Impact of gas turbulence on the instability of a two-phase mixing layer

Sylvain MARTY (doctorant)

Alain CARTELLIER, Jean-Philippe MATAS

LEGI

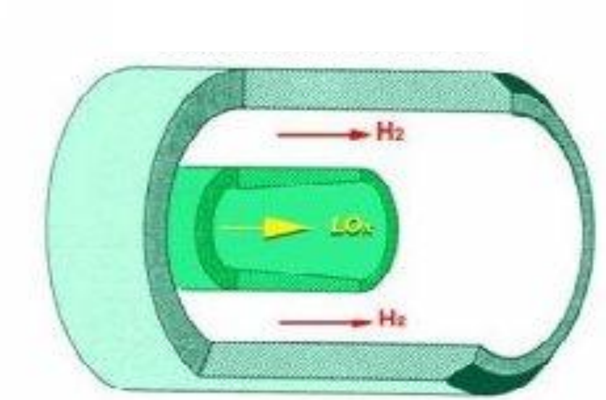
LABORATOIRE DES ECOULEMENTS GEOPHYSIQUES ET INDUSTRIELS

Liquid atomization

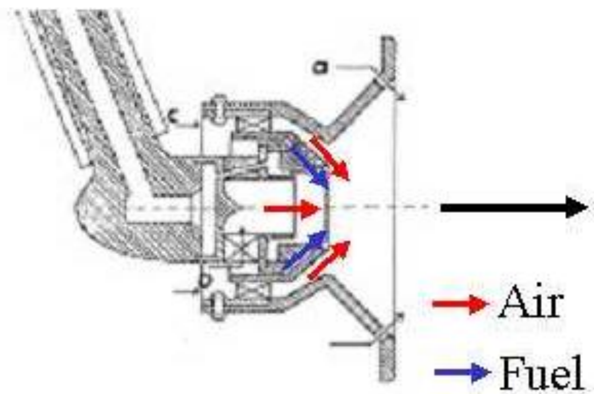
Gas assisted atomization used to strip droplets out of a continuous liquid stream:

smaller droplets = better combustion

Cryogenic engines



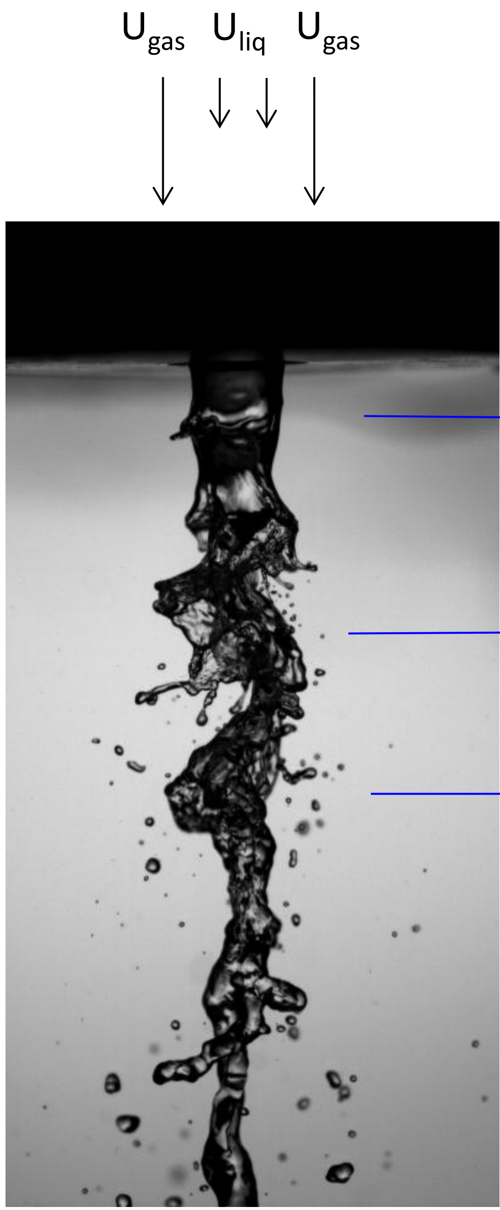
Turboreactors



Marmottant & Villermaux (JFM 2004)

