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SKYLAB III AND IV SCIENCE DEMONSTRATIONS PRELIMINARY REPORT

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16. ABSTRACT

Twelve Marshall Space Flight Center science demonstrations were accomplished on the Skylab III and IV missions. These were defined in response to crew requests for time-gap fillers and were designed to be accomplished using onboard equipment. Nine of these demonstrations were in the area of materials science and space processing. The following 12 are described and the preliminary results are given:

Skylab III

Diffusion in Liquids	No number
Ice Melting	No number

Skylab IV

Liquid Floating Zone	TV 101	Fluid Mechanics Series	TV 107
Immiscible Liquids	TV 102	Neutron Environment	TV 108
Liquid Films	TV 103	Orbital Mechanics	TV 110
Gyroscope	TV 104	Charged Particle Mobility	TV 117
Rochelle Salt Growth	TV 105		
Deposition of Silver Crystals	TV 106		

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The team is also grateful to the many individuals at the Marshall Space Flight Center (MSFC), the Johnson Space Center (JSC), and mission contractors, without whose help the project could not have been done. Special thanks go to Mr. Jack Waite, Mr. Carmine DeSanctis, and Mr. Frank Graham of MSFC; and to Astronaut J. Allen, Astronaut R. Parker, Mr. J. Knight, Mr. J. Cox, Mr. L. de Luca, Mr. R. Heselmeyer, Mr. R. White, and Mr. C. Chassay of JSC. Special appreciation goes to Mr. J. Vellinga, Mr. S. Buzzard, and Mr. S. Daley of the Martin-Marietta Corporation, one of the primary contractors supporting the Skylab mission.

The author also wishes to thank the investigators for their untiring efforts.

FOREWORD

In late August 1973, Science Pilot Owen Garriott radioed from Skylab III that the crew desired to perform some interesting science demonstrations to obtain additional science data from space, to serve as time-gap fillers, and to provide a change of pace for the crew. Within a few days, approximately one dozen ideas were defined at Marshall Space Flight Center (MSFC). Working with the MSFC Skylab Corollary Experiments Office and the Skylab Mission Scientist at Johnson Space Center, Dr. Robert Parker, the science demonstration team defined two demonstrations that seemed to be most compatible with Skylab III, considering the scientific objectives, time remaining in the mission, and procedures. These were the Ice Melting and Diffusion in Liquids Demonstrations. The onboard equipment for these demonstrations was identified, and a procedure was worked out in the Skylab mockup. On September 17, a photographic test was run in the mockup by the Scientific Engineering Division of the Space Sciences Laboratory at MSFC. Approval was received from the Flight Management Team on September 18. The demonstrations were initiated on board Skylab III on September 20.

Between the Skylab III and IV missions, 17 additional science demonstrations were defined; ten of these were performed on Skylab IV. A science demonstration kit, Rochelle salt solution, and neutron environment tabs were launched for use in the science demonstrations.

The objective of this report is to describe these science demonstrations and to give the preliminary results. Because most of the science demonstrations were done on Skylab IV and most used video recording that has to be transferred to movie film, the conclusions given in this paper may change slightly in the final analysis. Each demonstration investigator has been requested to write a quick-look report and a final report. The target date for completion of the final report is June 1974.

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SKYLAB III AND IV SCIENCE DEMONSTRATIONS PRELIMINARY REPORT

I. INTRODUCTION

Twelve Marshall Space Flight Center (MSFC) science demonstrations were performed successfully on Skylab (2 during mission III and 10 during mission IV). Most of these demonstrations concerned the behavior of fluids in space and rigid body mechanics, and they were performed primarily with equipment already on board the Skylab. These activities were integrated into the astronauts' work schedule during appropriate times and were planned so that they could be done at the crew's option for the varied purposes of (1) obtaining new scientific data, (2) better demonstrating known principles of science for educational and Public Affairs Office use, and (3) providing a change of pace for the crew.

The success of the demonstrations is directly attributable to the interest and diligence of the Skylab III and IV crews. The crews' interest was in large measure responsible for generating the program, and their diligent effort on board was responsible for its success. It must be kept in mind that these demonstrations were performed at minimal additional cost and crew training, and in most instances they were conducted by improvising onboard equipment designed for other purposes.

In the following section, each science demonstration is described and some of the preliminary results are given. Final reports from the respective investigators are forthcoming. Some of the preliminary conclusions may be modified in the final analysis.

II. SCIENCE DEMONSTRATIONS AND PRELIMINARY RESULTS

A. Skylab III Science Demonstrations

Two demonstrations defined at MSFC were done on Skylab III.[1] These demonstrations were quickly put together in response to Science Pilot Owen Garriott's request for additional science demonstrations to do on Skylab III. They were subsequently performed by Pilot Jack Lousma.

1. Diffusion in Liquids. The first demonstration was Diffusion in Liquids (no number). Barbara Facemire of the Space Sciences Laboratory was the investigator for this experiment. The Diffusion in Liquids Demonstration[2] showed the long times required in space for pure molecular diffusion. In particular, the diffusion rate and shape of the interface were to be determined. A plastic forceps tube holder (1.5 cm o.d., 1.3 cm i.d., 15 cm length) which looks very much like a test tube was used as the test container. The crew injected the tube three-fourths full of water with a hypodermic syringe. A concentrated solution of instant tea (seven times stronger than normal drinking tea) and water was made and injected carefully on top of the water (Fig. 1). The diffusion of the tea into the water was periodically photographed over a period of 3 days. Although the camera was slightly out of focus, it was evident on the film that diffusion occurred in the described system. In 51.5 hr, the visible diffusion front advanced 1.96 cm.

Ground tests were performed to determine the diffusion rate in 1 g and to determine what concentration of tea in water would be visible in the film. After 45.5 hr, three distinct zones of tea were visible: (1) a dark area, (2) an area of medium darkness, and (3) a very light area. The very light area would probably not have been apparent on the out-of-focus film if it were present in the flight test. Therefore, the advance of the second area was used for comparison to the flight. This medium-colored area had advanced 1.6 cm in 45.5 hr. The effects of convection on the ground test (possibly the very light area was caused by convective mixing) make absolute comparison to the zero-g case impossible. To estimate the predicted rate of advance of the diffusion

1. Simon Ostrach, Skylab Science Demonstrations. Presented at ESRO Space Processing Symposium, Frascati, Italy, March 25-27, 1974.

2. Preliminary data for both Skylab III science demonstrations are given in the document MSFC Science Demonstrations Performed by Pilot J. Lousma on Skylab III, by B. Facemire, T. Bannister, L. Lacy, G. Otto, and P. Grodzka, Quick-Look Report, Space Sciences Laboratory, MSFC, November 5, 1973.

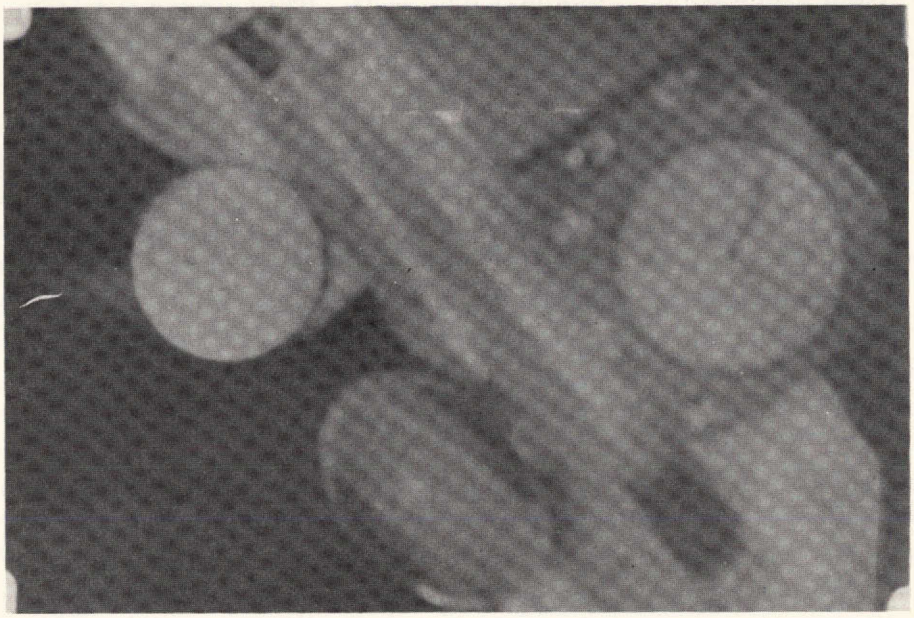

Figure 1. Diffusion in Liquids and Ice Melting Demonstrations.

front in the space environment, a one-dimensional analysis was made by using simplifying assumptions. The following equation was used to predict the relative concentrations at a distance from the original position after a given time:

$$\frac{C}{C_o} = 1 - \frac{2}{\sqrt{\pi}} \int_0^{X/(2\sqrt{Dt})} e^{-X^2}\, dX$$

where C is the concentration at front, C_o is the original concentration and equals 1, X is the position of front, D is the diffusion coefficient of sugar (the tea solution contained sugar; the D of tea is not known at present), and t is time.

