Thermal ripples at the interface of an evaporating liquid. Results of the ITEL-2/MASER-10 sounding rocket experiment.

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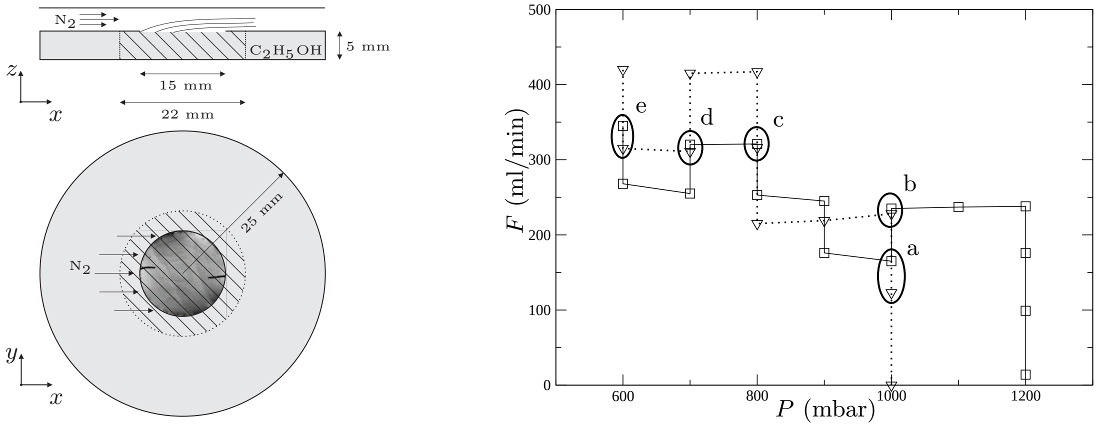
Dynamics of thermal ripples is studied experimentally at the interface of an evaporating ethyl alcohol layer under ground (*1g*) and microgravity (*0g*) conditions. The vapor is removed by an inert gas (nitrogen) flowing along the interface. The evaporation rate is varied by regulating both the gas flow rate and the gas pressure allowing to scan the evaporation rates from low to large values and therefore to scrutinize the transition from quasi-periodic to chaotic behavior, along with various topological processes whose results are presented here.

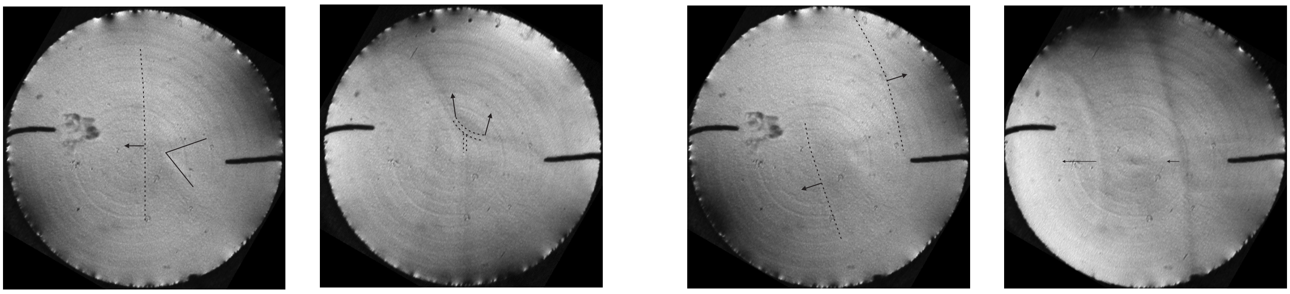
The geometry of the system is presented in figure 1(a). Ethyl alcohol (C_2H_5OH) was evaporated through the 15mm-diameter opening and removed by the nitrogen (N_2) flow from left to right. Two optical diagnostics were used, both sensitive to refractive index variations. The first one is a Schlieren system orthogonal to the fluid surface working in double transmission via a mirror placed at the bottom of the liquid layer. The second one is a six-view tomograph allowing the reconstruction of the 3D temperature field in the liquid layer. Figure 1(b) shows the experimental points both in *0g* and *1g*. The control parameters were the gas pressure P (mbar) and the gas flow rate F (ml/min).



(a) (b)

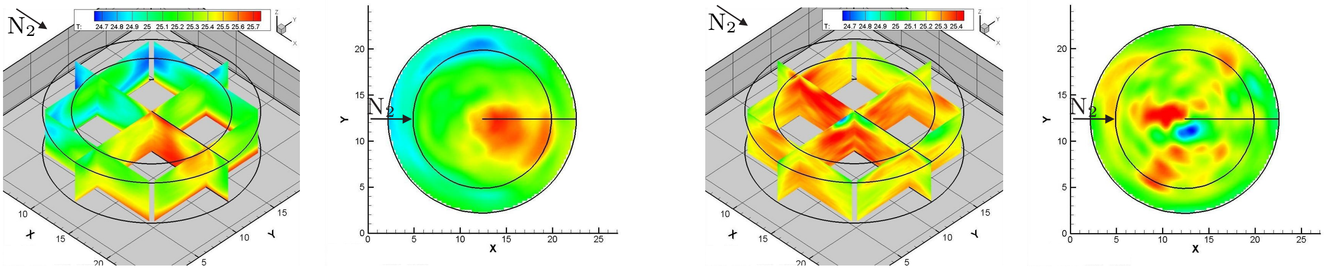
FIG. 1: (a) Side and top views of the experimental cell containing ethyl alcohol (in grey) with an active control on the flatness of the liquid-gas interface. The picture fitting the opening has been obtained with the Schlieren system. The hatching indicates the zone in which the 3D temperature field has been reconstructed by tomography. (b) Experimental points *0g* (□) and *1g* (▽) in the pressure/flow-rate parameter space. Letters refer to results presented hereafter.

