# DESIGN AND MANUFACTURING OF AN APTF TO TEST FLUID BEHAVIOUR IN MICROGRAVITY ENVIRONMENT

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Abstract.- The present paper deals with the design and manufacturing of an APTF (Advanced Plateau Tank Facility) in order to carrying out earth experiments, previous to space experiments, of fluid behaviour in microgravity environment. This work has been done in collaboration between Manufacturing and Microgravity Laboratories in the Polytechnic University of Madrid, and analyses the requirements and restrictions that must be considered for an APTF design and manufacture. Mechanism employed in each part of the prototype are described in detail, emphasising those that suppose new solutions rather previous designs.

Keywords.- Microgravity, Plateau, Tank Mechanical, Design

## 1 INTRODUCTION

Very important scientific and technological advances have been reached since spaceships were put in orbit. Special conditions in the spacecraft have allowed to carry out many different kind of experiments in several research lines.

Nevertheless in this way there are many interesting fields that stay in the beginning of research and practically they still have not been successfully applied in the industry. One of these fields is the work in low gravity acceleration levels, usually called Microgravity work.

Materials behavior under reduced gravity conditions, particularly fluids behaviour, has been studied many years ago. The first purpose of these studies was reliability in equipment elements on the spacecraft. Afterwards some studies were directed towards those manufacturing processes that, carried out on earth, used to need very especial conditions to reduce gravity effects and also towards those processes that could produce new and interesting products. Two samples of this are monocristals and special alloys manufacturing. Both could have perform a very important role in microelectronics develop.

Although the first prospects in space manufacturing were encouraging, comparison between earth and space manufacturing is at present favourable to the first from economics point of view. One of the reasons for this situation is the lack of enough space experiments with adequate equipments to this purpose. Because of high equipment payload cost for spacecraft experiments and for astronauts training earth simulation is needed.

There are several methods to get negligible gravity effects on earth. One of these methods often utilized in fluid behavior knowing under microgravity conditions is the study of simple configuration systems usually named "liquid/bridges" or "floating/zone".

This method places a liquid volume between two flat discs separated by a prefixed distance as is showed in figure 1, providing information about mechanical fluids behaviour in weightlessness.

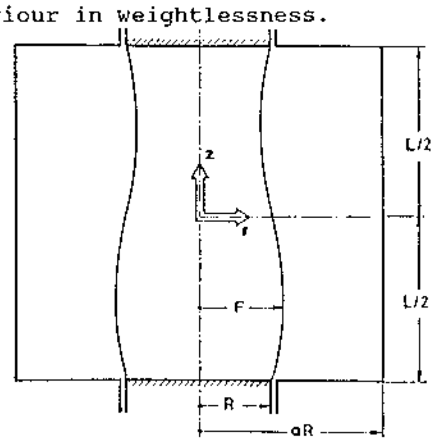


Figure 1. Floating zone configuration

With initial configuration a great variety of trials have been carried out. Some of obtained results have not been completely explained by theory at the moment. This makes necessary to carry out more tests under different boundary conditions that provides enough information to build a theoretical model which can explain all the results obtained in previous trials.

The scope of the present paper does not cover this interesting studies, but it can be found with further details in references [1]..[7].

The present paper shows the mechanical design of an equipment to build and test liquid bridges behaviour in earth microgravity conditions, as a first step towards the space behaviour study. This equipment was named APTF (Advanced Plateau Tank Facility) in contrast to previous PTFs builtup.It was completely designed, developed and manufactured by the μ-Lab group in the Aeronautical Engineering School of the Madrid Polytechnic University.

## 2 DESIGN REQUIREMENTS

The first technical problem is to maintain the liquid column between the discs in a steady way. This is done by means of two non-mixed fluids or liquids with similar values of their density. One liquid, usually silicon, forms the column and the other liquid, usually alcohol and water mixed, avoids the effect of gravity to the formed column.

Watertightness and surface resistance against corrosion are two requirements that must be considered in mechanical design and materials selection. Another design requirement is the need for maximum visibility, in order to allow geometric measurements on the different configurations reached by the system.

