Collective Interactions in High Frequency Combustion Instabilities.

C. Rey†, S. Ducruix†, P. Scouflaire†, L. Vingert‡ and S. Candel†

†Laboratoire E.M2.C.
Ecole Centrale Paris and C.N.R.S.
F-92295 Chatenay-Malabry Cedex
Fax: (+33-1) 47 02 80 35
cedrey@em2c.ecp.fr

‡ONERA
DEFA/PLAP
F-91120 Palaiseau

Keywords : Multi-phase Flow - Combustion - Acoustics - Aerodynamics

Combustion dynamics is a central problem in many practical applications. This is the case, for example, in high performance rocket engines. The instability involves a strong coupling between combustion and acoustic modes of the chamber which lead to high amplitude oscillations. In liquid propellant rocket engines the most unstable motions are found in the high frequency range and they are coupled by tangential or radial modes (see for example [1]). The transverse mode produces a sloshing motion of the multiple jets originating from the chamber backplane. Neighbouring jets of reactants can interact very effectively and thereby produce localized sharp combustion fluctuations [2]. In typical geometries the reactive jets are closely packed and one can imagine that a mechanism of collective interaction may constitute the source of instability. The transverse acoustic mode causes modulation of the multiple injectors which will respond differentially because of their different positions with respect to the acoustic modal structure. The reactant jets often feature a low speed inner core which behaves like a wake. These jets or compound jet/wake flows interact with one another and generate spots of combustion fluctuations. If these perturbations in reaction rate occur in phase and are well-localized with respect to the acoustic mode, the Rayleigh criterion will be satisfied and a combustion instability will be induced [3,4].

This paper aims to give some experimental results on the latter process. Systematic experiments have been carried out on a new Multiple Injector Cryogenic Combustor (MIC Combustor) mounted on the Mascotte cryogenic combustion facility [5] at a mean pressure around 1 MPa. A schematic view of the MIC together with the experimental configuration is represented in figure 1. The injection backplane of the test chamber comprises three coaxial LOx/GH_2 injectors which are close enough to allow interactions between adjacent jet flames when destabilized by the modulation. The MIC is also equipped with two lateral quartz windows allowing natural OH radical emission imaging of the reactive flow as well as imaging by backlighting. Two intensified CCD cameras are used to this purpose. The combustor is equipped with a modulator nozzle. The throat of this device is periodically blocked by a toothed wheel generating cyclic perturbations in the chamber. Four pressure probes are flush mounted on the chamber upper and lower walls and detect acoustic signals in two axial sections of the combustor. The signal from a photodiode mounted on the modulation wheel can be used to trigger the two CCD cameras to get phase-locked images of the flame region.

A preliminary acoustic characterization of the chamber under hot fire conditions is carried out. The modulation signal delivered to the wheel is ramped up beginning at 40 Hz, and ending at 3800 Hz. The frequency is increased linearly over a time period of 9.4 s. A short time Fourier transform analysis of the pressure signal exhibits three resonant peaks. The first tangential mode is found at 3330 Hz. This is close to the frequency determined theoretically.

It is then possible to excite the MIC on its first tangential mode by ajusting the rotation frequency of the modulated nozzle wheel. Figure 2 shows the time averaged radical OH emission images in the unexcited case and in the excited case at 3330 Hz. One notices a change of flame shapes between situations where the modulation is on or off. When excited the three flames are shorter and localized spots of heat release are formed in the downstream region. Phase conditioned emission and backlighting images will be used to analyse the coupling between combustion and the transverse acoustic field.

References

[1] Yang, V. and Anderson, W., editors. *Liquid Rocket Engine Combustion Instability*, volume 169 of *Progress in Astronautics and Aeronautics*. AIAA, Pennsylvania State University, 1995.

[2] Poinsot, T., Trouvé, A., Veynante, D., Candel, S., and Esposito, E. *Journal of Fluid Mechanics*, 177:265–292 (1987).

