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LASER VELOCIMETRY APPLIED TO ENERGETICS STUDIES

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Abstract

Two laser velocimeter are presently used by Energetics Department of ONERA on several experimental sets up. The aim of these determinations is to valid mathematical models of computation.

The fringe laser velocimeter (LDV) is devoted to measurements with combustion. Recirculation zones are studied behind a step and into a 2D experimental model of combustion chamber.

The two focus velocimeter is in operation on an experimental low speed centrifugal compressor and is used in conjunction to LDV to determine the aerodynamic field close the intake valve of a motor engine.

I. Introduction

The fast increase of computer system leads to use more and more performing theoretical methods and to develop more and more mathematical modelisations.

Their validation nevertheless requires a similar evolution of measuring instrumentation in order to permit local measurement in zones until difficult to be accessed by means of classical probes.

It is the case in combustion chambers where the very high ambiant temperature imposed the use of efficiently cooled probes. These thermical protections required large bodies dimensions of which were modifying the aerodynamic field to characterize. It is the case, when the transit of movable pieces, as blades of turbines or cylinders of motor engines, limits the investigations to surface measurements too. Just same local results can be obtained by use of detectors located on fixed parts or by means of movable detectors sticked on the surfaces of the moving parts with acquisition signals by rotating contacts, magnetic fields or HF emission. The achievement of the studies made during the ten last years about high power laser had then open the way to non intrusive optical methods use of which is now well generalised.

It is why the Energetics Department of ONERA purchased two different velocimeters in order to equip its experimental facilities.

The first is a fringer laser velocimeter (LDV) studied and built by the Physical Department of the Office [1]. The second is a two focus system studied by Dr.Schodl in DFVLR and manufactured by POLYTEC Sté [2].

Their essential characteristics are gathered in table I. It is very important to notice that these two instruments are not competetive but that each of them has its own domain of application.

Among the fundamental criterions which will oriented the experimentalist's choice we have to notice :

- the acquisition time
- the incidence of laser beams and the location of the measuring volume
- the flexibility of use.

The probability that an emitting particle cross over the two focus points of the L2F is much smaller than those required to pass through the ellipsoid measuring volume of the LDV and a lot of measurements, for several angular positions are necessary to know the direction of V.

The LDV will be imposed as soon as the acquisition time will be limited by secondary effects like overheating, fast combustion, instationnary measurements...

Unless, if the incidence exceeds some degrees, the focus spots, usually circular, become in shape of very narrow ellipses.

The same probing, using a LDV will not induce an important distorsion of the fringe network but only a slight translation of the measuring volume. This displacing can be easily take into account by an elementary optical calculation.

An other point is that if the two apparatus always give the velocity components in a plane (P) perpendicular to the incident laser beam axis, measurements by L2F is impossible as soon as the angle between velocity vector V and this plane P is up to 45 degrees.

This reserve eliminates the use of the L2F when the local turbulence is higher than about 20%. Furthermore, it have to be keep in mind that, for the models used in ONERA, the flexibility of the L2F is higher than those of the LDV.

L2F had not to be realigned before each new group of measurements and its compactness authorizes its use even in close spaces.

To image these uses of laser velocimeter we shall review the last experiments performed in the Center of Palaiseau and shall give the principal results we have obtained.

II. Application to combustion chambers - Determination of recirculation zones

II.1 Propagation of a turbulent flame stabilized by a step

This particular set up is devoted to the study of a very simple flow in which a recirculation zone is initiated by an abrupt fall of the floor (Fig. 1).

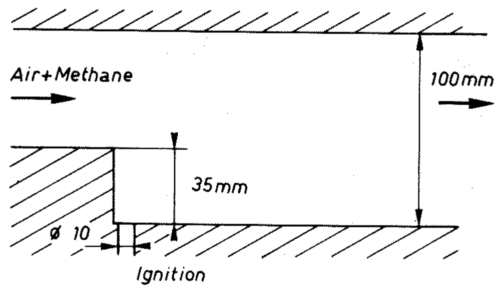

Fig. 1 : Experimental set up

This situation try to modelise some configurations encountered in combustion chambers and to compare results obtained by experimental way and by theoretical computations. The set-up devoted to the study of turbulent flame3 is equipped with a rectangular vein (65 x 100 mm) which opens on a square section element (100 x 100 mm) by a step of 35 mm high. The lateral parts are made of two large silicate windows which authorize an important domain of probing.

