Experimental analysis of the bubble-slug transition in a minichannel in microgravity conditions

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Outline

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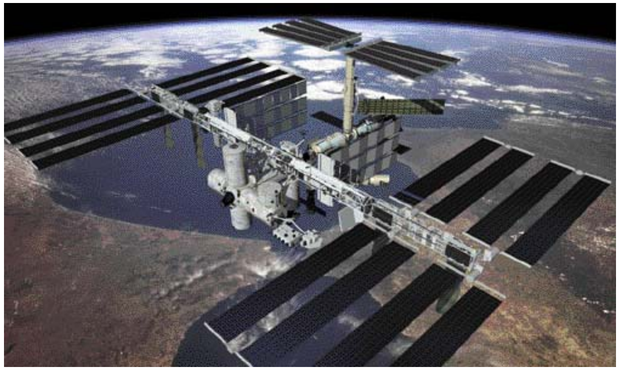
Motivation & objectives

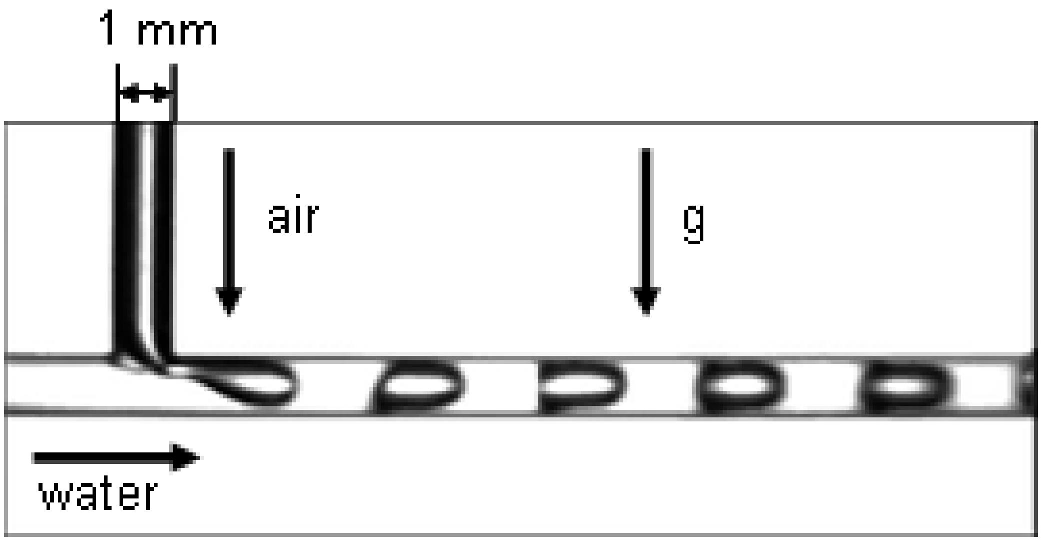
- Gas-liquid flows essential to space technology.
- Scientific and technological applications:
  - Power generation
  - Bioreactors
  - Propulsion systems
  - Heat management techniques
  - ECLSS
  - …



- 3 main flow patterns: bubble, slug and annular.
- Better understanding → mechanisms of transition.
- Experimental study bubble-slug transition.

General description

- Two-phase air-water flow.
- Minitubes on-ground [1].
- T-junction.
- Bubble, slug, churn and annular (stratified not allowed).



- *We* ~ 1, 10
- *Bo* ~ 10^{-1}
- *Re* ~ 10^{3}

→

- Capillary regime
- Independent of gravity
- Laminar regime

[1] S. Arias, X. Ruiz, L. Ramírez-Piscina, J. Casademunt and R. González-Cinca, Experimental study of a microchannel bubble injector for microgravity applications, Microgravity Science and Technology 21 (2009) 107-111.