Figure 2 shows Schlieren pictures at low evaporation rate (see experimental points a and b in Fig. 1(b)). In *0g*, ripples move parallel to the gas flow either downstream, or upstream as those shown in Fig. 2(a,c) (dashed line), but not specifically in alternation. They appear one by one at a rate of about 0.5 Hz and always from the same site located at the tip of the steady V-shape (solid line in Fig. 2(a)). The schlieren picture for the corresponding *1g* experiment (figure 2(b)) shows for small flow rate a λ-shape structure moving, on the contrary, perpendicular to the gas flow direction and at a slower speed. Notice that double ripples were also observed in *0g* (not shown). They were always present at low evaporation rate and disappeared systematically by increasing it. For larger flow rate, the ripples move always upstream in *1g* condition as shown in Fig. 2(d). Figure 3 shows the 3D temperature field at the same time than the snapshots of Fig. 2. In *0g* (Fig. 3(a), we observe one hot area in the middle of the cell which corresponds to the center of a single convection cell, the liquid reaching the hot middle by the bottom of the layer with an average velocity of 1mm/s and leaving it by the top with an average velocity of 5mm/s. The interfacial flow is indeed driven by thermocapillarity from hotter regions to colder regions. Assuming the ripples to be transported by this interfacial flow, it explains why the ripples can move upstream and downstream as observed in Fig. 2(c). However, the fact that the fluid velocity at or near the interface is larger than the speed of the ripples remains puzzling and demands further investigations. In *1g* (Fig. 3(b)), the inhomogeneity of the temperature field is much more pronounced and



(a) *0g* – $F = 162$ (b) *1g* – $F = 123$ (c) *0g* – $F = 235$ (d) *1g* – $F = 228$

FIG. 2: Schlieren pictures obtained for $P = 1000$ mbar. The gas flow F (ml/min) is from left to right. Dashed lines guide the eyes for the position of thermal ripples and arrows indicate the direction of their movements. Ripple speeds are (a,c) 2mm/s and (b,d) 0.5mm/s (short arrow) and 2mm/s (long arrow). In (a) the solid line shows a steady V-shape.



(a) *0g* – $F = 162$ (b) *1g* – $F = 123$

FIG. 3: Slices of the 3D temperature field as reconstructed by tomography for $P = 1000$. The slice in the (x, y)−coordinates represent the upper slice at $200\mu m$ underneath the interface. The arrows show the gas flow direction.

localized near the interface. These facts are attributed to buoyancy and explain why the ripples are more numerous and more disordered than in *0g*, for the same parameters. Figure 4 illustrate this statement for larger evaporation rates where polygonal patterns are observed only in *1g* (b). Note however that identical topological processes have been observed in *0g* and *1g* such as dislocation as shown on Fig. 4(a). Because of the short microgravity time of MASER (6 minutes), only transient regimes could be observed. Stationary regimes will be investigated in the frame of the CIMEX-1 experiment onboard the international space station.

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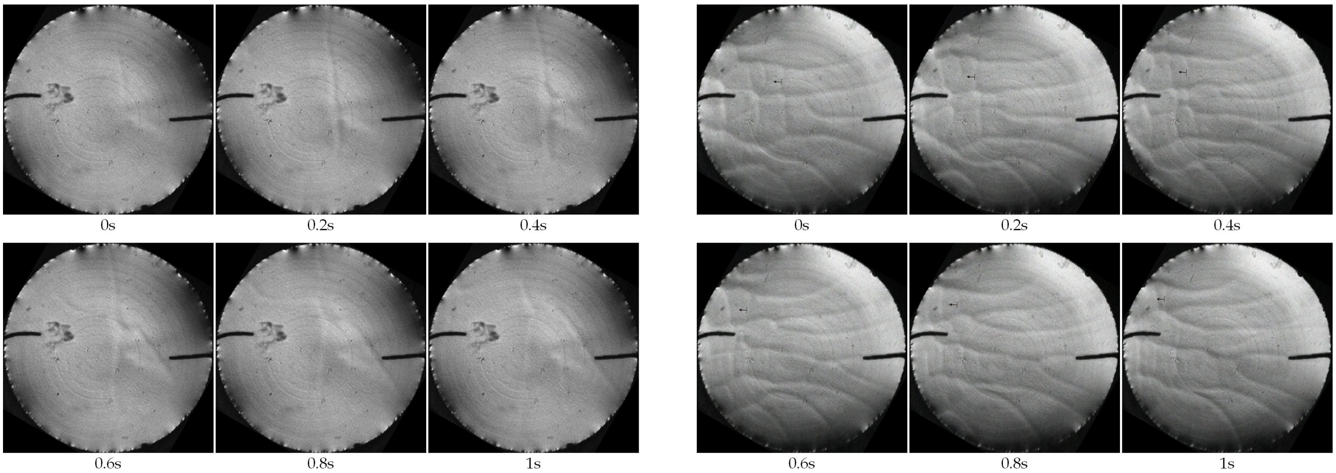

(a) *0g* – $P = 600$ – $F = 345$ (b) *1g* – $P = 700$ – $F = 316$

FIG. 4: Schlieren snapshots at different time (s).