**New features of drops dynamics under Marangoni effect**

R. Savino, R. Monti, D. Paterna, M. Lappa
Space Science and Engineering Department “Luigi G. Napolitano” University of Naples “Federico II”, P.le Tecchio 80, 80125, Naples, Italy

**ABSTRACT**

Following initial observations in microgravity, laboratory experiments have been performed to investigate wetting and coalescence phenomena in presence of Marangoni effect. The problem was also investigated by numerical simulations based on the existence of a thin air film between the adjacent surfaces (liquid-liquid or liquid-solid) convected by the Marangoni velocities. This entrainment effect results in a pressure increase that balances the pressure necessary to prevent coalescence or wetting of the surfaces. A number of experimental findings and numerical simulations are reviewed, including anchored or free drops on solid or liquid surfaces, and the behaviour of droplets in liquid matrices.
1. INTRODUCTION

Research studies on wetting and coalescence prevention by Marangoni flows originate by observations made during the Spacelab mission D2 (1992). The astronaut (Payload Specialist) working on the Fluid Physics Module (FPM) and the PI (R. Monti) on ground observed that it was difficult to create a liquid bridge by putting in contact two drops sitting on two circular disks before isothermal conditions were reached. Following this observation the research group in Naples initiated a number of theoretical, numerical and experimental studies on ground that have shown that both non coalescence and non wetting are caused by Marangoni flows that entrains ambient air in the gap between two drops (or one drop and a pool, or one drop and a solid surface) forming an air film that prevents intimate contacts between molecules that belong to the adjacent surfaces [1-3]. The efforts made in the basic research has given an explanation of a very intriguing class of phenomena that will find applications in the fields of materials sciences, sprays, combustion, diesel engines, etc. The authors believe that this is an excellent example of the type of spin-off that is to be expected from future microgravity activities on the ISS.

The following is a description of the most recent experimental results and of the numerical correlations obtained.

2. WETTING PREVENTION BY MARANGONI EFFECT

A number of experiments has been conducted to study wetting prevention by Marangoni effect. The drop is of silicone oil 5cs, a: ΔT=0; b: ΔT=25K)
performed to investigate the unusual behaviour that drops of different liquids (e.g. silicone oils and diesel oils) exhibit when put in contact with a solid surface maintained at a different temperature. In particular the prevention of the liquid wetting, observed when the liquid drop is warmer than the surface, has been explained introducing a fluid-dynamic model based on the assumption that a thin air film, separating the drop from the solid surface, is formed by the entrainment action induced by the Marangoni velocities along the liquid surface. The experimental system has been described in [4]. A pendant liquid drop is formed on a circular disk and is moved towards a solid surface by translating the disk downwards. When the disk and the horizontal surface are at the same temperature (ambient temperature) no motion arises in the liquid drop, as shown in Fig. 1a (motionless tracers); at these conditions, if the drop is put in contact to the wall, by moving the disk down, the liquid immediately spreads over the solid surface forming a liquid bridge (Fig. 1a2). If this experimental sequence is repeated after establishing a temperature difference between the disk and the horizontal surface (by heating the pendant drop and/or by cooling the solid wall with respect to the ambient temperature), then Marangoni flows will appear inside the liquid drop, due to the surface tension unbalance induced by the surface temperature differences (Fig. 1b1). In particular, since the surface tension is a decreasing function of the temperature, the velocity along the drop surface is downward (opposite to the imposed temperature gradient), i.e. is directed from the upper disk to the region of contact between the drop and the solid surface. By continuity, the flow inside the drop close to the symmetry axis is directed from the contact region towards the upper disk. When the drop is now slowly brought in contact with the surface, if the temperature difference is sufficiently large (of the order of few degree centigrade), no wetting occurs (Fig. 1b2). If the drop is pressed against the solid surface, it is deformed in a completely reversible way, similarly to an elastic balloon. If the temperature gradient is reversed (by cooling the disk and/or by heating the solid surface), then the Marangoni flow is reversed and is directed from the contact region to the solid support (along the liquid drop surface) and when the drop contacts the solid surface the liquid spreads over the solid surface (similar to what happens in the isothermal situation).

