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# Long Liquid Bridges Aboard Sounding Rockets

**Abstract** Large free liquid volumes, 30 mm in diameter and 80 mm long, anchored to coaxial discs, have been achieved during a sounding-rocket flight. As these flights provide some six minutes of microgravity and the formation of the liquid column takes only a matter of seconds, ample time is left for experimentation. The results of these trials are presented, and the equipment used to obtain them is briefly described.

**Résumé** Au cours d'un vol sur fusée-sonde, on a pu obtenir des grandes colonnes de liquide en suspension (30 mm de diamètre × 80 mm de long) entre des disques coaxiaux. Comme ce genre de vol procure environ 6 minutes d'apesanteur et que la formation de la colonne de liquide ne prend que quelques secondes, on dispose amplement de temps pour l'expérimentation. On décrit l'équipement utilisé et les résultats obtenus.

## Introduction

Experimentation with liquid bridges in microgravity is of great value for the understanding of basic phenomena in a variety of disciplines[1], which include single-crystal growth from a molten bridge. The problem lies in gaining access to the microgravity environment. Balancing the hydrostatic pressure of the liquid bridge in the ground-based laboratory with a bath of some other immiscible liquid of the same density is comparatively easy, but rarely satisfactory, since it heavily distorts the boundary conditions. Gravity's effects can be minimised by working with very small samples ( ~ 1 mm), but then the diagnostic techniques become problematical. By far the best approach is to have the liquid bridge floating free in a drop tower, on a parabolic aircraft flight, on a sounding rocket, or in Spacelab, the choice depending on the duration of the microgravity period needed (typically 3 s, 25 s, 6 min and open-ended, respectively).

The Spacelab option is obviously preferable, but the flight opportunities are limited and call for some five years of preparation. Consequently, until permanent Space Stations can offer a turnaround time of less than a year, sounding rockets are best suited to provide the microgravity environment, giving up to 6 min of research per flight. They are also of great help for testing new apparatus and procedures intended for Spacelab/Space Station. Consequently, it is not surprising that microgravity research aboard sounding rockets has proliferated during recent years.

However, a lot of material-science applications involve very slow mass- and heat-diffusion processes that operate over much longer periods, and the same was initially thought to be true with large free liquid masses. Experiments with small liquid bridges ( ~ 1 $cm^3$) have been going on since the first sounding-rocket flights[2]. Several liquid-release mechanisms have been proposed for freeing the liquid once in microgravity, thereby minimising both the time taken prior to experiment commencement and the residual motion generated. On the recent Texus-12 sounding-rocket flight, only 10% of the microgravity period provided by the rocket was consumed for establishing a long liquid bridge (60 $cm^3$ in this case), leaving a profitable 90% free for the investigations proper. It is worth consulting Reference 3 to compare the achievements of the Texus flight with those during the flight of Spacelab-1 in order to realise the particular advantages offered by the two types of carrier.

## Equipment on Texus-12

The equipment flown on Texus-12 on 6 May 1985 included the Liquid Column Cell (LCC) developed by ERNO (Bremen) for the European Space Agency (ESA). It first flew on Texus-10 on 15 May 1984, but a mechanical problem in the drive motor prevented it from functioning properly on that flight.

The LCC (Fig. 1) consists of a main quasi-cylindrical body, 0.15 m in diameter and 0.45 m long, weighing some 10 kg, plus mission-dependent external equipment for observation, image recording and electrical conditioning (Fig. 2). During this flight, background illumination (a panel of 5 W lamps) was used to highlight the deformation of the oil column against a translucent millimetric raster screen. The recording was done with a 16 mm cine-camera (at 20 fps). The apparatus can be operated on the ground as a stand-alone unit to support neutral-buoyancy experiments in the preparation of flight trials (a most desirable capability not provided by many more sophisticated facilities), or readily embarked on sounding rockets, Shuttle flights or Spacelabs.

In the equipment's present form, liquid bridges up to 60 mm in diameter by 100 mm long can be established between interchangeable end plates by injecting liquid through one of the plates.

Although the main emphasis during the Texus-12 flight was on the visual recording of the liquid's outward shape, several monitoring and housekeeping signals were made available on the ground in real time during the flight, including disc position and speed, liquid and chamber temperature and pressure, lamp and camera voltage and current, etc.

