# EXPERIMENTAL CHARACTERIZATION OF INTERFACE PROPERTIES IN THE FRAMEWORK OF MultiSECtioning STRATEGY: PRELIMINARY RESULTS

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## Abstract
MultiSECtioning strategy has been proposed as a methodological procedure to pursue a sequential approach to the evaluation and verification of non premixed diffusion controlled combustion processes. The starting point is the well known result that, when a non diffusive tracer is introduced into part of the flow, it determines the establishment of an interface. An experimental system aimed at reproduce the evolution of an interface in controlled conditions is presented in the paper. The system has been purposely designed in order to be suitable for a direct experimental/numerical comparison. Some preliminary results, obtained in properly conditions, are presented and discussed.

## Introduction
All the combustion processes of practical relevance are controlled by great number of chemical and physical parallel subprocesses, often combined in “non linear way”, sometimes “in complex way” [1]. This implies that even if single submodels can be thoroughly validated for each of the “simple” subprocesses, their separated, effective and proper influence on the total process cannot easily evaluated.
For such reason, strategies which select particular submodels and which exploit them in such a way that split effects can be separately introduced in more and more complex processes, should be preferred to other ones. This strategy could be named “MultiSECtioning” Process Evaluation Strategy by means of Sequential Enlargement Combination of Separated Effects Contributions for Side-by-side Experimental/numerical Checking [2].
This strategy has been proposed as a methodological procedure to pursue a sequential approach to the evaluation and verification of non premixed diffusion controlled combustion. In the paper the first step of the MultiSECtioning strategy, namely the characterization of the interface kinematics, is analyzed in detail. The starting point is the well-known result that, when a non-diffusive tracer is introduced into part of the flow, it determines the establishment of an interface defined as the surface of the flow where the concentration of the tracer is discontinuous passing from zero to a finite value on an infinitely thin interval. The relevance of the interface comes from the consideration that it can be considered a

direct marker of the evolution of the stirring process and, for this reason, of the diffusive mixing one. Experimental evaluation of the interface is discussed in relation of an experimental test rig, which has been purposely designed in order to be suitable for the experimental/numerical comparison. The techniques of particle seeding and of optical characterization on the interface are thoroughly described in order to stress the constraints and difficulties, which have to be faced to obtain both single and statistical characterization of the interface. Some comparison between the different fluid-dynamic structures, obtained in properly conditions, has been reported here to give some preliminary results about the effect of the jet velocity on the interface structure.

**Experimental setup and procedures**

The experimental apparatus used in this work was aimed to reproduce the stirring/mixing characteristics of gaseous jets under the perspective of the theoretical analysis of the problem. The test section of the system (sketched in Fig. 1) is a glass windowed channel with 140 x 128 mm cross-section, designed to operate at atmospheric pressure and environmental temperature conditions.

In order to face the difficulty mentioned in the introduction, the first requirement of the experimental flow to be investigated was fulfilled by choosing a flow configuration which is 3-D planar symmetric. The generation of such flow was selected according to some general considerations about the turbulence level control and repeatability of inlet conditions. The phenomenological choice has been guided by feasibility criteria and by the deterministic behavior of the involved flows. Therefore the design of the mixing test was such that both the building of the experimental apparatus and the numerical simulations were possible and meaningful. In this respect the most important features were considered to be the turbulent and three-dimensional character of the flow, as well as the choice of well defined, stable and easy to implement boundary conditions. A further characteristic, i.e. the spatial periodicity of the flow, is quite desirable in a numerical simulation of the fluid-dynamic pattern. A honeycomb structure, formed by square channels with a cell size of 2 mm, is used to obtain the desired fluid dynamics conditions in the test section. The structure before mentioned has 35 channels along the x- direction and 32 channels in the other one. Therefore, the cross section of the test duct has a very large aspect ratio (10). The length of the single duct (30 mm) is much larger than their width so that self-similar velocity profiles can develop. Furthermore the duct widths are chosen so small that, for the employed average velocities, relatively low Reynolds numbers are obtained and laminar Poiseuille-type flows can be reasonably supposed to develop in every duct of the honeycomb structure. This means that natural boundary conditions are used. Finally, in order to control the streak-lines roll-up process, the central ducts of the honeycomb structure are fed with different average velocity with respect to the other ones. Special care is devoted to assure an even distribution through the remaining ducts. The generation of the interface is obtained by seeding the central part of the flow with submicron particles. The particles have been dispersed in the air flow by means of a fluidized bed [3]. The interface corresponds to the discontinuity in the 2-D laser light scattering intensity due to the discontinuity of the tracer concentration.