Methodology

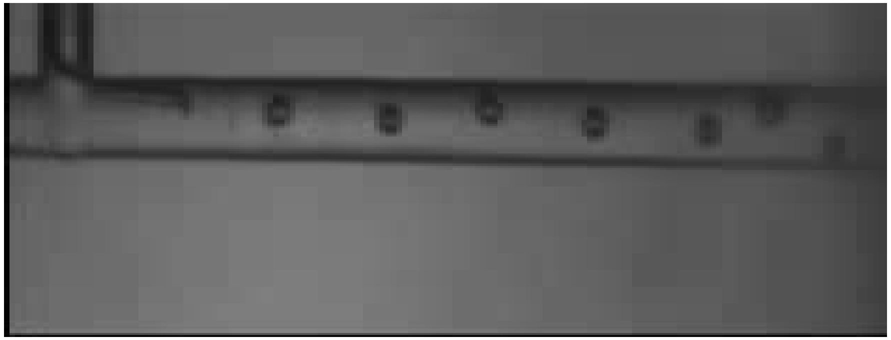
- Gas and liquid volumetric flow rates, Q_G, Q_L, controlled.
- Images taken for each couple Q_G - Q_L (4000 fps).
- Superficial gas and liquid velocities, U_{SG}, U_{SL}, estimated:

$$U_{SG} = Q_G / A \qquad U_{SL} = Q_L / A \qquad (A\text{: cross section})$$

- Gas velocity, U_G, measured from images.
- Void fraction, α, estimated: $\alpha = U_{SG} / U_G$
- Bubble length and diameter measured from images.
- Bubble-slug transition very susceptible → Dukler et al. criterion [2]

[2] A.E. Dukler, J. A. Fabre, J. B. McQuillen, R. Vernon, Gas-liquid flow at microgravity conditions: flow patterns and their transitions, International Journal of Multiphase Flow 14 (1988) 389–400.

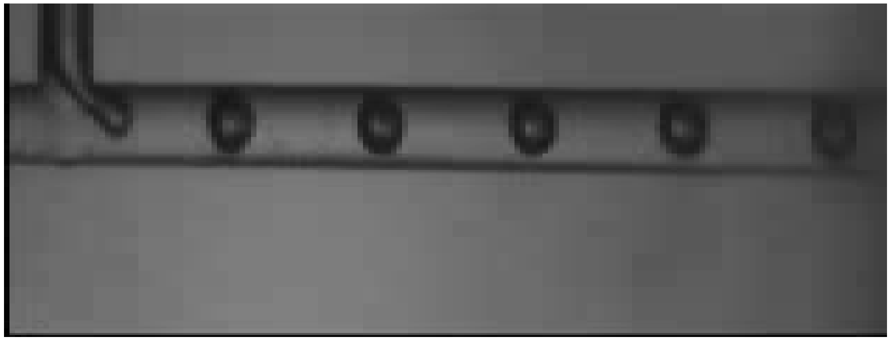
Examples (4000 fps)