[3] Lord Rayleigh, J. *Notices of the proceedings members of the Royal Institution (of Great Britain)*, 3:536–542 (1878).

[4] Lord Rayleigh, J. *The theory of sound*, volume 2. Dover, New York, 1945.

[5] Juniper, M., Tripathi, A., Scouflaire, P., Rolon, J., and Candel, S. *Proceedings of the Combustion Institute*, 28:1103–1109 (2000).

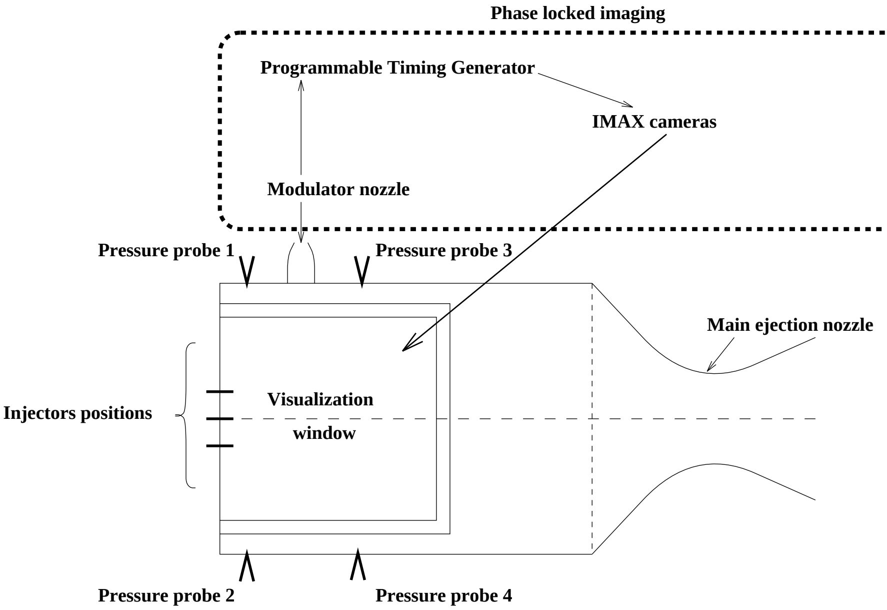
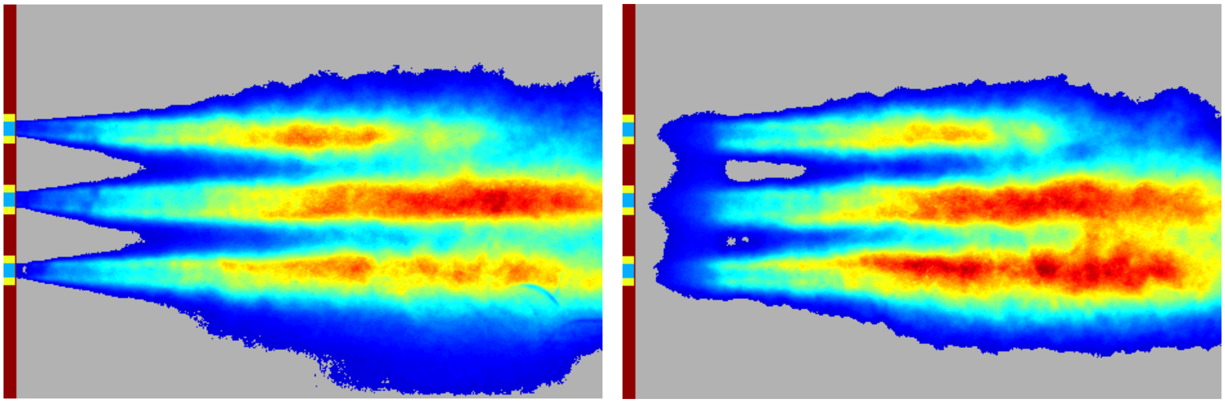


Figure 1: Experimental set up.



(a) Unexcited case.

(b) Modulation at 3330 Hz.

Figure 2: Time averaged natural OH radical emission images of the whole combustion chamber.