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# Surfactant-Free Liquid Films Under Gravity and Microgravity Conditions

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## Abstract

SINCE 1984, Utah State University, through support funding by Thiokol Corporation, has been studying gossamer films under low-gravitational conditions.[1] Much of this research focused on curable fluid systems for application to large, lightweight space structures. One of the major problems in this research was overcoming the need to modify liquids with surfactant (soap) in order that films could be drawn. The presence of the surfactant modifies the properties of the cured films. Mostly, these effects are adverse. In the liquid state, the surfactant can form micelles, which can severely modify the effective liquid viscosity making this basic fluid parameter very difficult to define. This then complicates scientific study of the liquid.

A series of experiments was conducted onboard NASA's KC-135 aircraft in conjunction with their Reduced Gravity Program. This aircraft has been modified to provide intervals of up to 30 s of microgravity (0.02 $g$).[2] Our experiments have shed new light on the role of surfactant in liquid films in the KC-135 microgravity environment. In these microgravity environments, liquid films are stable for tens of seconds without a surfactant being present in the liquid.

## Contents

The film-pulling apparatus consisted of a base plate with a reservoir and two vertical supports on which a guillotine film striker slid. All parts of the apparatus were made of aluminum. Figure 1 shows the film-striking apparatus and its dimensions. The bottom edge of the guillotine striker was machined to a thickness of 0.54 mm (see enlarged cross-section view in Fig. 1). The reservoir had a capacity of 1 cm$^3$ and the vertical rods were 0.32 cm in diameter. Surfactant and other impurities were removed by ultrasonic agitation in an acetone bath.

These experiments evaluated the film forming capabilities of three liquids: deionized water, Dow Corning DC 704 diffusion pump oil, and Union Carbide UVR 6110 uv curable epoxy. Rationale for these three test fluids was the following: water was chosen because it is a relatively simple polar molecule; DC 704 siloxane polymer was chosen because of the nonpolar nature of the molecule, as well as the potential usefulness of that chemical family in the low pressure LEO space environment; and UVR 6110 epoxy was chosen because it can be quickly cured.

Stable films from all three fluids were successfully produced. Film heights became more systematic once the experimenters became experienced in using the apparatus in microgravity. The largest film heights were produced during the final flights. Films were stable the entire period (~25 s) of microgravity. In microgravity, all of the data along with the experimenters' voices were recorded on video tape. The maximum attainable heights were measured for each fluid from the video tape. The maximum height for water was 11 cm, but this was limited by the height of the apparatus. DC-704 reached 4 ± 1 cm on video tape and may have gone higher, but these tests were not recorded. UVR 6110, the most viscous and dense liquid used, only reached 2 ± 1 cm in height.

We were able to estimate the average thickness of the films in microgravity by noting that all of the water in the reservoir was used during the pulling process after the 8-cm mark was reached. The initial amount of water in the reservoir was approximately 1 cm$^3$. This gives us an average thickness of ≈ 0.028 cm, or half the thickness of the top bar (see Fig. 1).

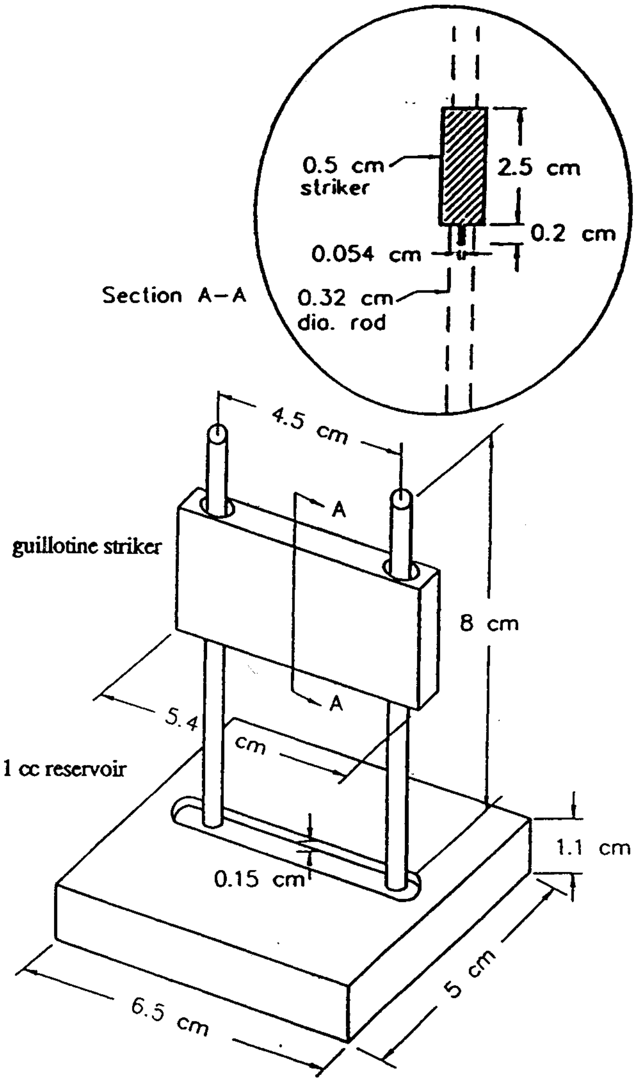

Fig. 1 Thin film striker.

