On ground study of bubble jets collision

F. Suñol and R. González-Cinca

Universitat Politècnica de Catalunya

International Astronautical Congress

September 30th, 2008

Outline

Introduction

Objectives

Objective: to study the structure of two colliding bubble jets in different gravity environments by:

- Changing the impact angle between jets.
- Using different separation distances between injectors.
- Varying bubble sizes and velocities.

Objectives

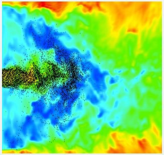
Objective: to study the structure of two colliding bubble jets in different gravity environments by:

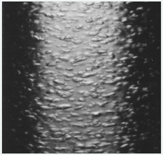
- Changing the impact angle between jets.
- Using different separation distances between injectors.
- Varying bubble sizes and velocities.

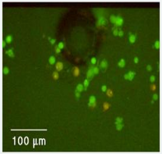
Motivation

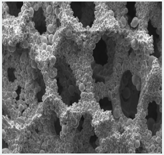
Two-phase flows with homogenized small bubbles have a wide range of applications:

- Thermal management.
- Transport and combustion processes.
- Life sciences (bioreactors, drug delivery, vesicle rupture).
- Material sciences.









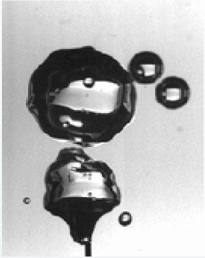
Injection of bubbles in μg

In normal gravity...

http://www.jupiterimages.com/

...the buoyancy force is the responsible for breaking the bubble interface.

In microgravity...



http://www.ieec.fcr.es/

...there is no buoyancy force:
$\Rightarrow$ Difficult control of size and frequency!

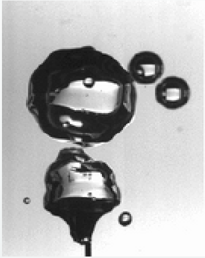
Injection of bubbles in μg

In normal gravity. . .

http://www.jupiterimages.com/

. . . the buoyancy force is the responsible for breaking the bubble interface.

In microgravity. . .



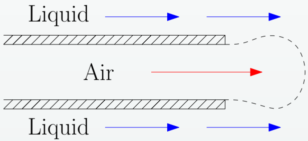
http://www.ieec.fcr.es/

. . . there is no buoyancy force:
$\Rightarrow$ Difficult control of size and frequency!

Which methods are used to create bubbles in zero gravity?

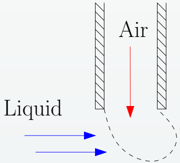
Coflow and crossflow configurations

Coflow



The Gas-Liquid interface tends to keep spherical shape. When the air zone is growing up, the liquid breaks the interface.

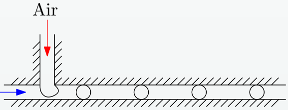
Crossflow



The liquid forces the bubble to high lateral stresses that can break the Gas-Liquid interface.

Bubble injector

The injection device is based on a crossflow configuration inside a capillary T-junction.



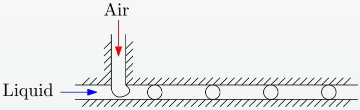
J. Carrera et al. *"Generation of a monodisperse microbubble jet in microgravity"*, AIAA Journal 46, 2010-2019 (2008).

- Bubble size is fixed essentially by capillary diameter.
- Control of bubble frequency formation, by varying liquid (Q_l) and gas (Q_g) flow rates.
- Insensitive to gravity level for low Bond numbers

$$Bo = \frac{\Delta\rho\, g\, d_c^2}{\sigma} \ll 1$$

Bubble injector

The injection device is based on a crossflow configuration inside a capillary T-junction.



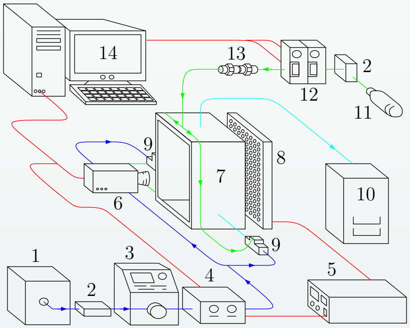
J. Carrera et al. *"Generation of a monodisperse microbubble jet in microgravity"*, AIAA Journal 46, 2010-2019 (2008).