Past theses at LEGI: L. Raynal (Hopfinger & Villermaux), P. Marmottant (Villermaux), M. Hong (Cartellier & Hopfinger), F. Ben Rayana (Cartellier & Hopfinger)

Liquid atomization



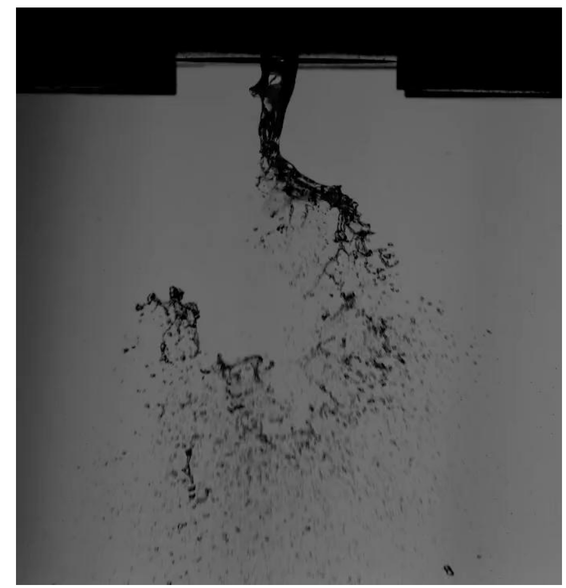
Successive mechanisms in spray formation