2.1 EXPERIMENTAL ANALYSIS AND NUMERICAL SIMULATIONS

With the same experimental procedure described in the paragraph 2, a number of laboratory experiments have been performed to evaluate the minimum value of the temperature difference (referred to as the critical temperature difference, $\Delta T_c$) that must exist between the drop and the solid surface to prevent the wetting of the solid surface, for given drop deformations. The critical temperature differences for which wetting occurs have been determined experimentally, for silicone oils (with different viscosities) and diesel oils, and for glass and copper surfaces.

To evaluate the thickness of the air film separating the liquid drop from the solid surface two experimental techniques have
been implemented: a) a direct visualisation of the air gap by means of a background illumination; b) an interferometric technique that provides interference fringes related to the change of the film thickness in the contact region [4]. At the same time a numerical code has been developed to evaluate the flow field in the liquid drop and the velocity and pressure distributions in the air film between the drop and solid surface. Typical numerical results for a liquid drop of silicone oil with kinematic viscosity of 5 centistokes in presence of a temperature difference $\Delta T=5\,\text{K}$ are shown in Fig. 2.

An extensive numerical experimentation has been performed to correlate the experimental

---

**Fig. 2** - Streamlines (a) and isotherms (b) in the case $\Delta T = 5\,[\text{K}]$, for $\Delta p R/\sigma = 2.8$ and silicone oil 5[cs].
with the numerical results. In particular, for a given drop shape, corresponding to a given value of the pressure jump across the surface exposed to the surrounding ambient pressure, and for an imposed temperature difference, the equilibrium thickness for which the pressure in the air film balances the pressure in the liquid drop has been determined numerically, for the different liquids.

The numerical results, concerning the equilibrium thicknesses of the gap (h), the dimensionless pressure difference ($\Delta pR/\sigma$), the temperature difference ($\Delta T$) and the non-dimensional drop deformations ($\Delta x/R$), confirm all the experimental observations both qualitatively and quantitatively [4].

3. INVERSE CALEFACTION

Liquid drops (typically water), over a very hot iron, roll over its surface. This phenomenon, known as “calefaction”, is caused by the violent vaporization occurring mainly in correspondence of the liquid drop surface adjacent the iron surface, forming a layer of steam that avoids direct contact (wetting) between the liquid of the drop and the hot surface. As a result the drop quickly moves over the iron surface in random directions (if the iron surface is horizontal), propelled by the jet effect of the vapour generated at the drop-iron interface.

The Marangoni flows discussed in the previous paragraphs are responsible for an astonishingly similar phenomenon that we have called “inverse calefaction”, because it takes place at somewhat “reversed” conditions: a hot drop of a liquid (characterized by a surface tension that decreases with increasing temperature) also rolls over a surface at ambient temperature.

Figure 3a shows a drop injected by a syringe (Silicone oil at about 80°C), that moves over the iron, held at ambient temperature. The heater on the syringe is switched on, so that the initial temperature of the drop is of the order of 80°C. The iron has been slightly inclined with respect to the horizontal in order to make the drop move towards the iron tip. What prevents the wetting of the hot drop is the air film created between the drop and the solid surface by the Marangoni flow at the droplet surface, that generates an overpressure at the contact region and sustains the weight of the drop. In fig. 3b two positions of the drop are shown during the drop rolling and at the end of the run when the drop cools down and splashes over the iron surface.
The surface temperature distributions of the syringe, of the drop and of the iron (seen from the side) are measured by infrared thermocamera pictures (Figures 4). In Fig. 4a (inverse calefaction) the heater on the syringe is switched on (drop temperature of about 80°C, iron at ambient temperature); In fig. 4b (normal calefaction) the heater on the syringe is switched off (iron temperature of the order of 170°C, the drop is initially at ambient temperature).

In the central core of the drop a vertical (fountain-like) upward flow prevails that returns at the bottom along the drop surface. The motion at the interface convects the ambient air towards the contact point, creating an air film between the drop and the solid surface.