Gaz flow is injected at 580 K temperature and 1,1 bar pressure. It is composed of a mixing flow of air and methane. Experiments are carried out without and with combustion (φ=0,8).

A hole, 10 mm diameter, drilled in a vertical median plane, close to the step is use to inject the gas which ignits the principal flow at the beginning of each run.

These configuration which had been retained in order to keep the symetry, slightly modifies the aerodynamic field very close to the step and measurements are not take in account in this region.

The facility is not cooled so that for each run after 20s of stabilisation, data have to be recorded in less than 20s duration time.

This condition stands to reason why LDV is systematically used for all these experiments. In order to get a good signal/noise ratio the velocimeter works in forward scattered light mode and uses a reverse optical arrangement giving a better steadiness.

For each location of the measuring volume histograms are established on a sampling of 1000 valided particles. By a subsequent analysis are computed :

- the axial and transversal components of the velocity (u,w)
- the fluctuations of these components ($\sqrt{u'^2}$, $\sqrt{w'^2}$)
- the Reynolds stress (u'w')

From these results, it is possible to determine the limits of the recirculation zones, by drawing the trajectories[4]. These trajectories are obtained by numerical integration of the differential equation :

$$\frac{dx}{u} = \frac{dz}{w}$$

Fig. 2 shows the good agreement between values obtained by this way and those issued from a numerical method using a finite volume analysis applied to a 2D rectangular mesh.

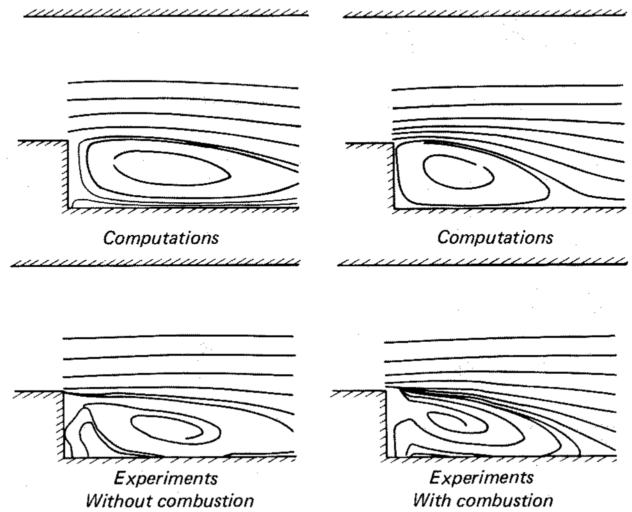

Fig. 2 : Experiments - Computation comparison

II.2 Modelisation of an elementary sector of combustion chamber

How it is difficult to closely modelize a sector of an industrial burner, a 2D simplified set up was built.

The theoretical mesh introduced in computation and based upon a bidimensional configuration, is maintained.

So that the circular injection holes of the combustion chamber are replaced by square openings (40 x 40 mm) and 3 pipes of square section (20 x 20 mm) put in place of the cylindrical injection pipes.

Fig. 3 gives a schematic view of the arrangement. The main flow is a pure air 950g s^{-1} flux. It is injected in the set up from the upper left side.

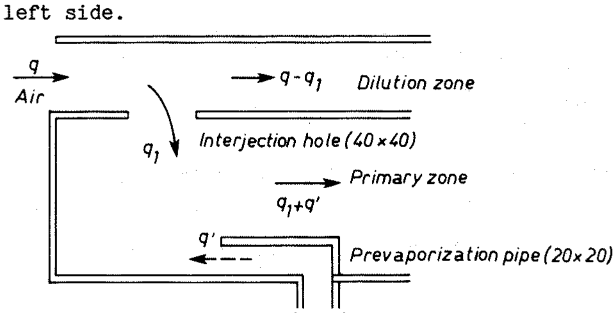

Fig. 3 : Schematic view of the set up

This flow is then divided in two parts :
- $q-q_1$ which is directed toward the dilution zone
- q_1 which is introduced into the primary zone through the injection holes.