Longitudinal shear instability

Transversal instability: Ligament formation

Droplet formation

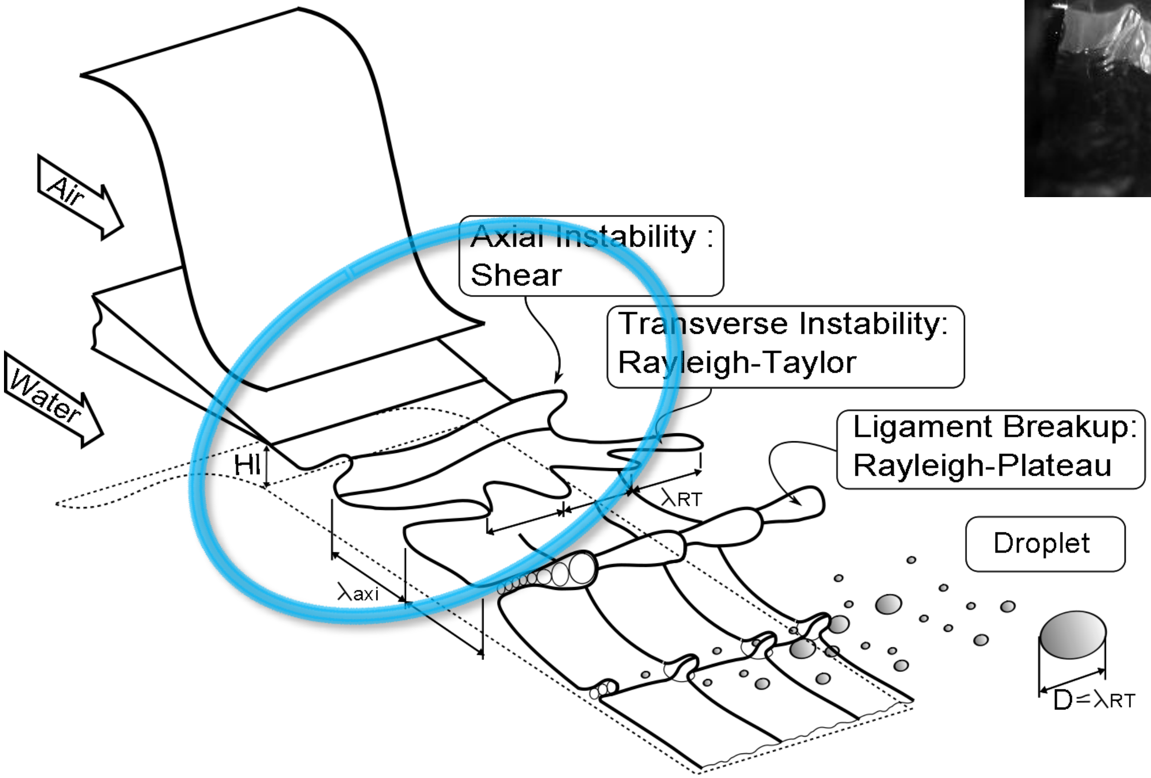
Flapping instability



Shear instability

Thesis of Sylvain Marty (co-adv. with A. Cartellier)
ANR VAA

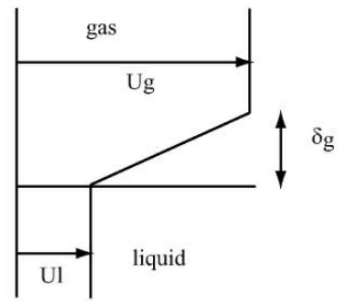
Mixing layer configuration



Mechanism?

- Raynal (1997) and Marmottant & Villermaux (JFM 2004):
  Simple temporal **inviscid** stability analysis accounts for experimental scaling of wavelength/frequency:

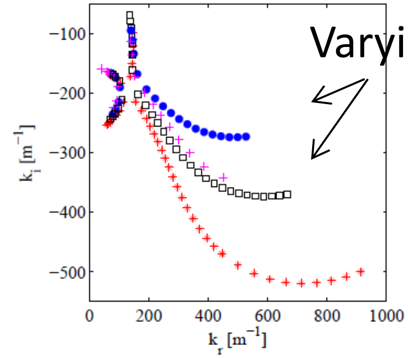
  $\lambda \sim (\rho_l/\rho_g)^{1/2}\delta_g$ and $f \sim (\rho_g/\rho_l)U_g/\delta_g$



  Basically: $d(ec)/dt = \rho_g u_i u_j D_{ij}$
  $\rho_l\, u^2\omega = \rho_g\, u^2 Ug/\delta_g$

- Temporal viscous stability analysis fails miserably (wrong f, λ, velocity etc): why does **simpler inviscid approach** succeed in the 1st place??

- **Answer**:
  - viscous mode + **absolute instability** triggered by confinement (finite liquid and gas stream thicknesses)
  - But pinch point at "low" wavenumber: perturbation fed by Reynolds stresses **inviscid mechanism**



Additional issue: *Hidden* parameter?

