A PLATEAU TANK FACILITY (PTF) FOR LIQUID BRIDGE EXPERIMENTATION BY USING BUOYANCY TECHNIQUE FOR MICROGRAVITY SIMULATION

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ABSTRACT

A Plateau tank is just a reservoir filled with a liquid inside of which there is another immiscible liquid of the same density. The behaviour of the inner liquid can be studied in some respects as in weightlessness.

Several Plateau tank facilities have been built-up in the last decade at Lamf/ETSIA. In this paper a new apparatus for liquid bridge experimentation in simulated microgravity conditions is presented. Such equipment allows to impose to the experimental configuration a wide range of controlled mechanical disturbances and incorporates appropriate diagnosis means. The apparatus may be operated either manually or from a desktop computer to which a remote controller can be linked for telescience operation.

Keywords: Liquid bridge, neutral buoyancy, microgravity, experimental facility, telescience.

1. INTRODUCTION

The aim of this paper is to describe a new facility (PTF, Plateau Tank Facility) developed to perform experiments on earth concerning the fluid mechanical aspects of fluid-fluid interfaces like liquid bridges and anchored drops, mainly in near microgravity conditions. A liquid bridge is a large and slender liquid mass spanning between two solid coaxial discs (Fig. 1). Among the mechanical aspects of more interest there are the following ones: the equilibrium shapes and their stability, breakage dynamics, resonant frequencies and deformation modes, and the influence on them of the main parameters involved, as volume, disc size and separation, external forces (as a small gravity field).

The neutral buoyancy is the technique implemented in the PTF to perform experiments on earth in near microgravity conditions. It consists in surrounding the liquid mass of interest by another liquid immiscible with it and of precisely the same density. This technique has been selected based on two main reasons: its suitability to perform scientifically relevant experiments and its capabilities to simulate the operation of experiments to be carried out in real microgravity conditions on board space laboratories.

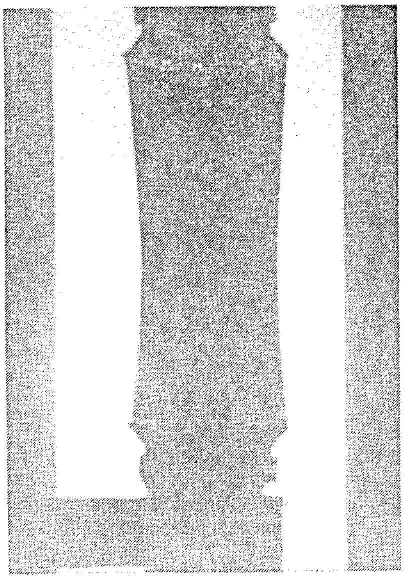

Fig. 1 Liquid bridges between coaxial circular discs with conical edges.

Concerning the first point, ample experience exists with this technique and the theory behind is very well developed. In the experimental side, for axisymmetric configurations, the following aspects have been studied: the minimum volume stability limit of a liquid bridge between equal disks [1] and short inflated bridges [2], the influence of the outer bath and the resonant frequencies [3], the breaking dynamics [4], the combined effect of residual gravity and unequal discs [5], the stabilizing effect of electric fields [6] and the influence of the injection speed on the formation of a liquid bridge [7].

Previous papers contains also the corresponding theoretical study. Complementary numerical and theoretical studies can be found in [8; 9; 10; 11; 12; 13; 14; 15; 16; 17; 18; 19; 20].

Non axisymmetric liquid bridges has received some attention. Effects on long bridge stability of several perturbation sources such as disc desalineation and residual transversal gravity have been theoretically studied[21], and non axisymmetric oscillations have been considered both experimental and theoretically in [22].

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Concerning captive drop shapes and stability, it is a classical subject that has received a large and long lasting attention due to its basic and wide spread interest. A review of the literature published in this subject can be found in [23]. However, resonant frequencies of captive drops have not receive attention until a few years. Among the work devoted to that point, some theoretical [24; 25] and experimental [25; 26] studies can be pinpointed.