The space data agree approximately with calculated values for $C/C_o \sim 0.50$. One outstanding feature of the diffusion data that is visible on the film and that was reported by Pilot Lousma was that the diffusion front became more parabolic as time passed. From these observations it was concluded that very little diffusion occurred near the test tube wall. This means that some retarding force, not usually seen on earth, was present; this force is hypothesized to be electrostatic repulsion.

2. Ice Melting. The second demonstration (Ice Melting) on Skylab III was also performed by Pilot Jack Lousma. The investigators for the Ice Melting Demonstration (no number) were Dr. G. Otto of the University of Alabama in Huntsville and Dr. L. Lacy of the Space Sciences Laboratory at MSFC. This demonstration provided visual information on containerless melting in space which has applications to the Space Processing Applications Program. The purpose of this science demonstration was to illustrate the difference between the melting process in zero gravity and the same process on earth. The first and main objective of the demonstration was to observe the temporal progression of the liquid-solid interface in the melting material. The second objective was to obtain data for thermal analysis of zero-gravity melting. A cylinder of ice was frozen on a cotton swab in an empty pill dispenser bottle (3 cm diameter, 7.4 cm long). Twenty-four hours later, the dispenser bottle was taken from the freezer and weighed, and the ice cube was removed from the bottle and mounted by taping the free end of the cotton swab in front of the 35-mm camera near the previously discussed Diffusion in Liquids Demonstration (Fig. 1). Periodic photographs were made, and the rate of ice melting in zero gravity without convection and the shape of the liquid on the unmelted ice portion were determined.

The cylindrical ends melted first, while the diameter of the ice remained approximately constant. This conclusion can be obtained from Figure 2, where the diameter of the ice and the diameter of the water globule are plotted as a function of melting time. The lower curve, which depicts the ice diameter, remains constant, while the diameter of the water globule is increasing. This shows that the melting is taking place on the cylindrical ends for the first half of the melting process.

As can be seen in Figure 1, the water from the melting ends is driven by surface tension onto the cylindrical surfaces. The overall shape goes from cylindrical to spherical, with an intermediate general ellipsoidal shape.

This demonstration showed that containerless melting in space is quite different from that on earth because surface tension becomes a dominating force in weightlessness. The surface tension forces the liquid to form spherical shapes on all exposed surfaces of the melting solid.

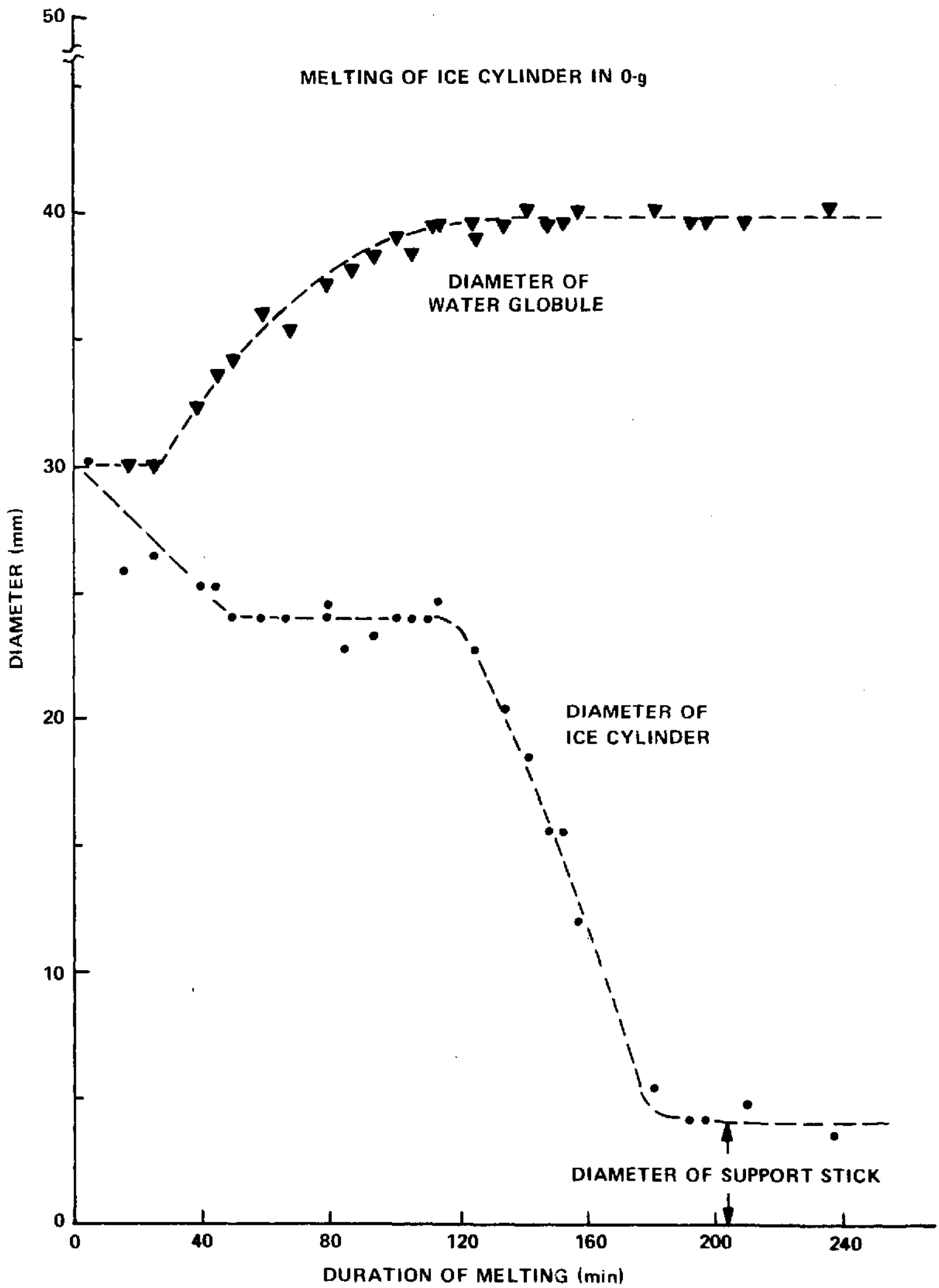

Figure 2. Diameter of the water globule and melting ice cylinder.

On completion of the Ice Melting Demonstration, a large globule of water remained attached to the retaining stick. As suggested by Dr. P. Grodzka of Lockheed Missiles and Space Company (LMSC), the crew added a small drop of soap solution to the large globule of water by means of a syringe. After the effects of the addition of soap solution were observed, a small drop of grape juice was added, also by syringe. A mixture of soap solution and air was then injected directly into the globule by means of the syringe.

The surface of the globule retracted vigorously when touched by the soap solution or grape juice. Vigorous fluid motion was seen by bubble and grape color movement for some moments after the addition of the surface active solutions. Astronaut Lousma observed that "the water leaped out after the soap" when he approached the water globule with the soap solution. It was also observed that the globule oscillated or vibrated. Astronaut Lousma attributed the oscillations to small air currents. When soap solution and air were injected directly into the globule (Fig. 3), small bubbles were formed which persisted inside the globule. Astronaut Lousma observed: "It appeared that the globule wanted to contain only so many bubbles; i.e., at the end additional injections caused bubbles to come out of the water, it started spitting." This means that the cluster of air bubbles in the soapy water reached a critical size. This result is very surprising and may be of interest to several fields of science.

B. Skylab IV Science Demonstrations

More time was available for planning the Skylab IV demonstrations. A science demonstration kit, a 10.16-cm (4-in.) food can filled with Rochelle salt, and a 10.16-cm food can filled with neutron environment tabs were flown to provide critical hardware parts for use in these demonstrations. Still, 90 percent of the parts used consisted of onboard hardware. The Skylab IV demonstrations were designated by numbers. Most of these demonstrations were recorded on video tape which was converted to 16-mm movie film and given to the investigators in March 1974.

