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## POSITIVE COMMANDABLE OILER FOR SATELLITE BEARING LUBRICATION

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### ABSTRACT

The results of a feasibility study show that on-orbit commandable lubrication of ball bearings can be accomplished by direct oil application to the moving ball surfaces. Test results for the lubricant applicator portion of the system are presented in conjunction with a design approach for the reservoir and metering components.

### INTRODUCTION

Oil lubricated ball bearings are key elements in satellite rotary systems. Reaction wheels, scanning devices, and communication satellite despin mechanical assemblies are examples where long life and uniform low torque performance are dependent on rolling element bearings.

Maintenance of a thin, clean, and uniform lubricant film at and near the bearing EHD ball-to-race contact zones and ball-to-retainer pocket interfaces is essential to performance. Lubricant for this purpose can be provided by passive means during the design life as long as on-orbit conditions do not vary from the design predictions. Thus oil loss from the bearing cavity by surface creep and molecular flow can be balanced by the same phenomena using porous retainers and reservoir sources. Experience indicates that this passive equilibrium can be maintained for at least five years to provide a reliable film thickness (references 1 and 2).

For longer life requirements, it becomes increasingly desirable to have available a commandable oiler to replenish the lubricant when necessary. Positive control of the lubricant quantity can provide a safeguard against premature depletion and avoid the ensuing bearing degradation.

A basic design constraint in active oiling is to deliver all of the lubricant in a small metered charge uniformly to the ball pockets and to the contact zones of both inner and outer races. These regions are not easily accessed. Preferably, the relubrication should be done slowly by a device which is compatible with unmodified bearings and does not introduce contamination.

In a recently reported oiler for space applications, the lubricant charge is ejected onto one raceway by a single stroke pump immersed in a vented oil reservoir (reference 2). The present system uses an entirely different approach. Here the reservoir is sealed to prevent contamination and the lubricant is

applied slowly and evenly to reduce torque transients and assure uniform distribution.

The oiling technique described below slowly transfers a metered quantity of lubricant upon command directly to the bearing balls by means of a pressure-fed applicator. The applicator design is important and will be discussed in detail. Several reservoir/metering system approaches can be used for applicator feed, one of which is outlined to indicate feasibility.

## SYSTEM DESCRIPTION

### Operation

The oiler is designed for high surface energy oil such as Apiezon C. The high surface energy of hydrocarbon oils provides the stabilizing force for the lubricant droplet on the applicator tip. The system is best suited for large bearings where there is sufficient space between the retainer dynamic envelope and raceway to accept the applicator.

Figure 1 illustrates the applicator location with respect to the bearing and includes a representative reservoir/metering system.

The degassed lubricant supply is stored in a flexible metal bellows. Pressure is maintained by an external spring pack. Opening the release valve permits oil to inflate an adjustable-stroke metering bellows. Subsequent closing of the valve and opening of the metering valve starts the flow to the applicator. Metering pressure is sufficient to overcome the characteristic back pressure of the applicator and to provide the desired flow rate. A metering orifice provides a flow rate adjustment capability.

The applicator is supported rigidly in the space between the outer race and inner race guided retainer. In a 110 mm bore bearing with 1/2 inch ball diameters, the space is approximately .15 inches wide. A standoff distance separates the applicator tip from the ball path, typically by five times the expected launch-induced axial ball movement. A combination of toroidal tip shape and Teflon coating enables the applicator to support an oil droplet which spans the standoff distance. In the operating bearing, the passing balls wipe off a portion of the distended hemispherical droplet. In this manner, oil is slowly and uniformly transferred from the balls to the retainer ball pockets and both raceways. The droplet is continuously replenished by flow from the metering system during the 2-4 minute relubrication cycle.

### Applicator Design

Figure 2 indicates the dimensions of the breadboard applicator. A 0.032 inch diameter steel tube supports a .07 inch Teflon toroid. The toroid was lathe-turned, using a form tool, and polished to reduce surface roughness.