The film thickness is somewhat proportional to the temperature difference between the drop and the surface; during the process the drop temperature decreases in time towards the iron and the ambient temperature, the film thickness becomes thinner and thinner so that, eventually, the molecules at the liquid surface will contact the solid surface and wetting suddenly occurs.

4. COALESCENCE PREVENTION BY MARANGONI EFFECT

The experimental apparatus used for the ground experiments has been described by Monti and Savino [2]. Two cylindrical copper disks sustain two drops of the same liquid. The disks can be translated along the vertical axis, changing the relative distance between the two drops. A temperature difference can be established and controlled between the disks. The motions in the liquid drops are evaluated by visualizing tracers added to the liquid illuminated by a laser light cut in the meridian plane. A CCD camera and a video recorder are used to record the video images. The experiments show that under isothermal conditions the drops immediately coalesce. On the contrary, if a temperature difference is established between the supporting disks, the drops do not coalesce even if pressed against each other (see Fig. 5).

Similarly, if a pending drop is formed on the circular disk and is moved towards a pool of the same liquid (at the same temperature), when the drop and the liquid pool are put in contact, the drop immediately spreads over the liquid pool surface. On the contrary, if
this experimental sequence is repeated after establishing a temperature difference (by heating the pendant drop and/or by cooling the pool with respect to the ambient temperature) then Marangoni flows will appear inside the liquid drop, due to the surface tension unbalance induced by the surface temperature differences. If the temperature difference is sufficiently large (of the order of few degree centigrade), no spreading occurs (Fig. 6).

### 4.1 ON GROUND EXPERIMENTAL ANALYSIS

Laboratory experiments have been performed to evaluate the minimum value of the temperature difference (referred to as the critical temperature difference, $\Delta T_c$) that must be imposed to prevent the coalescence. The experimental sequence is the following. A relatively large temperature difference is imposed, and the two drops are pressed (or a drop is pressed against a pool surface) producing a flattening of the contact interface, measured by the drop deformation parameter $\delta/R$, where $\delta$ is the difference between the undeformed interface distance and the same distance after deformation, and $R$ is the disk radius.

The drops are left in this position and the temperature difference is progressively reduced (with a sufficiently small temperature ramp, in order to minimize unsteady effects); when the temperature difference reaches a critical value ($\Delta T_c$), the drops coalesce.

The critical temperature difference is a function of the drops deformation and of the liquids employed. A number of experimental
results have been obtained using silicone oils with different viscosities [2].

4.2 NUMERICAL MODELLING AND CORRELATION WITH EXPERIMENTAL RESULTS

To explain the phenomenon and to correlate the experimental results, a fluid-dynamic model has been formulated, based on the assumption that, again, a thin air film is formed between two liquid drops (or between a drop and a liquid pool surface), due to the fact that Marangoni flows convect ambient air to form an air film.

The numerical simulations include the solution of the flow and temperature fields inside the deformed liquid drops (or in the liquid drop and in the liquid pool), and the evaluation of the velocity and pressure distributions in the air film at the touching interfaces.

The equations governing the temperature and velocity fields in the different volume phases are the continuity, Navier-Stokes and energy equations. They have been solved for the two-dimensional axisymmetric case with the numerical model described by Savino and Monti [3]. The boundary conditions include: no slip conditions for the velocity and prescribed constant temperatures on the support disks; the momentum balance and energy conservation along the contact surface in the contact region; the Marangoni condition for the velocity and the adiabatic condition along the curved drops surfaces.

An extensive numerical experimentation has been performed to correlate the experimental results with the numerical ones. The numerical simulations (see e.g. Figs. 7 and 8) support the assumption that a thin film of air, separating the two interfaces, is entrained by the drop surface velocities caused by the Marangoni effect. The film is thick enough to prevent the molecular contact between the liquid surfaces. The experimental findings have been correlated by a number of numerically computed parameters (film thickness, critical temperature differences).

A good agreement was found between numerical and experimental results [1-3].

