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UCLA SCHOOL OF ENGINEERING AND APPLIED SCIENCE

SPACE HARDWARE DESIGNS

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SOLAR SAIL DEPLOYMENT MECHANISM

Abstract

The design is described of a solar sail space vehicle with a novel sail deployment mechanism. The sail is triangular in shape and is deployed and stabilized by three miniature spacecraft, one at each corner of the triangle.

Description

The task assigned to the students was to design a prototype solar sail vehicle that would be capable of carrying a small scientific payload from near Earth vicinity to a Mars flyby. Direct ascent from the Earth to the Mars orbit, as well as several orbits about the sun - hence longer travelling times, but smaller sail area -- were to be considered.

The principal new feature of the design is the mechanism proposed to deploy and stabilize the sail. As shown in Fig. 1-1 the deployed sail is oriented approximately perpendicular to the direction from the sun. Each corner of the sail is attached to a miniature vehicle of about 20 kg mass when fueled with hydrazine. The initial ejection of the three miniature vehicles from the carrier rocket (a modified Minute Man II launch vehicle) is accomplished by spring release, with subsequent pull on the folded sail by small thrusters on the miniature vehicles. At the same time the sail is made, by additional thrustors on the miniature vehicles, to slowly spin, so that once deployed, the sail's shape is maintained by the centrifugal force of the three vehicles without further expenditure of propellant.

As designed, each miniature vehicle is pie-shaped (Figs. 1-1 and 1-2) and fits into the circular cross-section of the Minute Man II, Configuration B, shroud. The principal components on each vehicle are a hydrazine tank pressurized from a small helium tank, the thrusters, and avionics. The avionics would have to include a guidance package needed to maintain the attitude of the sail, a communications link between the three vehicles, and up and down links for command and telemetry.

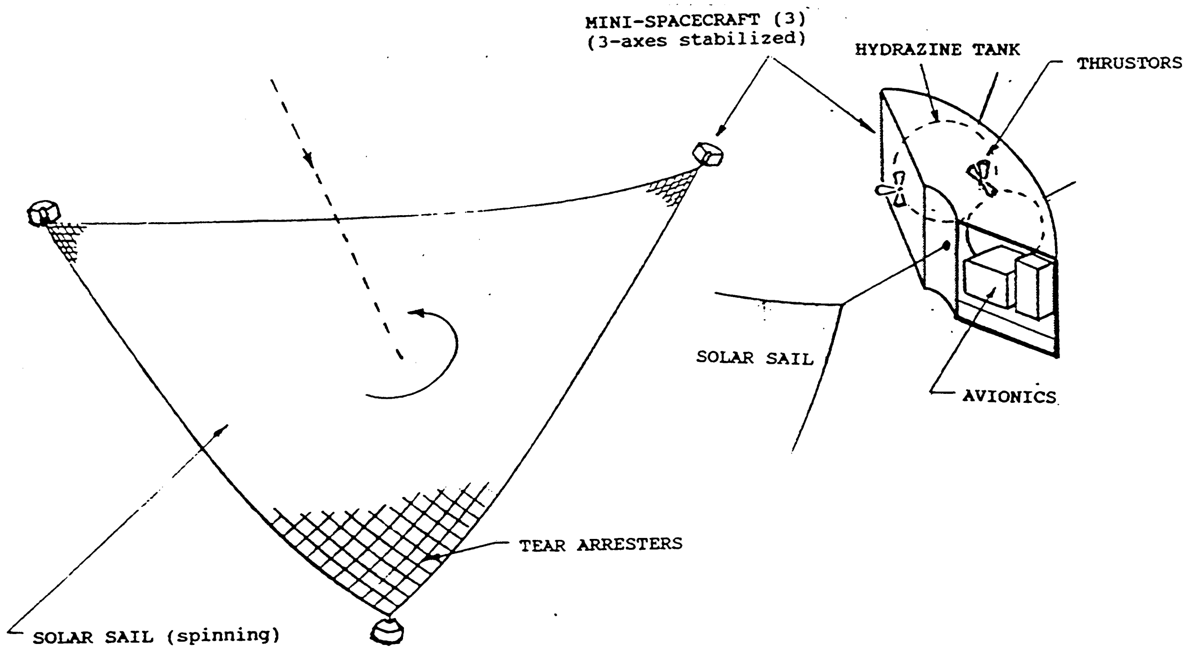

Figure 1-1: Deployed Solar Sail with its Three Miniature Spacecraft.