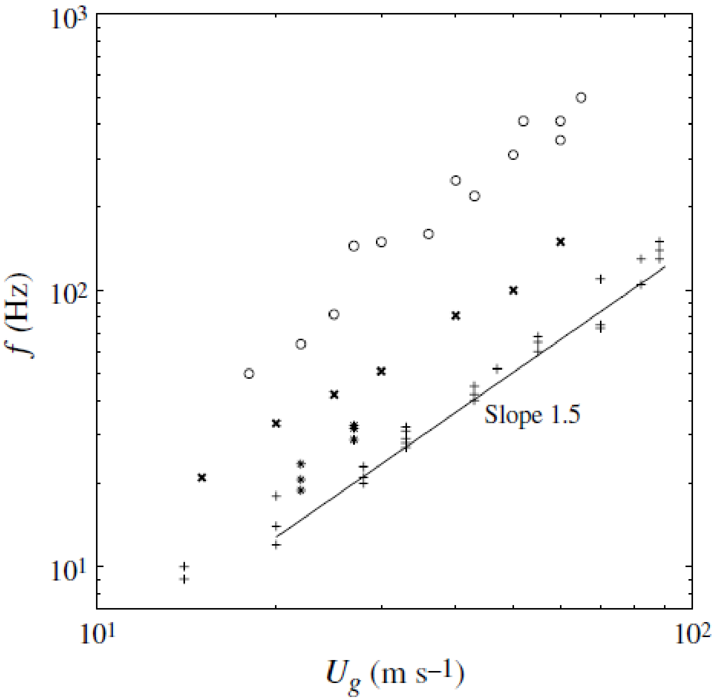


FIGURE 1. Experimental frequency versus gas velocity for various sets of experiments with $M > 4$. Data obtained by: +, Raynal (1997) $M = [4.2 : 2115]$; ○, Marmottant & Villermaux (2004) $M = [4 : 108]$; ×, Ben Rayana (2007) $M = 16$; and ⁎, Matas, Marty & Cartellier (2011) $M = \rho_g U_g^2/\rho_l U_l^2 = [5 : 14]$. The most unstable frequency is shown to scale as $U_g^{3/2}$ for large M.

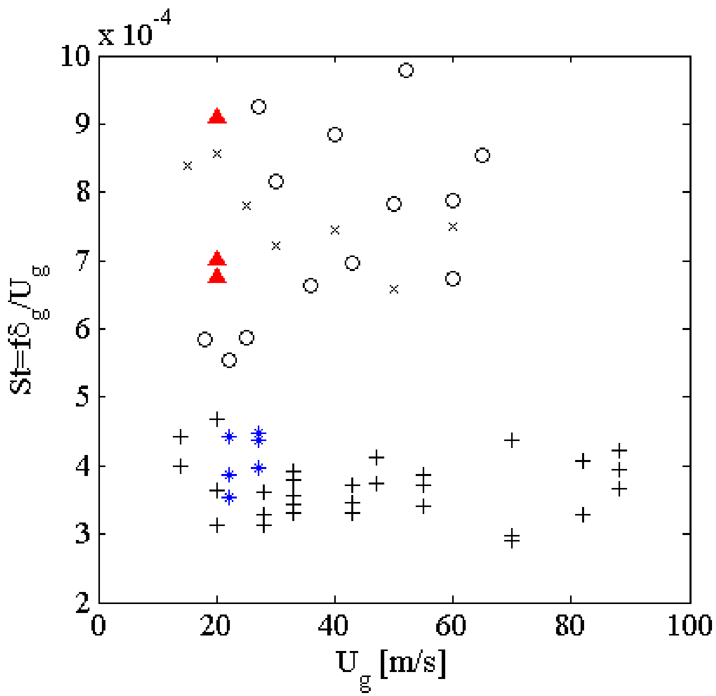
Experiments by different users on mixing layer experiment show:

- Frequency ~ $Ug^{3/2}$ at large $M=\rho_g V_g^{2}/\rho_l V_l^{2}$
  consistent with $f \sim (\rho_g/\rho_l)U_g/\delta_g$ and $\delta_g \sim U_g^{-1/2}$
- But different prefactors!

Reproducibility??

Hidden parameter?

Variability in our own experiments as well!!!!!!



+ : Raynal (1997)

o : Marmottant & Villermaux (2004)

x : Ben Rayana (2007)

* : Matas, Marty & Cartellier (2011)

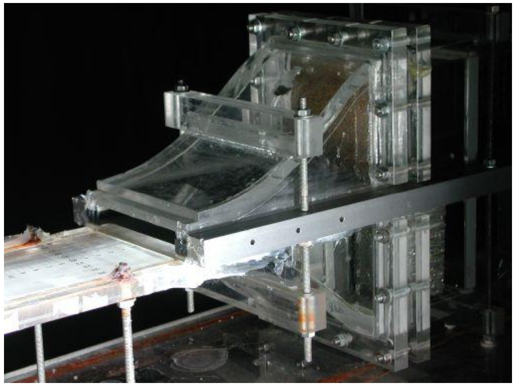
▲ : Fuster et al (2013)

Hidden parameter?

