

## Academy Transactions Note

# PLATEAU TANK FACILITY FOR SIMULATION OF SPACELAB EXPERIMENTS†

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**Abstract**—A Plateau Tank Facility (PTF) has been designed and built as a ground support equipment for the Spanish experiment on the First Spacelab Mission. The PTF is a rough mechanical substitute of the sophisticated Fluid Physics Module (FPM) to be flown, and it is best suited to neutral buoyancy experiments where a floating zone up to 130 mm long can be subjected to stretching, filling, rotation, vibration, etc. and its outer shape and inner motions be monitored and recorded from both lateral and axial views.

### 1. INTRODUCTION

One of the multiuser facilities provided by ESA for the First Spacelab Payload is the FPM[1] presently a part of the Material Science Double Rack. In this first flight six experiments will be performed with it in different areas of fluid physics: drop oscillation damping, liquid spreading on solids, surface tension driven convection, disjoining pressure in liquids, sloshing and stability, most of them making use of the floating zone technique. NASA is also developing floating zone experimental facilities to be flown on later Spacelabs.

Although applications of floating zones are in fact mostly concerned with phase change processes (crystal growth and purification by remelting) its study is normally restricted to the simpler liquid bridge between parallel, coaxial, equal discs. At present equilibrium shapes are well documented and their stability limits known for most familiar configurations, but surface distortions and inner motions due to mechanical or thermal disturbances are still open problems.

To gain some knowledge on several problems encountered during the development of the FPM a series of trials were carried out at ESTEC in 1980 where it was realized the need of a deeper understanding of some crucial points for the proper outcome of the Spacelab experiments, mainly fluid injection and visualization.

### 2. EXPERIMENTAL TECHNIQUE

Most research teams on floating zone and liquid behaviour in microgravity have developed some kind of Plateau tank for their experimental work. A Plateau tank is just a reservoir filled with liquid inside which another liquid, immiscible with the former and with the same density, can be studied as in weightlessness (in some respects). In a large scale it is similar to the water tank used for training astronauts to work. Of course this

method does not simulate completely Spacelab conditions because of the presence of the outer liquid, but helps in gaining experience on the above mentioned difficulties, apart from the intrinsic interest of performing experiments on interfacial phenomena with isodense fluids.

Other methods of minimizing gravity effects have also been used: reducing the scale of the experiment to a millimetre or less, electroacoustic or electrodynamic levitation etc. but the constraints they impose on size are undesirable. Just for equilibrium configurations even a soap film in an appropriate wire frame can be of much help, but real experiments on microgravitational fluid-mechanics demand cancelling gravity with inertia forces, thus recourse is had to free fall towers, aircraft parabolic flights, sounding rockets and orbiting platforms, depending on the time required.

The PTF has a tank similar to the FPM test chamber, but being free from the heavy constraints on mass, volume, safety and interfacing imposed upon the FPM, it is a handy and more accessible apparatus from the user's point of view. The first neutral buoyancy experiments reported are those of Plateau[2] who used olive oil as working liquid in a bath of water-alcohol mixture. More recently Mason[3] reported similar experiments using isobutyl benzoate in distilled water. Carruthers and Grasso[4] used instead the water-alcohol mixture as working liquid and nujol oil for the outer bath. Rodot and coworkers[5] used silicone oil in a water-alcohol mixture and aniline in a water solution of BrK to study forced oscillations of supported spheres. Tagg *et al.*[6] at JPL used silicone oil in a water-alcohol mixture. As seen, there is no agreement on the best couple of liquids for neutral buoyancy. Availability is a deciding aspect and stability a major concern; a water-alcohol mixture stratifies and evaporates thus changing the density (experiments are to be performed soon after preparation). However, most work with the PTF is being done with oil in a water-alcohol mixture, though a mixture of dibutylfthalate-dioctylfthalate in a distilled water bath is also used for more precise measurements.

Evaluation of density differences between working

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and outer liquid, interfacial tension, viscosity, and their gradients if a mixture is present, are difficult to perform. Control of wetting conditions is a real burden and it is well known that much of the past failures in related experiences were due to a poorly defined wetting; this is particularly true for the early stages of the floating zone formation where human intervention is most desired.