The suitability of PTFs to simulate most of the operations in real microgravity conditions has been demonstrated by their use in the training program of the payload specialists of the Fluid Physics Module (FPM) and in the preparation of experiments performed on space laboratories [7; 27; 28; 29].

The capabilities demonstrated for almost real microgravity experiment operation, the large outcome of scientific results and the existing supporting theoretical models lead themselves to the neutral buoyancy technique as a good candidate to be considered in the near times for studying the intrincacies of the new methods (e.g. telescience) which are being developed to perform experiments in space platforms in the years to come.

In the following, the main design drivers of the PTF are presented (§ 2), a summary description of its main subsystems is performed (§ 3) and the relevant capabilitites are outlined (§ 4).

2. DESIGN DRIVERS

A liquid bridge is formed by injecting the working liquid between two parallel discs. Most often the injection is performed through a hole located in one of the discs. In the neutral buoyancy technique, an outer liquid should be previously present in the test chamber in order to provide support to the working liquid against gravity.

A typical experiment with liquid bridges or drops would consist in at least some of the following actions: preparation (bath supply and formation of the anchored liquid mass), changing the configuration (variation of volume, change of disc position), stimulation (oscillation or rotation of the discs, breakages), recovery and finalization.

From the lessons learned with the work performed with an existing facility [30], besides providing the required operation performances, the following characteristics are made available. The tank which contains the liquid is sealed in order to avoid evaporation and bath leakages, and at the same time allows accessibility for modifications or changes. Maximum visibility is obtained by means of the four windows of the tank. Bath recirculation is foreseen in order to avoid stratification of the surrounding liquid (generally a mix of liquids of different densities in the appropriate ratio to obtain the required density). The liquid cell have small weight and size to facilitate the oscillation as a whole. The PTF can be remotely controlled to bring the possibility of use it in telescience operations.

3. APPARATUS DESCRIPTION

An sketch of the PTF is shown in Fig. 2. It consists of three main blocks: the Liquid Cell (LC), where liquids and motors are located, the Electronics Box (EB), where electronic boards for driving the motors are located, and the Intelligent Controller (IC), a microcomputer with data acquisition and image processing capabilities.

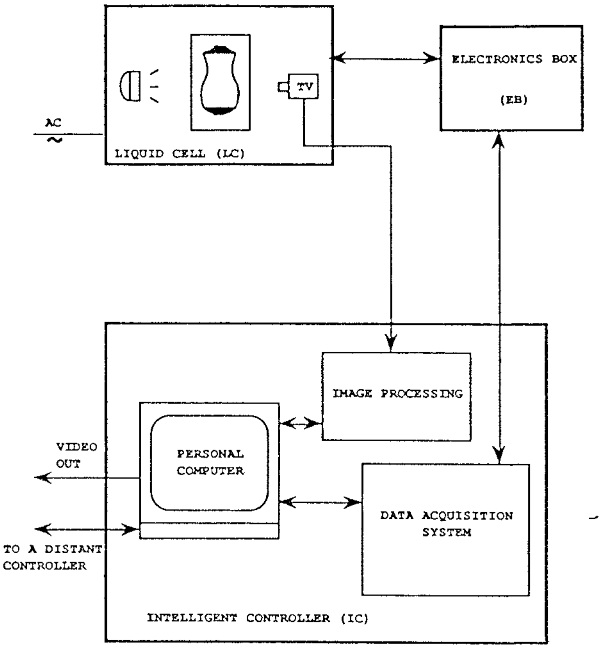

Fig. 2 Sketch of the PTF.

3.1 Liquid Cell

The LC can be driven either directly by means of a control panel in the EB or remotely via the attached computer. The main characteristic of the LC is that all the mechanisms are placed together in one (the upper) side of the experimental cell. Even the support of the lower disc is rigidly fixed to the frame of the upper disc axial displacement. In this way a tight paralellism and alineation of both discs can be achieved and kept fixed even after the removal of the tank for cleaning. Some overall views of the LC are shown in Fig. 3. The LC consists of the following subsystems:

Tank

It is totally independent of the mechanisms involved in the operation of the liquid bridge. In this way its manipulation for cleaning and maintenance do not influence the alignment of the discs. It allocates the bath recirculation ducts, the bottom plate with holes for distributed withdrawal, and injection holes in one of the four corner columns. It is fixed in place to the upper side by a seal and a bayonet locking for easy mounting.