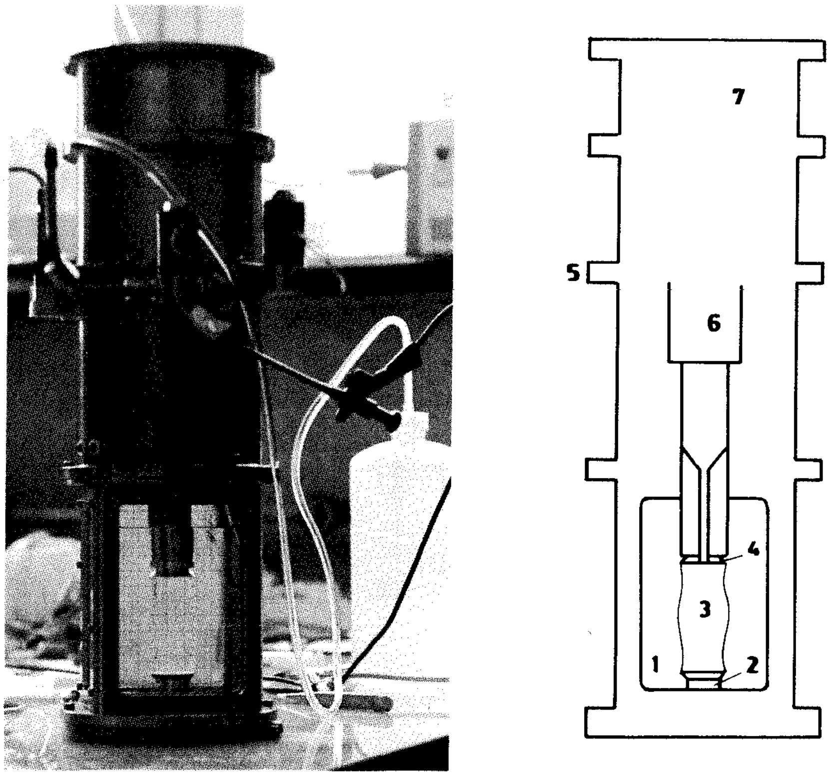


**Figure 1. The Liquid Column Cell (LCC) being operated on a desk top.**

1. **Test chamber filled (to nine tenths), with a neutral bath**
2. **Fixed disc**
3. **Liquid column**
4. **Injection disc**
5. **Connectors for syringe filling and temperature and pressure probes**
6. **Syringe device**
7. **Motor box to drive the syringe piston (feed disc)**

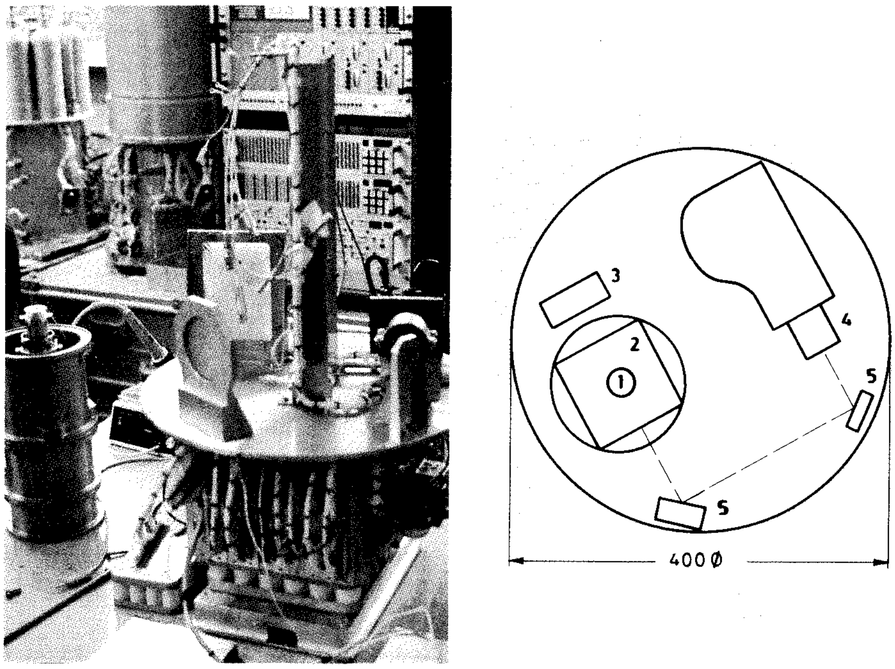


**Figure 2. Observation system used on Texus-12**

**(a) The standard 400 mm-diameter platform for the Texus sounding rocket is seen in the foreground, with the Liquid Column Cell dismounted for clarity (upside down on the left)**

**(b) Plan view:**
- **1. Liquid column cross-section**
- **2. Test chamber**
- **3. Light box**
- **4. Cine-camera**
- **5. Mirrors**