As for the water-alcohol mixture, several methods are currently used to measure the density and its vertical gradient, perhaps the best known being the positioning of density tracers (small oil droplets of known density). With the PTF what is currently done is to prepare a coarse mixture, establish the liquid bridge, and then use it as follows: injection of a cylindrical zone as slender as possible (here cylindrical means with a volume equal to that of a cylindrical zone of the same slenderness) and then addition of water or alcohol while gently stirring until the outer shape seems cylindrical. By repeating these operations for more slender zones accuracy is gained, but instability is also approached.

Temperature variations pose also a problem because the associated density change and, most of all, the interfacial tension gradients that it generates. Up to now the only step taken into the PTF to minimize this effect has been the use of a low intensity (60 W) diffuse background illumination and saving lightning time.

Interfacial tensions are measured by the ripple method (Rayleigh, 1896[7]) in an auxiliary tank, but the possibility of *in situ* evaluation with the floating zone itself is being investigated.

### 3. DESIGN AIMS

The primary goal of the PTF is to serve as a ground support experimental facility for the Spanish experiment 1-ES-331 to be performed with the FPM on Spacelab 1, so that expertise be gained in the handling of liquids and the visualization of interface shapes and interior movements for the actual FPM and its future versions.

The main philosophy has been to get a Plateau tank similar to the test chamber of the FPM, but freed from other subsystems that render the FPM complex, so that mechanical drivers, electric controls, liquid reservoirs, lighting system, recording devices, etc., are all separate independent parts. At its more crude description, the PTF is but a glass box screwed to a motor box through broken shafts so that it can be easily removed and washed under a tap.

This is seen as an intermediate project worked out at the University premises (most parts are made of brass, perspex, glass or wood), but lessons are to be learnt for the possibility of developing small flight hardware for use in rocket programs, for instance.

The first major experiments on the PTF are to be the study of the breakage of initially cylindrical zones near their stability limit.

To ensure a practical outcome, a modular concept and a priority list were established during the development phase. First the tank itself was thought out and because a close resemblance to the FPM test chamber was intended, its size and shape were adopted, although

all the sides were to be glass panelled instead of closed as in the FPM.

With the same idea in mind, no effort was made to solve the drawbacks so far encountered during tests on the present FPM version (as regards optical path obstacles and so on) most of which are obviated by a change in the highly flexible visualization system of the PTF.

Inside the tank there are the two parallel coaxial equal discs to form the zone and transmit *all* the mechanical perturbations envisaged. The upper disc has a hole in its centre for liquid filling (both the working and outer liquids are kept in external reservoirs and are recoverables).

### 4. DESCRIPTION

The PTF comprises a glass test chamber held in a tubular structure with two frames and a large hollow cylinder in between (just to simulate the actual FPM). At the top a motor box is attached and at the bottom the control box and a safety pan stand. The tank itself is screwed at the middle, hung so as to have optical access from below. All joints to the structure are made through elastic elements for mechanical isolation.

#### 4.1 Motor box

There are three electric motors: one for each disc rotation and one for axial displacement of the upper disc, and a small electric vibrator for bottom-disc axial oscillations. All the controls are in the control box. Motors are asynchronous with two senses of rotation and a built-in reduction; they are bulky (1.8 kg) have a consumption of 32 W (220 V) and furnish a torque of 0.3 Nm at 60 rpm. The vibrator is a small (0.9 kg) highly controlled unit (1.5–1000 Hz,  $\pm 2.5$  mm) with a maximum load of 9 N and a consumption of 5–10 W.

#### 4.2 Tank

The tank is a frame of brass sheet 1 mm thick with two vertical perspex bars simulating the air inlets and outlets of the cleaning system of the FPM. Preliminary work was performed about the convenience of reproducing the air flow (by whirling on the outer liquid) to study the disturbances introduced to the zone, but the cleaning system will only operate after zone breakage, so no further steps were undertaken. The tank shape is that of a pentagonal prism, all sides and bottom panelled with 3 mm thick glass. There is a 140 mm hole on the top acting as sliding guide for the large cylinder that supports the upper disc through which the injection is made; this cylinder houses the mechanisms for feeding-disc rotation. The base of the tank houses the mechanisms for rotating, vibrating the laterally displacing the bottom disc.

During preliminary test, an appendage has been also developed to prolong the feeding disc and have then access to the tank inside for manipulation, as can be seen in Fig. 1 where a perspective view of the PTF is shown.