Upper disc displacement and rotation, and liquid injection

The distance between the two disks can be changed by sliding the support of the upper disc along a linear guide. This movement is performed by using a thread and a servomotor which allow to control the displacement speed. The injection and withdrawal of liquid inside the zone is performed through a hole placed in the upper disc supported by a hollow axis. As the disk rotates, a seal is employed to connect the rotating axis to the feeding tube. The feeding tube carries the liquid from an external syringe. The position of the piston is measured by a potenciometric transducer.

The gear fixed to the hollow axle of the upper disc is used to drive the rotation of this disc. The mounting of the disc on the axis is of the bayonet type to ease the changing and cleaning.

Lower disc oscillation and rotation

The oscillation of the lower disk has to be variable in frequency and amplitude and single senoidal to avoid the presence of higher harmonics. This characteristics have been achieved by using a desmodromic eccentric whose eccentricity can be changed by axial displacement of a desmodromic linear inner lever. This axial displacement is driven by an electric motor and is measured by a potenciometric transducer which allows to know the oscillation amplitude.

As the axial and lateral oscillations of the lower disc are not simultaneously activated, they can be performed by the same mechanism. A desmodromic eccentric push on one of two slides that move in perpendicular directions. Which slide is pushed depends on the turning direction of the motor that drives the rotation of the lever through a helicoidal gear pair with crossed axes. Due to the load projection in this kind of gears, in one rotation sense the lever acts against one of the slides, and against the other one when rotating in the other direction. This solution eliminates the need for two separated oscillation driver mechanisms reducing overall weight although some care should be taken when changing from one direction of oscillation to the other one which should be performed with the lever at the zero amplitude position.

The motion of the slides is transmitted to the lower disc by a L-shaped arm. The frontal sections of the L-arm have been reduced to a minimum in order to decrease the induced motion of the bath. Through the larger side of the L-arm runs a transmission axle, which is connected via a pulley with the lower disc, allowing for the rotation of this disc. As the rotation motor is fixed to the LC frame and the transmission axle, together with the L-arm, is a moving part, the connection between both rotating parts is made by a modified Oldham joint.

One of the most often used pair of liquids is silicone oil as working fluid and an adjustable mix of water and alcohol as bath. Silicone oil is not reactive and do not present compatibility problems. The alcohol-water mix is corrosive for ferrous materials. This is one of the reasons for employing anodized light alloys, brass and teflon in the construction of most parts of the LC. The material for the discs depends on the liquids to be used. For the above mentioned combination Perspex shows a satisfactory behaviour. The discs are shaped as a frustrum cone whose sharp edges could offer an anchoring place for the three-phase contact line.

3.2 Electronic Box

The EB is designed following a modular concept around an analog backplane bus to which each module is connected. The existing modules are the following ones: LC-EB, Channel Readout Display, Power Supply Module, Visualization Control Panel, Upper Disc Rotation, Disc Oscillation Amplitude, EB–IC Connector, Backplane Bus Connector, Bath Recirculation Pump, Lower Disc Rotation, Disc Oscillation Frequency, Upper Disc Displacement and Syringe Piston Displacement.

3.3 Intelligent Controller

The IC consists of a microcomputer (AT Compatible) which includes a data acquisition and control system (DACS) and a video image processor (VIP).