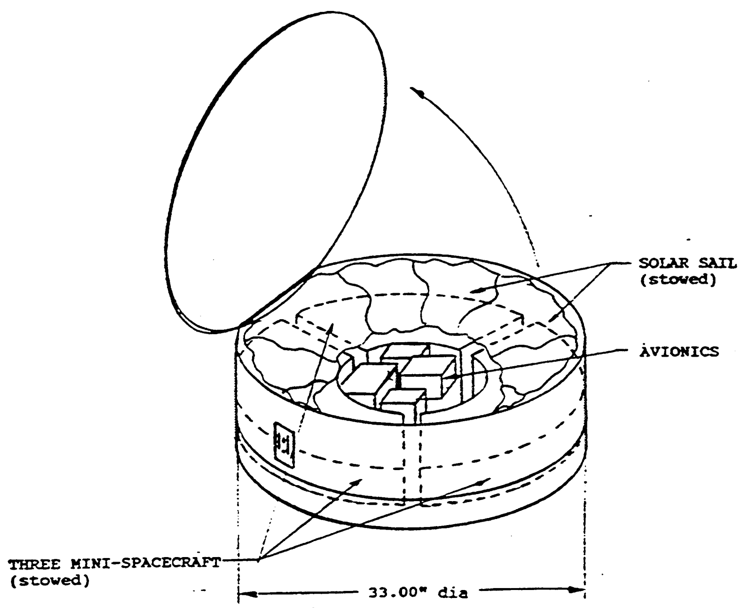

Figure 1-2: Launch Vehicle: Modified Minute Man II, Configuration B, Near-polar Orbit, 200 nm altitude.
Total mass, including sail: 150 kg
Mass of each vehicle: 20 kg
Elapsed time from Earth to Mars orbit: 5 years
Sail area: 17,000 m^2 (for direct Earth-Mars ascent)
4,000 m^2 (for 3.5 orbits about the sun).

SPHERICAL MICRO-ROVER FOR PLANETARY SOIL ANALYSIS

Abstract

In this hardware project, the students designed a concept demonstrator for a novel microrover for the exploration of a planetary surface. In the actual application, a large number of such microrovers would be released from a landing craft. Each rover would be equipped with a Cd 109 radio-isotope source for irradiating the planetary surface and an x-ray fluorescence detector to determine the elemental composition. The device developed by the students was limited to demonstrating the mechanical and electrical drive. The geometric external shape is a sphere; hence there is no danger of the rover being turned on its back and stopped. Propulsion is by means of an interior mass eccentric to the sphere and driven by an electric motor. The motion of the rover is random. The electric circuitry will reverse the motor, causing the rover to begin on a new path, if an obstacle is encountered. In an inter-disciplinary effort in mechanical and electrical engineering, the students designed the mechanical parts, built the circuit board and tested the device.

Introduction

As a precursor to any manned facilities on Mars or other terrestrial bodies, surface exploration will be carried out by unmanned robotic vehicles. Several concepts exist for these vehicles, some of which have been designed and built. Examples include Rocky III of the NASA Jet Propulsion Laboratories and Marsokhood of Russia. Most rover concepts rely on wheels, tracks and/or legs for locomotion. In addition, they require sophisticated on-board control systems for autonomous travel and rely on two way telemetry equipment for extended operation.

It is possible that certain surface exploration missions can be accomplished with much simpler and cheaper microrovers. One of these tasks may be planetary soil analysis. The objective of the students was to design such a rover.

Micro-rover Concept

The student-designed vehicle (Figs. 2.1. 2.2, 2.3) is composed of a hollow spherical casing driven by the movement of an eccentric mass around an axis of the sphere. An electric motor imparts a torque to the shell by lifting the eccentric mass, causing the rover to roll. All components of the rover are inside the sphere. Power for the rover would be provided by a radioisotope thermal generator (RTG) which would allow years of operation. The RTG would make up most of the eccentric mass. The motion of the rover would be semi-random depending on the terrain. The use of a sphere allows even small surface fluctuations to change the rover's direction. Given a large amount of time, the rover will cover it's sampling area. The only control would be an on board system to reverse the motor if the rover encounters an obstacle which stops all forward motion.