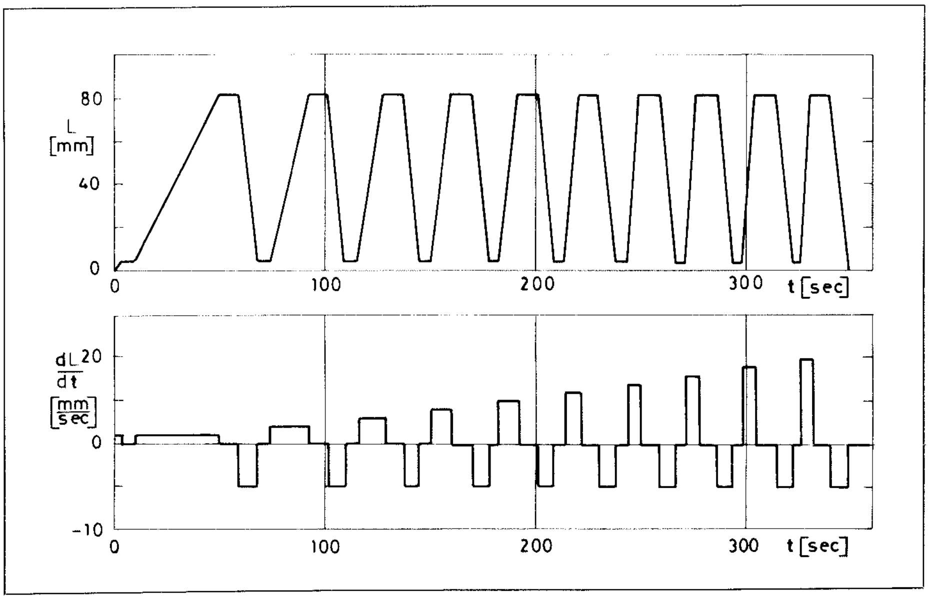
## The experiments conducted

The prime goal for the Texus-12 experiment was to establish a long cylindrical liquid column in the minimum time. Because liquid spillage is irreversible, a smooth, progressive approach was followed, filling and recovering the liquid back to the syringe at increasing disc speeds, from 2 mm/s to 20 mm/s, in steps of 2 mm/s (Fig. 3).

The liquid used was dimenthyl-silicone oil, with a surface tension of 0.02 N/m, a viscosity of $5 \times 10^{-6}$ m$^2$/s and a density of 920 kg/m$^3$. The aluminium discs used were 30 mm in diameter, with the rim edge (5 mm) cut back at 45° to provide an enhanced edge effect (anchoring capability).

Ground testing in a neutral-buoyancy configuration indicated that the maximum injection rate would be in the range 10 to 15 mm/s, so that rupture was expected to occur near the sixth stretching (Fig. 3). Instead, it took place at the end of the third (Fig. 4d), helped by strong inertia forces in the abrupt stop at the end of the span. This behaviour had not been apparent on the ground because of the

Figure 3. Nominal disc position L and speed dL/dt, both as a function of time t, for the Texus-12 experiments



damping effect of the outer bath (a water-methanol mixture to match the density of the oil).

Another relevant finding during the ground tests was the negligible influence of the withdrawal speed, which greatly simplifies the removal phase. Some striking inertia waves showed up in flight near the end of the removal steps, but they did not endanger the integrity of the bridge.

During the first stretching during the Texus flight (from a to b in Fig. 4), the liquid column behaved as expected. For most of the time the zone was perfectly cylindrical; finally, a slight 'necking' developed near the injection disc, giving rise to slow oscillations (period ~ 1 s). The withdrawal was nominal except for the rapid reflecting waves at the end, which we have already mentioned.

During the second stretching, the column grew astonishingly cylindrical up to point c (Fig. 4), but then, after stopping at that point, an unexpected necking started near the fixed disc. The semi-period was close to 8 s, but its further development could not be followed because withdrawal then started. The necking retained an almost constant amplitude until the end, at which time larger reflecting waves than before could be observed.

During the third stretching the column quickly developed a permanent necking (about 30% of radial deformation peak-to-peak), surprisingly, near the fixed disc and much in contrast to ground-test experience. This undulation continued after stopping at d (Fig. 4) and gave way to the liquid-bridge disruption shown by e, f, g and h in Figure 4.

Slow breaks are not fatal on the ground because the drops can be easily merged and the bridge re-established, but on this flight the large oscillation in the big drop remaining on the feeding disc produced an edge angle greater than 180° and the liquid overspread towards the back of the disc, causing a loss of working liquid. In the subsequent operations air was sucked into the syringe, mixed with the oil and the usual emulsion mess developed.

## Conclusions

The Texus-12 experiment has demonstrated that large liquid masses can be freed from a reservoir and accurately positioned between two solid coaxial discs, all in less than a minute in weightlessness, thus enlarging the range of possible experiments with liquid bridges aboard sounding rockets.

Once more, inertial forces have been shown to play a dominant role in the behaviour of large liquid masses under microgravity, and careful attention must be paid to them in the future.