This flux q_1 is mixed with the flow q' which is added by means of the injection pipes directed towards the rear of the chamber. This configuration induces two vortex, axis of which are parallel to oy.

The former is located between the injection pipes and the second, which is particularly studied is located on the left of the combustion chamber. The difference of the aerodynamic field in reacting and non reacting flow can be observed on figures 4 and 5.

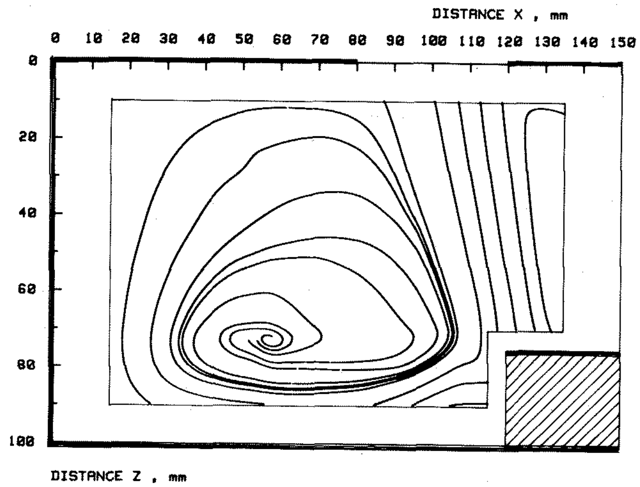

Fig. 4 : Trajectories without combustion

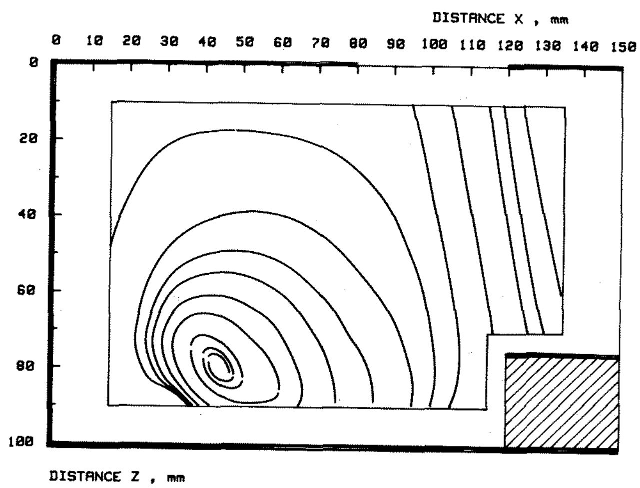

Fig. 5 : Trajectories with combustion

The total amount of measurement began in 1983[5] had been achieved so that it was now possible to use the method formerly described to draw the trajectories with and without combustion. We see that the combustion, increasing the velocities bends strongly the flow coming from injection pipes toward the floor and moves the center of the recirculation zone toward the rear of the combustion chamber.

These results (fig. 6) are confirmed by the 2D-theoretical results giving the aerodynamic field without combustion and 19 ms after ignition of the combustion[6].

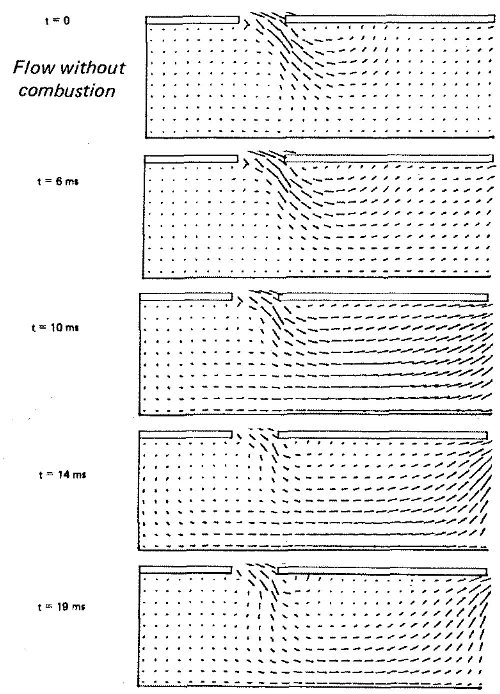

Fig. 6 : Location of recirculation zone during ignition phase

II.3 New experiments

Through this set up is not exactly the model of an industrial combustion chamber, results are of a great help in the validation of numerical model and it is planed to apply a similar technic to try to determine the aerodynamic fields in cases where the injection systems are equipped with a lot of swirls.