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These microgravity thin film results were quite different from those expected in a gravity environment. Under laboratory (1 $g$) conditions, striking and maintaining stable films with the three liquids used in the microgravity experiments requires the addition of surfactant. To quantify the differences between microgravity and laboratory surfactant-free films, the experiments were repeated in the laboratory (1 $g$). The same three fluids were tested. All three fluids formed films in gravity. The maximum attainable heights and the lifetime (stability) of each film at a given height were measured (Table 1). In comparison to the microgravity results, these gravity films were smaller and unstable.

The comparison of the KC-135 microgravity results with those at our normal gravitation level indicate a significant difference. In gravity, surfactant must be added to the fluid to make it stable. Addition of surfactant gives a system physical properties completely different from the surfactant-free film. Surfactant also greatly complicates analysis of the fluid system. These ideas can be demonstrated using the following film drainage experiment.

The main effect of gravity on films suspended parallel to the gravity vector is to cause drainage of the film. This drainage manifests itself as a thinning of the film with time. For an ideal fluid film, the variation of the thickness $\delta$ with time $t$ is given in Eq. (1),[3]

$$\delta^2 = \left(\frac{4\mu}{\rho g}\right)\frac{z}{t} \qquad (1)$$

where the fluid parameters of relevance are the density $\rho$ and the viscosity $\mu$. The variable $z$ is the vertical distance measured from the top of the film. Equation (1) implies that the thickness of a fluid film is larger when a more viscous fluid is used. We tried to verify this trend in the laboratory by curing thin films with varying amounts of surfactant. UVR 6110 UV curable epoxy and 3-M FC-430 surfactant were used. Films were formed of the fluids with 0.8, 1.3, and 2.0% surfactant and cured after 6 s. No difference was noted in curing time. The addition of surfactant causes an increase in the viscosity (see Fig. 2). Theoretically, this should give an even thicker film. However, we found that, although viscosity is increasing, the thickness is decreasing (see Fig. 2). This is in conflict with the theoretical trend for an ideal fluid given by Eq. (1). This phenomenon is similar to that described by Wasan and Malhotra,[4] where micelles of surfactant in the bulk fluid cause an increased drainage rate. When surfactant is added to a fluid, it no longer obeys the simple drainage equation. However, in the reduced gravity environment, the fluid film without surfactant would behave according to Eq. (1).

Thus, we have demonstrated a microgravity fluid mechanics experiment that cannot be replicated in the laboratory. The microgravity liquid films are significantly simpler than their laboratory counterparts because of the absence of surfactant, which leads to simpler models of the fluid systems.

We have carried out a series of liquid film experiments in the microgravity conditions on the NASA KC-135 aircraft. These experiments were repeated in a laboratory under normal gravity. The results of these experiments and their implications are as follows:

1) Liquid films were drawn in a $g_{KC135} < 0.02\, g$. These films were of water, oil (DC-704), and uv curable polymer (UVR 6110), all without surfactant (soap). The films were stable at least as long as the duration of a KC-135 microgravity period (~ 25 s).

2) Films from the same fluids, when drawn in normal gravity, are unstable (they rupture in a few seconds). To make them stable, surfactant (soap) must be added. This modifies and, in the case of a curable fluid, renders it less useful.

3) Although the addition of surfactant increases the viscosity of the fluid, the film drains more rapidly due to a modified micelle fluid structure. This indicates that the fluid can no longer be modeled as a simple fluid. We have shown that the simple fluid model can be used on surfactant-free films in microgravity.

**Table 1 Surfactant-free liquid film parameters in gravity**

| | Water | DC-704 | UVR 6110 |
|---|---|---|---|
| Average height, cm | 1.1 ± 0.2 | 1.5 ± 0.3 | 0.6 ± 0.1 |
| Height for lifetime test, cm | 1.25 | 1.5 | 0.5 |
| Lifetime, s | 1.7 ± 0.7 | 4.3 ± 1.0 | 4.2 ± 2.0 |
| Number of films | 40 | 24 | 35 |

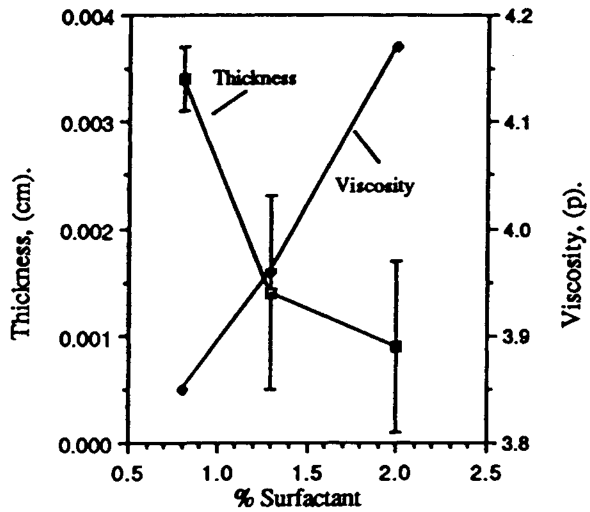

**Fig. 2 Experimental thickness and viscosity as functions of percent weight of surfactant in UVR 6110.**

The findings of this study open the door for the reconsideration of fluid film experiments in the space environment as a means of studying liquid systems dominated by surface effects, as well as paving the way for a liquid based ultraviolet cureable space technology.

Scientifically: The absence of surfactant in the fluids immediately gives the advantage of the fluid being as simple as the modeler or theoretician needs, its physical properties being readily defined, i.e., water.

Technologically: The use of ultraviolet curable fluids in space could have significant advantages. Without the addition of surfactant, the cured material can be optimized for LEO use. Repair work, structural modification, and construction would also be possible.

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