Detailed analysis of the data gathered is still proceeding, but a proposal has already been made for future Texus flights to study the deformation of a long

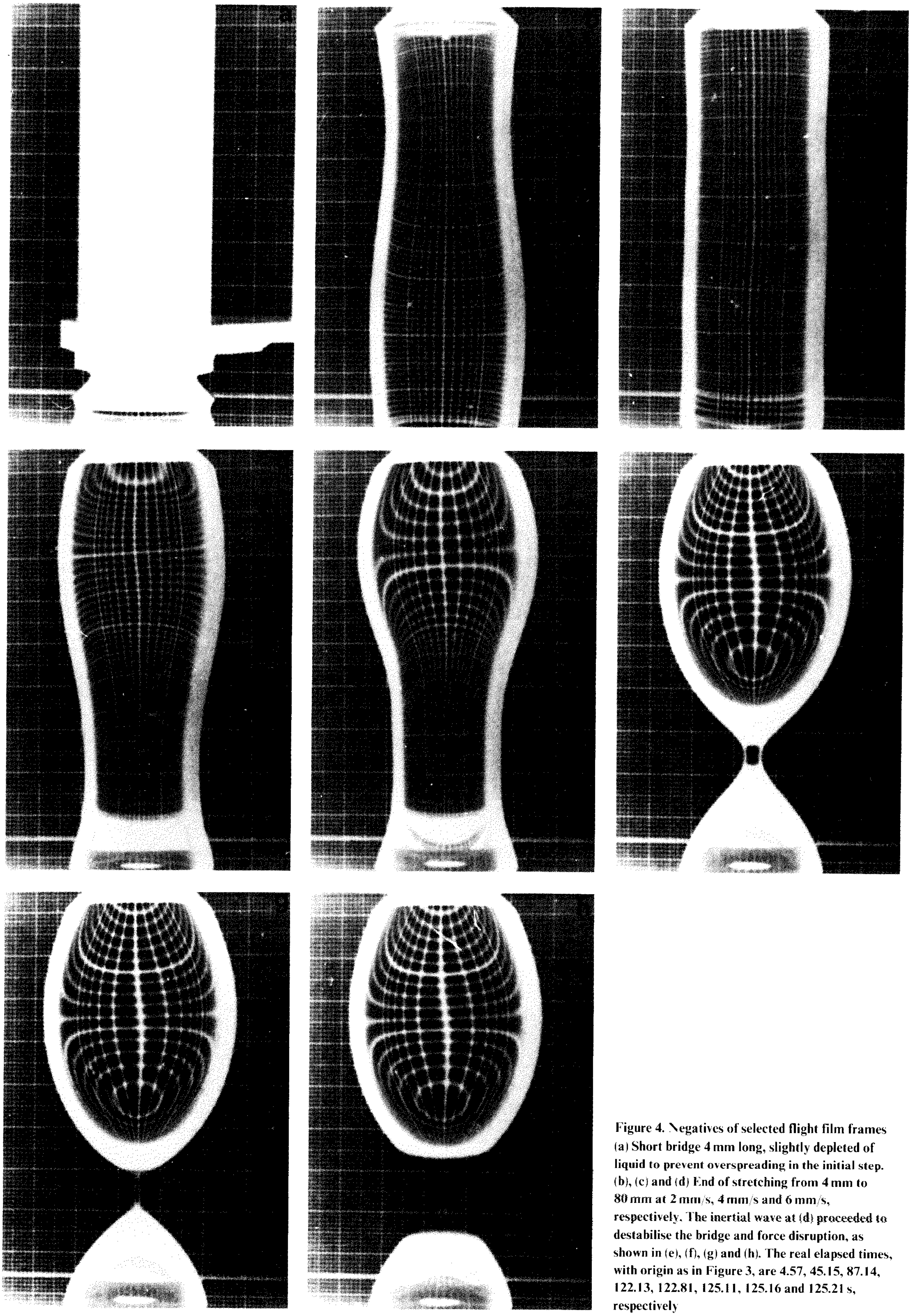


Figure 4. Negatives of selected flight film frames (a) Short bridge 4 mm long, slightly depleted of liquid to prevent overspreading in the initial step. (b), (c) and (d) End of stretching from 4 mm to 80 mm at 2 mm/s, 4 mm/s and 6 mm/s, respectively. The inertial wave at (d) proceeded to destabilise the bridge and force disruption, as shown in (e), (f), (g) and (h). The real elapsed times, with origin as in Figure 3, are 4.57, 45.15, 87.14, 122.13, 122.81, 125.11, 125.16 and 125.21 s, respectively

liquid column established between the feed disc and a new opposing disc. The latter, instead of being fixed as on Texus-12, will be made to rotate eccentrically to excite a skipping-rope-like movement in the liquid column.

## Acknowledgement

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