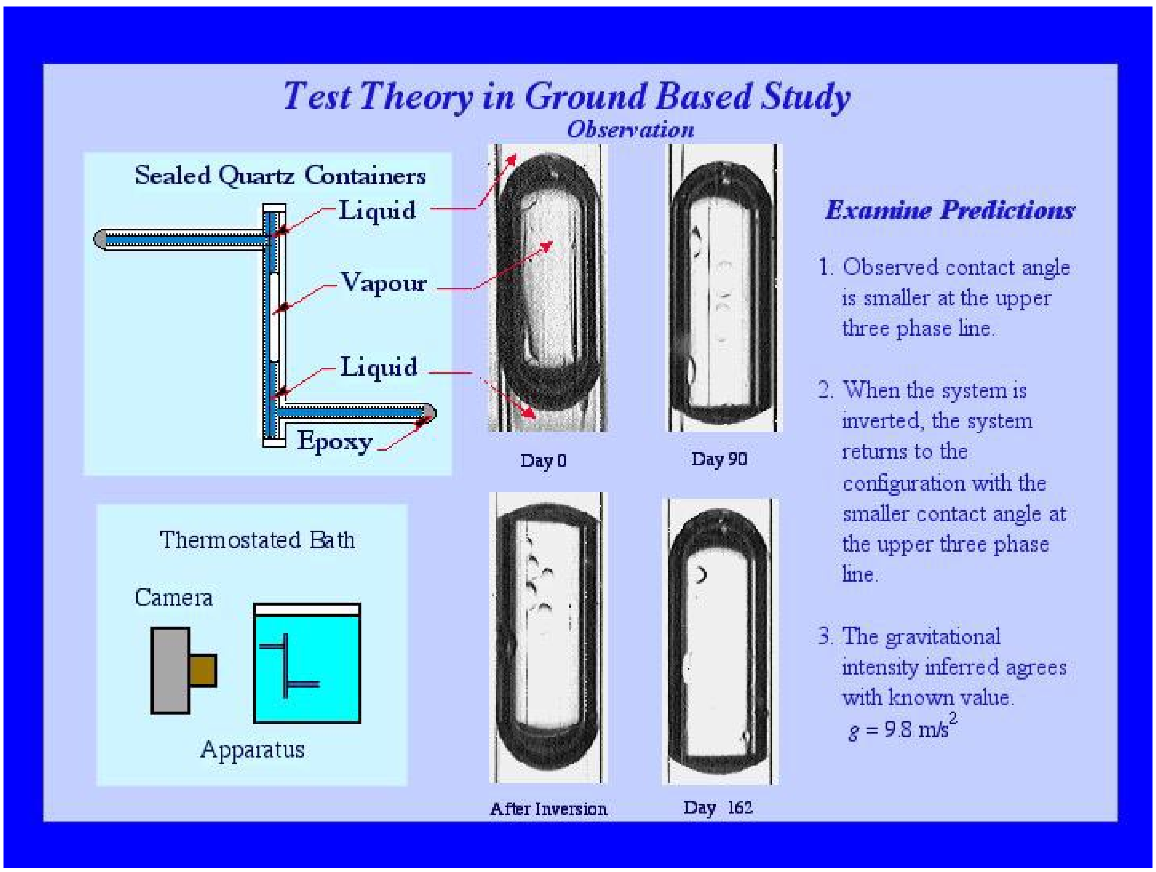
BEHAVIOR OF CONFINED FLUIDS

The behavior of fluids when confined and subjected to a field (gravitational or rotational) is determined by the bulk and surface properties of both the fluid and the confining volume. Under equilibrium conditions, the interaction of these properties can be predicted from thermodynamics. However, these predictions raise questions about the validity of our understanding of surfaces. To challenge that understanding, experiments are being performed in which the predictions are compared with experiments.