1. <u>TV 101 Liquid Floating Zone</u>. The first science demonstration (TV 101, Liquid Floating Zone, by Dr. J. Carruthers, Bell Research Labs and chairman of the recent Gordon Crystal Growth Conference) was an important one and was performed by Science Pilot Ed Gibson. The onboard television camera was used for video recording. Its primary purpose was to simulate

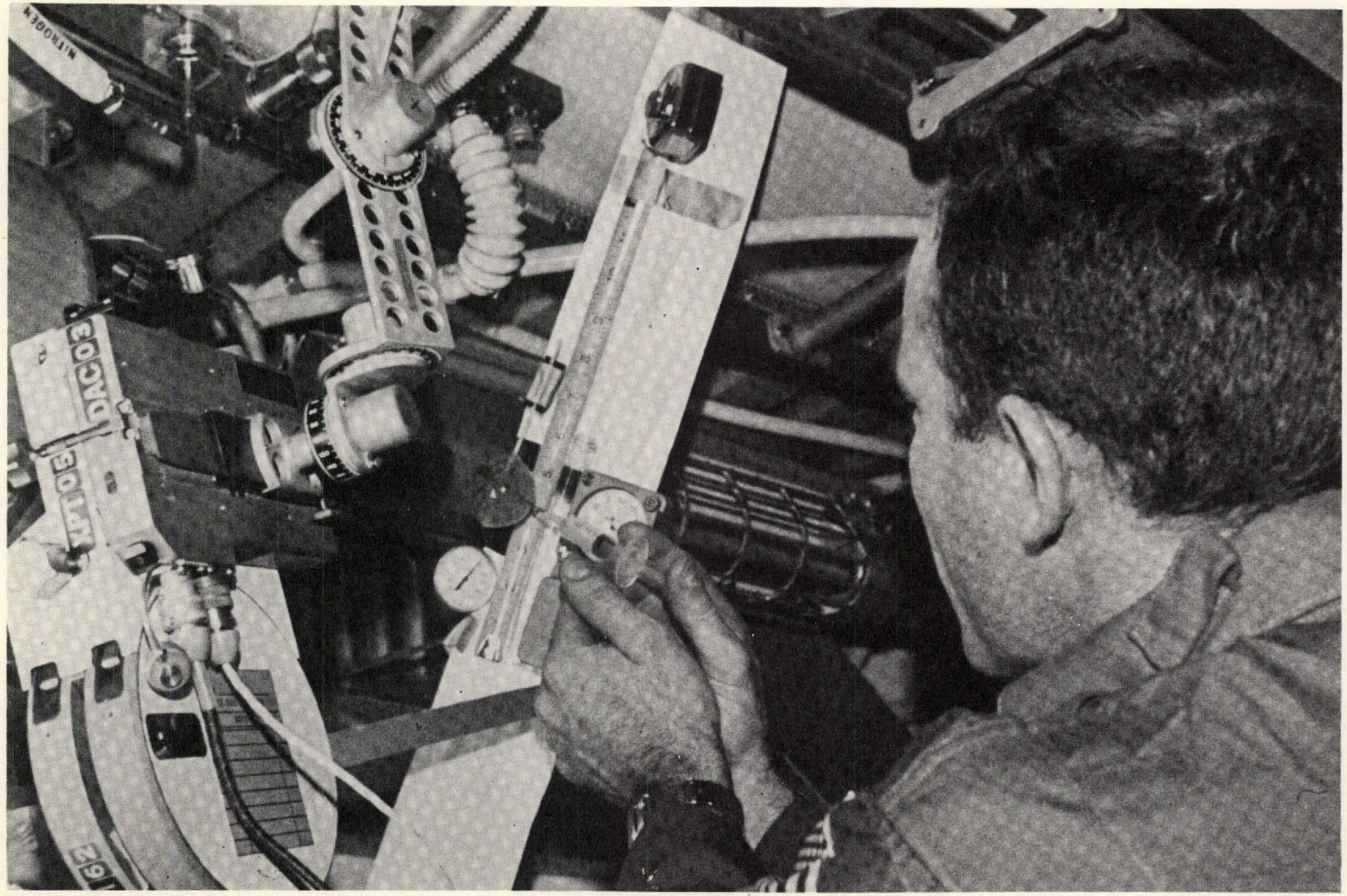

Figure 3. Pilot Lousma adding soap to water globule.

a key crystal growth method, floating zone melting, by suspending a column of water between the ends of two metal rods (Fig. 4). The rods were then manually rotated in various directions. The ends of the rods had special metallic discs taped to them to obtain the proper surface tensions. These discs were flown in the science demonstration kit.

Fluid flow patterns and instability modes in the low-gravity environment were recorded. Scientists are very interested in the details of fluid flow for the improvement of crystal growth processes, both on the ground and in space. The preliminary indications verify theory and show that surface tension and viscosity dominate the behavior of the fluid.

Briefly, the demonstration consisted of attaching a pure water liquid hemisphere to each rod and adding a soap solution to one of them. The rods were then tapped on their ends to obtain oscillation data for the hemispheres. The amplitudes of the oscillations were greater and the damping time was less for the hemisphere with the soap solution. A complete liquid zone was then formed. Stability of the zone was obtained by extending the zone length; when its length exceeded its circumference, the zone broke. This criterion is in agreement with the prediction of Lord Rayleigh. The two rods were then rotated at various rates up to about 33 rpm in the same direction. At a mid-range rpm, the liquid zone assumed a "jump-rope" instability (i.e., it appeared like the letter C which rotated about its ends) which damped out rather quickly when the rotation ceased. When the liquid zone surface tension was reduced by adding a soap solution, it could not sustain the same rotation. When one rod was rotated while the other remained fixed, the zone sheared immediately into two hemispheres. In addition, onion chips and air bubbles were used to determine the internal flow. The flow was found to be essentially circular, with very little flow from one rod to the other.

As a practical engineering matter, information gained from such experiments will be important to the development of fluid-handling procedures on the Shuttle. Dr. Carruthers commented on January 14, 1974, that approximately one-third of the single crystals made from silicon material are grown using the liquid floating zone techniques; however, the crystals so produced are not uniform due to unexplained flow behavior. He further commented that some of these basic flow patterns could conceivably result in many, many millions of dollars savings in semiconductor crystals growth in the electronics business.

2. TV 102 Immiscible Liquids. TV 102, Immiscible Liquids, was performed on Skylab IV by Pilot W. Pogue. The investigators for this demonstration were Drs. L. Lacy of the Space Sciences Laboratory at MSFC and G. Otto, Physics Department, University of Alabama in Huntsville.