A family of stable droplets at equilibrium with a downward gravity field is shown in Figure 3. Surface adhesion bonds the oil to the Teflon while the metering pressure maintains a balance against the oil surface tension. The resulting hemispherical droplet exhibits a characteristic surface contact angle with the Teflon toroid. This combines with the toroid shape to center the droplet on the toroidal axis. The centering force is appreciable and is effective over a wide range of droplet sizes and external forces.

Droplets larger than shown in Figure 3.4 flow back onto the outside of the applicator shank, and are drained to the outer raceway. The back of the toroid separates the overflow oil from the new droplet at the orifice. This important separation effect prevents a short circuit between the distended droplet and applicator shank. In practice, the droplet will only overflow if the bearing is not moving during delivery, or if the metering rate exceeds the design margin.

Figure 4 illustrates the droplet centering and stabilizing effect. Consider a centered droplet (A) to be laterally displaced to the right on the toroid without changing the droplet shape (B). The resulting contact angle  $\theta'$  on the left is larger than the characteristic or minimum energy angle ( $52.5^\circ$  for Apiezon C on polished Teflon). Similarly, the angle  $\theta''$  on the right is less than  $52.5^\circ$ . If the angles are corrected by changing the droplet shape (C), the oil surface curvature on the right will be greater than that on the left. Since the curvature is balanced by internal fluid pressure, a pressure gradient will form which tends to move the droplet back to a centered position. In the presence of a body force such as gravity, the displaced position is stable when the restoring pressure gradient balances the externally applied force.

It is interesting to note that this geometry was discovered while evaluating the failure of a previous applicator design. The first applicator was based on a "barrier" approach where the droplet was intended to be contained on a flat steel tube end by a surrounding barrier surface provided by a Teflon sleeve. By equating energies, it was shown that the droplet should grow in place on the iron. In reality, the oil easily flowed past the iron/Teflon barrier and accumulated on the sleeve end, held there by the slightly rounded outer Teflon edge. Microscopic examination showed that the iron/Teflon interface was minutely rough and irregular. This roughness was probably reducing the oil/Teflon surface energy difference and destroying the barrier effect for bulk oil. (See Reference 3 for a description of surface energy principles.) The present toroidal design does not rely on a metastable barrier.

#### Applicator Tests

The test apparatus shown in Figure 5 rotates a preloaded pair of 110 mm bore 440-C bearings which have 23 half-inch diameter balls per bearing and inner race riding phenolic retainers. A variable speed motor drives the inner races. Speed is monitored by an interrupter and electronic counter. A strobe light and stereo microscope, not shown, facilitate viewing the oil transfer process. The applicator location is shown in Figure 6.

Tests were conducted to determine oil transfer properties and droplet stability for a wide range of speed, flow rates, standoff distances, and gravity orientations.

It was found that for a given bearing speed and standoff distance, there was an upper limit to permissible flow rate. This occurred when the applicator was worst-case oriented (horizontal) with respect to gravity. Beyond the flow rate limit, the droplet would exceed its maximum stable .05 inch standoff size between ball passings. At 60 rpm, the flow rate limit occurred at approximately four times the normal operating rate of .1 cc in 2 minutes. For a standoff distance of 0.02 inches, the applicator functioned properly for the speed range 60-700 rpm for various flow rates between 0.1 cc in 30 seconds to 10 minutes.

Oil is transferred without loss or splatter. During contact with the ball, a portion of the applicator droplet bonds to the ball surface, Figure 7. Separation of the ball and droplet carries a portion of the oil away on the ball and the remainder re-forms in a hemisphere on the applicator. The centering force of the applicator toroid stabilizes the droplet against the viscous ball shearing force. Oil on the ball surface is transferred to the retainer ball pockets, and from there to both raceways. Examination of ball-to-ball surface oil transfer patterns indicated that the lubrication was uniform.

A temperature sensitivity test was made using a heated ball and an inclined V-groove. The equivalent speed range tested was 0-420 rpm. Since the surface energy of hot oil is less than that on the cooler applicator droplet, the droplet might not have wetted and bonded to the ball surface. However, the transfer occurred properly for a 70°F-200°F ball rolled past the delivery head, thus indicating that the necessary wetting will occur for a broad range of bearing and reservoir temperatures.