- Bubble size is fixed essentially by capillary diameter.
- Control of bubble frequency formation, by varying liquid (Q_l) and gas (Q_g) flow rates.
- Insensitive to gravity level for low Bond numbers

$$Bo = \frac{\Delta\rho\, g\, d_c^2}{\sigma} \ll 1$$

Experimental setup

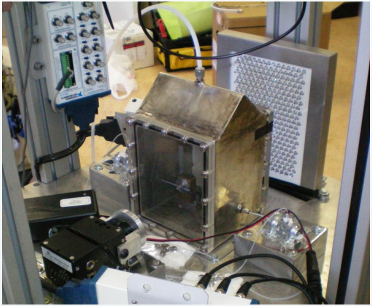
Sketch of the experimental setup



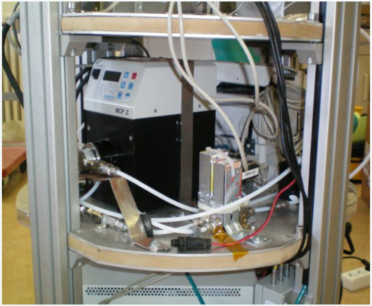
— Electric connections
— Gas tubes
— Liquid tubes
— Gas+Liquid tubes

1. Liquid reservoir
2. Gas/Liquid filters
3. Liquid pump
4. Liquid flow meter
5. DC power supply
6. High speed camera
7. Test cavity
8. Illumination source
9. Bubble injectors
10. Residual tank
11. Gas pressure bottle
12. Pressure controller and gas flow meter
13. Choked orifice
14. Computer

Experimental setup



Test cavity, illumination source, injectors and high-speed camera.



Liquid pump, gas flow meter, pressure controller and liquid tanks.

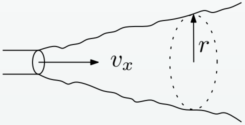
On ground results

Definitions

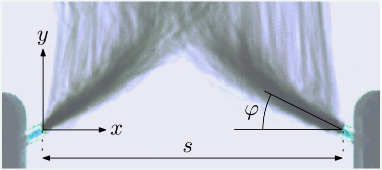
- Momentum flux J

$$J = 2\pi\rho \int_0^\infty r v_x^2 dr = \text{constant},$$

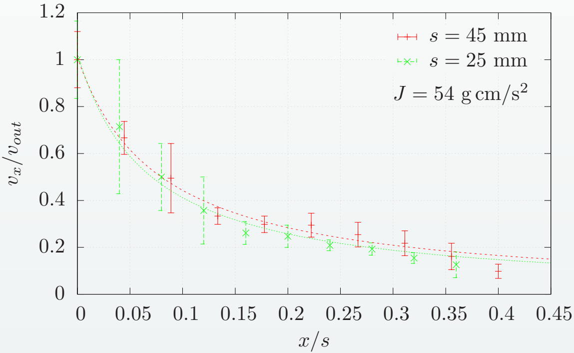
$$J = J_G + J_L = \frac{4}{\pi d_c^2}\left(\rho_g Q_g^2 + \rho_l Q_l^2\right).$$



- Separation distance between injectors (s).
- Impact angle between jets (φ).



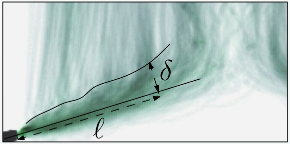
Bubble velocities



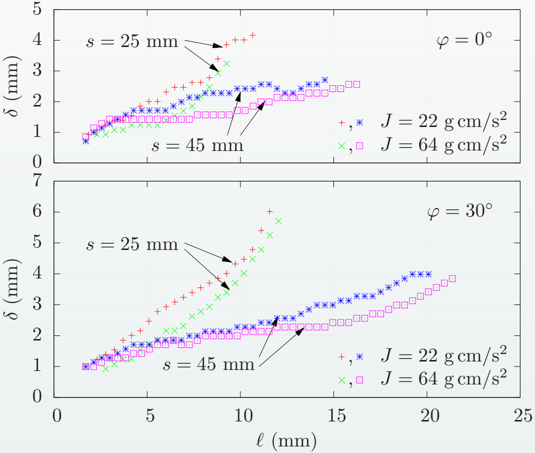
- Decrease in velocity in the central zone → Interaction.

$$\frac{v_x}{v_{out}} \approx \frac{a}{b + x/s}, \quad v_{out} = 159 \pm 16 \text{ cm/s}.$$

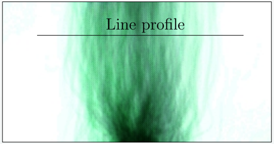
Turbulence and buoyancy regions

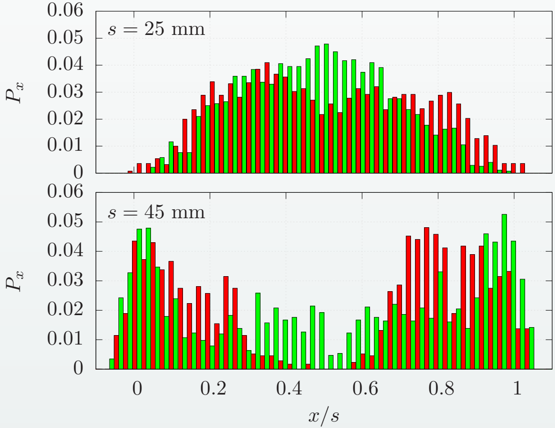


- $\delta(\ell)$ nearly linear behavior.
- Increase in slope at high values of ℓ $\longrightarrow$ Interaction.