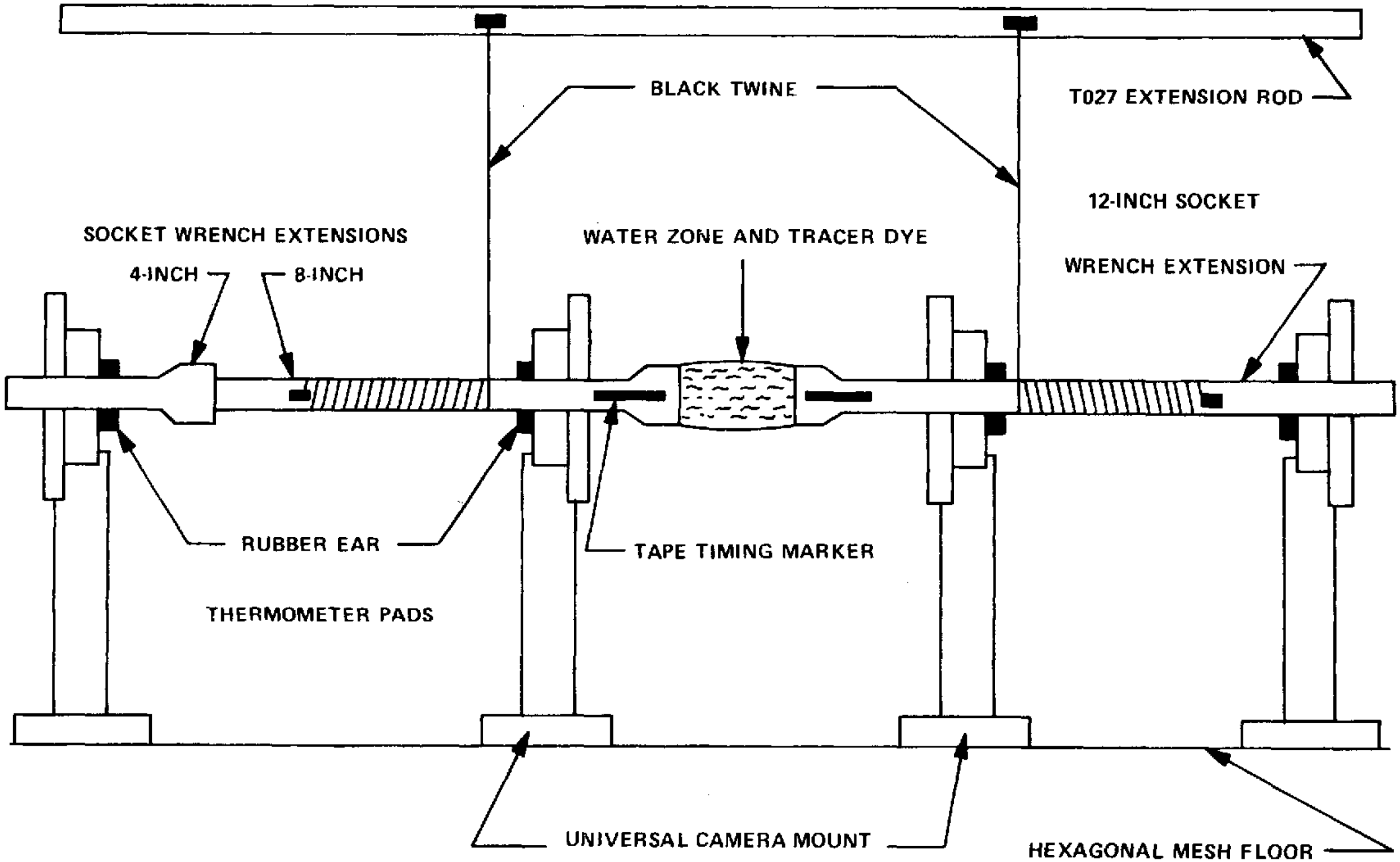

Figure 4. Diagram of liquid floating zone setup.

The purpose of this science demonstration[3] was to illustrate and study the different behavior of two immiscible liquids (clear oil and colored water) in zero gravity as compared to earth. The main objective of the demonstration was to test the stability of an emulsion without the aid of an emulsifying agent and to determine the time required for fluid recombination by coalescence during random collision. The demonstration provided visual information on the behavior of emulsions in zero gravity. These data should provide insight into the stability of finely dispersed immiscibles mixed in space which will be useful in obtaining solidified immiscibles.

The appearance of the emulsion was video-taped over a period of 2 min and also sequentially photographed (35mm) over a period of 10 hr. The 35-mm color photographs are dark, and it is difficult to determine whether there was negligible coalescence or if the differences are masked because of low contrast. The video-taped data indicate that the emulsions formed in zero gravity are stable up to 2 min, whereas on the ground oil and water separate in about 10 sec. (A calculation of the separation time in 1 g by the Principal Investigators revealed that the oil would separate from the water in 0.1 sec and the water would separate from the oil in 10 sec.)

Immiscible materials may be defined as two or more component materials which are mutually insoluble when intimately mixed at a given temperature and pressure. Krytox oil and water were chosen for this demonstration because their characteristics are well defined. The basic properties applicable to this experiment are given in Table 1. Because the two components of this system have different densities, dispersion of one of the components into the other liquid matrix will result in the separation of the two phases when the operation is performed on earth.

The experimental package designed for the Skylab IV mission consisted of three transparent, plastic, 10-ml vials (Oak Ridge type centrifuge tubes, made of unbreakable polycarbonate), each containing a different fraction of oil and red-colored water, mounted in a stainless steel frame. To prepare the vials for the flight package, they were filled to 25, 50, and 75 percent volume, respectively, with degassed Krytox 143 AZ oil and then were filled up with colored degassed water (one part Hewlett Packard red recorder ink in 16 parts distilled water was used as a dye).

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3. L. L. Lacy and G. H. Otto, Skylab 4 Science Demonstration TV 102: Immiscible Liquids, Quick-Look Report, Space Sciences Laboratory, MSFC, Mar. 15, 1974.

TABLE 1. CHARACTERISTIC DATA FOR KRYTOX OIL AND WATER AT ROOM TEMPERATURE (20°C)

	Krytox (143 AZ)[a]	Water
Viscosity (Centipoise)	63	1.0
Density (g/cm^3)	1.86	1.00
Thermal Coefficient of Volume Expansion ($^\circ C^{-1}$)	11×10^{-4}	2.1×10^{-4}
Surface Tension (dynes/cm)	16.0	72
Refractive Index	1.30	1.33

a. Krytox oil is a nontoxic-fluorinated oil with excellent oxidative and thermal stability and with a high degree of chemical inertness, complete inflammability, and good compatibility with metals, plastics, and sealing materials.

The dispersion of the oil in the water was achieved by shaking the vials; the dispersion was aided by using a small brass nut as an agitator. A string, 50 cm long, was attached to the top of the stainless steel frame containing the vials. This allowed the astronaut to swing the vials in a circular arc to generate a centrifugal g-force of about 2 g. To enhance visibility and aid in evaluating the results, a card with black parallel lines was installed in the back of the frame so that the lines would be visible through the liquids. The experiment was designed so that the parallel lines were invisible for a good emulsion and visible when the liquids were separated.

It should be noted in Table 1 that the density of the oil is 1.86 times greater than that of water and that, although the viscosity of the oil is much greater than that of water, the surface tension (in both cases measured in air) is higher for water.

Figure 5 consists of two black and white reproductions from color video tape showing the appearance of the two fluids after gentle shaking in zero g. The upper picture was taken 16 sec and the lower one 109 sec after the dispersing action. An emulsion of the liquids had been achieved in all three vials, as can be seen by the absence of the parallel lines and the uniformity of the

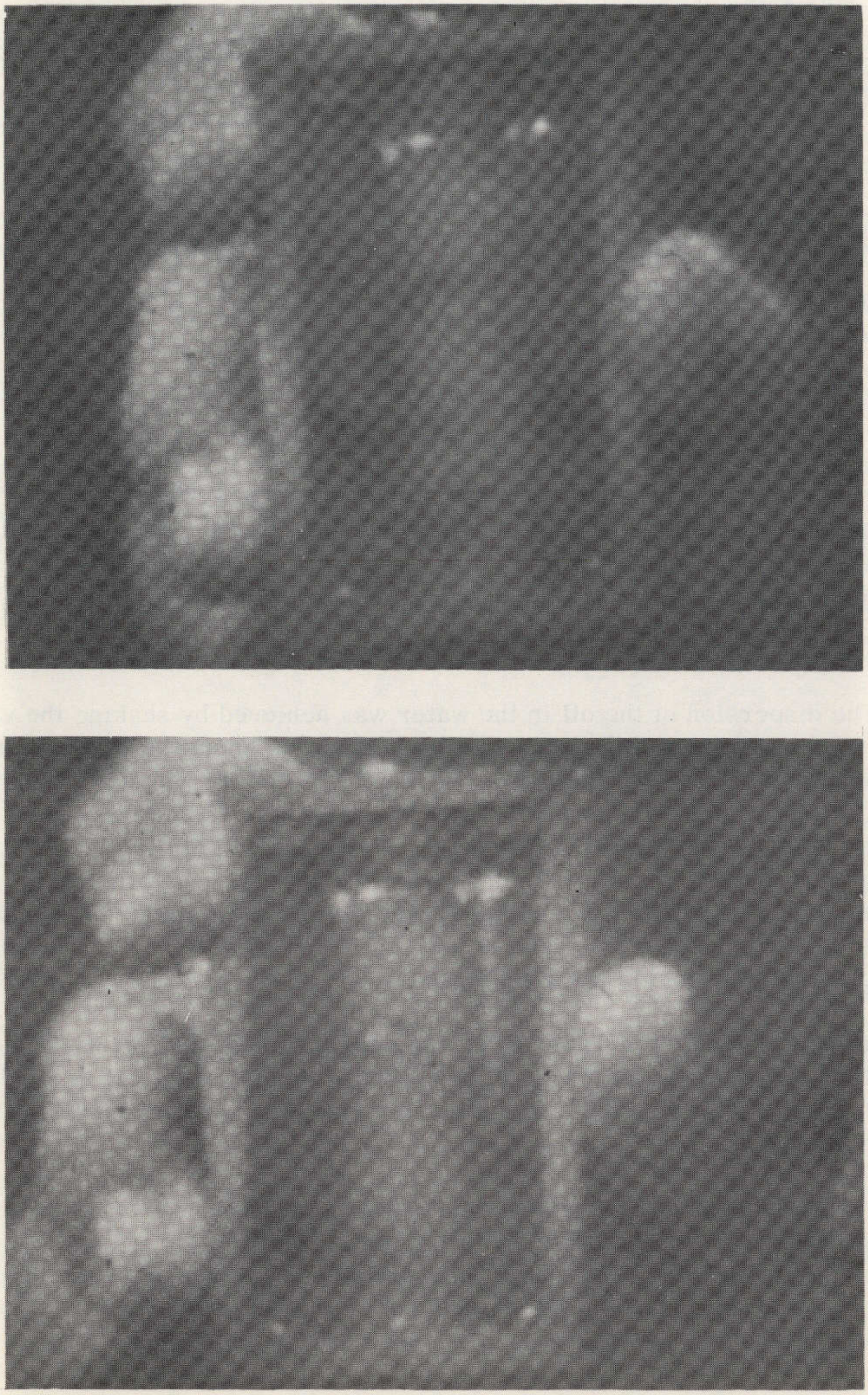


Figure 5. Video shots of immiscible liquids.

red coloring. No separation of the two liquids can be detected even after 109 sec. The long-term stability (up to 10 hr) of the emulsions will be determined by the 35-mm color photographs presently being developed.