Fig. 7 shows the results of numerical simulations, for the same conditions of Fig. 5. In particular the numerical results show that, due to the direction of the Marangoni flows in the drops, the temperature of the contact region is smaller than the average value between the temperatures of the
supporting disks, and this causes a surface temperature gradient larger in the hot drop (and consequently an entrainment effect along the hot drop larger than the opposite effect along the cold drop). This was confirmed by experimental results obtained with an infrared thermocamera (Agema 900) that has been used to visualize the surface temperature distribution of the drops. The operating range of this thermocamera is 8-12 µm, that allows one to perform accurate measurements since the used liquids are opaque in this infrared band. The equipment includes optical lens able to zoom on microzone of few millimeters and a dedicated software for the elaboration of the infrared images. Fig. 8 shows that, if the temperature difference is sufficiently large, a liquid drop can be completely immersed in a pool of the same liquid [5].

### 4.3 PROPOSED MICROGRAVITY EXPERIMENT

Due to the limited size of the drop no local measurement of velocity and temperature is practically possible on ground to get a good correlation between experiments and computations. Furthermore the presence of gravity affects the drop shape and the motion inside the drop.

A microgravity experiment on the Maxus Sounding Rocket will be performed to form much larger drops (of the order of centimetres of diameter) and to take intrusive and/or non intrusive local measurements of the thermo-fluidodynamic field.

Hemispherical liquid drops of silicone oil will be formed through a syringe; each drop will be attached to a cylindrical rod. Typical diameters of the drops will be 1 cm. Tracers will be suspended in the liquid to visualize the motion.

A temperature difference between the drop and a solid surface (10 < ΔT < 40°C) will be established. The wall will be held at constant, lower temperature, whereas the temperature of the disk supporting the drop will be increased with a resistance type heater. In this way a steady flow field, due to the dependence of the surface tension with the temperature will be achieved.

The Marangoni convection in the drop will be visualized by illuminating the entire fluid volume with a visible laser, reflecting light from the tracer particles seeded in the fluid. The drop will be pressed against the cold wall...
causing a flat contact surface. The shape of the drop will be detected from video images using a background illumination system. After the measurements of the thermo-fluid-dynamic field at non-wetting conditions, the temperature difference between the disk and the solid surface will be reduced until the drop will spread on the surface. An appropriate slow temperature ramp will be applied in order to minimize unsteady effects. The spreading of the drop on the solid wall will be detected with a high resolution CCD camera at high acquisition speed. Numerical computations have been performed to evaluate the optimum experimental conditions (see Fig. 9). In addition, the numerical simulation will be performed in real time, during the flight experiment, helping the Principal Investigator (PI) in the remote control of the experimental procedure in Telescience operation.

Fig. 9 – Temperature and velocity vector distributions in a silicone oil drop ($\Delta T=T_{\text{support}}-T_{\text{disk}}=40 \, ^\circ\text{C}$)

Fig. 10 – Proposed experimental sequence on Maxus Sounding Rocket
The experimental procedure is formed by five steps (see Fig. 10):
1) formation of the hemispherical liquid drop;
2) establishment of a temperature difference and squeezing of the drop against the solid wall;
3) decreasing of the temperature difference and liquid injection to form a liquid bridge;
4) bridge stirring;
5) study of non coalescence;
These steps will be repeated several times. The wall will be coated with a thin surface (copper or polyethylene or other materials). After the spreading of the drop over the surface, the liquid drop will be partially extracted by suction, either with an extraction pipe or through the injection needle; the surface with the remaining liquid will be removed by utilizing a wall roller.

4.4 BEHAVIOUR OF FREE DROPLETS ON LIQUID POOL

The behaviour of free droplets on a liquid pool at different temperature has been investigated in laboratory experiments. Typically a single droplet with volume ranging from 5 to 20 microliters is formed with a microsyringe that can be heated by an electrical resistance at known temperature. In presence of a temperature difference between the droplet and the liquid pool the droplet is released on the liquid surface. The behaviour of the drops has been observed with a CCD camera. At the same time the infrared thermocamera has been utilised to detect the time evolution of the droplet temperature. The experiments show that, for silicone oils with a relatively small viscosity (ranging from 1cs to 10cs), when the initial temperature of the drop is smaller than the temperature of the liquid pool (typically at ambient temperature), the drop does not coalesce but remains at a fixed position until thermalization (stable configuration). Similar behaviour has been observed if a water drop (that is heavier than the silicone oil) is released on a pool of silicone oil. In this case the Marangoni flow in the liquid pool entrains air between the droplet and the liquid pool surfaces and creates a stable film which sustains the drop. Fig. 11 shows a water drop floating over the liquid pool surface until thermalization. When finally the drop temperature reaches the pool temperature the drop sinks.