Most of expected trials using this APTF version are based in works with different configurations in length or diameter of the liquid column, subjecting them to small dynamic disturbances in order to compare obtained results with theoretical predictions based in a mathematical model.

Paying attention to equipment operation, the first step in whatever work to be done is the liquid bridge forming. As was told in precedent paragraph, liquid column is supported between two flat discs, all immersed in a second liquid which avoids the gravity effects. Discs must be close enough (depending on feeding hole diameter) at the column fluid injection start in order to be enable the whole space filling between them and push out environmental fluid. Afterwards, while discs are separated adequate liquid volume must be injected until the desired column length is reached. There are test equipments that only allows this possibility in order to perform stability tests respect maximum column length and forming rate.

Once the liquid bridge is formed with static stability the trials usually will work in one of this four ways:

a) Periodic variation of the column length by means of Z-axis oscillation of one disc. This oscillation should be adjustable in amplitude and frequency.

b) Transversal oscillation ( X-axis) between discs with adjustable amplitude and frequency

c) Clockwise and counterclockwise rotation between discs at different frequencies

d) Rotation of the two discs as a whole

Besides these requirements, the APTF is requested to other operative features. In first place, liquid zone must be easily accessible to manipulation and to implant those measurement or auxiliary devices that are necessary. In second place, the environment liquid must have a recirculation system to eliminate stratification effects.

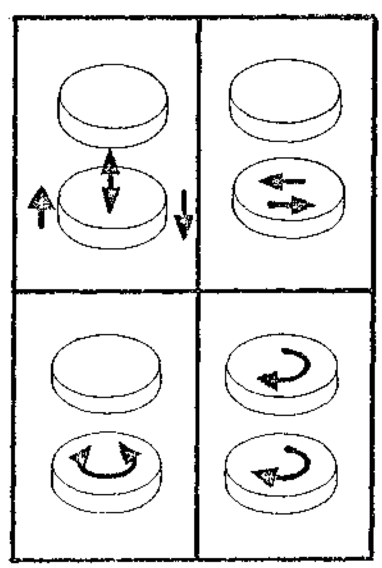

Figure 2. Experimental requirements

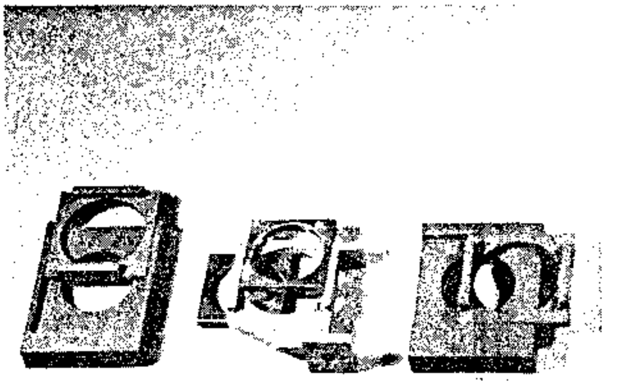

Figure 5. Axial and transversal oscillation slides

To use this mechanism an specific operative is required in order to reach a right work. The change of rotation sense must be done only when oscillation amplitude is null. This is the only use restriction since amplitude can be regulated from zero to its maximum value at the same time that frequency is adjusted in every value.

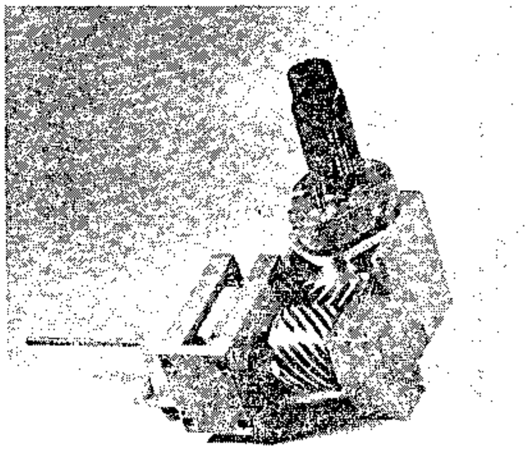

Figure 6. Oscillation main driver and gear transmission

3.3 Column length feed and control

As was told previously the first stage in liquid column forming requires proximity between the two flat discs. In this situation a certain volume of liquid (depending on desired geometric configuration) is injected until the two flat surfaces are completely impregnated of fluid.