Bubble

U_{SG} =0.08 m/s

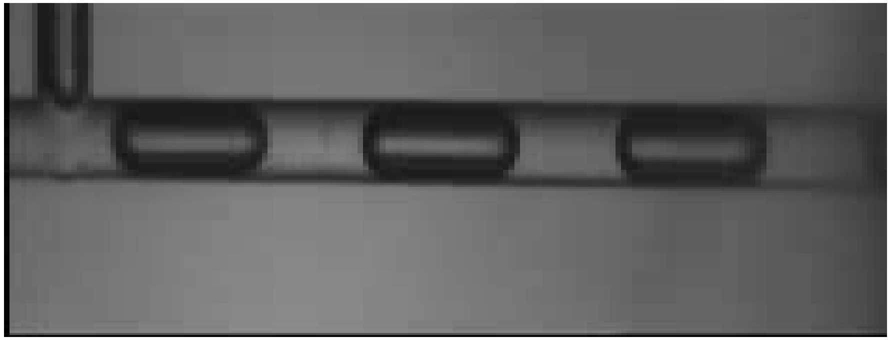
U_{SL} = 1.48 m/s



B-s transition

U_{SG} =0.11 m/s

U_{SL} = 0.53 m/s

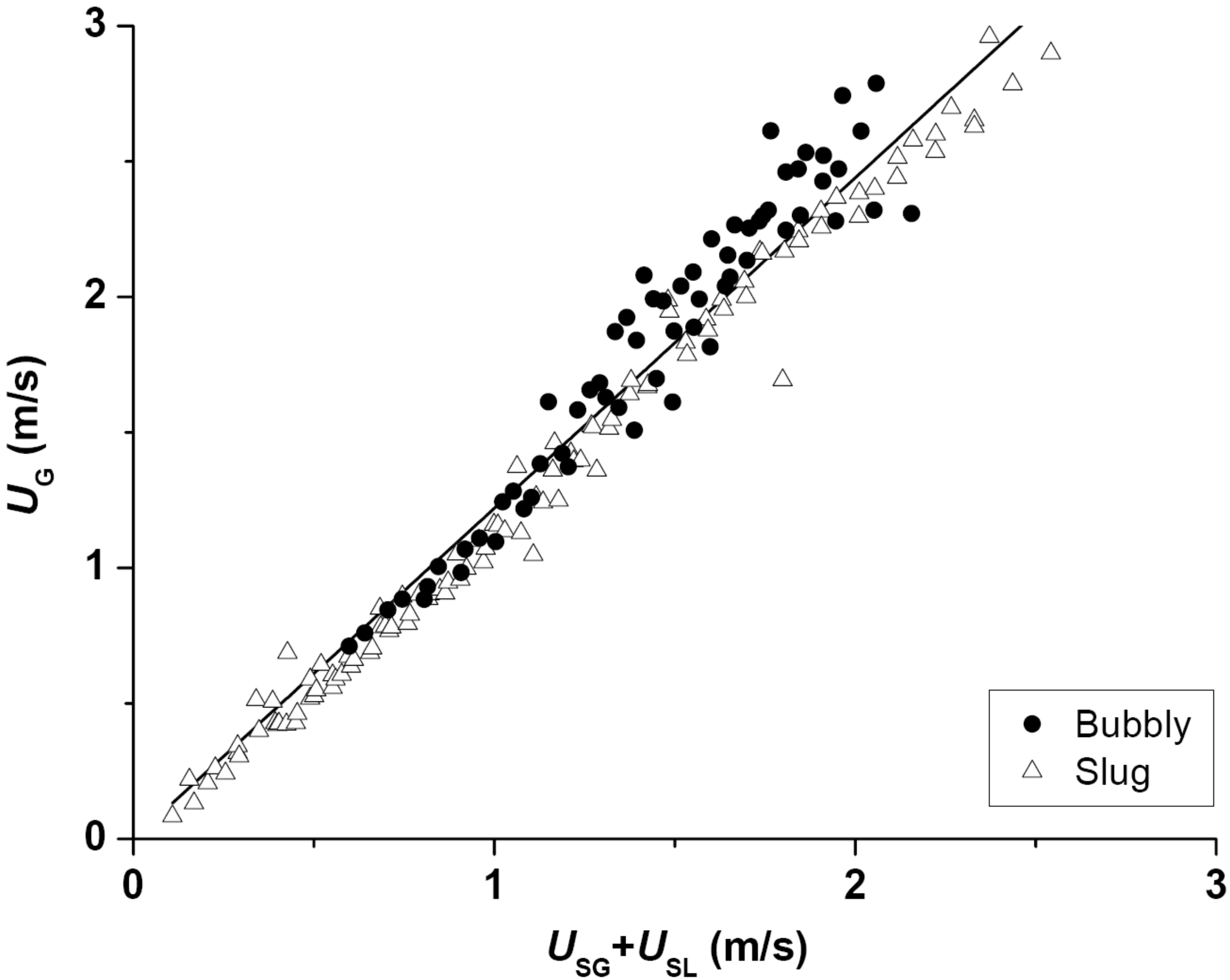