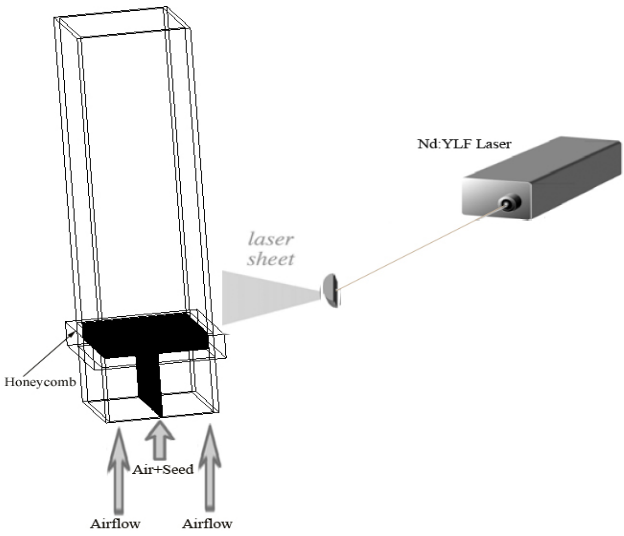
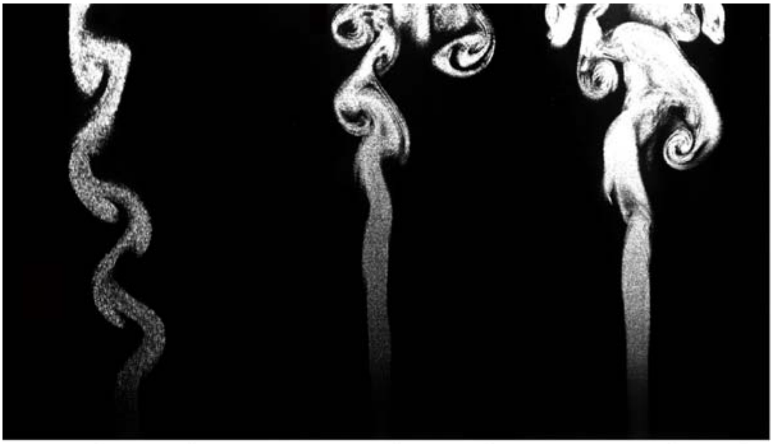



**Figure 1.** Sketch of the Experimental apparatus with the optical diagnostic.

In fact, an interface is formed by a tracer which, by definition, is a non-diffusing, fully convected material. This means that no gaseous components can be used for such a purpose because it is not possible to prevent their diffusion. However, the diffusion of particles dispersed in a gaseous medium can be considered negligible with respect to gaseous diffusion. In this case particles have to be dragged in such a way that they are representative of the gas displacement. It is worthwhile to note, that the type of particles, for which $Sc \gg 1$and $St \ll 1$, is the only possible choice of tracer in a gaseous system [4]. A particle, for instance, between 0.1 and 1 μm is sufficiently large in dimension to ensure that Brownian diffusion is low, but it is sufficiently small to immediately follow a flow. The optical characterization of the surfaces is performed by recording the pattern of the light elastically scattered when a laser sheet illuminates the tracer. The Nd:YLF pulsed laser was tuned on the second harmonic wavelength ($\lambda$ = 527 nm) and its beam was shaped by a set of cylindrical lenses to a sheet of constant thickness. It was varied in height by the extension of the objective field. Patterns of elastic scattered light was detected by a CCD camera with a variable-focus telescope. Since each pulse is in a different frame, there is no directional ambiguity for the velocity vectors. The time and space scales were limited by the laser thickness and the tracer production time and therefore are not sufficient for measuring any range of length scales. Nevertheless, they are smaller than interface separation distances and the residence time needed to characterize the prototypal flows presented here. A shadowgraphic scheme has been adopted to collect images of the jets, with a proper system of lens. The pulsed laser frequency is 1000 Hz, the digital camera acquire 8-bit 1280 x 1024 pixel frames at 1000 Hz, and a BNC delay generator has been used for time base generation and synchronization. For each test condition a set of 1000 frames has been collected. The study of mixing process between the central seeded jet and the air flow requires the estimation of fluid-dynamics properties of the gaseous streams at the test conditions. For which regard airflow velocity, has been chosen a velocity of 1 m/s that has been kept constant for all the experimental tests. These value have been chosen to reproduce transitional/turbulent flow conditions into the test section. In fact, at environmental pressure and temperature conditions, the mean Reynolds number into the chamber results about 4000. On the other hand, three different values of the seeding velocity has been chosen to evaluate the effect of the central flow velocity on the stirring process.