- We measure the frequency of the most unstable mode for two versions of the experimental set-up, for the **same experimental point**, U_g = 27 m/s and U_l = 0.28m/s.

  - Older version used by F. Ben Rayana → *Manip* 1

    Optical probe measurement → f=42 Hz

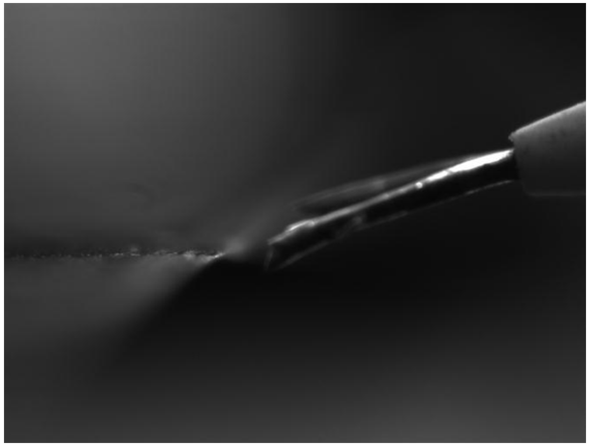


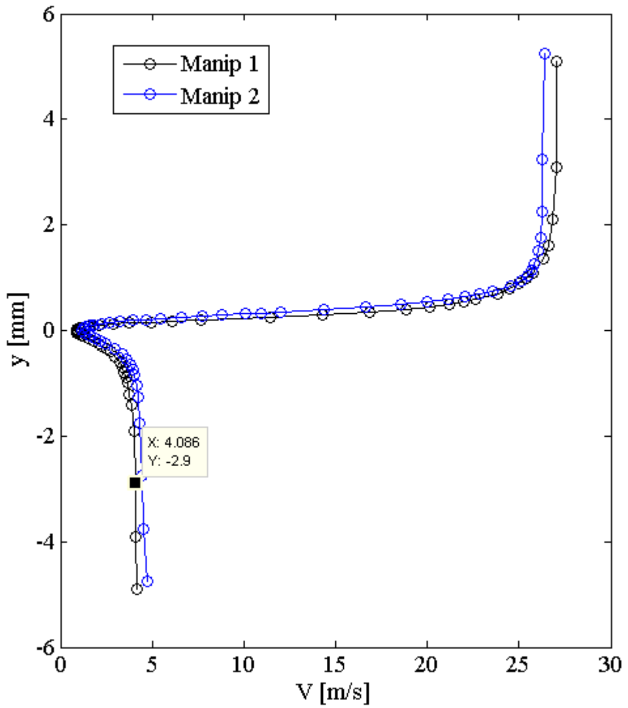
  - New set-up built by S. Marty → *Manip* 2

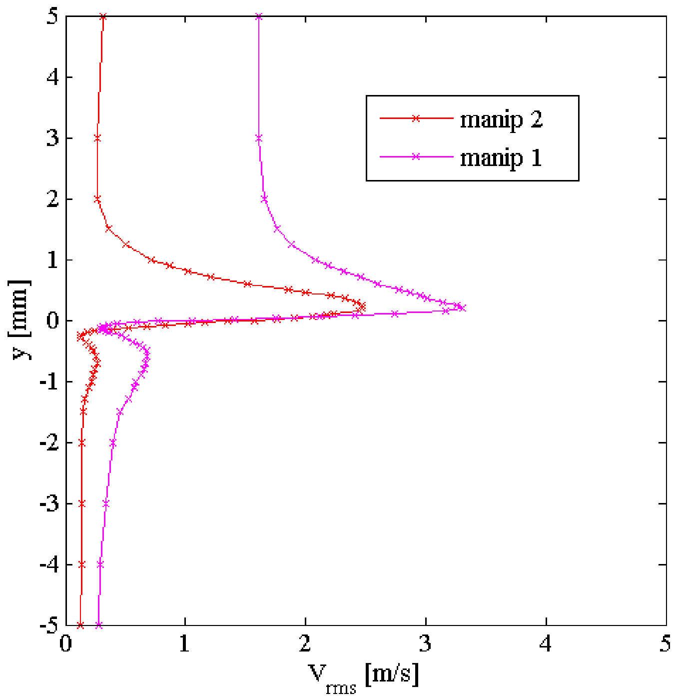
    Optical probe measurement → f=27 Hz

Role of velocity profile?

