinder axis. The intake ports at the top provide the tangential component of the flow necessary for swirl.

Some gas engine components require a tumble motion flow pattern in order to mix fluid with oxygen. Tumble flow circulates around an axis perpendicular to the cylinder axis, orthogonal to swirl flow. Figures 1 and 2 show swirl and tumble motion.

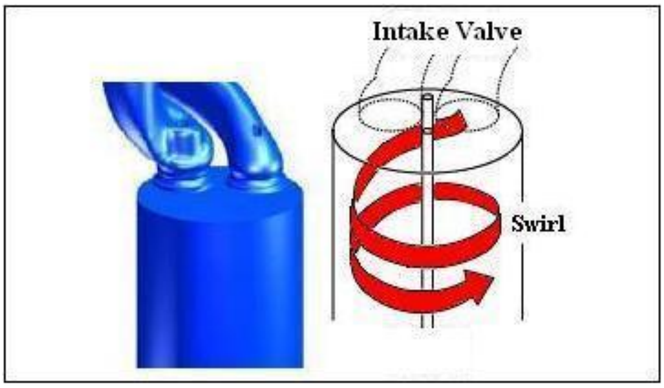

Figure 1. Swirl motion (Laramee et al., 2004).

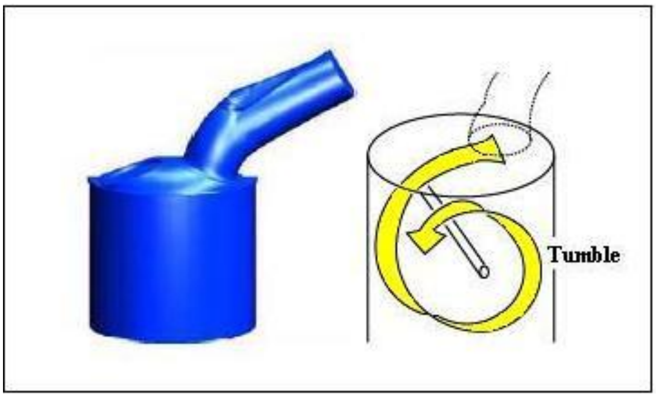

Figure 2. Tumble motion (Laramee et al., 2004).

The structure of the turbulence flow field in the cylinder of an internal combustion engines is a dominant factor in the combustion process. By way of enhancing pre-ignition turbulence, fast burning rates, reduced cyclic variability, improved fuel economy and reduced exhaust emissions (via enhanced operability with lean/dilute mixtures) can be realized for spark-ignition engines (Liu et al., 1996) .

1.1. Internal Combustion Engine's Characteristics

The Lycoming IO-540-K1D5 engines are horizontally opposed four-cylinder, direct-drive, air-cooled models. The cylinders are of conventional air-cooled construction with heads made from an aluminum-alloy casting and a fully machined combustion chamber. Table 1 presents engine characteristics.

Table 1. Engine aircraft characteristics (LYCOMING, 2007)

Type	4 Stroke SI
Number of cylinder	2 + 2 boxer
Compression ratio	8.5:1
Stroke (inches)	4.375
Bore (inches)	5.125
Cubic inch displacement	360
Rated horsepower	180 hp @ 2700 rpm

2. TEST BENCH ARRANGEMENTS

Particle Image Velocimetry (PIV) is an optical measuring technique for determination of local velocity distributions in flow planes. The technique makes use of the scattered light of tracer particles which are introduced into the flow field under investigation. A pulsed Nd:YAG (Yttrium - Aluminum – Garnet) laser serves as a light source to generate a thin light sheet which is brought into the flow field by means of a system of optical lenses. During a PIV analysis, a plane of the flow field is lighted by two consecutive light pulses.

The particles which are introduced into the flow are illuminated and thus made visible when moving through the laser sheet. The scattered light within the sheet is imaged by high-resolution cameras under a specific observation angle. Local velocities can thus the determined by registering particle displacement during the time interval between the light pulses. The analysis of two consecutive images is performed using cross correlation techniques which yield vector of particle displacement in the investigate flow plane. In case that the time interval between the two laser pulses is sufficiently short, the trajectory of the particles is approximately linear and the velocity along this distance constant (Funken et al, 2008).

