REDUCED GRAVITY
FLUID DYNAMICS
WETTABILITY
FLUID FLOW
GAS-LIQUID INTERACTI

VAPORS
FILM THICKNESS
INTERFACIAL TENSION
GRAVITATIONAL EFFECTS
PERTURBATION

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FLUID BEHAVIOR IN MICROGRAVITY

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ABSTRACT

An experiment designed to study some fundamental aspects of microgravity fluid dynamics has been built and is scheduled for flight. The purpose of the experiment is to investigate differences in behavior of wetting and non-wetting fluid systems at low Bond numbers. Methods have been developed to determine liquid quantity, estimate vapor contact area and measure liquid layer thickness. Both the responses of the fluid systems to external perturbations and the transfer of liquid through a connection between two containers can be studied.

INTRODUCTION

The objective of the experiment is to study some aspects of microgravity fluid mechanics and quantity determination. In particular, the focus of the work is to develop measurement methods capable of quantitatively measuring the behavior of liquid-gas mixtures in microgravity [1,2]. The systems to be studied are dominated by surface tension effects as compared to gravitational effects and, so, are characterized by very small Bond numbers. Measurement techniques were developed to enable determination of liquid phase volume, estimation of vapor (or gas) phase contact area, and surface layer liquid thickness. In addition, provisions have been made to investigate liquid migration due to surface tension and perturbations such as g-jitter.

Two fundamentally different fluid systems are compared using identical experiment modules. One system utilizes an aluminum container with a Freon™ 11 fluid system. The freon is known to wet the aluminum strongly and will tend to coat interior surfaces somewhat uniformly in search of a minimum energy configuration. The Freon is maintained at saturation conditions so that the liquid and vapor phases can be the same substance. The second system utilizes a water/ethylene glycol liquid mixture with nitrogen "vapor". The container surface is TFE which forms a non-wetting system with the liquid. This system will tend toward a floating mass or masses of liquid not in contact with container walls.

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Each experiment module is actually two containers connected by a motor activated valve as shown in Figure 1.

