

## Monodisperse bubble suspensions in turbulent flows in microgravity. Drop tower experiments

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The physics of bubbly flows in the absence of gravity is very different from that of a neutrally buoyant colloidal suspension (which could be studied in normal gravity), in several crucial aspects: (i) the slip boundary condition in a bubble has strong implications in the generation of vorticity and thus the resulting effective drag on the bubbles; (ii) bubbles are in principle deformable through their interaction with the carrying flow; (iii) bubbles can coalesce and break-up. In addition, given the difficulty to generate bubbles of controlled size in the absence of buoyancy, there is virtually no experimental information on the physics of monodisperse bubble suspensions in microgravity. On the other hand, the numerical difficulty to accurately simulate two-phase flows is well-known in general, but in particular if the carrying flow is turbulent. The problem nevertheless is of primary importance for the rocket industry and for Life Support Systems in space.

Recently, a series of microgravity experiments in the ZARM Drop Tower in Bremen<sup>1</sup> have introduced a new method of bubble generation (later tested also in Parabolic Flights<sup>2</sup> and on ground<sup>3</sup>), which is insensitive to gravity and which is capable to inject large numbers of virtually monodisperse bubbles of prescribed size into a liquid cavity in the absence of gravity. It is thus possible for the first time to study monodisperse bubble suspensions in microgravity.

During 2009 a new experimental set-up is being constructed and tested in the ZARM Drop Tower, which provides 4,7 seconds of high quality microgravity. This new experiment has scheduled 36 drops, in which a combination of four injectors of the type of Ref.<sup>1</sup> will produce an approximately uniform bubble suspension in a co-flow pipe with Reynolds number up to 20000. The conditions are designed such that typical bubble sizes (1.5 mm) are larger than the Kolmogorov cut-off length, but smaller compared to the most energetic eddies (typically 10 mm), which are in turn smaller than the pipe width (100 mm). These parameters are optimized so that bubbles have a significant interaction with the turbulence, but are efficiently spread through the pipe with minimal degree of coalescence. The Weber number is also sufficiently small so that the bubbles are spherical (but not point-like). The regime studied is interesting from a fundamental perspective within the

theory of turbulence and lies outside the accessibility of any of the possible analytical approximations.

At the same time, large scale numerical simulations of the same problem are being carried out within a Lattice-Boltzmann numerical scheme, following a specific implementation for the case of spherical, non-coalescing bubbles<sup>4</sup>. The interplay and mutual feedback between the numerics and the experiments is of crucial importance to gain theoretical insights and a fundamental understanding of a challenging problem of great relevance to space technology.



Figure 1. Jet of bubbles in a cubic cavity of 10 cm side in microgravity conditions<sup>1</sup> from a drop tower experiment.

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<sup>2</sup> S. Arias, R. González-Cinca, X. Ruiz, J. Casademunt, and L. Ramírez-Piscina, 47th ESA Parabolic Flight Campaign (2007).

<sup>3</sup> S. Arias, X. Ruiz, J. Casademunt, L. Ramírez-Piscina, and R. González-Cinca, *Microgravity Sci. Tec.* **21**, 107 (2009).

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