The test bench is equipped with 3D-PIV calculator including the data and management software LabView. The test bench is showed in Fig. 3 and the experimental conditions are given in Tab. 2. The cylinder's diameter (D) is 113 mm.

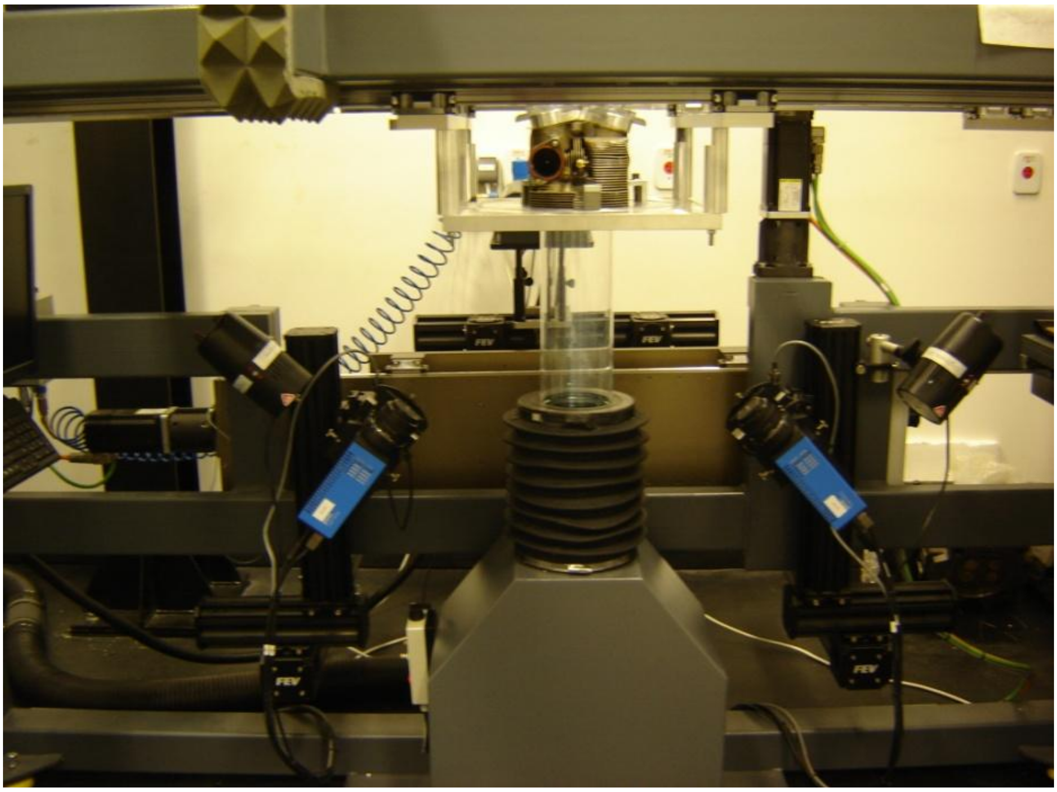

Figure 3. Test bench

Table 2. Conditions for swirl and tumble measurements

Distance from intake valve (mm)	Intake Valve Lift (mm)	Swirl Measurement	Tumble Measurement
0.25D	11	Yes	No
0.5D	11	Yes	No
1D	11	Yes	Yes

3. DETERMINATION OF FLOW COEFFICIENTS

The characteristic numbers used to describe in-cylinder charge motion are swirl, tumble and cross-tumble. For detailed analysis only parts of the cylinder can be investigated so that characteristic numbers for specific regions can be evaluated.

The definitions of the characteristics numbers are illustrated in Fig. 4. In the picture the intake ports and the cylinder liner are illustrated further more a coordinate system and the flow rotation definition is shown.

Figure 4. Cross-tumble (Tr_x), tumble (Tr_y) and swirl (Tr_z) number

The numbers are calculated with the measured velocities from all three directions in space. The numbers are a ratio of angular velocities of a rigid body motion and the average axial velocity ca. The angular momentum calculated with the average axial velocity is normalized with the bore diameter. The rigid body angular velocity is the ratio of an angular momentum and the inertia momentum. It can be assumed that the density (ρ_i) in the interrogation áreas are the same, futhermore all interrogation areas (A_i) have the same size. That's the reason why the density and the areas can be cancelled.