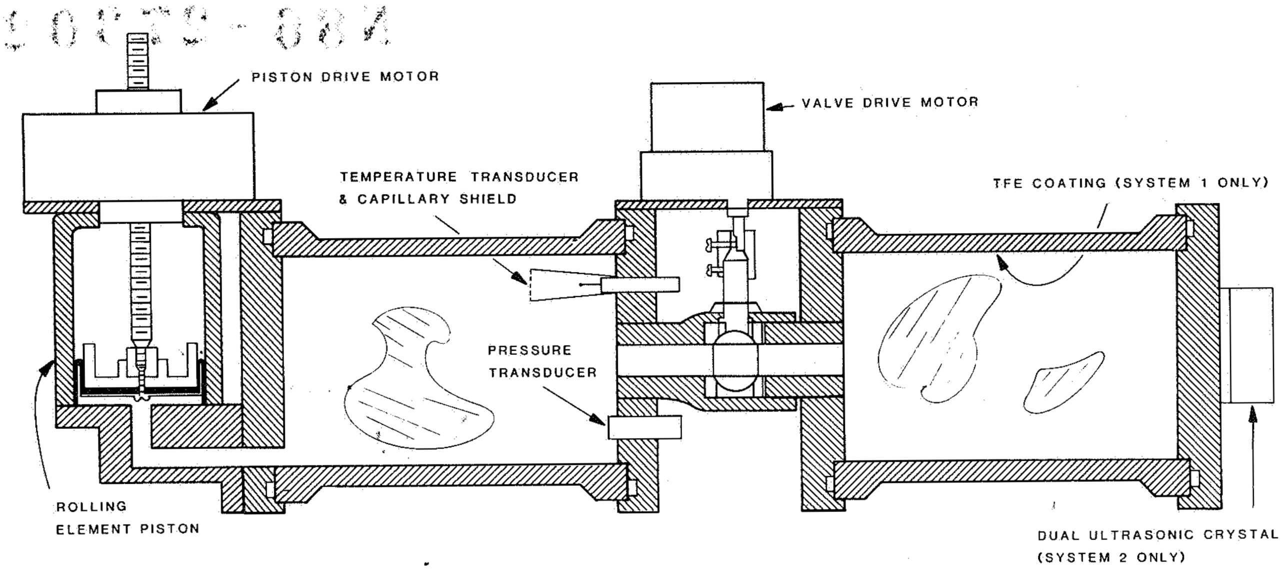

Figure 1 MODULE SCHEMATIC

Initially, most of the liquid will reside in one of the module containers. During the 2 day experiment program, the connecting valves will be periodically opened allowing liquid and vapor exchange between the containers. It is expected that the wetting system will quickly redistribute by capillary action to approximately equal liquid volume in each container. The only driving force for the nonwetting system to redistribute, however, will be the kinetics of the liquid globules driven by orbiter accelerations. The redistribution will thus be a probablistic process depending on the acceleration spectrum encountered. The liquid present in one of the module containers will be periodically monitored so that the redistribution process can be analyzed after the flight.

METHODOLOGY

By perturbing the container volume a small amount, dV, in a short time, the vapor phase undergoes an essentially isentropic process. It can be shown that the corresponding vapor phase temperature excursion is

$$dT = -T(\gamma-1)dV/V$$

where γ is the ratio of specific heats. Simultaneously, the container pressure undergoes an excursion

$$dP = -P\,\gamma\,dV/V$$

Thus, if the volume perturbation is prescribed while the temperature and/or the pressure response is measured, the volume, V, of the vapor phase can be determined

$$V = -(\gamma-1)dV/dT$$

$$V = -P\gamma\,dV/dP$$

The liquid phase volume is thence found by subtraction from the total volume.

Typically a small volume change is desired in order to minimize the displacer mechanism size and power. The perturbation must, however, produce measurable temperature and/or pressure responses. It is, perhaps, easiest to measure the pressure response. In order to achieve reasonable resolution with existing transducer technology, it is necessary to use volume perturbations of the order of 5% of the total volume. While this can be achieved with nearly full tanks, it becomes a problem for nearly empty ones.

Greater resolution can be achieved through temperature measurement although the methodology is more complex. The sensor must be protected from liquid contact because the liquid phase remains fixed in temperature during the perturbation. The isolation can be accomplished with capillary control shields. The sensor must have a very small time constant and the measurement circuitry must be arranged to minimize self-heat error.

After the initial perturbation equilibrium is slowly re-established with heat transfer occurring between the vapor, the liquid, and the container. The proces is complicated by mass transfer as well but in global terms, the time constant of the (exponential) return to equilibrium is proportional to the contact area of the vapor. In this sense, the time constant reflects the configuration of the liquid-vapor mixture. A dispersed system, such as many droplets or globules, would return to equilibrium much faster than a coherent film type system.

By measuring the temperature decay curve, the time constant can be established. The sampling methodology has been designed to take advantage of the statistics of acceleration events at selected levels. It is expected that accelerations will cause the liquid configurations to change thus producing measurable differences in the time constants of the decay curves. A companion accelerometer package will provide a time history of acceleration events for correlation with the heat transfer data. The sensitivity of the three-axis accelerometer package is 5×10^{-5} g/bit which is sufficient to characterize thruster firings and crew motions [3].

A relatively straight-forward method of ultrasonic film thickness determination is utilized. A dual-element transducer of 2.25 MHz natural frequency was selected in order to simplify the electronics and provide high resolution. The transducer was fitted against a PMMA window which was coated with epoxy to protect it from the Freon™ 11. In operation, one of the transducer elements is excited with a step voltage which causes about 7 cycles of 2.25 MHz compression waves to be generated. The waves propagate through the window which is impeadance matched to the Freon™ 11. Wave reflection from the liquid-vapor interface is received by the second transducer element. The electronic circuitry directly measures the time elapsed from transmission to reception and thus is proportional to film thickness.