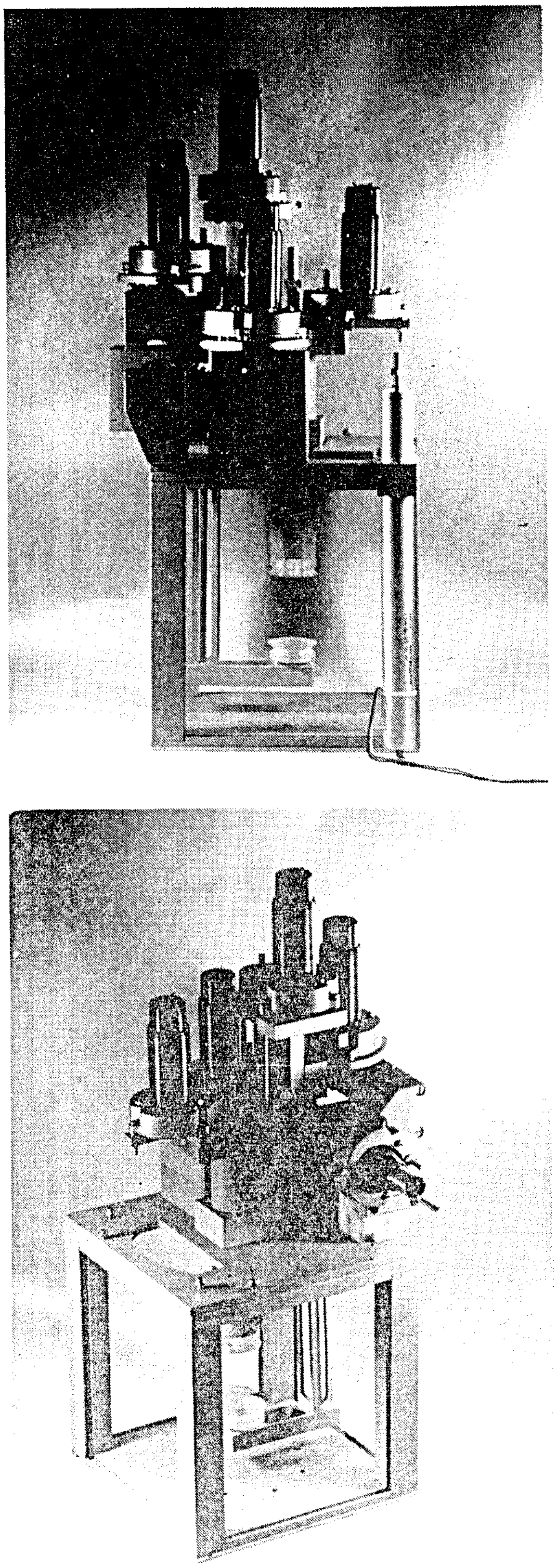

Fig. 3 Overall LC views.

The main characteristics of the DACS (Keithley 570, configured for this application) are the following ones: 12-bit 31 kHz ADC, 32 single ended analog inputs and seven 12-bit analog outputs.

The VIP consists of a high resolution frame grabber (DT 2851) and dedicated software. The frame grabber can adquire video images in real time digitizing the image in a matrix of 512 x 512 elements and 8 bit resolution gray levels. The existing look-up tables allow for the online execution of several operations as, for instance, sophisticated gray level multiple thresholding in pseudocolor, which should be very useful for the setting up of the structured illumination needed to support high precission interface shape measurement.

The computer gathers data from DACS and VIP allowing for the simultaneous measurement of analog scalar data (position and speed transducers) as well as vector data (interface shape). The IC can be used in a number of ways, from a mere keyboard simulation of the EB control panel to a programmed performance of an experiment, till complex supervision of operations (detection of liquid bridge breakage by comparing actual shapes and stable shapes) if the appropriate software is used.

4. EQUIPMENT CAPABILITIES

The degrees of freedom of the experimentation and their typical ranges are as follows:

4.1 Experimental Volume

Geometry

- Tank dimensions: 150 x 150 x 150 mm^3
- Discs size: typically both are equal circular discs of 30 mm in diameter, although other end-plates of special geometry can be accommodated.
- Discs separation: from 0 to 100 mm.
- Liquid injection: from 0 to 140 cm^3.