When the silicone oil droplet is at larger temperature than the silicone oil pool and the temperature difference is sufficient for coalescence prevention, the drop moves on the liquid surface until thermalization. In fact in this case the coalescence is prevented by the entrainment effect due to the Marangoni surface velocities along the liquid drop, but the initial configuration is unstable due to the direction of the Marangoni flows in the drop

![Fig. 11 – Water drop floating on a pool of silicone oil 3 cs (the drop temperature is smaller than the pool temperature) (CCD image).](image-url)
and in the liquid pool. If the contact point is subjected to an initial small perturbation, the surface velocities are directed in such a way that this initial perturbation is amplified.

Fig. 12 shows the infrared thermographic images of a silicone oil with kinematic viscosity of 5cs moving on a liquid pool of the same liquid. One can see the thermal wake formed behind the droplet, caused by the relative velocity between the drop and the pool. The velocity of the drop is larger than the thermal diffusion velocity ($\alpha/L$), i.e. the characteristic Peclet number ($VL/\alpha$) is large. Therefore energy diffusion behind the droplet is prevented and heat is “blown” away from the drop before it can spread far laterally, giving rise to a narrow wake downstream of the drop (it is evident the analogy with shock waves formed in the aerodynamic supersonic flow, when the speed of the body is larger than the sound speed).

When the viscosity of the liquid pool increases the velocities in the liquid pool decrease and the non coalescing drop remains floating over the pool surface.

5. BEHAVIOUR OF A FREE DROPLET IN A LIQUID MATRIX

This subject is of great relevance in the field of Material Science in microgravity and in particular in problems related to the separation of immiscible alloys, where a number of different phenomena are not well understood (Marangoni migration, drops coalescence and wetting to the container walls). Preliminary experiments on ground with microscale facilities show that Marangoni effects at the interface of two immiscible liquids (e.g. silicone oil and fluorinert, [10]) play the same role as in liquid-air systems, preventing coalescence and wetting. This phenomenon might be also responsible for drops pushing by a solidification front and could lead to separation of the minority phase and to its concentration in the “hot” zones. As mentioned before, the authors believe that the problem of wetting and coalescence prevention of drops in an external liquid matrix, up to now unexplored, is of particular interest in the field of Material Science. Liquid-liquid immiscible alloys (e.g. In-Al,
Al-Pb, etc.) formed by two melts at different compositions can be fully exploited only if a uniform finely-dispersed minority phase can be preserved in the solid state (e.g. materials for self-lubricating bearings with a soft dispersed phase in a high mechanical strength matrix; Lead or Indium dispersions in an aluminium matrix are the most promising). In the Earth’s gravitational field the usual differences in density cause rapid separation of the alloy components through sedimentation or floatation.

Material Science experiments dealing with metallic alloys processing in Microgravity resulted in a number of disappointing results (see Fig. 13 and [7-8]). The anticipated structure of uniformly distributed intrusions of the minority phase in the external matrix after solidification was not found. In many cases a separation occurred and the minority phase accumulated in the “hot” region during the solidification process. This means that the minority phase (initially uniformly dispersed in the majority phase) moved to the region that solidified later (one end of the cartridge, for directional solidification or the internal region when cooling takes place at the external walls). Explanation of the microgravity results has been attempted by assuming that liquid drops in a liquid matrix migrate towards the hot region due to Marangoni effect. The idea being that if the solidification front advances with a velocity larger than the drop migration velocity then it engulfs the drop; vice versa there is a separation of the two materials. The recent findings on wetting and coalescence prevention and the extended ground experiments performed in the last four years strongly suggest to study all the phenomena that occur during alloys solidification (migration, dissolution, wetting and coalescence of drops). Of particular interest is the wetting prevention that could explain the drops pushing by solidification fronts that may be responsible for the phases separation (as observed at the end of the solidification).