Depending on the transducer beam angle, the returning signal can only be detected for a range of surface angles to the transducer normal. In addition, wave reflections from the window/liquid interface will occur because the impeadance match is not perfect and blanking must be used. The resolution, however, is excellent being 0.015 inch/per bit. An 8 bit counter was used giving a range of about 2 inches. It is not difficult, of course, to increase the range significantly.

IMPLEMENTATION

The two modules are shown schematically in Figure 1. Except for the fluid/vapor and surface treatment, they are identical. Each module consists of two 500 cc chambers separated by a motor operated ball valve with a 1 cm bore. A rolling diaphram piston assembly driven by a linear displacement stepper motor is used to produce volume perturbations. The stroke is software controlled with a nominal displacement of 5 cc in 1 second.

An Entran pressure transducer having 25 psia full scale range is used in conjunction with precision signal conditioning and a 12 bit Analog Devices A/D converter. The temperature is sensed with a Thermometrics "Fastip" thermistor probe and similar processing circuits. The thermistor bridge is pulsed for 40 ms to avoid inaccuracy due to self-generated heat. In addition, it is fitted with a conical capillary control shield and screen to ensure that the element will always be in the vapor and/or gas phase. On launch, very little liquid is in the left chamber so that the screen will not be defeated.

Water in conjunction with TFE coating constitutes the non-wetting system. Freon ™11 in conjunction with machined aluminum forms the wetting system. The ultrasonic film thickness system is fitted only to the wetting system. Figure 2 is a photograph of the TFE coated system.

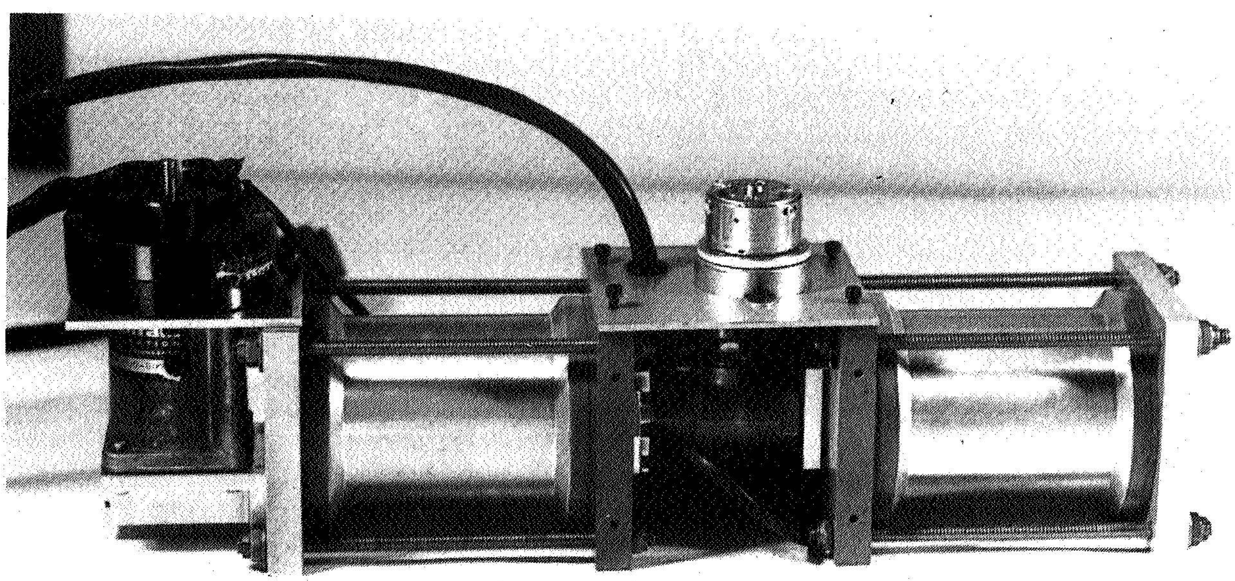

Figure 2 EXPERIMENT MODULE

Both experiment modules are controlled by an electronics assembly, Figure 3, which contains six circuit boards. The system block diagram is shown in

