Drop Physics Module

Project Scientist: Arvid Croonquist,
NASA Jet Propulsion Laboratory

Almost everyone is familiar with the three basic states of matter: solids, liquids, and gasses. What sets these three states apart is the amount of attraction between similar atoms and molecules. In solids, these forces are so strong that materials will retain their basic shapes even under pressure. In liquids, the attractive forces, known as *van der Waals forces*, are strong enough to cause liquids to pool and form a boundary, called an *interface*, with other fluids such as air. Yet the attraction is weak enough to allow liquids to flow when an external force, such as gravity, is applied. In gasses, the attractive forces are so small that there is almost no interaction between the molecules. Because they will flow, or change shape, if an outside force is applied, liquids and gasses are known as fluids. The basic goal of fluid physicists is to understand how fluids flow under the influences of external forces, how particles and gas bubbles suspended in fluids interact with solid boundaries, and how fluids change phase, either to form solids or to change from one fluid state to another.

One of the most significant forces affecting fluid behavior on Earth is gravity. Gravity is much stronger than either the van der Waals forces or the attraction between the molecules that make up the surface of a liquid (*surface tension*). The "pull" of Earth's gravity causes large drops to break apart and distorts the shape of small drops. An example of this distortion is the "teardrop" shape formed by many drops seen in everyday life.

Gravity also influences fluid behavior when differences in density exist in the fluid. Density differences result when a fluid is heated unevenly, a system contains more than one phase (such as solid particles dispersed in a liquid), or a system contains two non-mixing (*immiscible*) liquids, such as oil and vinegar. Under these conditions, a gravity-driven phenomenon called *sedimentation* occurs, causing heavier (denser) substances to sink and two layers to be formed.

Density differences are also responsible for causing a phenomenon called *buoyancy-induced flow*. For example, heat applied to the bottom of a soup pot is conducted by the metal of the pot to the soup inside. The heated soup expands and becomes less dense than the soup above. As the cool, dense soup is pulled down by gravity, the warm, less dense soup rises to the top. A circulation pattern develops that mixes the contents of the soup pot.

In microgravity, the effects of gravity are nearly eliminated, making it the nearly ideal place to study fundamental fluid physics. In the absence of gravity, very large drops can be formed because surface tension is now the dominant force affecting a liquid drop.

The Drop Physics Module has been developed so scientists can study several fluid physics phenomena: a simple surface, such as the sphere formed by a liquid drop in the absence of gravity; how a drop reacts to different forces (*drop dynamics*); and how surfaces and compound drops — a drop of one liquid surrounding a drop of a different liquid — interact. Experiments in the module will allow scientists to observe how flows inside a drop and the surface forces interact to provide a variety of dynamic events, including symmetric oscillations becoming wild (causing drops to gyrate), dramatic splitting events where a drop breaks into two drops (*fission*), and the centering of one drop within a second drop. The data gathered will allow current fluid physics theories and models to be challenged and expanded. This could benefit a variety of industries on Earth, from pharmacology to industrial chemistry.

Drop Physics Module

• Sample Summary

Samples	Liquid drops, liquid shells, solid samples
Diameter	0.5 to 2.7 cm drops
Temperature Range	Ambient

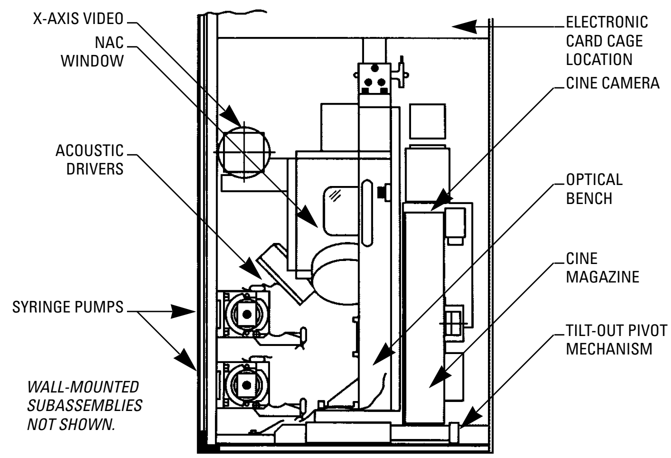
• Acoustic Drive

Carrier Frequencies	750 to 5,000 Hz
Pressure Modulation	1 to 30 Hz
Sound Pressure Level	135 to 155 dB per axis
Torque	0 to 1.0 dyne/cm

• Instrumentation

Video Imaging	30 frames/sec with 1/60- to 1/1,000-sec shuttering resolution: 120 μ with 47-mm field of view
Cinefilm Imaging	16-mm monochrome variable frame rate: 10 to 400 frames /sec
Thermocouples	±1 °C accuracy

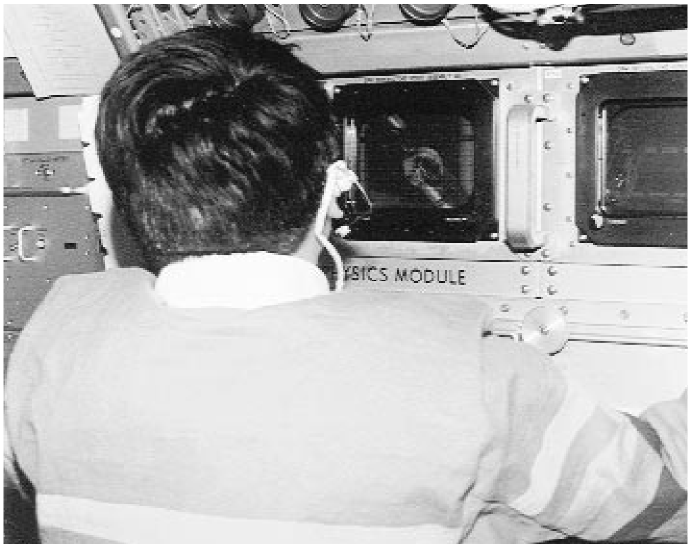
Hydrostatic pressure, humidity, and temperature sensors
Laser-sheet lighting illumination
Cathode-ray tube and system parameter displays
Process Control and Data Acquisition microprocessor
Digital data telemetered at 64 bytes per half second



A crewmember conducts an experiment in the Drop Physics Module by directly selecting commands from menus on the two video displays or by selecting a sequence of preprogrammed commands. The crewmember monitors the response of the drop on an adjacent video display, choosing one of two views of the drop. All selections are made through a novel integrated video menu display/infrared touch grid.