III. Compressor and motor engine applications

III.1 Experimental centrifugal compressor

The centrifugal compressor used for these experiments is the low speed research model (3000 r.p.m.) on which a lot of classical measurements was previously carried out[7].

The seeding were recently modified by use of a generator giving a better drop size distribution and very similar to those used by Dr. Schodl in DFVLR. In same time the computation of the histogram was improved.

Data are very closed to those previously obtained[5] and we can conclude that L2F is an apparatus well fitted for this kind of measurements so that we plane to made in next time new determinations on faster industrial comrpessors.

III.2 Motor engine

Improvement of motor engines can be obtained by a better knowledge of the flow closed to the intake valve. It stands to reason why several computation models are involved but it is very important to check their fitting with the real engine.

For this purpose a particular set up was built in which the valve is moved by means of an electrical motor. It is designed in order to simulate the cylinder, the cylinder head, the intake valve and the exhaust hole. The upper part is closed by a circular window made of glass.

To measure velocities closed to the exit of the valve, and the avoid reflection light on the head cylinder, the best way is to use the L2F.

Though the probing domain is quickly restricted because the angle between the velocity vector and the plane of the cylinder head becomes up to 45° and it will be necessary to made further measurements for which the optical axis of the L2F will be horizontal and to use a fringe laser velocimeter working in back scattered mode to achieve the probing.

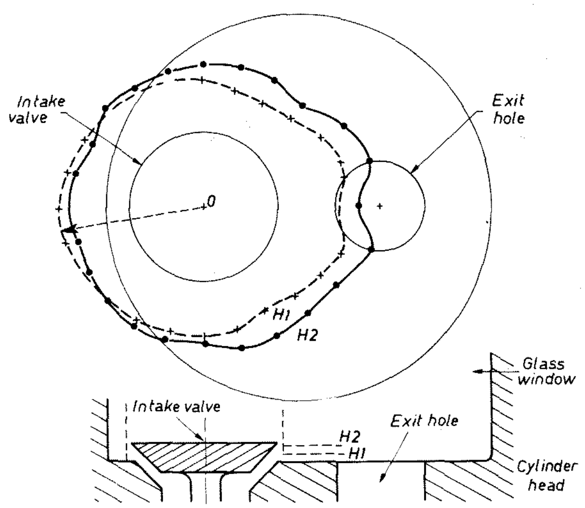

Fig. 7 : Radial profile of velocities

Nevertheless, fig. 7 gives the first results obtained around the valve on a circular probing (26,5 mm radius) for two level (h = 2,5 mm and h = 5 mm). The valve is set 2/3 of the total opening valve position (6,6 mm). This is an example of experiment for which it is convenient to mix the use of a L2F with a LDV in order to made measurements in a very large domain and here the character of complementarity of the two apparatus becomes obvious.

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Characteristics	LDV (ONERA)	L2F
Laser power	15w	2.5w
components	u et v simultaneously	Module $\vec{V}$ Arg $\vec{V}$ step by step
Measuring volume	Ø ≃ 200 µm Interfringe ≃ 10 µm n > 11 fringes	2 points Ø 10 µm distance d = 210 µm
Incidence	i ⩽ 60°	i ⩽ 5°
Direct approach	d > 5mm	d > 0.5 mm
Mode	Forward scattered light or back scattered light out of axis	coaxial back scattered light
Synchronisation	External (possible)	Internal (multi window operation)

TABLE I - COMPARISON OF CHARACTERISTICS OF LDV AND L2F