Bubble upstream x probability

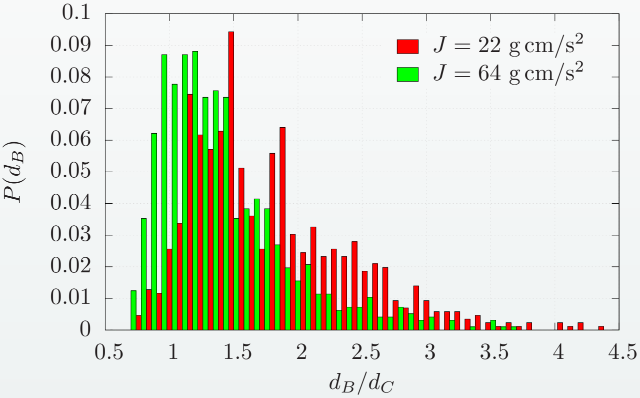




- 1000 frames at $\varphi = 0°$ and $h = 3$ cm.
- More dispersion at high values of J.

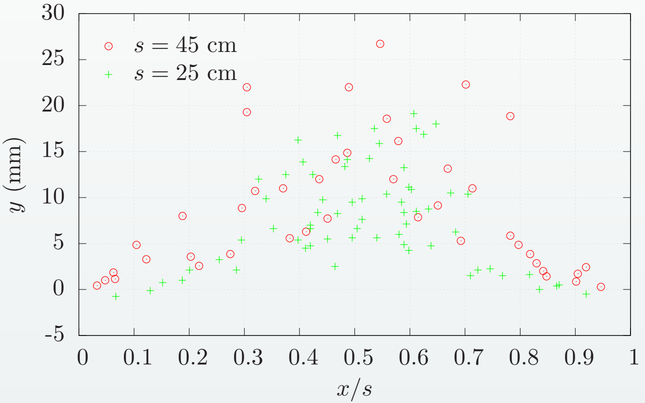
Red: $J = 22\ \mathrm{g\,cm/s^2}$.
Green: $J = 54\ \mathrm{g\,cm/s^2}$.

Mean bubble diameters



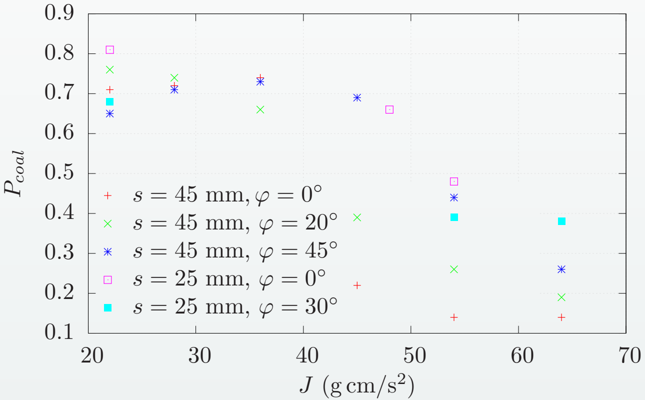
- Larger bubbles are due to injector performance and coalescence.

Coalescence events



- Coalescence events in $\Delta t = 0.2$ s at $\varphi = 30°$ and $J = 54$ g cm/s^2.
- Large number of coalescences near the outlet of the injector.

Coalescence probability



- P_{coal} decrease with J since d_B is smaller.

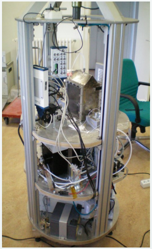
Conclusions and future work

Conclusions:

- An experimental setup for the study of bubble jets collisions has been designed.
- Preliminary on ground results on collective and individual behavior have been obtained.
- On ground experimental results are appropriated to be compared with those obtained in microgravity conditions.

Current and future work at the INTA drop tower:

- Variations in separation distances between injectors, and impact angles.
- Use of different kind of fluids (surface tension, fuels, . . .).
- Changes in injector's diameter.



Thank you for your attention!