- Measurement of velocity profile (hotwire). Velocity in bottom channel is fixed to Ug_{bottom} = 4.2 m/s (same Re as in air/water experiment where U_l = 0.28 m/s)
  - Mean velocity profile very similar
  - Much larger RMS value for *manip* 1 (older set-up)!

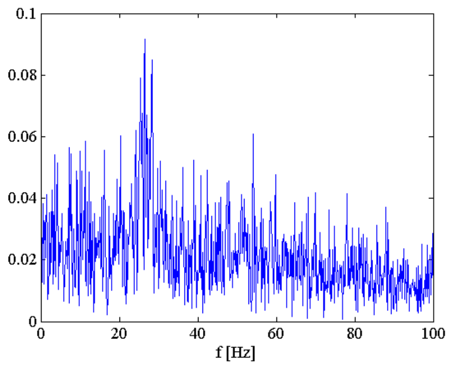


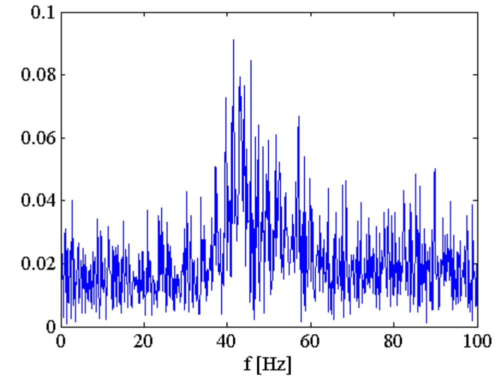




Role of porous plate!

- We insert **old** porous plate on **new** experimental set-up





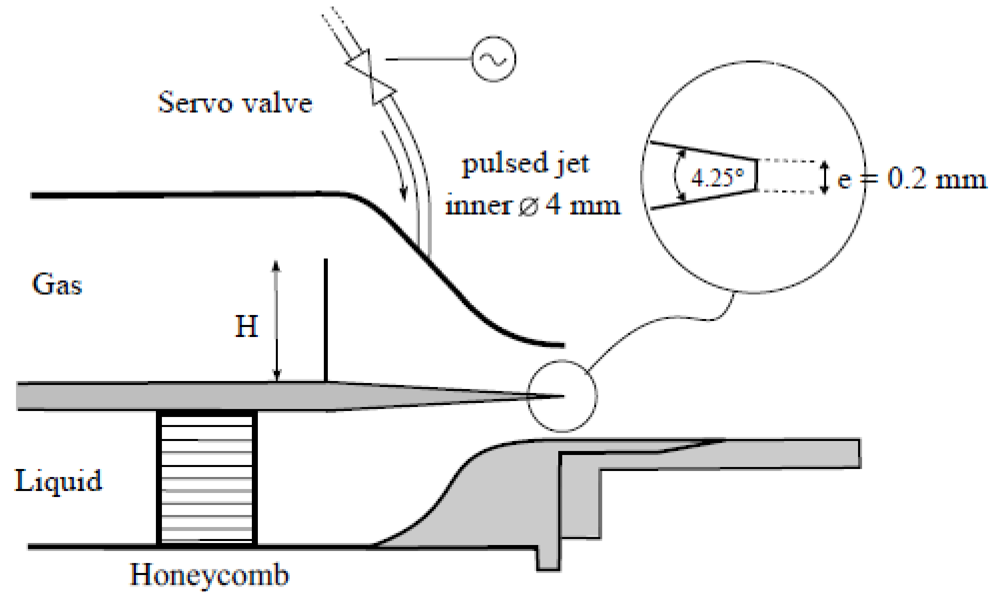
→ Frequency shifted from 27Hz to 42Hz !