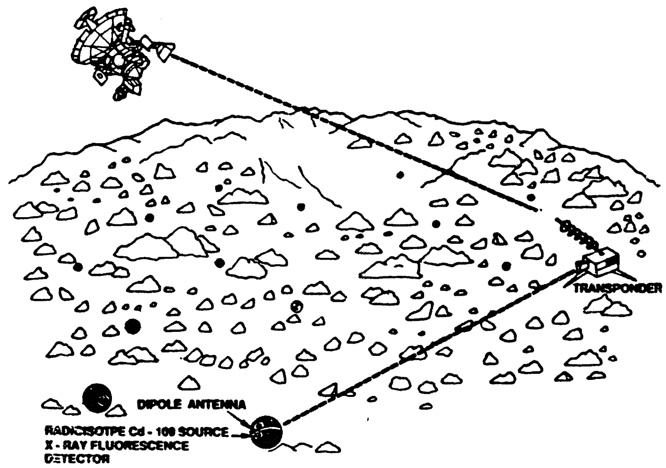

Figure 2.1: Random Motion, Spherical Microrovers Released from a Landing Craft on Mars. Data is sent via central transponder to an orbiting satellite.

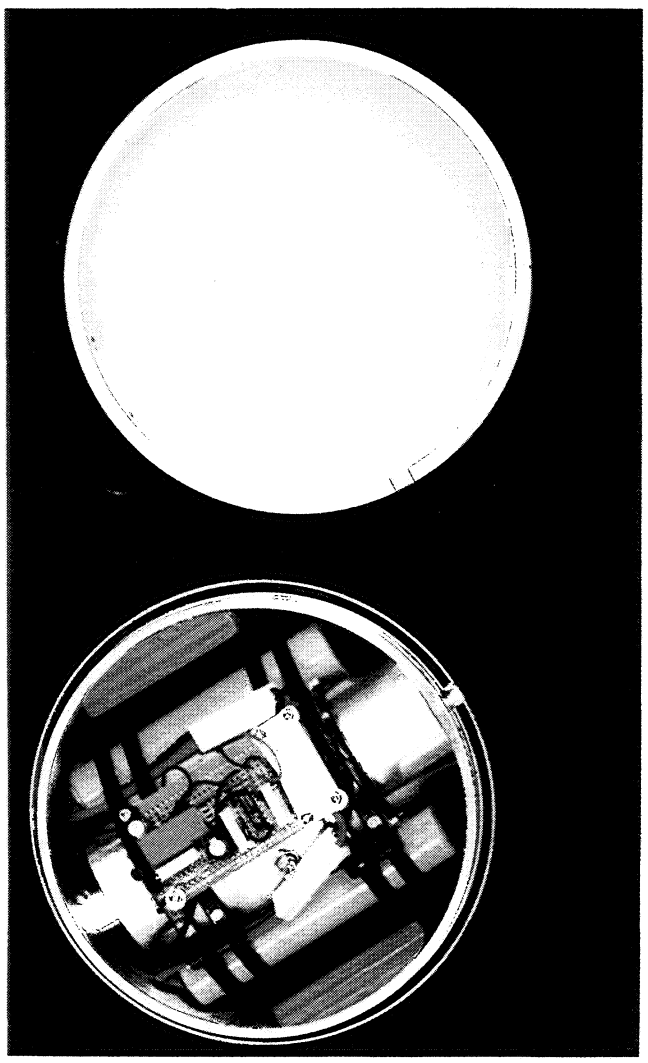

Figure 2-2: Student-designed concept demonstrator for a spherical microrover to be used in planetary exploration.