$$T_r = \frac{\omega_{rigid\_body}}{\omega_{c_a}} \tag{1}$$

$$\omega_{rigid\_body} = \frac{Angular\_Momentum}{Inertia\_Momentum} \tag{2}$$

$$\omega_{c_a} = \frac{\pi D_{cylinder}}{4 c_a} \tag{3}$$

Using the definitions is possible to obtain Trx, Try and Trz (Funken et al., 2008)

$$Tr_x = \frac{\pi}{4} . \frac{D_{cylinder}}{c_a} . \frac{\sum_{i=1}^{n}(w_i y_i)}{\sum_{i=1}^{n}(y_i^2)} \tag{4}$$

$$Tr_y = \frac{\pi}{4} . \frac{D_{cylinder}}{c_a} . \frac{\sum_{i=1}^{n}(-w_i x_i)}{\sum_{i=1}^{n}(x_i^2)} \tag{5}$$

$$Tr_z = \frac{\pi}{4} . \frac{D_{cylinder}}{c_a} . \frac{\sum_{i=1}^{n}(v_i x_i - u_i x_i)}{\sum_{i=1}^{n}(x_i^2 + y_i^2)} \tag{6}$$

4. SWIRL RESULTS

The position of the intake and exhaust valves and the position of the spark are essential for analyzing the results of swirl, tumble and cross-tumble. Fig. 5 shows the location of these components and presents the velocities V_x, V_y and V_z projected on the XY plane. From Fig. 5 it is possible to observe the formation of two vortices in the direction of the cylinder axis, which characterizes the swirl. These vortices have cores well-defined with opposite directions. This behavior decreases the swirl number calculated due to the fact that they have opposite directions. However they increase the energy inside the cylinder due to the collision of particles. The cores are located near the swirl zero position of the axis y.

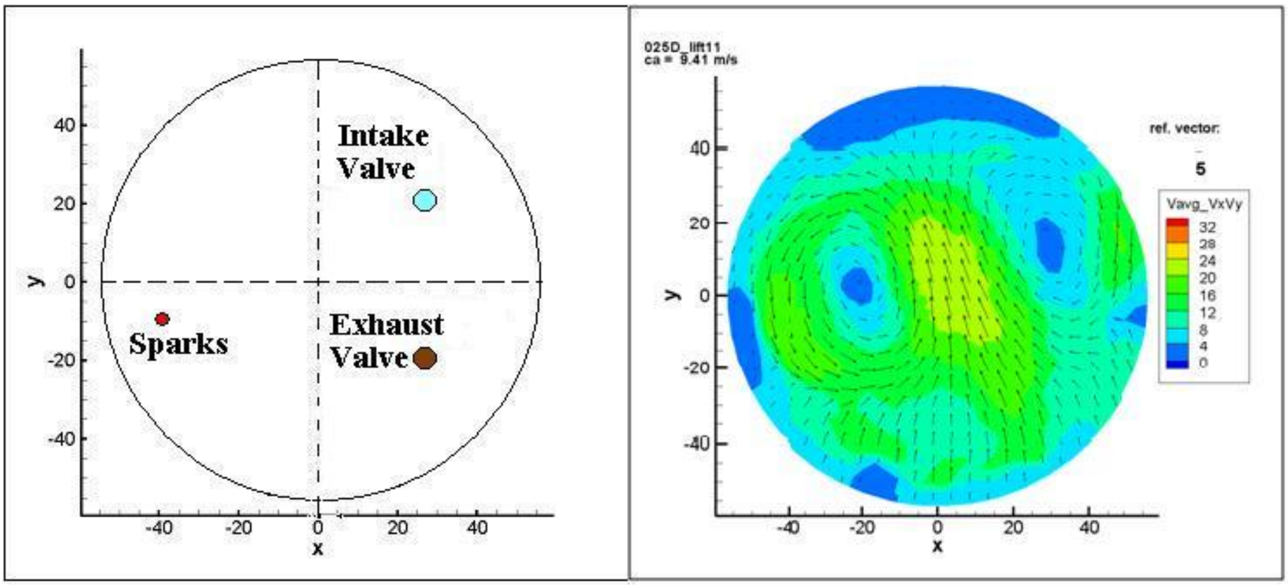

Figure 5. Sparks, intake and exhaust valves position and velocity fields image using swirl plane

Figure 6 shows the swirl number as a function of distance from the inlet valve. The swirl increases with the opening of the valve due to the greater amount of flow into the cylinder. The higher the flow, the turbulent flow and the greater the influence of the geometry of the valves and gateways. The swirl mostly influenced by the geometry of the system than by the position of the measure, since positions in far more remote from the swirl intake valve tended to stabilize faster.