Fluids

- Silicone oils of viscosities 5, 20 and 100 centistokes have been tried as working liquid.
- Water-alcohol mixture as outer bath.

Visualization

- Fiber optic cold background illumination
- CCD camera for shape recording

4.2 Estimuli

- Axial displacement: from 0 to 100 mm, one disc (accuracy ± 0.2 mm).
- Lateral displacement: ±1 mm, one disc.
- Axial oscillation: from 0 to 2 Hz with 0 to 1 mm amplitude, one disc (accuracy ± 0.01 Hz).
- Lateral oscillation: from 0 to 2 Hz with 0 to 1 mm amplitude, one disc (accuracy ± 0.2 Hz).
- Rotation: from 0 to 30 rpm both discs independently. Eccentric rotation can be achieved by using special off-axis discs (accuracy ± 0.3 rpm).

Besides the forced stimuli above mentioned, the influence of the natural g-jitter of a µg platform could be investigated if the PTF is mounted on a vibration table.

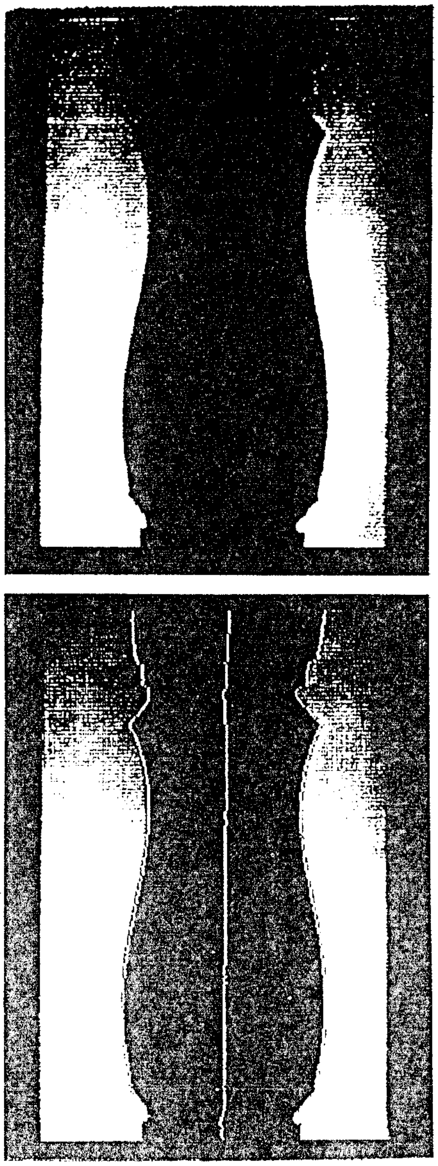

Fig. 4 a) Liquid bridge video image.
b) Interface position and mean line generated by the image processor.

4.3 Diagnosis

The diagnosis of the fluid response to stimuli is based primarily in the analysis of the liquid free-surface shape, helped with the visualization (and some measurement) of the internal fluid motion in a meridian plane (made visible by tracers in the fluid and a light sheet). At present, only the outer shape visualization is available, although provisions for future enhancement in this direction have been undertaken.

Automated image analysis is being developed, f.i. the liquid contour can be extracted in near real time from the video frames (Fig. 4). This could be used to automatically avoid bridge breakages when unwanted, automatically find resonant frequencies, drastically compress the downlink data for complex telescience operations, etc.

5. CONCLUSIONS

In this paper, a summary description of the PTF has been performed. First, the interest, both scientific and operational (regarding preparation of experiments onboard spacecrafts) of the neutral buoyancy technique has been outlined, together with some account of the past and present use of this technique to simulate reduce gravity conditions.

The main design drivers and the relevant details of the subsystems have been described together with the relevant capabilities.

The existence of such a facility will largely help to the experimentation with both liquid bridges and anchored drops, and the conception of the instrumentation, developed around an Intelligent Controller, whould help a lot both to the performance of experiments on earth and also to the training of experimenters in the new type of experiment operation on real microgravity environments, by the possibility to try software-simulated from panels and remote control (including line delays).

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