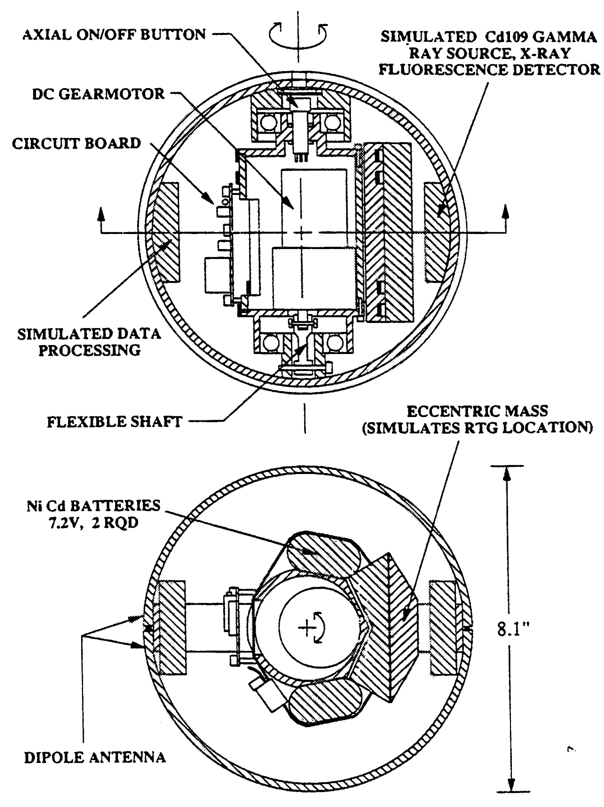

Figure 2.3: Cross-sections of the student designed microrover concept demonstrator shown in Figure 2.2.

UCLA MODEL		AN ACTUAL MICRO-ROVER	
1.	Spherical, driven by eccentric interior mass	1.	Same
2.	Random walk motion	2.	Same
3.	Backs off automatically when stopped by obstacle	3.	Same
4.	Dipole antenna for data transmission. Outer casing is made from two hemispherical shells, electrically insulated from each other	4.	Same
5.	Simulated	5.	Cd 109 radioisotope source (100 millicurie) and Ge X-ray detectors for determination of elemental ground composition
6.	Powered by NiCd rechargeable batters	6.	Powered by radioisotope thermal generator
7.	Simulated	7.	Data processing and rf transmission equipment

Table 2-1: Comparison of some feaures of the UCLA demonstrator to the actual microrover concept.

The spherical casing could be a membrane or a rigid thin shell. If a membrane is used, the rover can be inflated after deployment saving valuable space in the delivery craft. In addition, the membraneallows absorption of shock loads encountered during vehicle operation and the weight savings aids hill climbing capabilities. A rigid metallic shell consisting of two hemispheres, electrically isolated from each other, would be more reliable, and could serve as a dipole antenna.

For soil analysis, the rover would be equipped with a cadmium 109 radio-isotope source (a gamma ray emitter) to irradiate the planetary surface and a germanium crystal detector to receive the x-ray fluorescence resulting from the gamma rays. Together these devices allow the determination of the soil composition by elements even if some are present only in trace amounts. A miniaturized, hand-held device has already been developed by the South African Bureau of Mines for use in gold mines.

Mechanical and Electrical Design

The demonstrator designed by the students is limited to demonstrating the mechanical and electrical drive system. A simple rigid, aluminum shell was used. Other similarities and differences between the actual microrover and the demonstrator are listed in Table 2.1.

Features of the microrover demonstrator other than those listed include: A flexible shaft coupling from the motor to the shell to protect the motor gears from shock induced by an abrupt termination of forward motion; a DC permanent magnet gear motor; a push button which is activated along the axis of rotation allowing the rover to be turned on and off without taking the shell off; a circuit board for motor control.

In an interdisciplinary effort, the students designed not only the mechanical parts, but designed and built the circuit board (Fig. 2-4). The task of the board is to reverse the motor direction if all forward motion is stopped for more than 0.5 seconds. The circuitry reverses the current direction when the motor stalls for more than 0.5 seconds. The second feature of the board is the variable resistor connected in series to the motor. This allows the stall torque of the motor to be varied without affecting the regular motor speed.

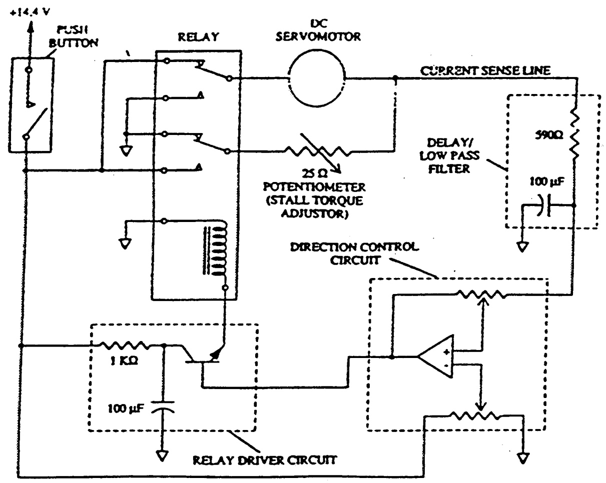

Figure 2-4: Student-designed Circuit for the Microrover (motor controlled).