Liquid injection and evacuation are done through a central hole inside the upper disc. On the other hand, impregnation of flat surfaces basically depends on used materials (column-fluid, environment-fluid and discs material) although disc geometry could have some influence on it, especially to obtain stable configurations of liquid bridge.

The column fluid feeding system should not have problems if the disc could stay fix. Due to the disc must have rotation capabilities (see second paragraph), is necessary to prevent completed watertight of the system with this movement.

When this first step is done and discs can be separated, an adequate liquid flow feeding and separation rate must be obtained relating injector and discs diameters, screw pitches and driver speed. Figure 7 illustrates the upper disc inner.

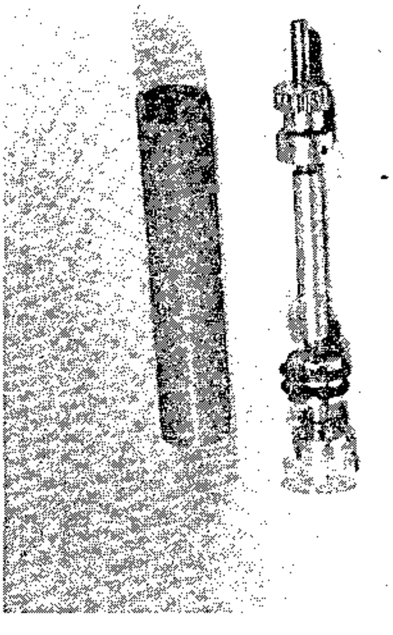

Figure 7. Upper disc inner system

3.4 Oscillation system

A new and interesting APTF innovation respect to precedent develops is the excitation mechanism placing in the upper external assembly part. The linking of this mechanism to the rest of the system allows more accuracy tolerances and more compact configuration of the whole system.

In order to transmit movements and hold the lower disc, an L-shaped piece was designed. Critical parameter design of this piece was minimize its influence in the floating zone. So frontal areas were reduced to their minimum values without deformations.

Two last suitable requirements (remember that APTF is a previous design to future space trials), are minimum size and weight and remote control capabilities.

## 3 APTF ELEMENTS

This paragraph shows the most relevant design features of APTF constitutive elements, and also show how these features solve design requirements and problems.

### 3.1 Floating zone container

In precedent PTFs, liquid container was responsible for disc positioning and driving mechanisms holding. This solution caused several problems in lining up lower and upper discs each time that cleaning and maintenance operations were done.

Current design has an independent container from displacement mechanisms. On the one hand this provides higher visibility, more simplicity and less accuracy requirements in pieces manufacturing, and on the other hand the possibility that the container itself has inside the environment fluid recirculation system.

The container structure has been built through four lighted-columns with glasses between them, and two sheet-covers in each extremes. One of the columns allows the circulation of the environment fluid. This fluid is token from the lower cover by an star distributed pipes, in order to decrease the influence of this flow on the floating zone, and sent back by a gear pump through a hole placed at the top of the column.

The upper cover is formed by two sheets that allow easily manufacture a quick "bayonet" locking for a faster assembly/disassembly of the parts. All the system is watertight by means of a O-ring joint linked to the container top sheet and a glass silicon sealing.

### 3.2 Adjustable eccentricity lever

A common needed feature for every external oscillations is a adjustable frequency and amplitude. On the other hand, periodic displacement must have sine wave form in order to eliminate interferences in experiment results. To satisfy these requirements a desmodromic system was designed. This consist in an eccentric lever with adjustable eccentricity, regulated through a second desmodromic linear lever with axial displacement. This mechanism is showed in figure 4

Axial lever is driven by an internal screw, powered by a DC driver. In order to know oscillation amplitude, a second screw (with the same pitch) is used. This screw push the extreme of a potentiometric sensor and so the displacement is known. Besides this second screw allows the use of displacement limiter switches to avoid accidental damages.