Two sets of working discs are in use: couples of 30 and 60 mm diameter. They are mounted on an intermediate disc-holder that accept discs up to 100 mm diameter.

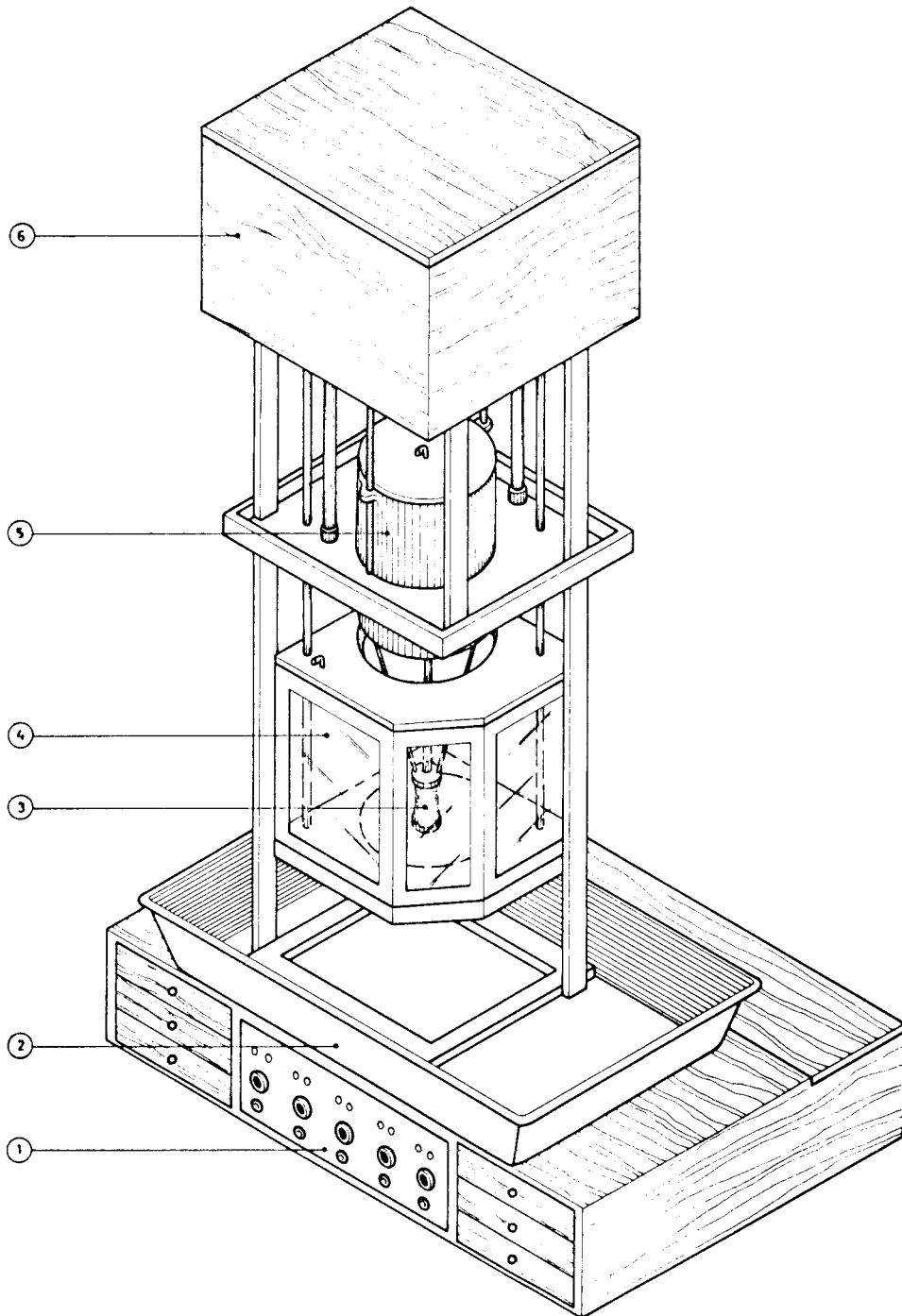


Fig. 1. Sketch of the PTF. (1) Control panel. (2) Safety pan. (3) Floating zone. (4) Plateau tank. (5) Upper disc cylinder. (6) Motor box.