Conclusions

Initial testing of the microrover demonstrator shows it to be successful. The motion is a random walk. Good coverage of an area is achieved in a relatively short time. (The more obstacles the better the coverage.) Due to its motor reversal feature and "drunken" walk it is capable of extricating itself from situations where it is boxed in. The design is unstable on hills which indicates that this rover would be most useful in relatively flat areas with scattered obstacles.

OIL FILM MIGRATION IN THE WEIGHTLESS ENVIRONMENT

Abstract

Laboratory experiments have been conducted to study the migration of thin oil films on metal surfaces in the presence of a thermal gradient. These experiments are preliminary to a planned space shuttle GAS experiment on bearing lubrication in a micro-g environment.

Introduction

Low vapor pressure lubricants are used in a majority of spacecraft, most often in the form of thin oil films on metal surfaces. Their purpose is to reduce frictional torques and wear in the bearings used in gyroscopes, momentum wheels for spacecraft attitude control, and in scientific payloads that require mechanical motions. Adequate lubrication must be provided for the life of the spacecraft, which often exceeds ten years. This must take place in a weightless and vacuum environment where there is no possibility of replenishment or repair.

Premature bearing failures in spacecraft have occurred a number of times. Such failures have recently been reported in the NASA Hubble Space Telescope. Most often, these failures have been associated with high speed ball and roller bearings used in momentum wheels and 3-axis reaction wheel systems. The reasons for these failures have been speculative, but lubricant depletion is a possible cause.

Surface Tension Driven Flow

There are several possible mechanisms of lubricant depletion. An important effect which has been studied in the laboratory and which is to some extent amenable to theory is the slow migration of thin oil films on a metallic surface in the presence of a thermal gradient. It has been observed that thin films of the order of 2 to 5 μm on a polished metal surface with a temperature gradient of 2 to 5°C/cm will migrate over distances of several centimeters in as little as 300 hours [1]. The effect is due to the effect of temperature on the surface tension of a fluid. The tendency is for the oil to move from the warmer to the colder part of the substrate.

Preliminary numerical studies of the one-dimensional motion of a thin oil film under a temperature gradient have been carried out and qualitatively verify the observed behavior of the film. An example plot of the thickness distribution of a thin oil film before and after the application of a temperature gradient is shown in Figure 3-1. There is room for significant refinement of the finite difference model used in this study in order to improve the stability, accuracy, and generality of the model. One goal is the derivation of a 2-dimensional finite element model that can be applied to arbitrary plane geometries with arbitrary temperature profiles.

The physical phenomenon is complicated both by the influence of the nature of the substrate on the cohesive force between it and the oil, and by the surface roughness and discontinuities. Transport by evaporation from warmer surfaces and recondensation on cooler surfaces in vacuum has been studied, but vapor phase transport is believed to be negligible for the type of low vapor pressure lubricants (e.g. Apiezon C) that are used in spacecraft [2].

Attempts have been made to provide a lubricant replenishment mechanism for spacecraft bearings. The replenishment mechanism typically takes the form of a porous nylon (Nylasint) block that is saturated with oil before launch. As the lubricant in the bearing is depleted, it has been expected that oil escaping from the reservoir would replenish it. This mechanism is not well understood, and there is even some evidence that in some cases these reservoirs may actually be detrimental since the reservoir may actually cause a reverse flow of the oil from the high surface finish metal back to the capillaries of the reservoir [2].

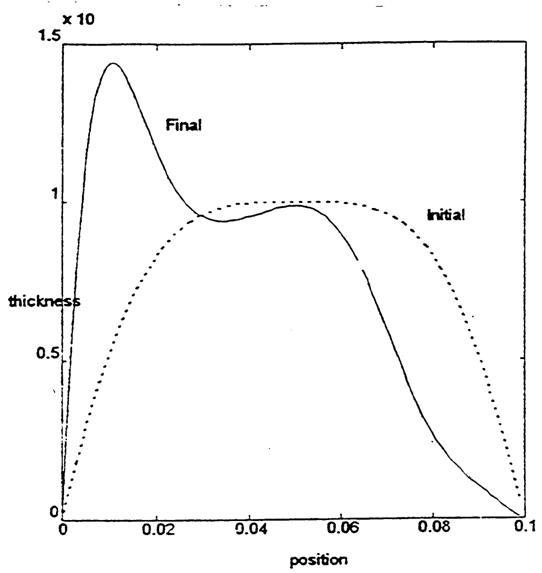

Figure 3-1.