## CONCLUSIONS

The droplet transfer system was shown to be a viable approach to positive commandable oiling.

## REFERENCES

1. Jacobson, P. E., "Long Life Ball Bearing Suspension System, A Present Possibility," AIAA Guidance and Flight Control, San Diego, Calif., August 1976.
2. Glassow, Frank A., "Assurance of Lubricant Supply in Wet-Lubricated Space Bearings," 10th Aerospace Mechanisms Symposium, 1976. JPL Tech. Memorandum 33-777, pp. 90-103.
3. Contact Angle, Wettability, and Adhesion. Advances in Chemistry Series, Vol. 43, American Chemical Society, 1964.

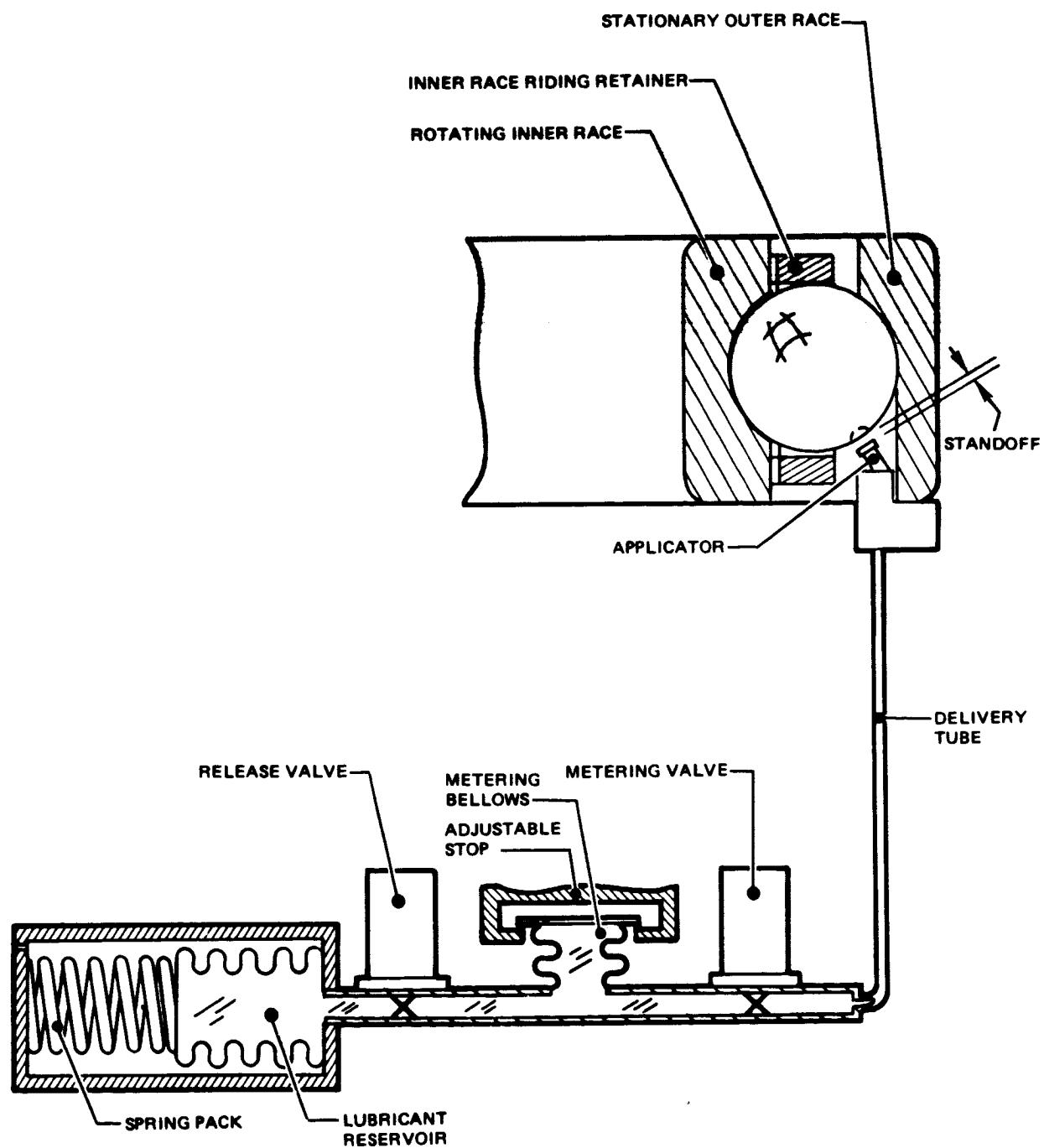


FIGURE 1. Oiling System Diagram

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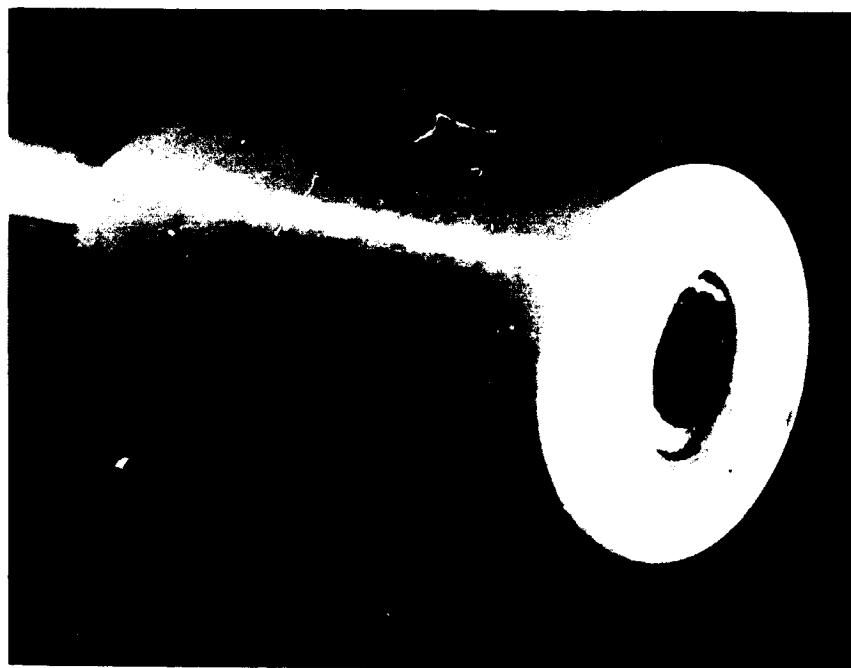
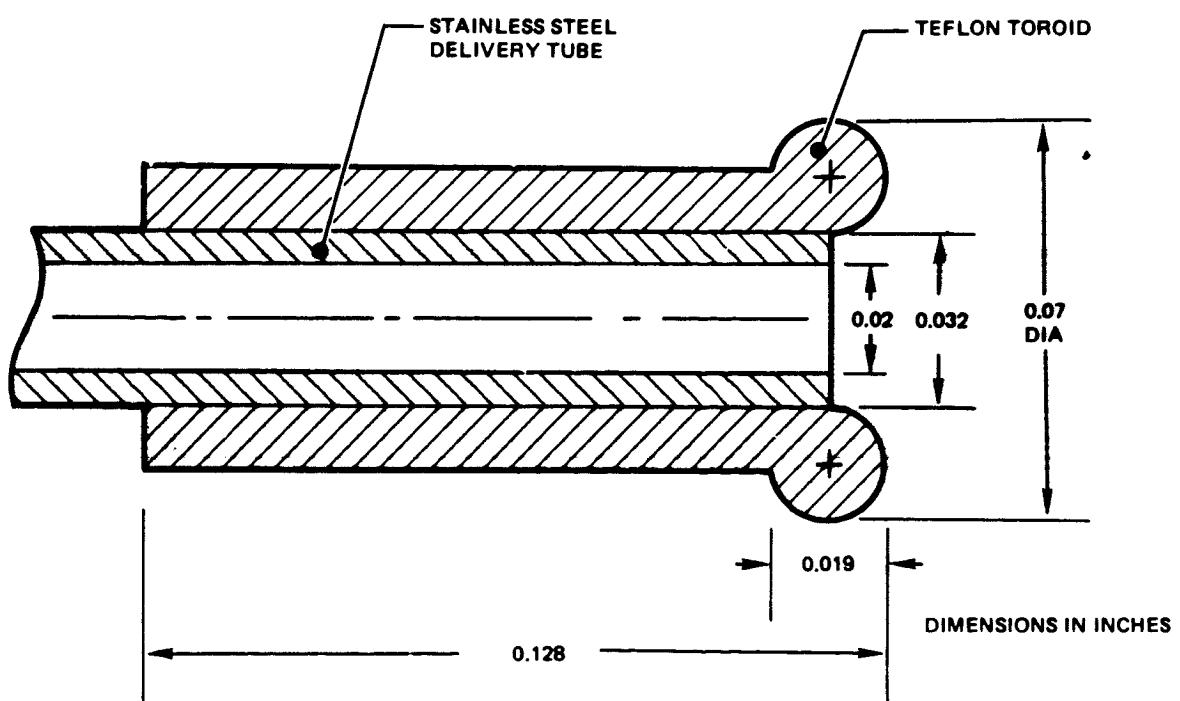