Forcing of turbulence

Two methods:

- Passive forcing (obstruction of varying height H)

- Active forcing (pulsed jet)



Both forcing methods yield same mean velocity profile, but differing turbulence intensity profiles.

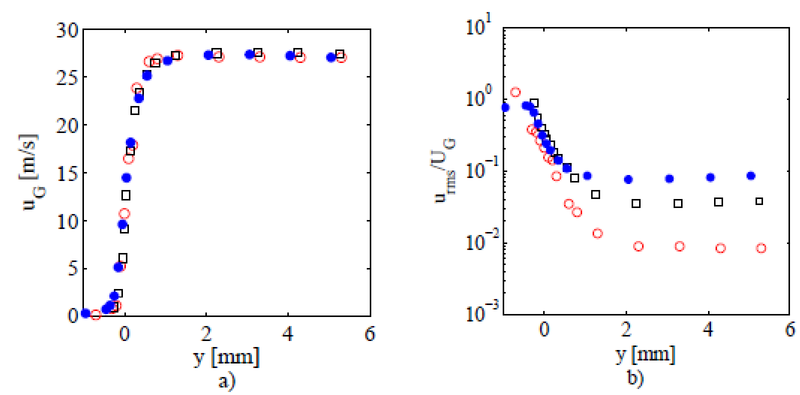
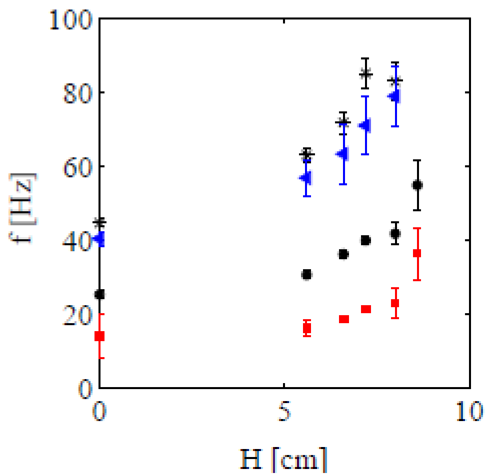


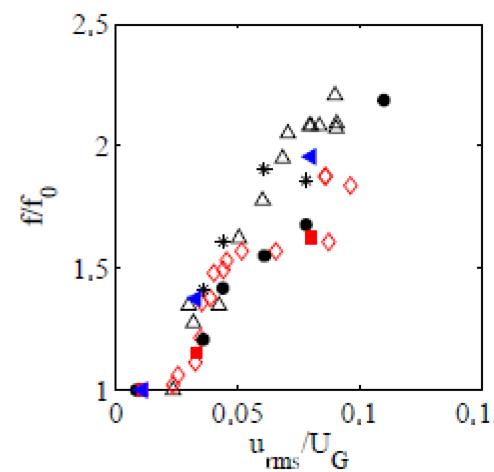
FIG. 3. (color online) Hot-wire velocity profiles for U_G = 27 m/s and varying obstruction heights H: ○: $H = 0$; □: $H = 5.6$ cm ; •: $H = 8$ cm ; a) Mean velocity profile. b) Turbulence intensity u_{rms}/U_G.