Liquid samples deployed into the rectangular experiment chamber are positioned by the sound waves so that film and video cameras can record the liquid's behavior. Small particles, mixed before the flight with most of the fluids, make the fluid motion inside the drop visible. The crewmember operating the experiment may manipulate the sound waves in the experiment chamber so that the sample is rotated, oscillated, or moved in some other way. Scientists on the ground may observe real-time video of the liquid and its behavior and discuss the experiment with the operator, do quick analyses of the images, and make suggestions to the operator to maximize the scientific return. After each experiment, the fluid will be retrieved, and if necessary, the interior of the chamber will be cleaned.

Drop Physics Module



Payload Specialist Dr. Eugene Trinh Operating the Drop Physics Module on USML-1

Drop Dynamics Experiment

Principal Investigator: Dr. Taylor Wang, Vanderbilt University, Nashville, Tennessee

Purpose: To gather high-quality data on the dynamics of liquid drops in low-gravity for comparison with theoretical predictions and to provide scientific and technical inputs for the development of new fields, such as containerless processing of materials and polymer encapsulation of living cells
Significance: Drop dynamics research deals with the fundamental understanding of the behavior of liquid drops under the influence of external forces. These studies provide a basis for understanding scientific and technological areas in which liquid drops have a role, ranging from rain formation and weather patterns to chemical processing.

The experiments on the Second United States Microgravity Laboratory mission include study of the fission of rotating drops (the breaking of one drop into two drops) and study of the centering mechanism in oscillating compound drops (how a drop of one liquid can be positioned at the center of a drop of a different liquid). On the First United States Microgravity Laboratory, the bifurcation of rotating liquid drops into a "dog-bone," or two-lobed shape, was studied in detail. The data from these experiments helped successfully resolve differences between theoretical predictions and previous experiment results. Results from this mission should help develop theoretical models for the drop fission process. Information gathered on the centering mechanism of oscillating compound drops will help scientists understand the differences between theoretical predictions and data from the first mission. Additionally, these studies may contribute to a field of medical research that uses cell transplantation to cure hormone deficiencies in humans, such as diabetes, by helping scientists understand how to keep living cells encapsulated at the center of special drops.
Method: Video and film (*cine*) records will be made of the oscillating and rotating drops. These records will be used to analyze the drop shapes, to obtain the oscillation frequencies, and to compare these data with theoretical predictions.

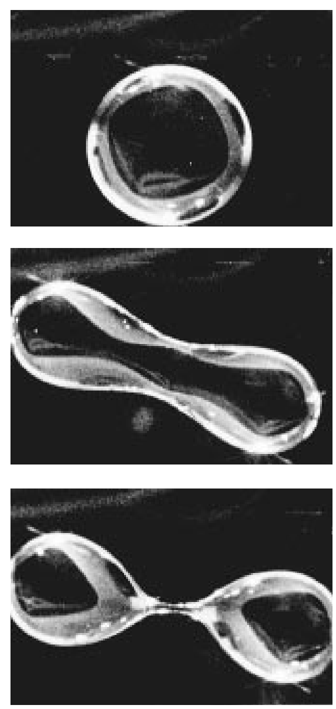
Science and Technology of Surface-Controlled Phenomena

Principal Investigator: Dr. Robert E. Apfel, Yale University, New Haven, Connecticut

Purpose: To determine the surface properties of liquid drops in the presence of materials called *surfactants*, substances that migrate toward free surfaces or toward the interface between two liquids
Significance: Surfactants play an important role in countless industrial processes, including the production of cosmetics, the dissolution of proteins in synthetic drug production, and the enhancement of oil recovery. These experiments, coupled with the current theoretical work of the science team, should give a better understanding of the molecular forces acting in the surface layer of simple water drops and should provide a better basis for industrial applications than earlier empirical results. The experiments also use a variety of techniques that disturb the interface between drops to investigate the coalescence of droplets with surfactants.

On the First United States Microgravity Laboratory, single water droplets containing varying concentrations of surfactants were squeezed and released so that their shape oscillated over a period of time. The results of these experiments are still being examined; however, preliminary conclusions indicate that the effect of surfactants on the frequency and damping of the drop oscillations is in line with theoretical expectations. Additionally, other phenomena that were observed during the experiments (though not originally included in the experiment goals) are being examined for their role in the outcome of the experiments.
Method: In the first set of experiments, single water drops containing varying concentrations of surfactants will be positioned stably by the acoustic field of the Drop Physics Module. The drop will be squeezed acoustically and then released, exciting it so that it oscillates in a quadrupole mode. The frequency and damping of the resulting free oscillations will be measured.

In the second group of experiments, two water drops containing varying concentrations of surfactants will be first positioned stably at separate nodes of the Drop Physics Module acoustic field. They then will be brought slowly into contact by carefully mixing acoustic modes to force the drops toward each other. A combination of static squeezing and then forced oscillation will be applied to the contacting drops with increasing strength, inducing them to combine.



A rotating drop passes through its critical "saddle" point as it splits in two during experimentation on USML-1