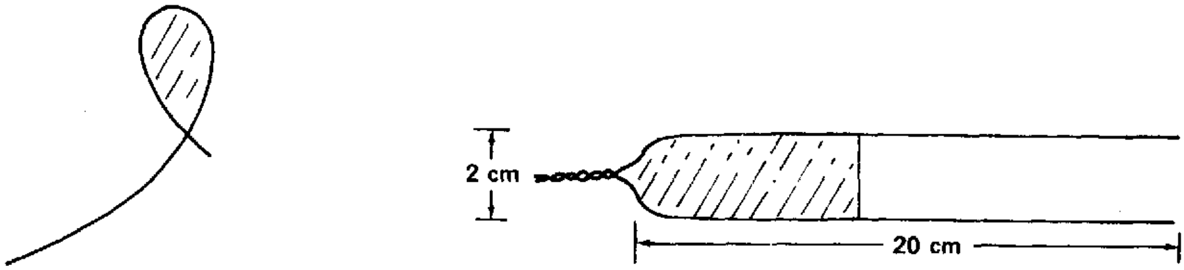
3. TV 103 Liquid Films. The science demonstration entitled Liquid Films (TV 103) was performed by Astronaut G. Carr on Skylab IV. The investigator was Wesley Darbro of the Space Sciences Laboratory at MSFC. Essentially, the experiment[4] was designed to construct liquid films from water and from a soap solution by two different methods, to photograph and to observe their formation, characteristics, and time to rupture. The formation in space of stable liquid films which can be solidified may offer the potential for making new materials, such as superconductors.

The first method placed a globule on a closed expandable wire frame. The spherical globule was stretched into a thin film; in a 1-g environment this cannot be done with water. The second method of film construction consisted of accelerating a closed wire frame submersed in a liquid. The inertial forces on the liquid allow the frame and bulk liquid to separate, leaving a liquid film bounded by the frame. This is similar to what occurs when one pulls a child's soap bubble hoop from the soap solution, except that it is mainly the earth's gravitational force which strips the liquid from the hoop, leaving only the soap film. The acceleration of the wire frames affects the thickness of the films (low acceleration results in thick films, high acceleration in thin ones or none at all).

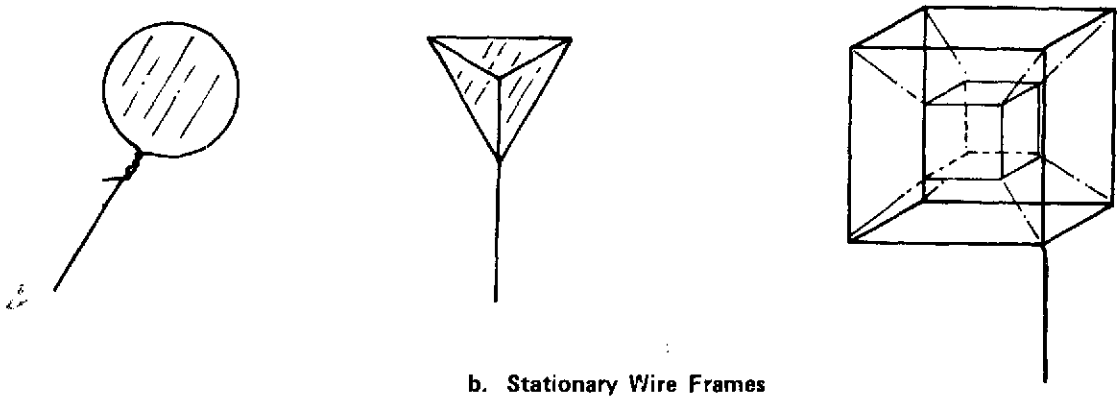
In the earth's environment, liquid films rupture primarily because of two problems: drainage caused by gravitation and surface tension, a characteristic of the liquid. In the Skylab demonstration, the rupture process was to be observed using water and a solution of water and soap. The soap solution was made from the shower soap, a weak concentration of 40 parts water and one part soap. The wire apparatus was made from a roll of safety wire. The five configurations are shown in Figure 6.

The first part of the experiment employed two expandable wire frames, a loop and a rectangle (Fig. 6a). According to Commander Carr, 1 ml of plain water was placed repeatedly, using a syringe, upon the loop and expanded to 4 or 5 cm in diameter before it ruptured. However, the video tape shows him drawing it out to about 7.5 cm. It is suspected that some soap solution may have gotten on the loop before the plain water globule was placed on it. The liquid films made from the soap solution could be drawn nearly the full extent of both the loop and rectangle. Similar results can be obtained in 1 g when the apparatus is held horizontally.

4. W. Darbro, TV 103 — Liquid Films Preliminary Report, Quick-Look Report, Space Sciences Laboratory, MSFC, Mar. 20, 1974.



a. Expandable Wire Frames



b. Stationary Wire Frames

Figure 6. Liquid film holder configurations.

The second part of the experiment involved accelerating each of the wire frames in Figure 6b while they were submersed in the 40-to-1 soap solution. Commander Carr first filled a food container (cylindrical can) with the soap solution, submersed a frame in the solution, and then jerked the frame from the liquid. This gave the desired film on the bounding frame but caused some of the liquid to spill. He found that a more desirable method was to slowly pull the frame from the liquid (in the case of the cube, he described having a "cube of liquid"). He then proceeded to shake the liquid from the wire frame back into the container, leaving thinner and thinner films with each shake.

Of the many "stable" film configurations, the one first formed for the cube was the one having a smaller cube in the center held in position by films extending from the wire cube. Having a rather high surface tension, this minimal surface ruptured quickly, taking on one configuration after another until finally all the liquid was concentrated in one film on one face. In general, the initial thin films lasted a minute or less before rupturing. This time was longer than that for a corresponding stationary film in 1 g but less than that for a film being rotated in 1 g.

Ground-based experiments, using high-speed photography, of rupturing liquid films are being made in connection with the analysis of this demonstration.

4. TV 104 Gyroscope. Demonstration TV 104, Gyroscope,[5] was used by Commander Carr to illustrate the stability of a gyroscope under the influence of a linear force and to illustrate precessional motion when a torque is applied. The investigator for this demonstration was J. Parker of the Space Sciences Laboratory at MSFC. The objective of this demonstration was simply to show the stability of a gyroscope in space for educational purposes. Commander Carr illustrated the principles of the gyroscope on video tape. The gyroscope displayed exceptional stability characteristics. Segments of this tape were shown on the Today show during January 1974. Also, Commander Carr used the gyroscope as an aid for explaining the operation of the Control Moment Gyroscopes on Skylab. This demonstration is excellent material for educational purposes. A classroom film is being prepared on this subject.

The gyroscope was a simple one (Fig. 7) obtained from the Alabama Space and Rocket Center in Huntsville, Alabama. The flywheel had a diameter of approximately 7.6 cm. The gyroscope was stripped and coated with Teflon and mounted in the science demonstration kit.

5. TV 105 Rochelle Salt Growth. The next demonstration was TV 105, Rochelle Salt Growth. The investigator for this demonstration was Dr. I. Miyagawa of the University of Alabama, Tuscaloosa. Pilot Pogue also performed this demonstration. The purpose was to study, in space, solution growth without the convection resulting from the buoyancy of the depleted layer around the crystal.