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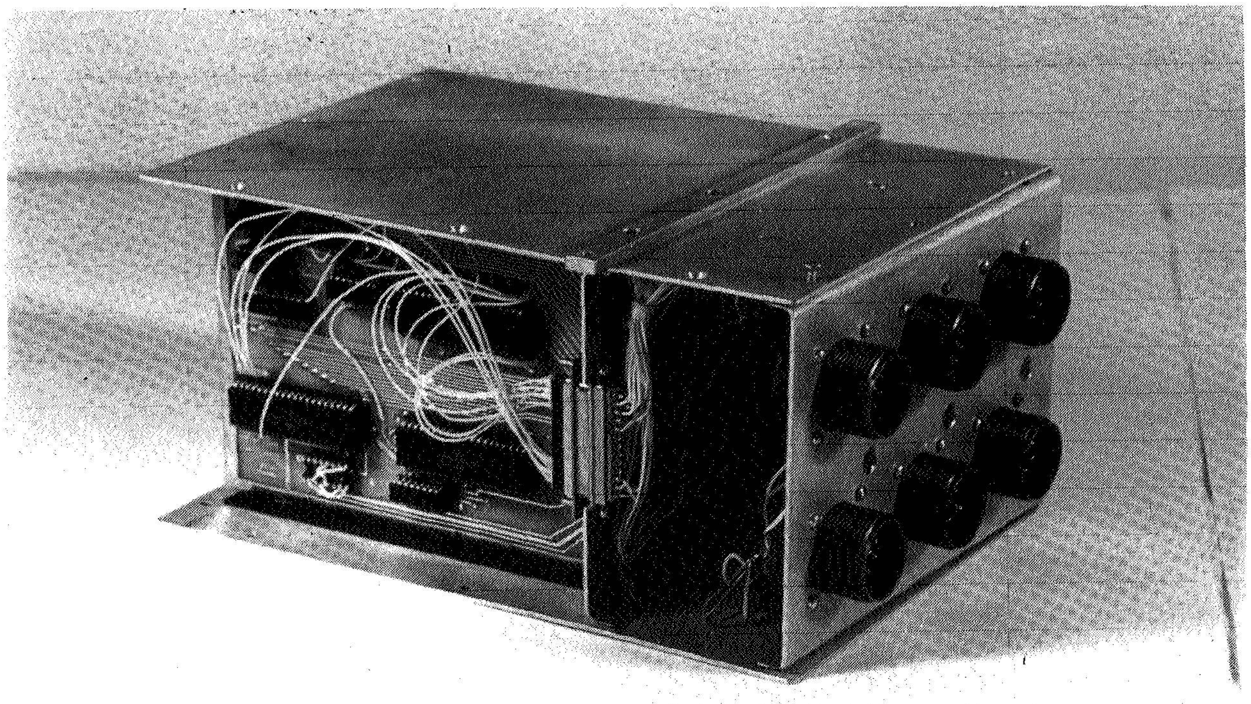

