Experimental investigation of a turbulent variable density jet impinging on a sphere

Marie-Laure Ducasse\textsuperscript{1}, Julien Dubois\textsuperscript{1}, Muriel Amielh\textsuperscript{1}, Fabien Anselmet\textsuperscript{1}

1: Institut de Recherche des Phénomènes Hors Equilibre, Marseille, France, \{ducasse,dubois,amielh,anselmet\}@irphe.univ-mrs.fr

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1. Introduction

Considering the use of hydrogen fuel cell in different applications (car vehicle, generator...) the risks related to hydrogen storage and the leak possibilities are to be considered. That is why, in a safety preoccupation, the dispersion of hydrogen due to any leakage has to be studied in detail, and especially, the identification and quantification of the main parameters that influence the dispersion of a gaseous leakage. Actually, the mixing behaviour of a variable density free jet are well known and described in the literature (Chen and Rodi 1980, Pitts 1986). However, the understanding of the influence of simple geometries (except plane and curve surfaces) on the jet dispersion presents a paucity of information. Therefore the aim of this work is to investigate the effects of a spherical obstacle placed in the near field of a jet.

To provide some response elements, an experimental work has been lead with an optical and non-intrusive measurement technique: the background oriented schlieren (BOS). This schlieren technique has been developed since the 2000s, in particular by Richard and Raffel (2001) works. It is based on the detection of changes in local refractive index, and allows the observation of flow density variations. In this experiment, a non-reactive gas, helium, replaces hydrogen due to safety issues. As the helium density $\rho_{\text{He}}$ has the property to be close to the hydrogen one ($\rho_{\text{He}}/\rho_{\text{H}}=2$), the density difference between ambient and jet fluid will be similar, and thus, the gas mixing behaviour in the ambient air as well.

2. Experimental technique

The BOS technique uses simple optical equipment: a CCD camera (Kodak ES 1.0, 1008x1018 px) connected to a computer records images of a pattern on a white paper sheet, placed in the background and back lighted by an halogen lamp. The pattern of the background consists of tiny and randomly distributed dots generated by a black paint spray. These points appear with a 3 pixel size on the camera sensor. The pattern and the camera are placed on opposite sides of the studied flow presenting density space variations.

The light beams coming from the background will be locally deflected from their initial trajectories due to the presence of density gradients in the jet. This deflection, named $\varepsilon_{\gamma}$, leads to a displacement $\gamma$ of the background pattern on the camera CCD sensor (Fig. 1). Therefore, the recording set-up is composed of two steps, both of them realized with the camera focused on the background in order to obtain maximum contrast at high space frequencies. Firstly, a reference image of the background pattern is recorded without flow. In the second step, the visualization is realized through the jet. Cross-correlation between the two images allows obtaining the local displacement field of a group of pixels, due to variation of the local refraction index of the jet. This correlation process is a merely particle image velocimetry algorithm. Finally, an average of fields of BOS cross-correlation is computed. The results presented in this paper are obtained from an average of 200 fields for a typical investigated area of 200x200mm$^2$.

3. Results

First, the validation of BOS technique is performed on a helium subsonic jet developing in the ambient air, and the effects of the obstacle are studied through the jet development and helium dispersion. Several configurations of impinging jet on spheres are tested, including different parameters such as the nozzle exit diameter $D$, the obstacle diameter $d$, and the impingement distance $X_{\text{imp}}$. As a first step, the self-similar behaviour of the impinging jet is checked, and the influence of the sphere presence on the jet development is investigated through the mass concentration of axial decay and Gaussian radial profiles, and the spreading rate of the jet in the impact region. Eventually, mean mass and volume fraction fields are determined for impinging helium jets with a sufficient spatial resolution so that equivalent H$_2$-flammable volumes can be estimated and compared to the free jet case.

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