5.1 MARANGONI FORCE ON THE DROPLET

This paragraph reports the results of numerical simulations for the evaluation of the Marangoni forces exerted on free droplets interacting with a solid surface at different temperature. The analysis is performed in terms of the forces acting on drops that are either
motionless in a liquid matrix or that migrate at constant velocity (e.g., with the Young velocity in an infinite medium). The force $F_M$, caused by Marangoni flows, can be computed by integrating the surface forces along the drop surface. This force consists of two parts:

a) the integral of the viscous force:

$$\tau_s = \mu \left( \frac{\partial V_M}{\partial n} \right)_s$$

where $V_M$ is the velocity field in the liquid matrix (subscript $s$ means that the derivative is taken at the surface);

b) the resultant of the normal forces (pressure) all along the drop, due to the motion of the liquid in the matrix, so that the Marangoni force reads:

$$F_M = \int \tau_s dS + \int p_n dS$$

The thermofluidynamic fields, inside and outside of the drop, is computed for finite dimension containers in an accurate way. A drop of liquid ($L_D$) is immersed in a matrix of liquid ($L_M$) at constant temperature. If the drop density is larger than that of the matrix then the drop falls to the bottom and if the matrix liquid wets the bottom surface more than the drop liquid then the drop will sit on the bottom and its net weight ($W_D$) will be balanced by the surface reaction forces ($F_R$):

$$F_R = W_D - F_M$$

$W_D$ being the drop weight. If a temperature gradient is established in the matrix, upwards along the vertical (cold bottom), then a Marangoni force is created due to the viscous tangential forces ($\tau_s$) directed along the surface ($s$) and to the pressure ($p$), directed normal to the surface $n$. The equilibrium along the vertical ($F_M$ is directed upwards, toward the hot side) now reads:

$$F_R = W_D - F_M$$

The computations made have shown an effect similar to the “ground effect” that appears on flying objects near the ground. Indeed when the drop is located near a solid surface the pressure forces on the drop (that are small far away from the wall) become large compared with the viscous forces (see Fig. 14). This results in a force on the drop that pushes the drop upward far from the cold wall and might explain the reason for the separation of minority phases during solidification of immiscible alloys, that tends to migrate towards the hot side (that solidifies last). Suppose now that we increase the temperature gradient ($\nabla T$) in the liquid matrix, then the drop will start floating when $F_R \equiv 0$ for a value of $\nabla T = (\nabla T)_F$.

The numerical computations have shown that, at a fixed $\nabla T$, $F_M$ is an increasing function of the drop diameter and an inverse function of the distance between the drop and the solid surface (Fig. 15). An evaluation of the (upward) migration velocity ($V_M$) could be made by assuming that the drag force is that pertaining to the viscous Stokes regime:

$$V_M = \frac{F_M - W_D}{3 \pi \mu D}$$

This value of the velocity should be accurate
New features of drops dynamics under Marangoni effect

Fig. 14 Computed stream-lines (a), isotherms (b) and pressure contours (c) for a droplet of Fluorinert FC43 in Silicone Oil 3cs (D=2mm; ∇T=20K/cm, h=100µm)

in the limit of low speed or small diameters (or $M_a = \frac{\sigma \Delta T}{\mu a} D \to 0$) i.e. when the drop migration does not disturb the thermofluidynamic field.

If h is the distance between the drop surface and the bottom wall, the total Marangoni force acting on the drop $F_M$ is a decreasing function of the distance and an increasing function of the Marangoni number (see the non-dimensional plot of Fig. 16). The limit for $\frac{h}{R} \to \infty$ corresponds to the classical Young solution.