FIGURE 2. Breadboard Applicator Dimensions

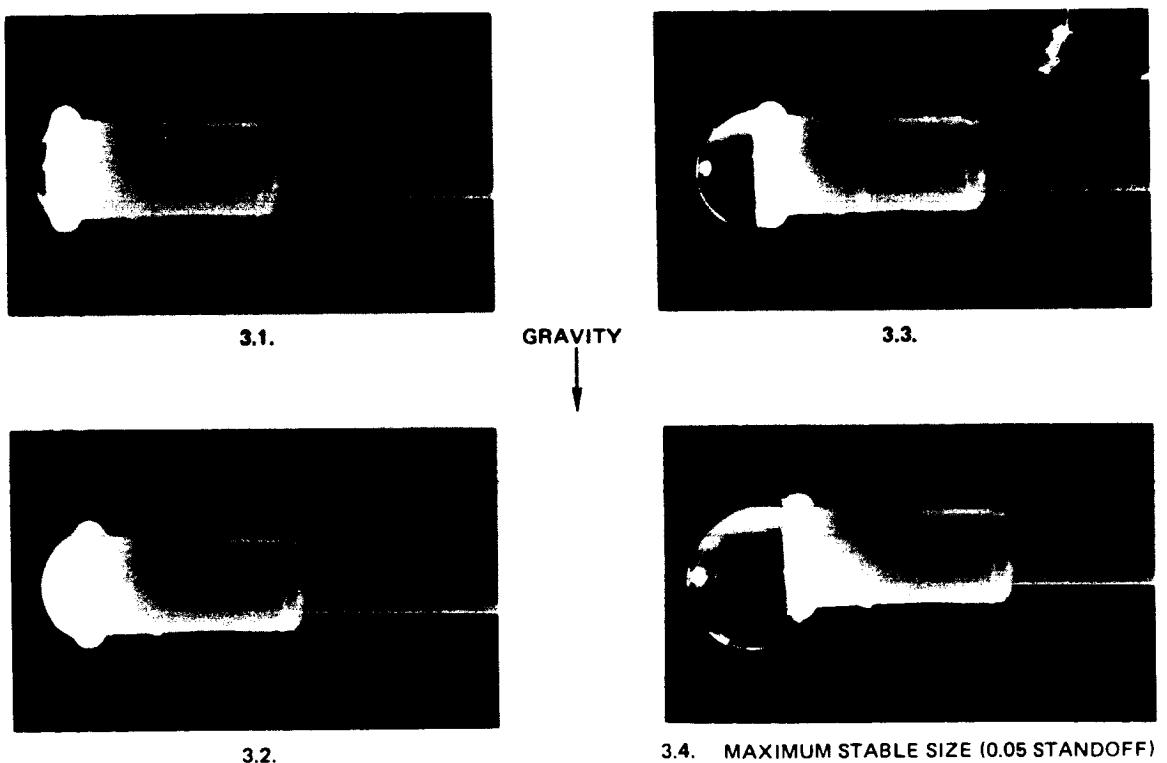


FIGURE 3. Stable Oil Droplets at Equilibrium

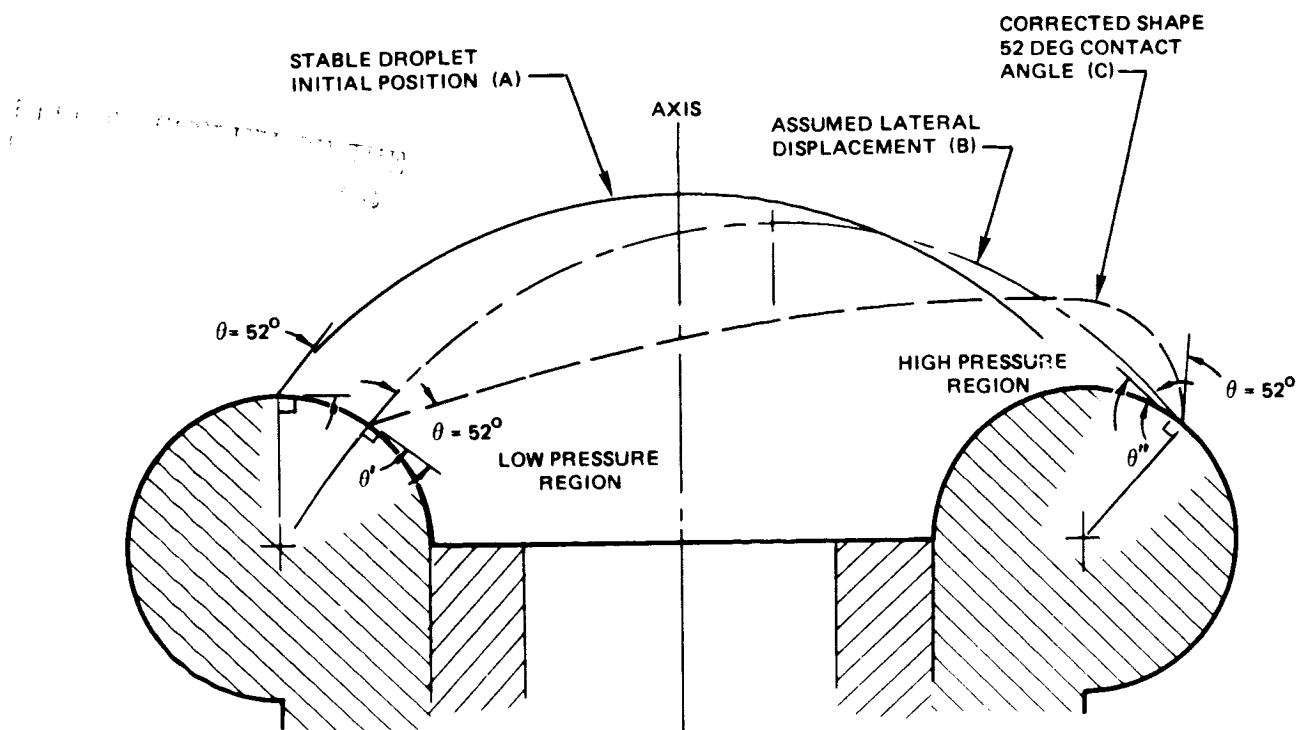


FIGURE 4. Oil Droplet Lateral Stability

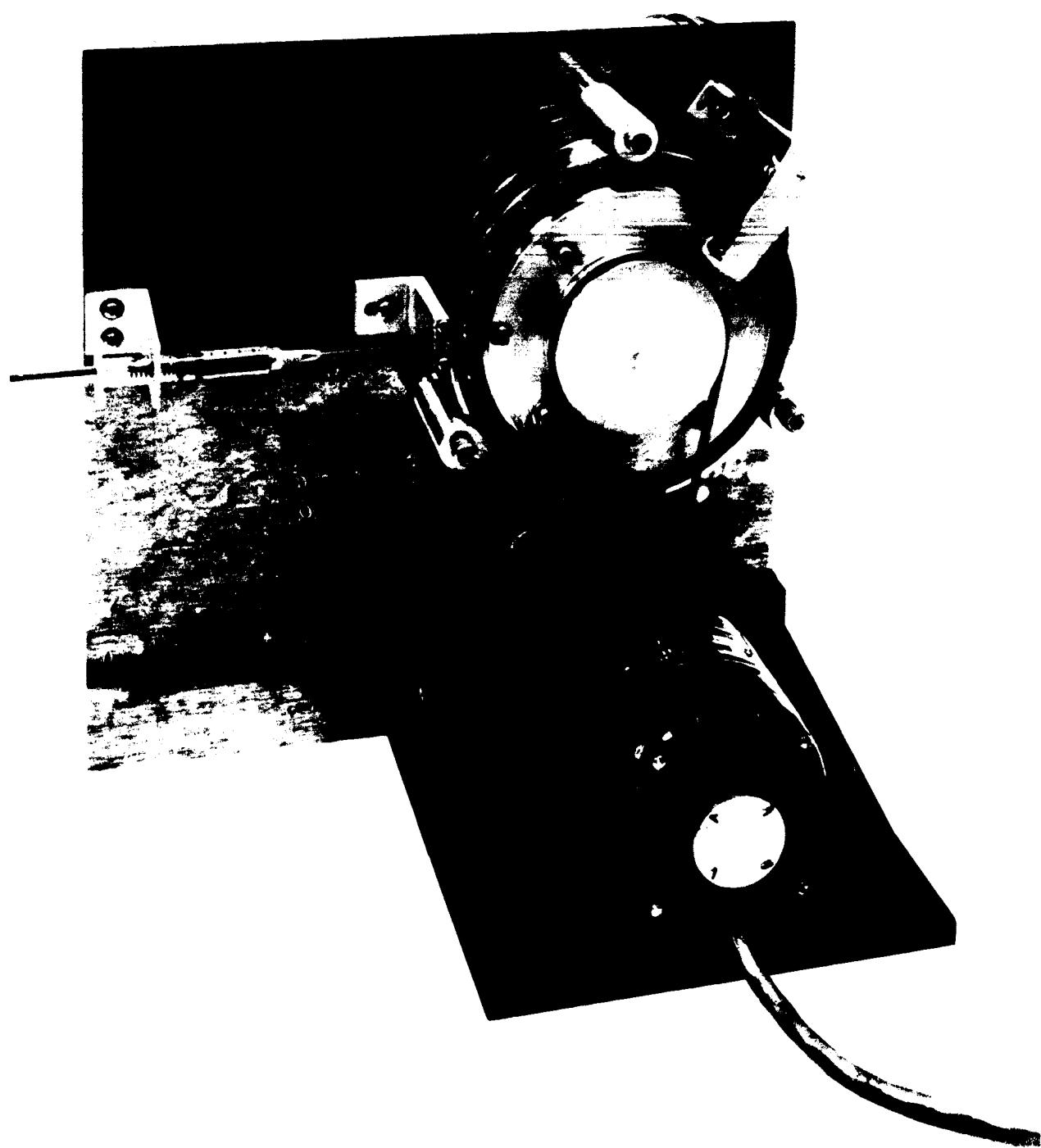


FIGURE 5. Bearing Spindle Drive Test Setup



FIGURE 6. Breadboard Oil Applicator Location

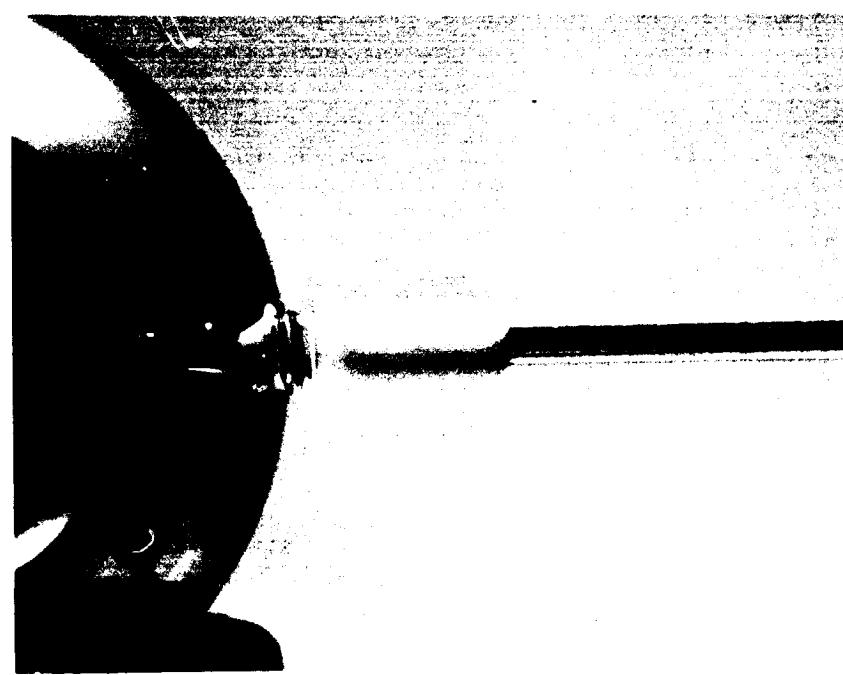


FIGURE 7. Oil Droplet Transfer to a Stationary Ball

## AN EXTENDIBLE-HIGH STIFFNESS SOLAR ARRAY

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### ABSTRACT

The requirements for an array, 20 ft<sup>2</sup> in area, a natural frequency of approximately 3.5 Hz, started a development program at LMSC which would last three years from conceptual trade studies to the final qualification tests. The array