Figure 3 ELECTRONICS ASSEMBLY

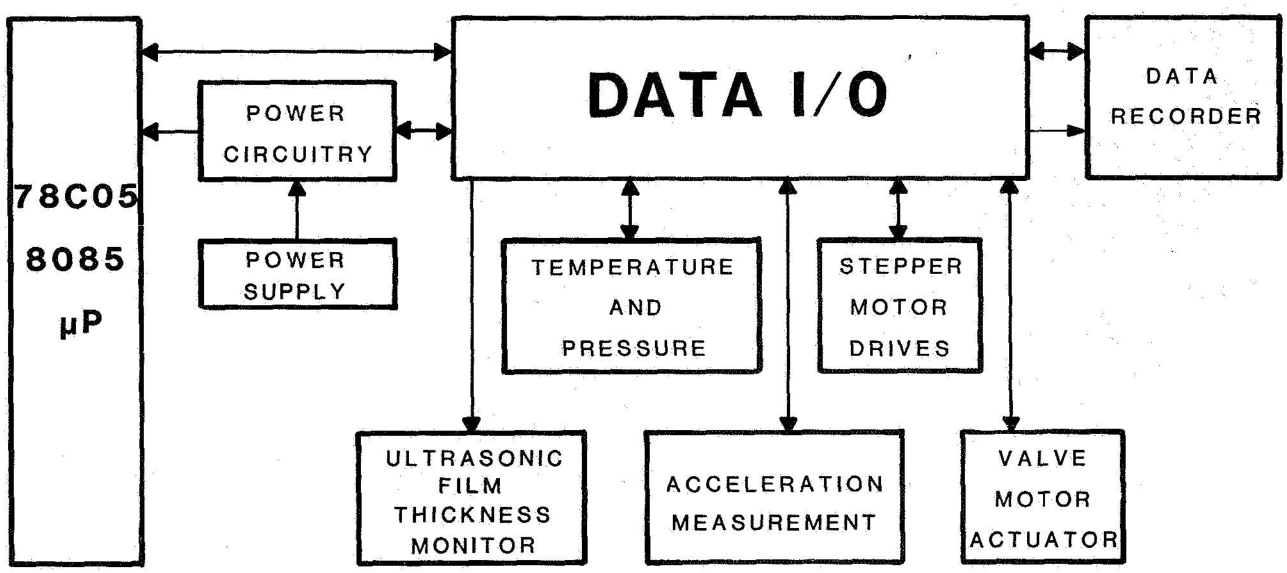

FIGURE 4 SYSTEM BLOCK DIAGRAM
MEASUREMENT AND CONTROL

Figure 4. A single board microcomputer is the basis for all measurement and control functions. It contains the operational software on PROMS which is booted when the GAS container is signaled by the crew when on orbit. A data I/O card provides all computer interfaces for measurements and controls. It utilizes both parallel and analog interfaces with other cards and performs serial data transmission to the (separate) tape recorder.

The primary signal processing and control functions utilize the remaining four circuit boards. These functions are:

1. Temperature and Pressure Measurement
2. Stepper Motor Drives
3. Ultrasonic Processor
4. Acceleration Measurement
5. Valve Motor Drives

In addition, auxillary functions are also included such as power switching reference voltage generation, clocks, and limit sensing. In order to maximize accuracy and resolution of temperature and pressure measurement, local signal conditioning was provided in each experiment module for the sensors. Figure 5 shows the Panametrics ultrasonic transducer fitted to the PMMA container endcap. The Wilcoxon accelerometers are housed in a separate box and utilize sample and hold circuits to establish the acceleration magnitudes over 5 second intervals.