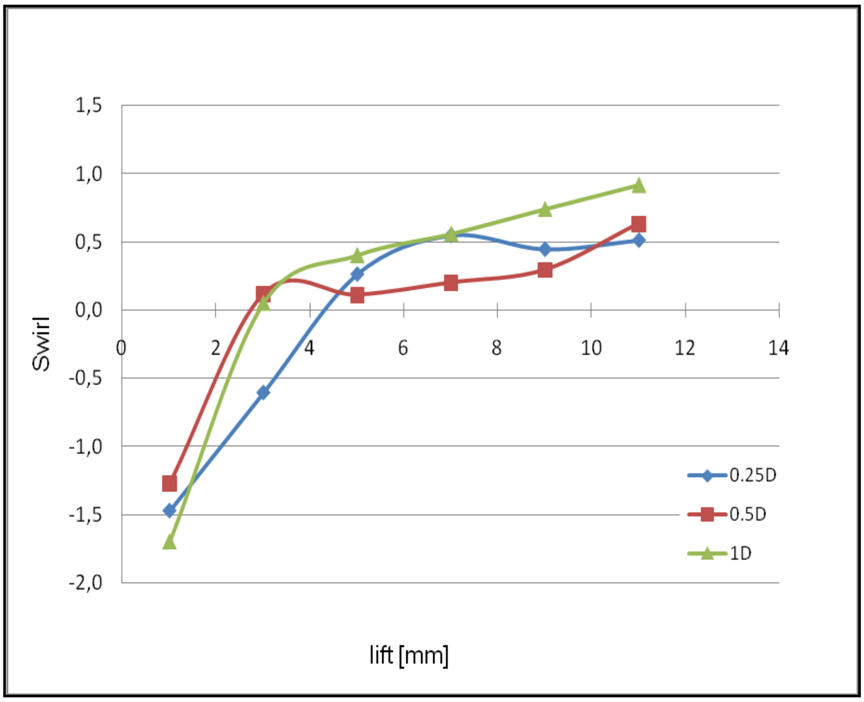

Figure 6. Swirl behavior

5. TUMBLE RESULTS

In Fig. 7 is showed the projected velocity vectors in the plane of tumble and the distribution of axial velocity w (velocity in z direction). From Fig. 7 one can conclude that:

- The distribution of velocities, kinetic energy and therefore is not symmetrical, since there is a higher concentration of kinetic energy in the quadrant (+ x + y), since Vw is the largest of the three speeds;
- The geometric position of the inlet valve causes a vortex around the axis Z featuring tumble;
- When measurements are carried out tumble the y direction becomes the direction of flow and consequently the highest intake valve openings imply higher values of velocity v;
- As the intake valve opens a movement appears to tumble in the quadrant (x, y) in the opposite direction to that produced in the plane (-x,-y). This effect gives a reduction in the number of tumble;
- Higher values of velocity component in Z are obtained near the spark plug to facilitate the start of combustion.