A 10.16-cm (4-in.) food can was filled with saturated Rochelle salt solution, Rochelle salt powder, and a 26-gm Rochelle salt seed crystal. This can contained a see-through membrane under the pull-top lid. Pilot Pogue removed the pull-top lid, placed the can in the spare food tray, and heated the solution until three-fourths of the seed crystal dissolved (at approximately 70°C). The can was removed, wrapped in several towels, and stowed. During storage in zero g, the seed crystal began to regrow as the can slowly cooled back down to cabin temperature over a period of two days. Pogue removed the

5. James Parker, Gyroscopes, Quick-Look Report, Space Sciences Laboratory, MSFC, Mar. 29, 1974.

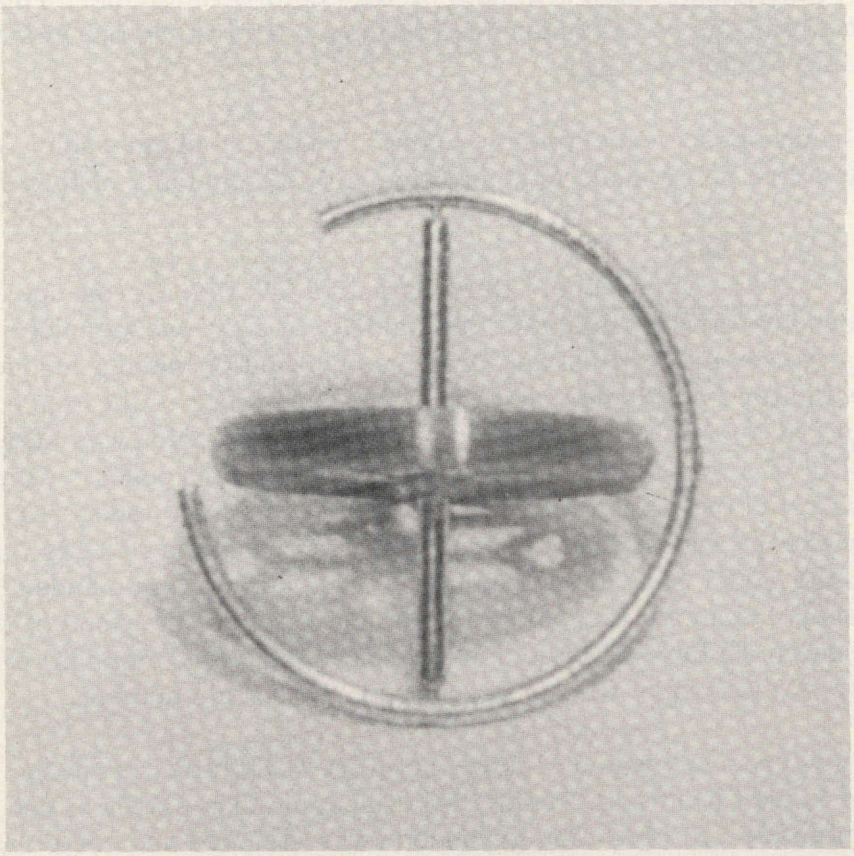


Figure 7. Gyroscope.

insulating towels at the end of the two days. Two weeks later, he removed the seed crystal from the solution to assess its growth in space. The seed crystal had regrown in the form of a large plate containing at least five single crystals (Fig. 8). The solution also contained many small Rochelle salt crystals that had nucleated from solution.

During the debriefings, Pilot Pogue described the solution as "slushy" and the self-nucleated crystallites as "mica-like." The space-grown crystals exhibit two unique features not found in crystals grown on earth. First, the crystals have long, narrow cavities (0.1 mm diameter by 1 cm long). Second, the crystalline plate contains at least five crystals whose axes are aligned. On earth, such crystals are usually randomly oriented. The regrown seed is presently being analyzed at the University of Alabama. The crystal generally has a side which is ragged and jagged, with the other end being smooth and containing one region approximately 2.54 cm by 0.64 cm by 0.32 cm of very good optical quality. Measurements will be made on the ferroelectric hysteresis of various parts of the crystal. The quality of Rochelle salt crystals, which are ferroelectric, can be ascertained by the shape of the hysteresis curve.

Figure 8. Rochelle salt grown in space.

6. TV 106 Deposition of Silver Crystals. Demonstration TV 106, Deposition of Silver Crystals, was performed by Commander Carr. The investigators for this demonstration were Dr. P. Grodzka of Lockheed Missiles and Space Company and B. Facemire of the Space Sciences Laboratory at MSFC. The objective of this experiment[6] was to demonstrate crystal growth by electrochemical reaction in low g and to compare the resultant crystals with those grown in 1 g. The experiment was designed to provide information on the operation of the microscopically controlled processes of diffusion and chemical reaction in low g.

6. P. Grodzka and B. Facemire, Growth of Silver Crystals Aboard Skylab IV, Quick-Look Report, Lockheed Missiles and Space Co., Huntsville, Ala., Mar. 18, 1974.

The experiment consisted of inserting a scored, insulated copper wire into a 5 percent aqueous solution of silver nitrate. A vial containing the silver nitrate and special clean copper wire was flown in the science demonstration kit. Silver crystals began to grow at exposed metal sites immediately. Commander Carr photographed the crystal growth after 6, 24 and 76 hr. The reason silver crystals deposit when a copper wire is placed in a silver nitrate solution is to be found in the following electrochemical reaction:

$$Cu + 2\,Ag^{+} \rightarrow Cu^{++} + 2\,Ag \quad ;$$

i.e., copper displaces silver ions from solution.

Convective currents play a definite role in the crystal growth process, and this has been clearly seen by means of a laser schlieren system.

Commander Carr inserted the copper wire into a vial containing silver nitrate solution just before his sleep period. The next morning he reported that the silver crystals were growing beautifully with "a classical lattice structure." Later, in a debriefing session, Commander Carr described the crystals as long dendrites.

The flight-grown crystals were received by the investigators on February 11, 1974. In Figure 9 the center tube contains the flight-grown crystals, and the other two vials contain crystals grown on earth for the same length of time. (The tube and vials are lying on their side in the picture.) The flight crystals as received were a loose powder, having been knocked loose from their growth sites in return handlings. Commander Carr also reported that most of the growth occurred during the first 24 to 48 hr, being almost complete by 72 hr.

Silver crystals have been grown in a centrifuge. They were much more compact and cohesive and more upwardly directed than crystals grown at 1 g; i.e., the centrifuge crystals grew in pronounced upward streamers.

In the case of electrolytically deposited metal crystals, the form of the deposit is dependent on the controlling crystallization rate: compact deposits are kinetically controlled; powdery or dendritic deposits are mass-diffusion controlled. Destruction of this gradient by convection reduces concentration polarization and leads to the formation of coherent deposits. The more powdery crystal dendrites obtained in nominally zero g and the progressively more compact dendrites (as g level is increased) seen in the ground tests are explained as follows: Convection increases as g level is increased, causing the electrochemical crystallization rate to change from a more predominant diffusion control to a more predominant kinetic control and resulting in a more compact deposit.

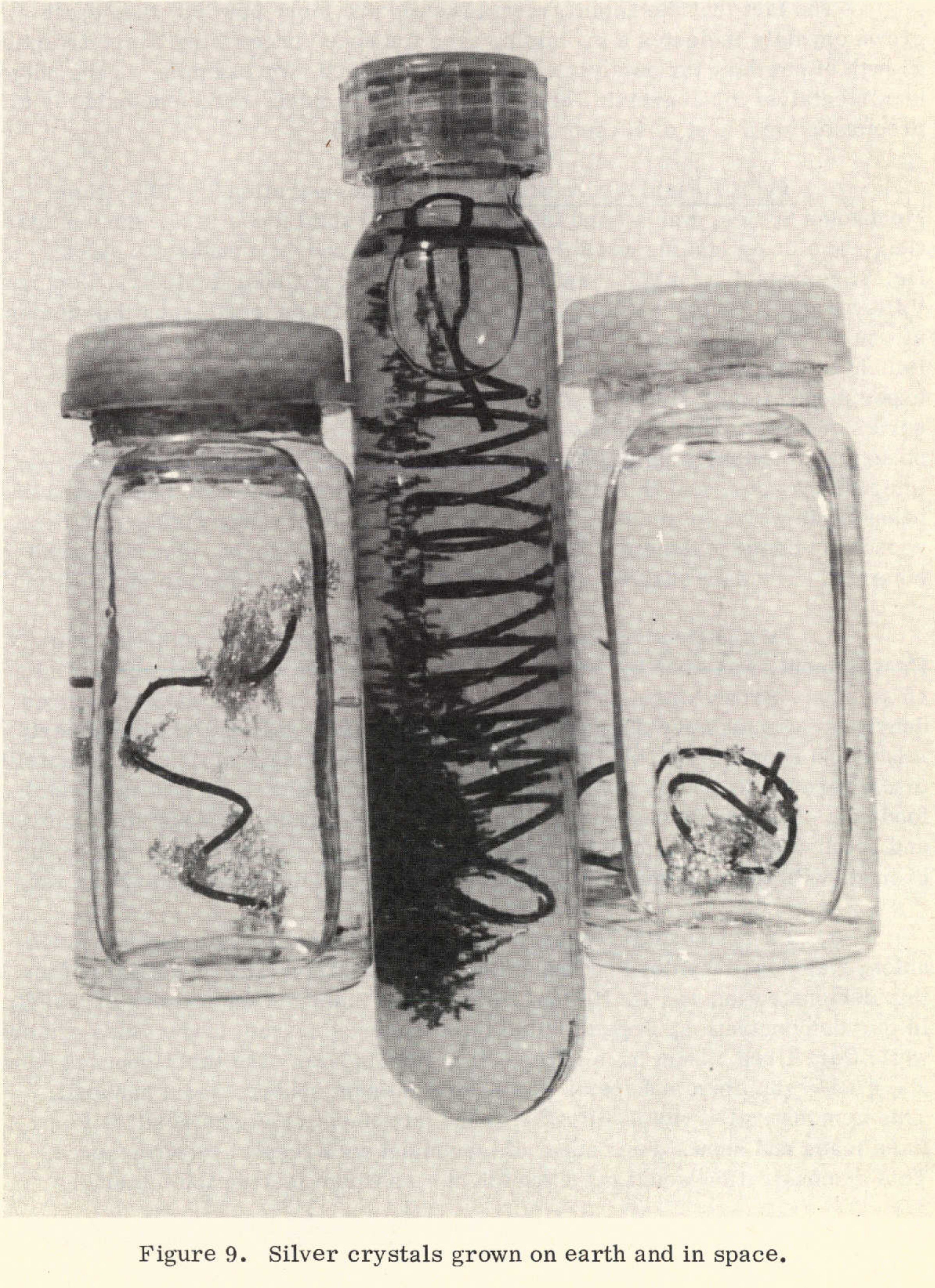


Figure 9. Silver crystals grown on earth and in space.