Slug

U_{SG} =0.10 m/s

U_{SL} = 0.10 m/s

Results: drift-flux relationship



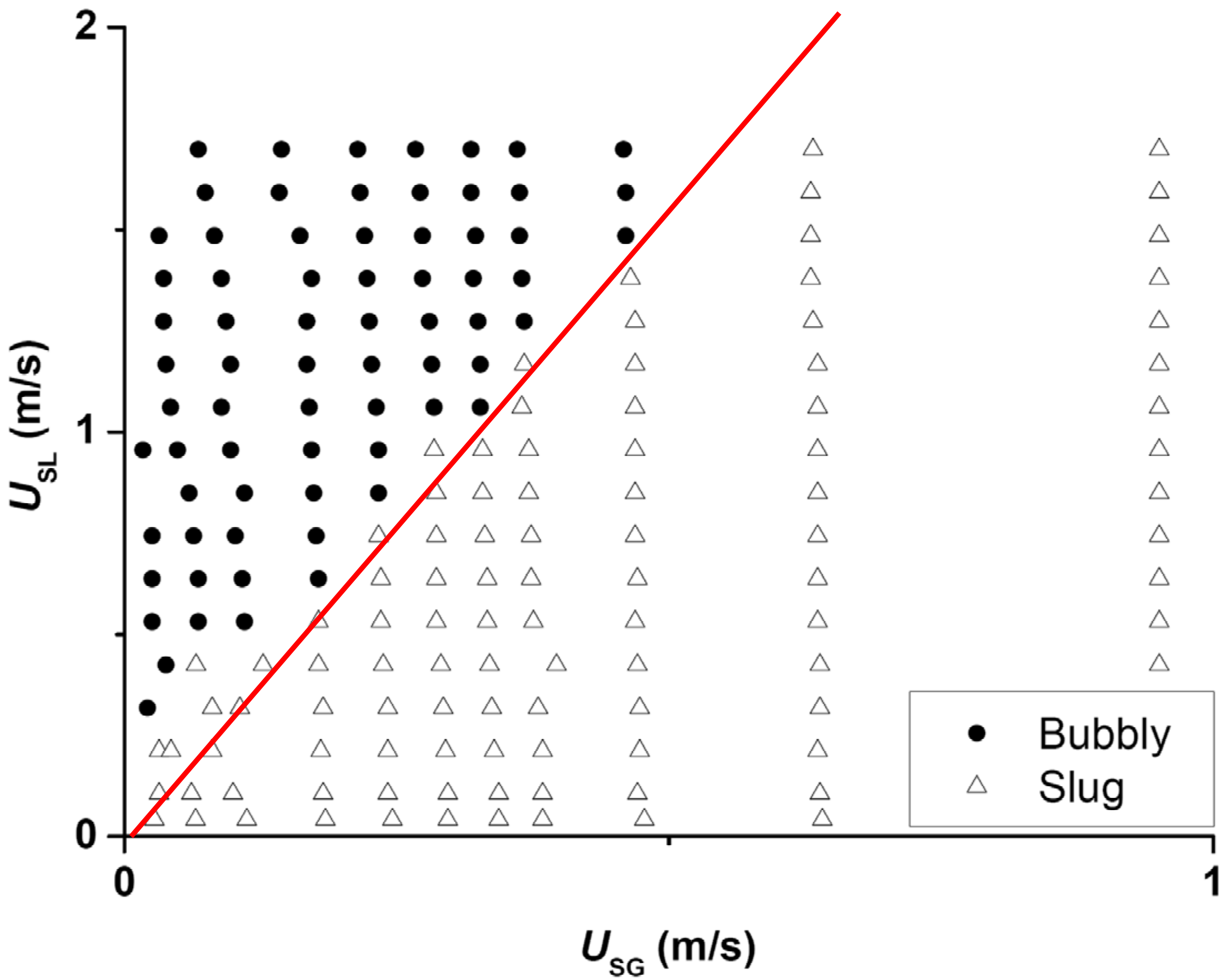
Drift-flux relationship:

$$U_G = C_0\left(U_{SG} + U_{SL}\right)$$
$$C_0 = 1.22$$

Transition expressed as:

$$U_{SL} = U_{SG}\frac{1 - C_0\alpha_c}{C_0\alpha_c}$$

Results: critical void fraction



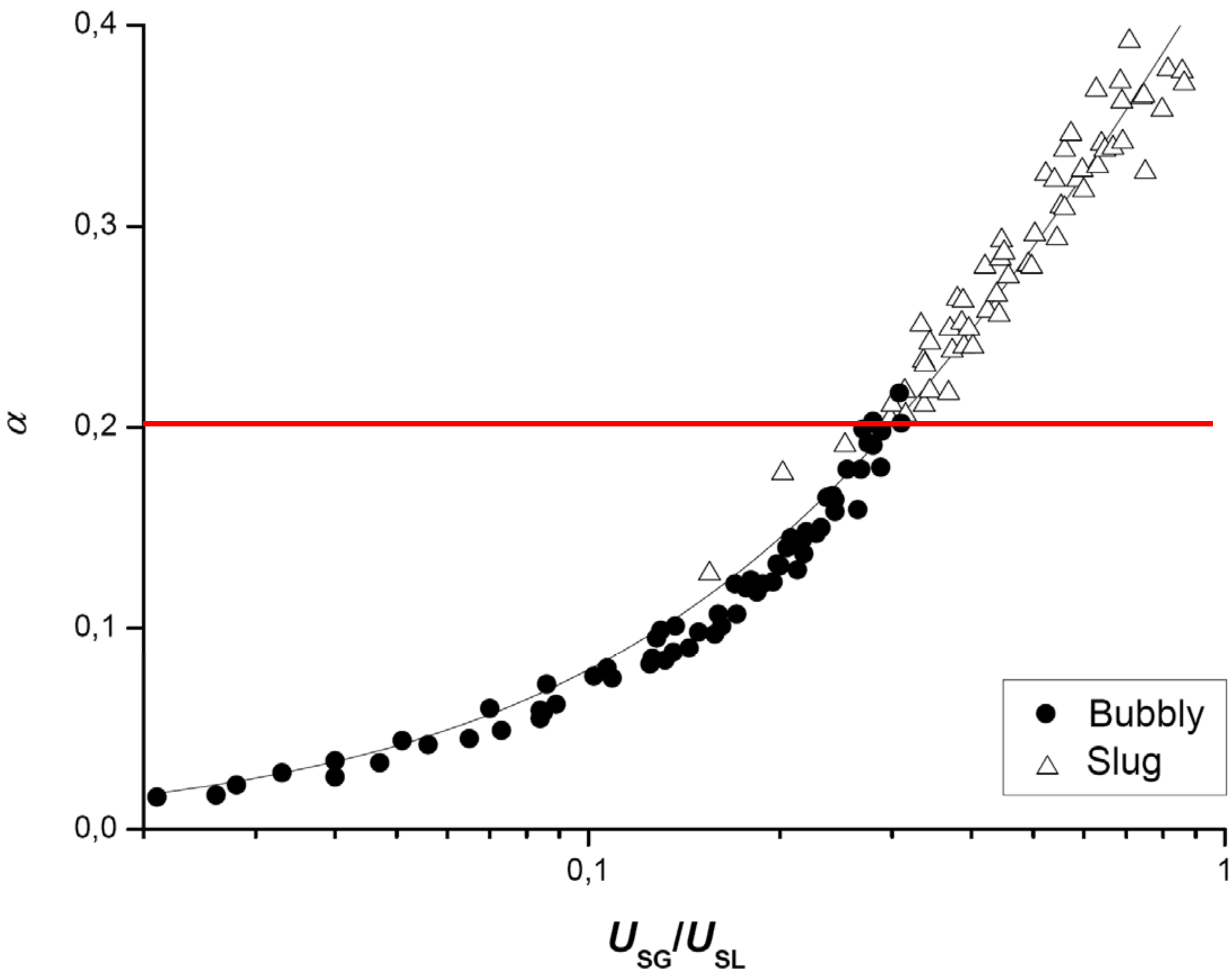
$$U_{SL} = U_{SG} \frac{1 - C_0 \alpha_c}{C_0 \alpha_c}$$