Similar effects can be found for a drop in a liquid matrix between two solid walls maintained at different temperatures. In this case the liquid around the drop is detrained, due to the Marangoni effect, from the liquid layer between the drop and the hot wall (upper) and entrained between the drop and the lower wall. The pressure is reduced in the upper part and increased in the lower one, resulting in an overall force pushing the drop in the direction of the temperature gradient.

Fig. 15 Computed force on the droplet versus drop diameter (D) and distance from the wall (h)
5.2 LABORATORY TESTS

A drop (D=120 [µm]) of Fluorinert FC 43 (1cS, ρ=1700 Kg/m³) in a matrix of Silicone Oil (3cS, ρ=910 Kg/m³) was confined between two solid surfaces at different controlled temperature (T_u, T_b).

A temperature difference between the upper disk (T_u) and the bottom one (T_b) T_u − T_b = ΔT > 0 was established by heating the upper disk: when the average temperature gradient across the cell (ΔT) is above a certain value then the drop is pushed away from the wall and finds its stable equilibrium condition at a distance h such that:

\[ F_M(h) = W_g = \frac{\pi}{6} D^3 (\rho_D - \rho_L) g \]  

When further increasing |∇T| (and F_M) the drop moves further up until \( \frac{h}{D} \) becomes large and if \( F_M(\infty) > W_g \), then the drops starts migrating along the temperature gradient.

The surface tensions and the interface tension at the Fluorinert-Silicone Oil interface have been measured at different temperatures using a tensiometer [9]. The numerical predictions (see Fig. 18a, b) were indeed confirmed by experiments in laboratory [9]. The drop, initially sitting on the bottom, immediately jumped at the equilibrium position (that moves upward with increasing ∇T).

Figs. 19 show the photographs of the experiments.

What was found numerically and experimentally for high Prandtl numbers liquids (e.g. Silicone Oils, Fluorinert, Ethyl Alcohol, etc.) can be extended to the cases of metal melts (very low Prandtl numbers) in...
New features of drops dynamics under Marangoni effect

Fig. 18
(a) Computed streamlines and pressure distributions from the numerical simulation of a drop (D=120 [µm]) of Fluorinert FC 43 in a matrix of Silicone Oil of 3cS confined between two plates at different temperatures, changing the distance from the lower and upper walls.
(b) Marangoni force acting on the drop as a function of the distance from the walls.

Fig. 19 Photographs of the laboratory experiment (a, b, c correspond to an increasing temperature gradient)

the presence of strong temperature gradient at solidification fronts.
Experimentally it is difficult to visualize the drop position in melts of real interest in Material Science and only numerical runs have so far been performed.
For a typical case of In-Al alloys the value of $F_M(D,\Delta T, h)$ was computed that show the very same trend as for large Prandtl number fluids.

6. CONCLUSIONS
Coalescence and wetting prevention due to Marangoni convection have been investigated by experimental investigations and numerical simulations. The numerical simulation supports the assumption that a thin film of air is entrained by the surface velocities caused by the Marangoni effect.
An experiment on the Maxus Sounding Rocket will be performed that will allow to form larger drops (of the order of centimetres of diameter) and to take intrusive and/or non intrusive local measurements of the thermofluidynamic field.

The phenomenon of the inverse calefaction is also investigated.

The numerical simulations and the preliminary laboratory experiments performed also show that Marangoni effects are responsible for a pushing (or attracting) force on a droplet interacting with a solid wall in presence of a temperature gradient. If the temperature of the wall is smaller than the drop temperature (as for the case of a solidification front) repulsive effects arise that prevent the wetting. Similarly, during solidification processes, Marangoni effects play a role in the solidification front/drops interaction by favouring the pushing (or, equivalently, by preventing engulfment/entrapment of liquid drops).

Laboratory tests with a drop of Fluorinert in a matrix of Silicone Oil, confined between two plates at different controlled temperatures, have confirmed the numerical predictions.

When the average temperature gradient across the cell is above a certain value the drop, which is heavier than the surrounding liquid matrix, is pushed away from the wall and finds its stable equilibrium condition at a distance such that the pushing force, due to the Marangoni effect, balances the net weight of the drop. Further experimental and numerical studies are in progress along these lines.

REFERENCES