Theory based on the Laplace-Kelvin equations for fluids with variable surface tension suggests that for very thin films (on the order of 2 to 5 μm), laboratory experiments with a plane, horizontal surface could duplicate the weightless condition encountered in space fairly closely. An apparatus has been constructed for preforming laboratory studies of thermal surface tension driven lubricant migration.

Experimental Apparatus

The experimental set-up consists of a cylindrical vacuum chamber, the top of which is a transparent window. A horizontal disk is suspended in the chamber just below the window, and a heater is attached to the center of the disk from below. The disk thickness is tailored to keep a nearly linear temperature gradient over most of the disk's surface. When an oil film is applied to the surface of the disk and the heater is turned on, the temperature gradient causes the oil to creep away from the center of the disk and form a bead around the edge of the disk. A qualitative description of the radial oil thickness distribution is obtained by illuminating the apparatus with ultraviolet light and observing the fluorescence of the oil, which is quite bright. Preliminary results demonstrate that the phenomenon can be easily demonstrated in the laboratory. Figures 3-2a and 3-2b are photographs of the fluorescing oil before the temperature gradient was applied and 12 hours after the heater was turned on. The motion of the oil is dramatic.

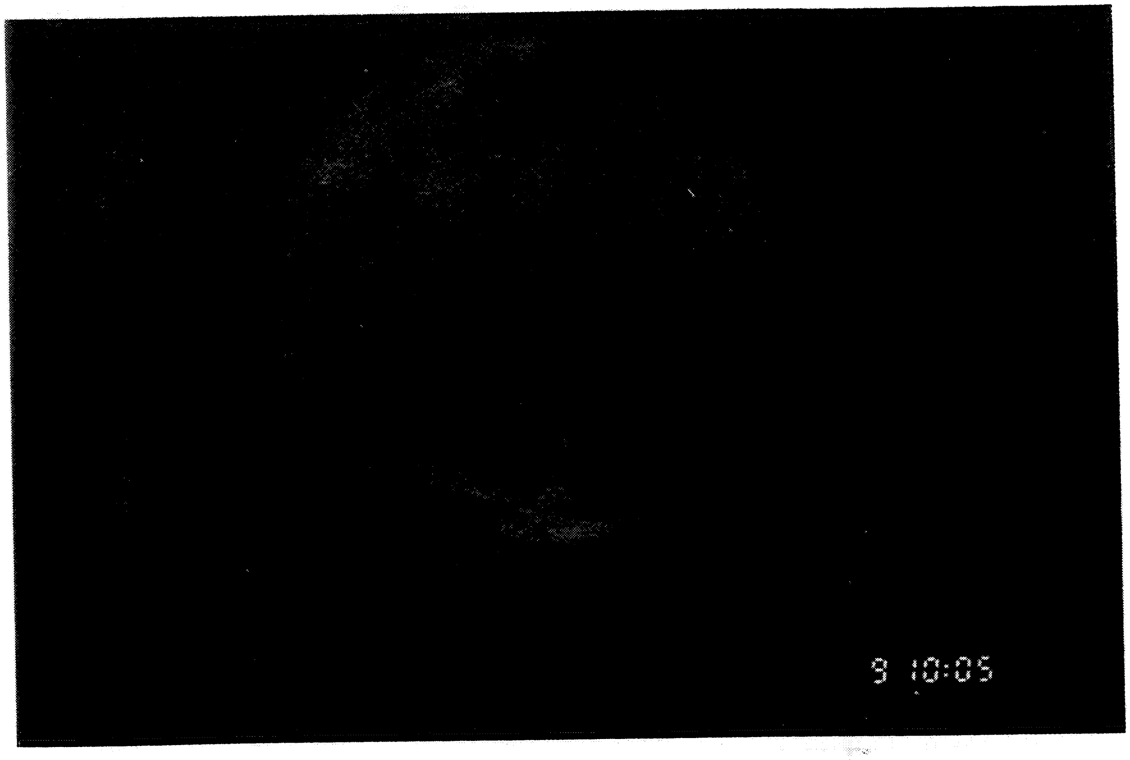

Figure 3-2.