Since oscillation trials are never carried out at the same time, and with the purpose of reduce the number of mechanisms, DC drivers and therefore weights, the design with only one linear lever mechanism was made for every oscillations. This solution is based in the displacement of the eccentric lever between two positions. At each of them the lever work with a different sliding piece which transmits required oscillation. Lever displacement is done making use of the same power unit used in oscillation through an helicoidal cross-axis-gear joint. Distribution efforts of this joint can be used at this purpose because changing the rotation sense of transmission changes axial loads sense (see figure 6)

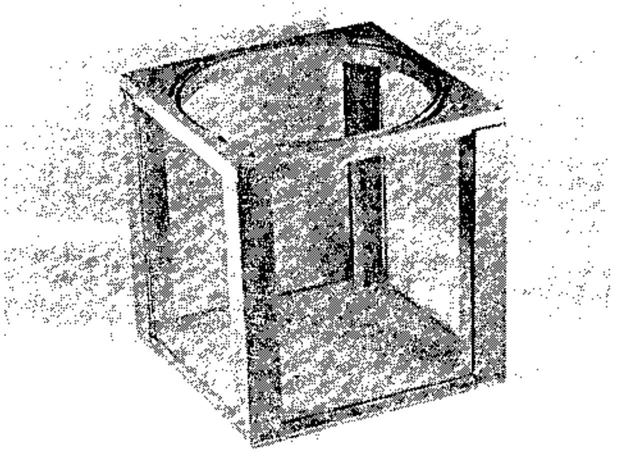

Figure 3. Floating zone container

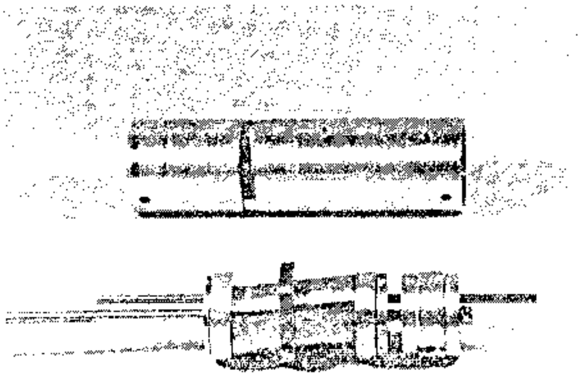

Figure 4. Adjustable eccentric lever

Longer side of the L-shaped piece has inside a transmission stick which makes possible the lower disc movement in collaboration with two pulleys.

Watertightness is reached through a rubber joint which allows displacements in X and Z axis and a O-ring joint placed on the stick. Although in this APTF version is not implemented, the stick can be used as secondary element to supply liquid to the floating zone (liquid bridge). Figure 8 shows L-shaped piece and lower disc.

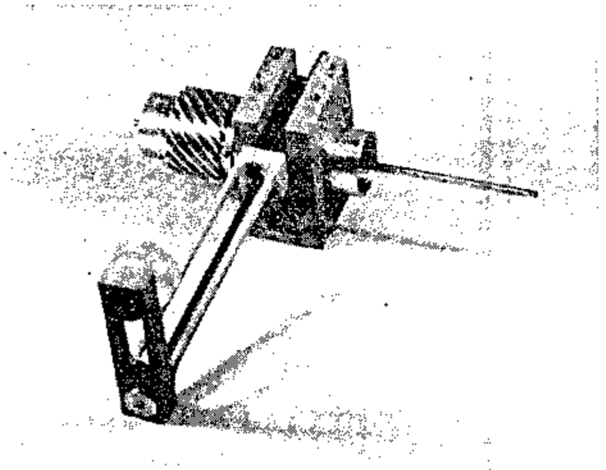

Figure 8. L-shaped piece and lower disc

As lower disc DC driver is held in a fix position during X and Z axis displacements of the lower disc, is necessary the use of a joint that can transmit rotation without obstruct axial and transversal oscillations. This is the modified Oldham joint showed in figure 9

This joint allows power transmission between two near parallel axis. Using Oldham joint is possible to work with rotation and linear oscillation at the same time.