**Preliminary results**

In this paper a set of 3 experimental conditions has been investigated. The seeding flow of $TiO_2$ particles is injected, through a central slot composed by 32 square channels that have a cross section of 2 x 2 $mm^2$. The airflow is injected in the remaining part of the honeycomb structure at 1 m/s initial mean velocity at 300 K temperature, 1 Atm pressure. The reference condition features seeding injected at 0.7 m/s initial velocity, the second condition differs from the reference case as regards seeding velocity which is 2.5 m/s. Finally the third condition holds seeding pressure and temperature at the environmental conditions, but its velocity is modified to 4 m/s. It should be stressed that the airflow velocity was kept at the same value for all the conditions here investigated. Moreover Reynolds number increase slightly with the increasing of the seeding velocity. The overall behavior of the three jets under investigation are summarized in Fig. 2, which basically reports images of the Mie scattering signal over samples of 1000 frames. For the three investigated conditions the images share some different features in dependence of the turbulence level. The Figure 2 reports interface images in order to give an assessment of the great variety of structures which can be established in 3D flows. The sequence of consecutive visualizations is taken at a 1000 Hz frequency. The patterns show a formation of oscillations of the whole jet and of antisymmetric vortices when the seeding velocity is increased. Later on, the number of convolutions in each single spiral structure increases with the central jet velocity and some couples of these structures are more in phase in the sense that they are more symmetric than before. Each of this couple, that we call 'macro-structure', seem to shorten the distance from each other (not necessarily adjacent) and seem to pair by squeezing away one or a couple of spirals. Very large couples of spirals appear to be isolated with respect to the others, even though they are linked to the main spirals by extended filament-like structures. A sharp discontinuity of $TiO_2$ particle concentration is detectable in the first part of the pattern. The experimental results, here described, suggest that ensemble of structures, i.e. a simple multi-scale system, can be used in order to explore all possible evolution of the system itself. This tool can be exploited to identify mixing isothermal regimes and to give statistical averages of the most relevant parameter affecting the stirring/mixing process.



Vseed= 0.7 m/s    Vseed= 2.5 m/s    Vseed= 4 m/s

**Figure 2.** Laser light scattering pattern of the median seeded jet at $V_{air}$=1 m/s and for three different values of seeding flow velocities.

Moreover, it is worthwhile to note that the measurement methodology must be able to evaluate the most relevant quantities regarding the stirring process, like stretch rate, stretch ratio and interface density [5]. Some previous works [6,7], devoted to give an assessment of the great variety of structures which can be established in 2D flows, shows the presence of similar behaviour obtained here for a three-dimensional case. They provide a methodological framework, based on the evaluation of lagrangian quantities, by which turbulent diffusion flames might be classified by means of well-defined criteria.

**Discussion and Conclusions**

Complex reactive flow systems need proper strategies for their modeling. These strategies should at least have the common feature to be realistic and quantifiable in their realism. A strategy allowing for the analysis of the influence of single sub-processes on the system has been conceived. The MultiSECtioning strategy has been proposed as a procedure to the evaluation and verification of non-premixed combustion processes. In the paper, the first step of this procedure, namely the characterization of the interface kinematics, was analyzed in detail, taking into account the most relevant quantities that characterize the stirring process. The different types of surfaces can be properly exploited in a framework which included all their relations both with kinematic properties and with semi-empirical characteristics which can be obtained either by experimental or numerical analysis partly presented in the following. This type of methodological approach has been

explored in a systematic way by Candel and co-workers [8] in order to show the potentials of coherent flame description. The ensemble of these works has yielded a framework which in time has given the evolution equation of the surface density following the works of Pope [9] and Trouve et al. [10].
The experimental test rig for the analysis of the stirring process in terms of Lagrangian quantities is described for the characterization of a prototypical fluid-dynamic configuration with some preliminary results obtained by varying the seeding flow velocity. A final comment, devoted to the diagnostic aspects, concerns the difficulty of performing Lagrangian measurements in a wide control volume. In this work it was decided to keep the whole spatial domain of measurement as small as possible. This resulted in a characterization of a 2-D field by means of light scattering technique. Nevertheless, in both types of surfaces (interface and intermaterial surfaces) the diagnostics problem is the same. It consists of detecting the concentration of the tracers, which are submicronic particles produced by various types of methods.

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