PTV-analysis of the velocimetry data generated during the
BAMBI - FOTON-M2 experiment

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Summary

The BAMBI (Bifurcation Anomalies in Marangoni-Bénard Instabilities) experiment has been successfully flown onboard the FOTON-M2 satellite in June 2005. A 5mm-thick 200 cSt silicone oil layer in a $10\times10cm^2$ wide container in contact with a similarly-sized Helium gas layer was heated from 'below' and cooled from 'above'. A range of temperature differences across the liquid and gas layers was scanned and the onset and evolution of the Marangoni-Bénard instability was thus examined. In the present contribution, velocity results obtained by PTV in the interface plane are presented and compared to theoretical and numerical predictions.

Keywords: Marangoni-Bénard Instability, Particle Tracking Velocimetry

Extended Abstract

During the 4 days available for the experiment, a 5mm-thick 200 cSt silicone oil layer in a $10\times10cm^2$ wide container, and in contact with a similarly-sized Helium gas layer was heated from 'below' and cooled from 'above'. By varying the amount of heating applied at each experimental step, a range of temperature differences across the liquid and gas layers was scanned and the onset and evolution of the Marangoni-Bénard instability typical for this type of configuration (Colinet et al. [2001]) was examined. The used optical diagnostics were Infrared Thermography of the liquid/gas interface, PTV (multiple views and heights in the liquid layer), Wollaston Interferometry and Electronic Speckle Pattern Interferometry. In the present contribution, only velocity results obtained by PTV in the interface plane are presented and compared to theoretical and numerical predictions.

To analyse the results, a new PTV code was written, capable of tracking each particle over as many images as it is visible and yielding complete trajectories with their associated velocities. This is different from 'regular' PTV where a local speed vector is given per couple of images. The advantage of the presented approach is that it allows us to apply a smoothing on the complete trajectory. The effect of the smoothing on the velocity results is visible in Fig 1(a). In solid lines, the extracted raw velocity magnitude is shown as a function of the position of the particle along its trajectory. In dashed lines, the smoothed result is shown. Note that this smoothing is applied on the trajectory and not on the velocity magnitude directly.

The maximum of this fitted velocity profile is then extracted and averaged over all trajectories visible inside the regular hexagons present in the image. This is repeated for the different experimental steps and the result of this procedure is plotted as a function of the temperature difference between the bottom of the liquid layer and the top of the gas layer in Fig. 1(b). As can be seen from this figure, there is a clear increase in maximum velocity as a function of the temperature difference applied across the two-layer system.

In addition, numerical simulations were performed using FLUENT 6.3. Here, the momentum and heat equations are solved in the gas and the liquid, where a viscosity variation with temperature is also taken into account. As boundary conditions on the liquid side, Marangoni stress was used and on the gas side there is an equality of velocity. More details on these simulations will be given elsewhere. The obtained results are shown in Fig. 1(b) as filled circles.

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Finally, a theoretical model based on amplitude equations analysis (Landau-type equations limited to third order) has been developed. These equations allow to determine the amplitudes of various patterns (rolls, squares, hexagons) and their stability. The model includes heat transfer in the (helium) gas, which is otherwise passive (small Peclet number, quasi-static approximation), as well as viscosity variation with temperature for the liquid, which is significant in the temperature range considered. This result is shown in Fig. 1(b) as a continuous line. Given the experimental uncertainties associated with fluid properties, the agreement between experiment, theory and numerics can be considered as excellent.

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References