## 4 ADDITIONAL DESIGN CONSIDERATIONS

Once showed how most important design requirements are solved by different solutions, is interesting the mention of other APTF design features related with equipment quality.

The first of these features is the adequate materials selection. Ferrous materials are not good selection due to are not enough corrosion resistant, especially to very oxidant water-alcohol solutions. Basic materials employed are aluminum alloys, brass, methacrylate, rubber, glass and teflon. Most pieces have been manufactured in aluminum alloys with a double purpose:

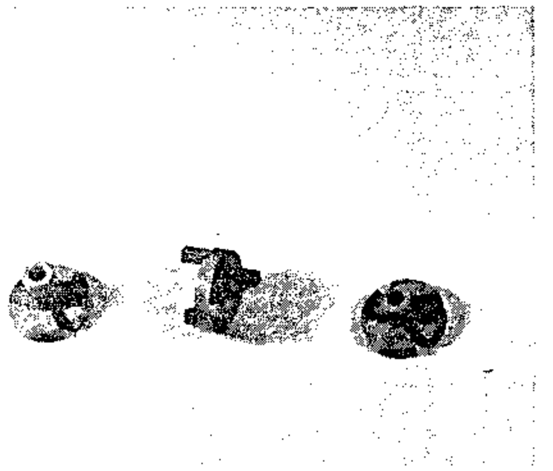

Figure 9. Modified Oldham joint

avoid corrosion and reduce weight. After machining pieces have been anodized to reinforce the first purpose. Second purpose is by the moment a way to take experience to future develops.

Brass and teflon have been used basically to decrease friction, since obtained results have not been satisfactory. Teflon has low rigidity in comparison with aluminum alloys, so its field of work is limited to small pieces without large efforts and pieces with low level of dimensional tolerances.

Translucent material chosen has been glass. One considered alternative was methacrylate, but it was not selected due to methacrylate increases its opacity with the pass of time and is easier than glass to be damaged. Nevertheless methacrylate has been suitable material in discs manufacturing.

Another feature to be considered is, from users point of view, APTF versatility in order to carry out different kind of trials. By the moment only dynamic tests with adjustable oscillations in the liquid bridge extremes have been mentioned, but there are other interesting research lines that can be carried out with APTF basis.
One of these is thermal studies and modelling on floating zone. This is the reason because the design has large free zones as is showed in figure 10, in order to set additional equipments required in these new experiments.

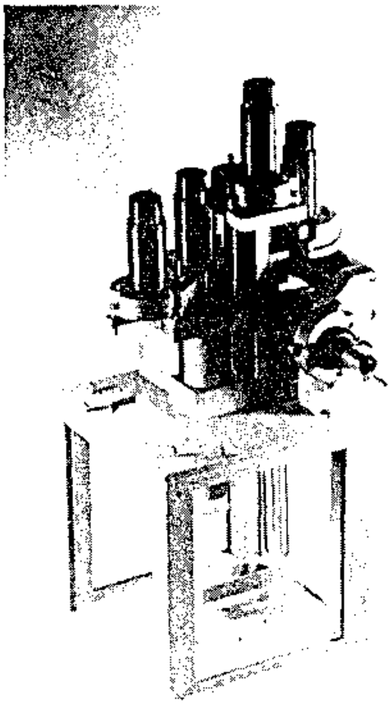

Figure 10. APTF mechanisms overall view

5 REMARKS

Results of first experiments in parabolic and orbital flies give higher gravity levels than those theoretically predicted. Therefore is necessary to carry out new experiments to correct and update theoretical models.

In order to study this behaviour an additional equipment is developed at present. It allows global excitation of the whole APTF, and is based on a similar lever mechanism than APTF's, although simpler than it because transversal displacements are not required.

This APTF version is only a prototype so its design and manufacturing processes can be improved. Some of these improves can be done in later versions of PTFs, but required investments advice to wait for an adequate system behaviour.

Finally, APTF supposes a powerful tool to carry out very important experiments and trials on a top space technology field.

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