Transition estimated:

$$U_{SL} = 3.1 \cdot U_{SG}$$

$$\alpha_c = 0.2$$

Results: void fraction prediction



Drift-flux relationship:

$$U_G = C_0\left(U_{SG} + U_{SL}\right)$$
$$C_0 = 1.22$$

Void fraction:

$$\alpha = \frac{U_{SG}}{U_G} = \frac{1}{C_0\left(1 + \frac{1}{\frac{U_{SG}}{U_{SL}}}\right)}$$

Discussion

Prediction upon the Suratman number (Colin et al. [3]):

$$Su = \frac{Re^2}{We} = \frac{\rho_L \sigma \phi}{\nu_L^{\ 2}}$$

$Su < 1.5 \cdot 10^6 \rightarrow \alpha_c = 0.45$ Inhibiting-coalescence regime

$Su > 1.7 \cdot 10^6 \rightarrow \alpha_c = 0.20$ Promoting-coalescence regime

In our experiments:

$Su = 7.1 \cdot 10^4$ ⇨ Inhibiting-coalescence regime but $\alpha_c = 0.2$

[3] J. McQuillen, C. Colin and J. Fabre, Ground-based gas-liquid flow research in microgravity conditions: state of knowledge, Space Forum 3 (1998) 165-203.

Conclusions

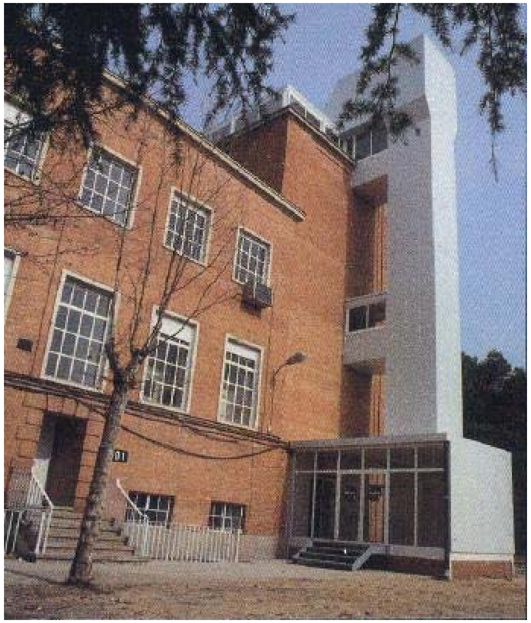
- Study on-ground of the bubble-slug transition in air-water flows.
- Minichannel (1mm) in microgravity related conditions, laminar and capillary regime.
- Good agreement with the drift-flux relationship.
- Good agreement with the void fraction prediction.
- Good agreement with the hypothesis of a critical void fraction.
- Prediction based upon Suratman number not applicable in this case.
- The critical void fraction is due to the entrance effects; no influence of the coalescence phenomena.
- Specific bubble-slug transition prediction in minichannel is required.
- Literature is not satisfactory in this case ⇒ further analyses are required.

Future steps

- Current **on-ground** experiments:
  - Changes of the capillary diameters.
  - Changes in fluids.
  - Explore other parameters regimes (larger flow rates).

- **CFD** data analysis:
  - Model of the injector.
  - Bubble formation and detachment.

- Experiments in **microgravity conditions**:
  - Drop tower INTA.
  - Future PFC.



Thank you
for your attention!

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