EXPERIMENTS AT NORMAL GRAVITY



Using the Gibbs description of an interphase, the necessary conditions for equilibrium of a closed, two-phase fluid system in the presence of gravity are the Laplace and Young equations and a condition on the chemical potentials. The last condition has been neglected in all previous examinations of contact angles in a gravitational field. After introducing explicit expressions for the chemical potentials, we find that the condition on the chemical potentials can be used to determine the pressure profile within the system. In a "two-interface" system in which a liquid phase is both above and below a vapor phase and the vapor phase forms a solid-vapor interphase in one region, the pressure profile in the liquid phases is the same as it would have been if the vapor phase were not there; thus in a gravitational field, the pressure is smaller in the liquid phase above the vapor phase than it is in the liquid phase below the vapor phase. This results in the contact angle at the upper three-phase line necessarily being smaller than that at the lower three-phase line. This difference in contact angles is conventionally referred to as contact angle hysteresis; however, we show that it is simply an equilibrium property of a capillary system in a gravitational field. The contact angle difference predicted to exist in the presence of gravity does not violate the Young equation, but the Young equation does impose a restriction on the equilibrium adsorption isotherms at the solid-vapor and solid-liquid interfaces. See C. A. Ward and M. R. Sasges, “Effect of gravity on contact angle: A theoretical investigation”, J. Chemical Physics 109, 3651-3660 (1998). These predictions were examined in: M. R. Sasges and C. A. Ward, “Effect of gravity on contact angle: An experimental investigation”, J. Chemical Physics **109**, 3661-3670 (1998).