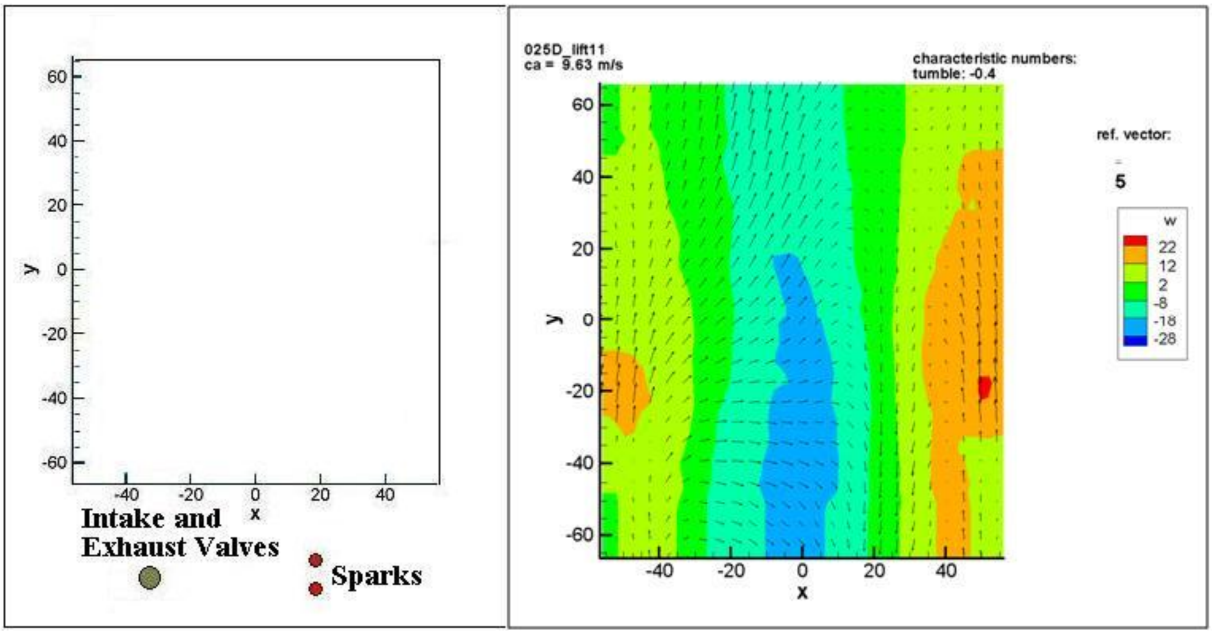

Figure 7. Sparks, intake and exhaust valves position and velocity fields image using tumble plane

The Fig. 8 shows that tumble number increases with the valve opening, reaches a maximum and back down. The tumble has gone through a minimum near the intake valve opening of 7 mm and subsequently the value of opening the same is growing again. This behavior is intrinsically linked to the project head, gateways and intake and exhaust valves.

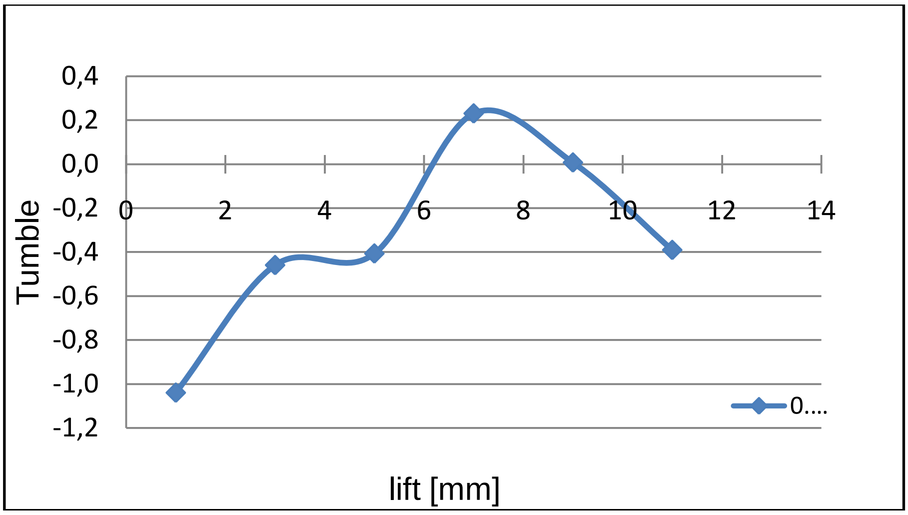

Figure 8. Tumble behavior

6. CONCLUSIONS

From the experimental study of characteristics turbulence flows in a aeronautical internal combustion engine using PIV, the following conclusions are drawn:

- There are two vortices in the direction of the cylinder axis, which characterizes the swirl and they have cores well-defined with opposite directions, decreasing swirl number. These vortices increase the energy inside the cylinder due to the collision of particles;
- The swirl increases with the opening of the valve due to the greater amount of flow into the cylinder;
- The swirl mostly influenced by the geometry of the system than by the position of the measure, since positions in far more remote from the swirl intake valve tended to stabilize faster;
- In tumble analysis it is possible to observe that the distribution of velocities, kinetic energy and therefore is not symmetrical and Vw is the largest of the three speeds;
- The geometric position of the inlet valve causes a vortex around the axis Z featuring tumble;
- Higher values of velocity component in Z are obtained near the spark plug to facilitate the start of combustion;

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