The fact that the flight-grown crystals are more powdery than earth-grown crystals indicates a promising area for space processing — electrolytic growth of powders for catalyst applications. Silver, for example, is the only known catalyst for converting ethylene to ethylene oxide. Ethylene oxide is a precursor for a host of subsequent petrochemicals.

7. TV 107 Fluid Mechanics Series. Demonstration TV 107, Fluid Mechanics Series, was a combination of several fluid ideas in one demonstration. The investigators were Barbara Facemire and O. Vaughan of MSFC, Dr. S. Bourgeois of LMSC, and Dr. T. Frost of the General Electric Company, Valley Forge. Science Pilot Ed Gibson and Pilot Pogue performed this demonstration. The fluid series data were supplied to the student investigator, Brian Dunlap of Youngstown, Ohio, who had earlier proposed a similar student experiment (Liquid Motion). The Fluid Mechanics Series was essentially a series of tests to obtain data on fluid oscillation times, dampening times, spherical rotational instability, wetting characteristics of fluids in space, internal vortices, and fluid flow patterns. Understanding these phenomena and behavior in weightlessness is essential for future space processing activities, especially containerless processing. Approximately 2 hr of video tape were obtained. The data analysis is awaiting conversion from video to movie film.

8. TV 108 Neutron Environment. Demonstration TV 108, Neutron Environment, was done by Commander Carr. The investigator was G. Fishman of Teledyne-Brown Engineering. The objective was to obtain data on neutron densities near massive objects (like the film vault), near the sleep compartment, and nonmassive objects on Skylab. Four pouches containing five metallic discs were made of beta cloth (Fig. 10) and flown inside a 10.16-cm (4-in.) food can. The pouches were placed in specified locations 10 days after launch and retrieved 3 days prior to return to earth. Analysis is progressing on the ground, with the specimens having the shortest half-life being analyzed first.

9. TV 110 Orbital Mechanics. Demonstration TV 110, Orbital Mechanics, was done by Pilot Pogue and Commander Carr. The investigator for this demonstration was R. Holland of the Space Sciences Laboratory at MSFC. In this demonstration, Pogue floated three spheres in front of the video camera while Carr fired a trim burn in the Command Module. The three spheres were a 1.27-cm aluminum sphere, a 2.54-cm aluminum sphere, and a handball. This demonstration vividly illustrates the movement of Skylab relative to a fixed mass and shows the concept of movement with respect to a reference. This demonstration would make excellent classroom instruction material.

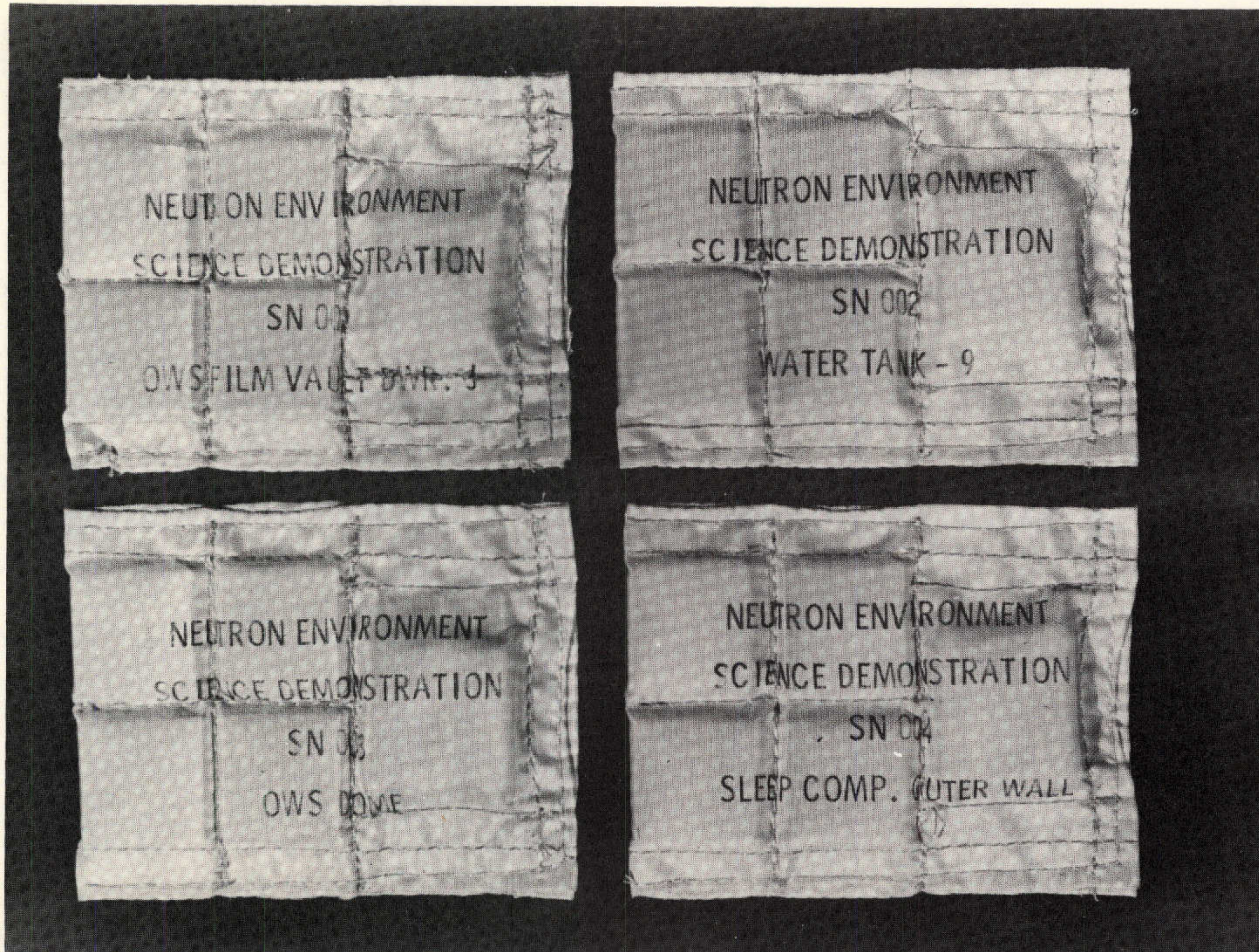


Figure 10. Neutron environment coupons.

10. TV 117 Charged Particle Mobility. The last demonstration was TV 117, Charged Particle Mobility. The investigator for this demonstration was Dr. Milan Bier of the Veterans Administration Hospital, Tucson, Arizona. Co-investigators were Dr. R. Snyder and S. Hall of Astronautics Laboratory at MSFC. Science Pilot Ed Gibson performed this demonstration. An experiment apparatus containing two cylindrical test cells with fluid cavities connected to each cell end was fabricated at the Veterans Hospital under the direction of Dr. Bier. An electrode was in each cavity, and a manually operated gate was installed at the cell entrance of the cavity containing the test specimen. The cavity of cell No. 1 contained human blood, while the cavity of cell No. 2 contained two proteins. Two buffer solutions were used (called isotachophoresis) to obtain a uniform diffusion front when the cell was operated. The study of cell movement under electric fields is important. Blood offers a known set of parameters and is not as sensitive to temperature changes as some other cells. A potential of 28 V was applied to the electrodes, and the gate was opened. The blood components, having an induced charge, moved down the cell under the influence of the electrical field. The unit was mounted on the bottom of the spider cage so that the spider experiment camera mount could be used for photography. Two high-intensity lights were placed on either side of the cage for lighting (Fig. 11).