Forcing of turbulence

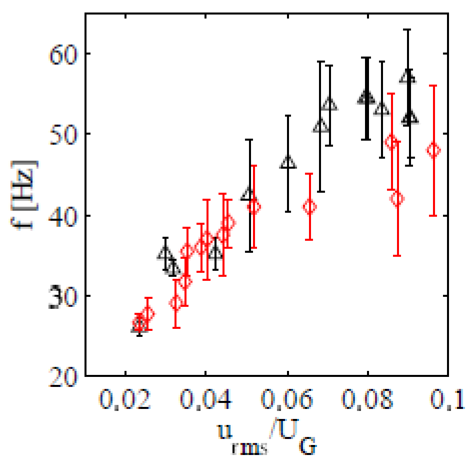
Obstruction method



● U_G = 27 m/s U_L=0.28 m/s
■ U_G = 17.5 m/s U_L=0.28 m/s
◀ U_G = 40 m/s U_L=0.28 m/s
* U_G = 27 m/s U_L=0.95 m/s



Pulsed jet method



U_G = 27 m/s U_L=0.28 m/s
and forcing at:
△ f= 34 Hz
◇ f= 70 Hz

- Frequency increases with turbulence intensity whatever the forcing method

- All data collapse when plotted as a function of u'/U_G

Impact on wavelength

u'/U = 2.3%
f= 26Hz and λ ~ 3.4 cm

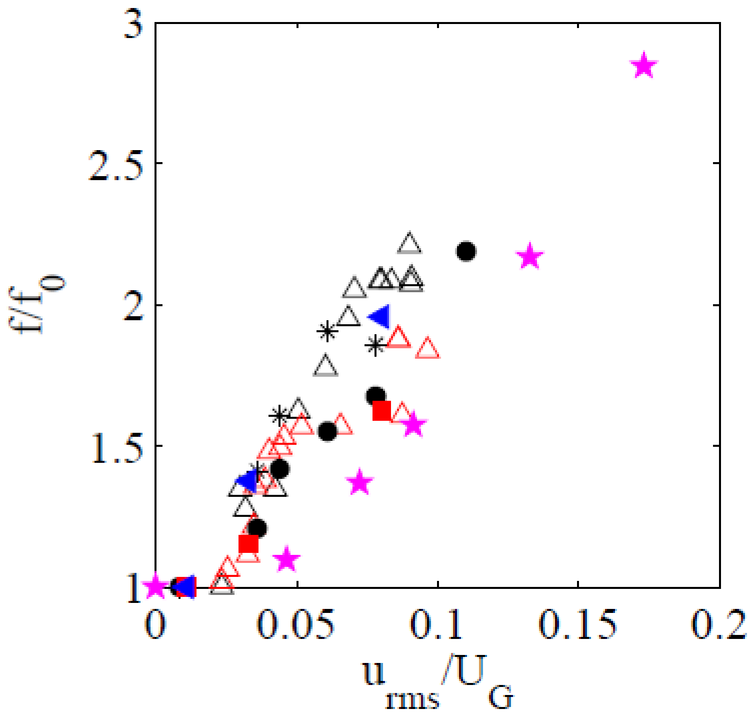
u'/U = 9%
f= 53Hz and λ ~ 1.6 cm

- Wavelength decreases with turbulence intensity
- Wave velocity ≈ constant ≈ $\frac{\sqrt{\rho_G}U_G+\sqrt{\rho_L}U_L}{\sqrt{\rho_G}+\sqrt{\rho_L}}$

Stability analysis?

Assumption: turbulent intensity modelled via Newtonian eddy viscosity, and injected in spatiotemporal stability analysis:

$$\rho u_{rms}^2 = \mu_{g\,turb} U_g / \delta_g \quad \rightarrow \quad u_{rms}/U_g = \sqrt{\frac{\nu_{g\,turb}}{U_g\,\delta_g}}$$



★ : stability analysis prediction

All other symbols: experimental data

Impact of turbulence

- Variability in past experiments related to variability of turbulence level in gas injection channel
- Increasing velocity fluctuations in gas phase leads to increase of frequency/wavenumber
- Effect is captured via simple Newtonian eddy viscosity model
- Questions:
  - Role of interface velocity
  - More sophisticated model for eddy viscosity? (cf O Naraigh et al JFM 2013)
  - Impact for application…?