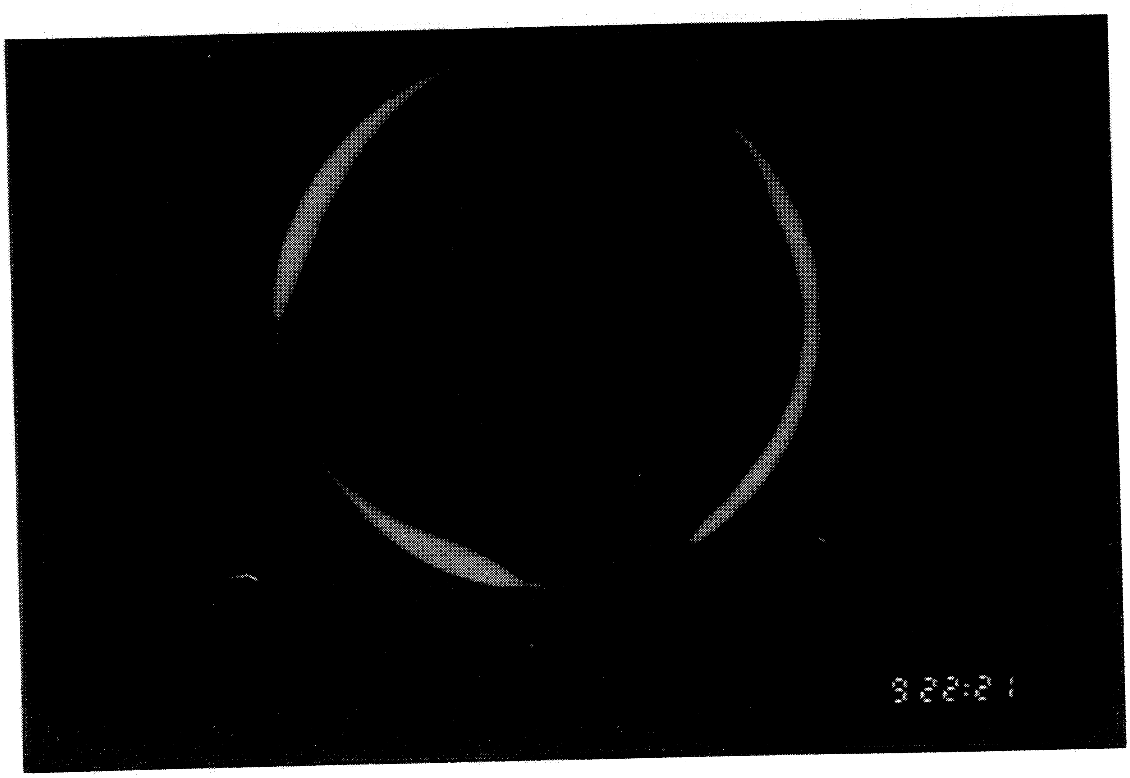

Figure 3-3.

Future Work

Several extensions to this work are planned in the future. The numerical prediction of the oil migration will be improved by developing a finite element formulation for solving the Laplace-Kelvin equations in both one and two dimensions. This will allow investigations on non-planar configurations, which cannot be accurately tested on earth due to gravity effects. The experimental work will be extended by quantitatively measuring the oil thickness profile, either by scanning the film with an ultraviolet laser and recording the intensity of the fluirescence, or by using a quartz micro-balance to physically measure the thickness of the film. The effects of discontinuities (i.e. steps) in the surface and the presence of porous lubricant reservoirs will be investigated.

[1] Fote, A.A., Slade, R.A., and Feuerstein, S., "Thermally Induced Migration of Hydrocarbon Oil," *Trans. ASME*, Vol. 99, No. 2, pp. 158-162, 1977.

[2] Dormant, L.M. and Feuerstein, S., "Lubricant Reservoir Systems: Thermal Considerations," *Journal of Spacecraft and Rockets*, Vol. 13, No. 12, pp. 755-757, 1976.