On the initial run in space, the front appeared flat but was distorted by the presence of bubbles in the tube. The potential was reversed, and the blood went back into the cavity. The crew was instructed in real time to tap the unit in such a way that the bubbles moved to the opposite end. The experiment was then repeated. The blood migrated down the solution and showed a somewhat bullet-shaped front (Fig. 12) (the two buffer solutions on this run were now mixed, resulting in electrophoresis rather than isotachophoresis). Further analysis is being made. Unfortunately, the protein in cell No. 2 was exposed to ambient temperatures in the Command Module for approximately 3 weeks, causing deterioration of the protein. No data were obtained from this cell.

III. CONCLUSION

Twelve science demonstrations were performed on the Skylab III and IV missions. Most of the demonstrations were designed to observe phenomena in a reduced gravity environment that either do not occur or were expected to be different under normal gravity conditions. These experiments were motivated by an in-flight request by Skylab III Science Pilot Owen Garriott. The first two demonstrations described in this report were performed on that flight using

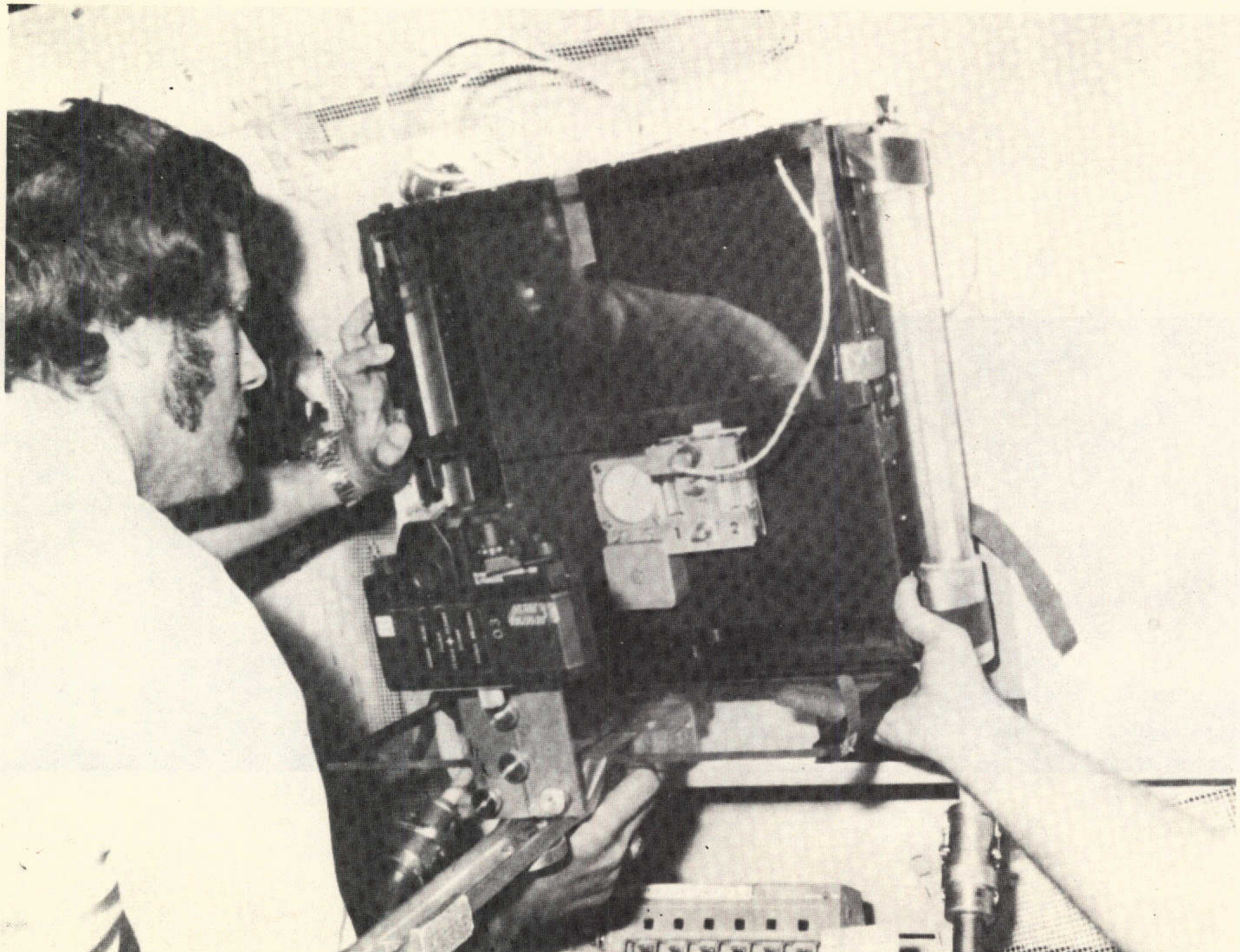


Figure 11. Charged Particle Mobility Demonstration.

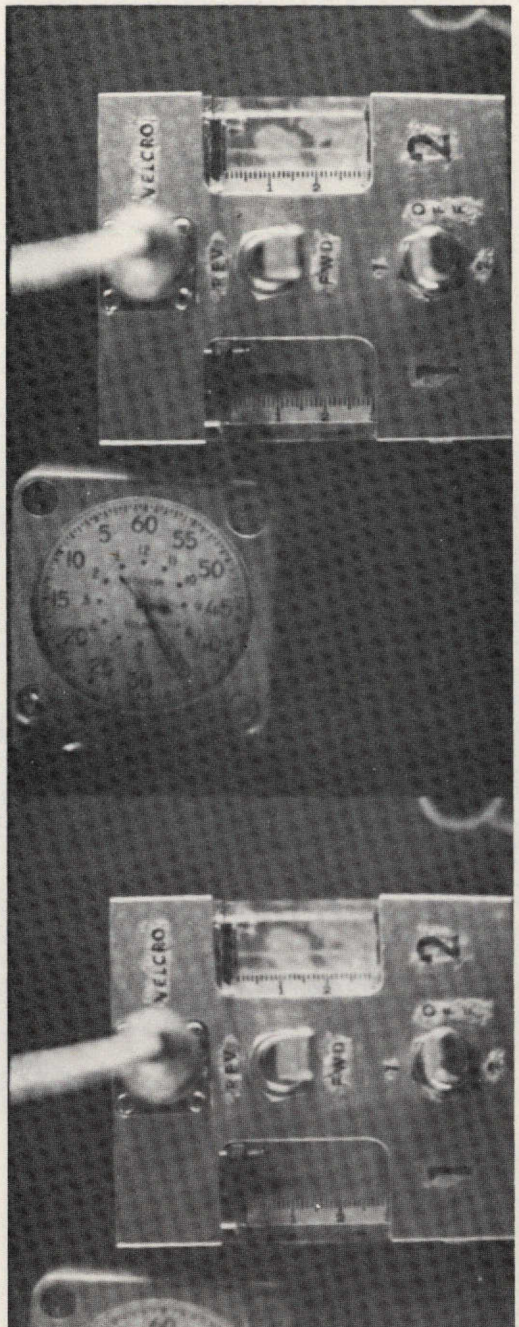


Figure 12. Charged Particle Mobility Demonstration, 2nd run.

onboard materials and hardware. More time was available for planning the demonstrations for Skylab IV, and a kit with some special equipment for the demonstrations (Rochelle salt solution, neutron environment coupons, and a charged particle mobility unit) was taken aboard by the astronauts. However, the apparatuses were still mostly composed of onboard hardware.

In addition to the scientific data obtained, two spin-off benefits were obtained. One is general knowledge of handling fluids in weightlessness and the other is the experience of a working mode that might be applicable to future Spacelab experiment operations. To elaborate, a new adaptation is required by man for handling fluids in space because surface tension and inertia predominate in space. During the crew debriefings, the astronauts repeatedly emphasized the diligence required to handle fluids. Initially, water was accidently spilled on the crew and wardroom walls. However, the crew quickly established a learning curve for handling fluids. This information can be of great benefit to future space processing, cloud physics, and similar experimental programs involving fluids. The use of membranes or thin containers which do not produce undesirable effects is recommended to control fluids where possible.

The Skylab science demonstration experience may be of great value for experimentation in the Spacelab/Shuttle era because the demonstrations were accomplished in very near real time. In other words, on the Spacelab, an experiment may be performed, the data analyzed, and the experiment repeated in a span of a few days, as opposed to carefully defining each precise step years in advance. In this type of operation, it is essential that a full-scale mockup be available for real-time simulation and that the mission control system be responsive to real-time procedure changes. The Skylab science demonstration experience approached this type of operation.

APPROVAL

SKYLAB III AND IV SCIENCE DEMONSTRATIONS PRELIMINARY REPORT

By Tommy C. Bannister

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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