#### 4.3 Transmissions

4.3.1 *Upper disc.* There are two movements: rotation (both senses) and axial displacement. The glass disc itself is stuck to a perspex disc-holder having a sprocket where an end of a telescopic shaft engages (the other end joins the corresponding motor in the motor box). This telescopic shaft makes compatible rotation and axial displacement. The displacement is achieved by means of two screwed pins, joint by a chain, one of them being

directly driven by the corresponding motor in the motor box.

4.3.2 *Bottom disc.* There are three movements: rotation (both senses), axial vibration and lateral displacement. The fact that optical access through the bottom disc was wanted posed a big problem. Rotation is accomplished via a broken shaft from the motor box, crossing the tank and ending in a sprocket engaged to a ring gear guided by two additional planetary gears. The

dis-holder has two concentric parts that can have a relative slide but whose relative rotation is restricted, so as to enable axial vibration of the disc. The movement is transmitted from the motor box via a broken rod to allow the tank being taken away. Lateral displacement is manually driven via a screw that swings the disc-holder round the fixed point used for rotation input (some 100 mm off axis).

#### 4.4 Controls

The control panel has at present only on-off switches to power the four motors (two for disc rotation, one for axial displacement and the fourth for liquid injection) and the vibrator. Besides that, the vibrator has its own controls (external to the PTF) for amplitude (up to 1 mm) and frequency (from 1.5 Hz upwards).

Disc rotation speeds can be selected from 2 to 18 rpm by a simple gear change, and axial speed is fixed at 1 mm/s. Two microswitches stop the motor at the ends of the travel.

The only manual movement is the lateral displacement of the bottom disc (up to 2 mm), but the possibility of incorporating an electric vibrator for this lateral capability is being thought.

#### 4.5 Improvements

Aside of the just mentioned enhancement, all motor speeds could be in a later step continuous, and all the relevant information gathered in the already available digital display to be recorded jointly with the liquid bridge image.

### 5. OPERATION

#### 5.1 Filling

Feeding and removal of the outer liquid is done smoothly through a hole on the bottom of the tank in order to avoid bubble formation. There is another hole in the top for venting and overflowing. Once the tank is filled with the outer liquid the floating zone is established in the following way: liquid injection from an exterior reservoir (a large syringe) until a good size liquid cap is seen on the supplying disc, then bringing the discs together and the cap squeezed in between until good contact is obtained and a liquid bridge formed. After that, feeding and disc separation are combined to get to the desired configuration.

#### 5.2 Illumination

In most of the work already done with the PTF, a diffuse background illumination has been used covering one side of the tank with white paper and shining a 60 W lamp on the rear. All other sides are shielded and the recording done from the opposite side. A grid is drawn on the white paper for ease of interpretation, and a corner of the area reserved for digital display signals.

For meridian plane and cross axis illumination a normal slide projector is used with appropriate slits (mounted on slides) to light from a perpendicular direction to that of viewing. In this case tracers are premixed

with the working liquid. Trials have been carried out for the determination of best tracer size and concentration for a given recording procedure, but it seems most dependent on particular experiment goals.

#### 5.3 Recording

Although liquid zones are several centimetres large and easily accessible, experience has shown the convenience of continuous monitoring with a video system also used for image recording. Digital displays on the viewed background help for simultaneous monitoring and registration of elapsed time, injected liquid volume and status lamps for the motors.

#### 5.4 Cleaning

In order to save in liquids, once the trials finished, first the working liquid is sucked back (up to some safety limit) and after the outer liquid is also removed. This sequence is just the opposite to the one described in Filling. Cleaning procedures depend on the needs: a normal washing is always performed by water circulation through the tank, adding dish cleaner and rinsing as in a home dish-washer machine; if more cleaning is wanted then the tank is unscrewed from the support frame and thoroughly washed under a tap, dismounting even the disc-holders and mechanisms if necessary.

### 6. CONCLUSIONS

A rough mechanical replica of the Fluid Physics Module to be flown on Spacelab has been designed and built for Plateau simulation of microgravity experiments. The test chamber is an all glass cage of 20 cm of side where floating liquid zones up to 130 mm in length and 100 mm in diameter can be established and subjected to several mechanical disturbances in order to check some theoretical work already done about stability limits, inner motion due to filling, spin-up, vibration, etc. Additional thermal capabilities are being considered for implementation in a near future.

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