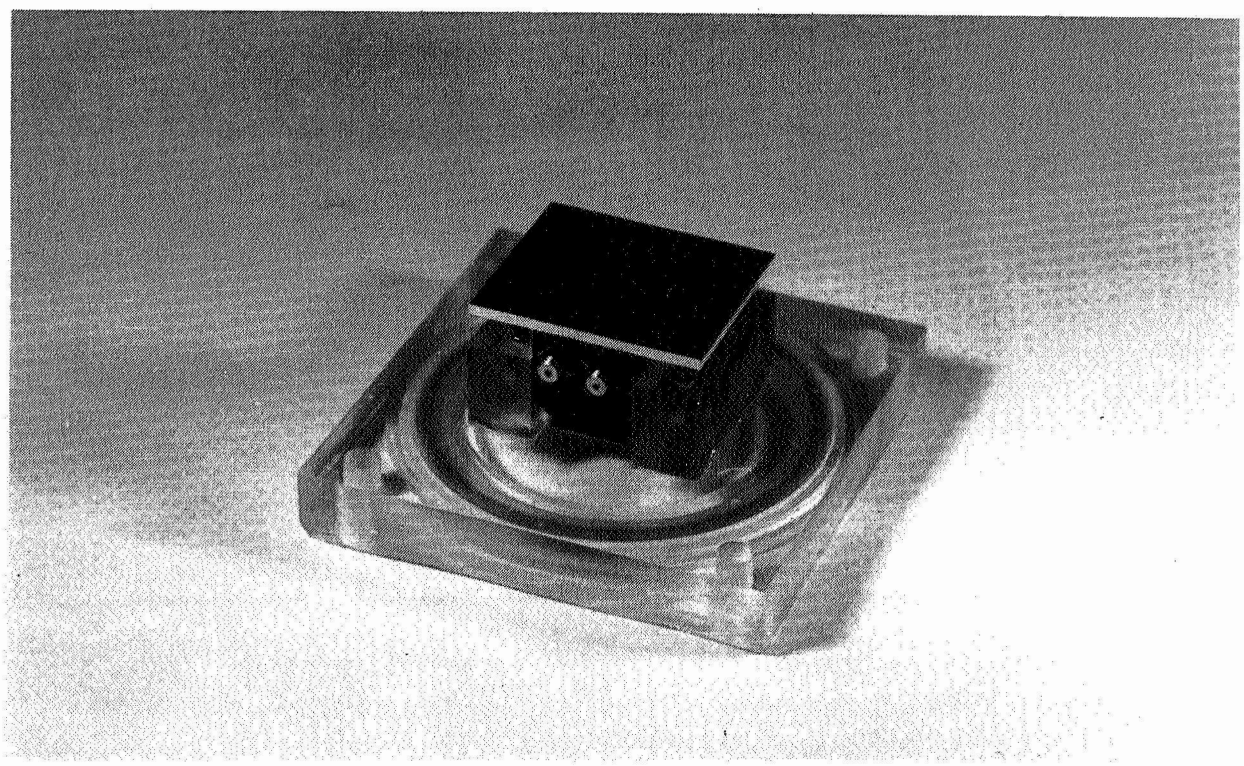

FIGURE 5 ULTRASONIC TRANSDUCER

TESTING

Environmental testing includes the acceleration spectrum specified for GAS payloads [4] on all three axes and function testing over the design range of 0-30^oC. Vibration testing uncovered some unsuitable component mounting practices which were remedied with suitable fasteners and RTV sealant. In addition, stepper motors were found prone to drift so that software was added to "home" the motors before use. Because the pressures in the experiment modules vary differently than that in the GAS container with temperature the bias force on the stepper motors varies limiting the operational temperature range. The 0-30^oC range was predicted from a canister thermal analysis and the piston assemblies spring biased for this range. The microprocessor checks the temperature and conducts experimental runs only when the range is satisfied.

Operational status was achieved using a Motorola 8085 emulator system to debug each board with its associated software. The software strategy was to utilize a subroutine for each measurement and control function. A supervisory program then called the subroutines in the desired sequence. The system executes a complete measurement cycle every half-hour including data storage from RAM to tape. The programmed duration is 72 hours unless powered down by the redundant actuator, experiencing low voltage, or signaled-off by the crew.

Considerable effort was applied to achieving very accurate temperature, pressure, and film thickness measurements and calibrations. The resolutions were ultimately limited by 1 bit for temperature and pressure and 1 ultrasonic wavelength for the thickness monitor. The final resolutions were 0.007^oC, 0.006 psi, and 0.4 mm.

SUMMARY

This experiment was conceived as both an investigation of fundamental differences in the behavior of wetting and non-wetting systems and a demonstration of measurement techniques in the microgravity environment. It is one of a number of experiments to be flown in G-408 by the WPI/MITRE Space Shuttle Project program. It formed the MQP activity of two groups of students over a two year period. Eleven students majoring in Electrical Engineering, Mechanical Engineering, and Physics designed, fabricated, and tested the system.

The MITRE Corporation donated the GAS container and is providing overall project support. The Fluid Behavior experiment received substantial financial and engineering support from the Instrument Systems Division of Simmonds Precision. The contributions of these and other firms to the WPI effort are gratefully acknowledged.

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