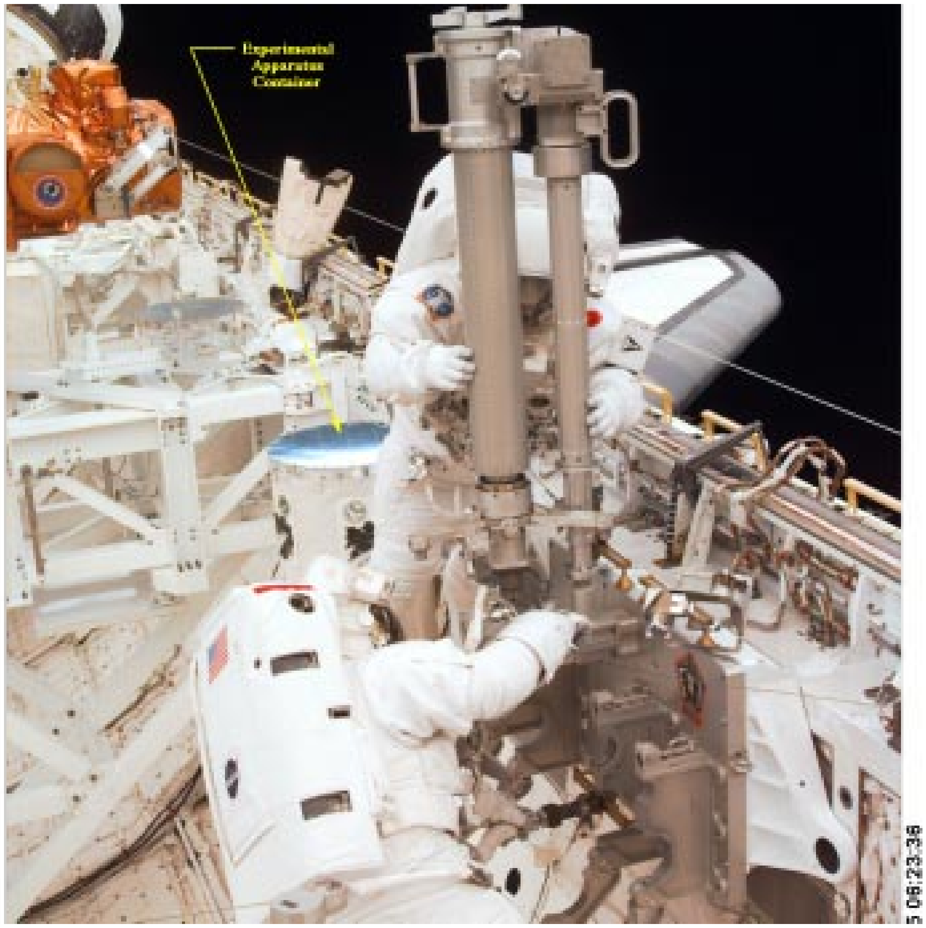
DROP TOWER EXPERIMENTS

An examination of the axisymmetric equilibrium configurations of fluid systems in cylindrical containers in an arbitrary gravity field has been undertaken. The derived theory allows the effects of gravity on an interface shape to be quantified. When these effects may be neglected, the resulting predictions for equilibrium are contrary to those of previous theories. The theoretical approach adopted herein leads to the prediction that the equilibrium configuration is dependent on the contact angle and on the amount of fluid in the container. These predictions have been examined through a series of experiments conducted in a drop shaft, and the results support the new theoretical approach. See M. R. Sasges, C. A. Ward, H. Azuma and S. Yoshihara, “Equilibrium fluid configurations in low gravity”, J. Appl. Phys. **79**, 8770-8782, (1996).

PARABOLIC FLIGHTS IN AIRCRAFT

A method is reported for predicting the shape of the phase boundary in two-phase isothermal constant-volume constant-mass rotating fluid systems. In contrast to previous methods that have employed the continuum concept of pressure, the proposed method uses the thermodynamic concept. The latter requires, in addition to the usual condition of a force balance existing at the boundary, that the equilibrium phase boundary shape be such that there is no net mass flux. The latter condition is imposed by requiring that the chemical potentials in the different phases be equal at the phase boundary. A non-dimensional parameter is defined that allows one to determine when the effect of a gravitational field acting at 90° to the axis of rotation may be neglected. Experiments have been performed under conditions where this restriction is satisfied. With known values of the experimentally controllable variables, the proposed method has been used to predict the length of the vapour phase. To within the experimental error, the predicted lengths are found to be in agreement with the measurements. If, however, a gravitational field of a sufficient magnitude is imposed the vapour phase has been found to become unstable and to break into two or more separate bubbles. Using the variable-gravity environment of an aircraft following a parabolic flight path, this instability has been investigated. By approximating the gravitational effects, the theoretical description has been extended and a method proposed to determine the conditions under which the phase boundary becomes unstable. If the angle of action of the net viscous shear force on the bubble were known, a prediction of the breakup could be made entirely in terms of experimentally controllable parameters. Using arguments for the value of this angle, bounds on the breakup condition are compared with experimental results. See J. A. W. Elliott, C. A. Ward and D. Yee, “Bubble shapes in rotating two-phase fluid systems: a thermodynamic approach”, J. Fluid Mechanics, **319**, 1-23 (1996).

SHUTTLE FLIGHT



Our experiment was flown in the above canister G-036 on the Space Shuttle flight STS-87.

When the two fluid phases of a substance are present in a cylinder, one of the possible equilibrium configurations is for two liquid phases to be present, one above the vapour phase and one below. If surface tension dominates the gravitational effects, the two-interface configuration is the thermodynamically favored one. When the system is in the two-interface configuration, the difference in pressure between the two liquid phases is predicted to be the same as it would have been had no vapour phase been present! Although the pressure profile can not be measured directly, it is predicted to cause the contact angle value at the upper three-phase line to be smaller than that at the lower three-phase line. This difference in contact angles can be measured, and from the measured values, the theory can be used to determine the value of the gravitational intensity. In an experiment conducted on a Space Shuttle flight, the configuration adopted when glass cylinders of different diameters were each partially filled with water was recorded. The fluid in each cylinder was found to adopt the two-interface configuration, as predicted. A 56 mm diameter glass cylinder that had a height of 86 mm was observed to have a contact angle at the upper three-phase line of 6.7 ± 1.3° and 26.5 ± 4.0° at the lower. The value of the gravitational intensity inferred from the measured contact angles agrees with that reported from the (NASA) electronic Space Acceleration Measurement System (SAMS). This agreement supports the prediction that contact angle hysteresis is generated by a difference in pressure between the two liquid phases of the two-interface configuration. See C. A. Ward, P. Rahimi, M. R. Sasges and D. Stanga, "Contact angle hysteresis generated by the residual gravitational field of the Space Shuttle, J. Chemical Physics, **112**, Apr. 22, (2000).