wing is designed as a two panel add-on to the aft equipment rack of an Agena spacecraft. After release and deployment, a means of stiffening the panels was necessary. A hinge development program was initiated and conducted which resulted in selection of a 4 bar link locking hinge capable of transferring sufficient panel-to-panel stiffness to meet the natural frequency requirement. One significant feature of this array is that the panels are randomly deployed with no rate control, but only a balance between spring power and friction with sufficient energy and structural margins for deployment.

A mobile fixture was developed for zero-g simulated testing of the solar array wing. Deployment tests and natural frequency tests were conducted with satisfactory results (Figure 1).

As the spacecraft was developed, it was necessary to increase the stiffness and/or damping of the solar array wing from 0.5 percent at 3.5 Hz to 0.5 percent at 30 Hz or an increase in damping with a corresponding lower natural frequency. Three methods were considered: (1) Struts, (2) Tethers and (3) Squeeze Film damping. Struts seemed difficult to implement into the system, therefore, a tether system was pursued. After design, fabrication, and test of development hardware, modifications to the system were required which made this design very sensitive and difficult to practically control the damping characteristics.

The squeeze film damping hardware was designed, fabricated and tested in parallel with the tether system but appeared to require a comprehensive and long term test program to assure its satisfactory operation.

Another look at integrating struts into the array wing resulted in time delayed struts consisting of cables passing through close fitting tubular segments. Once the wing was deployed the cables were tensioned by viscous dampened spring actuators which aligned and compressed the tubular segments into stiffened struts. With the wing deployed, one end of the struts is fixed to the center of the outboard panel while the other is attached to the actuators which are dynamically isolated from the support frame with silicone rubber pads.

The array wing with the struts was successfully deployed in both air and vacuum for as many as 50 deployments on a single unit. The stowed wing has also successfully completed flight qualification testing.

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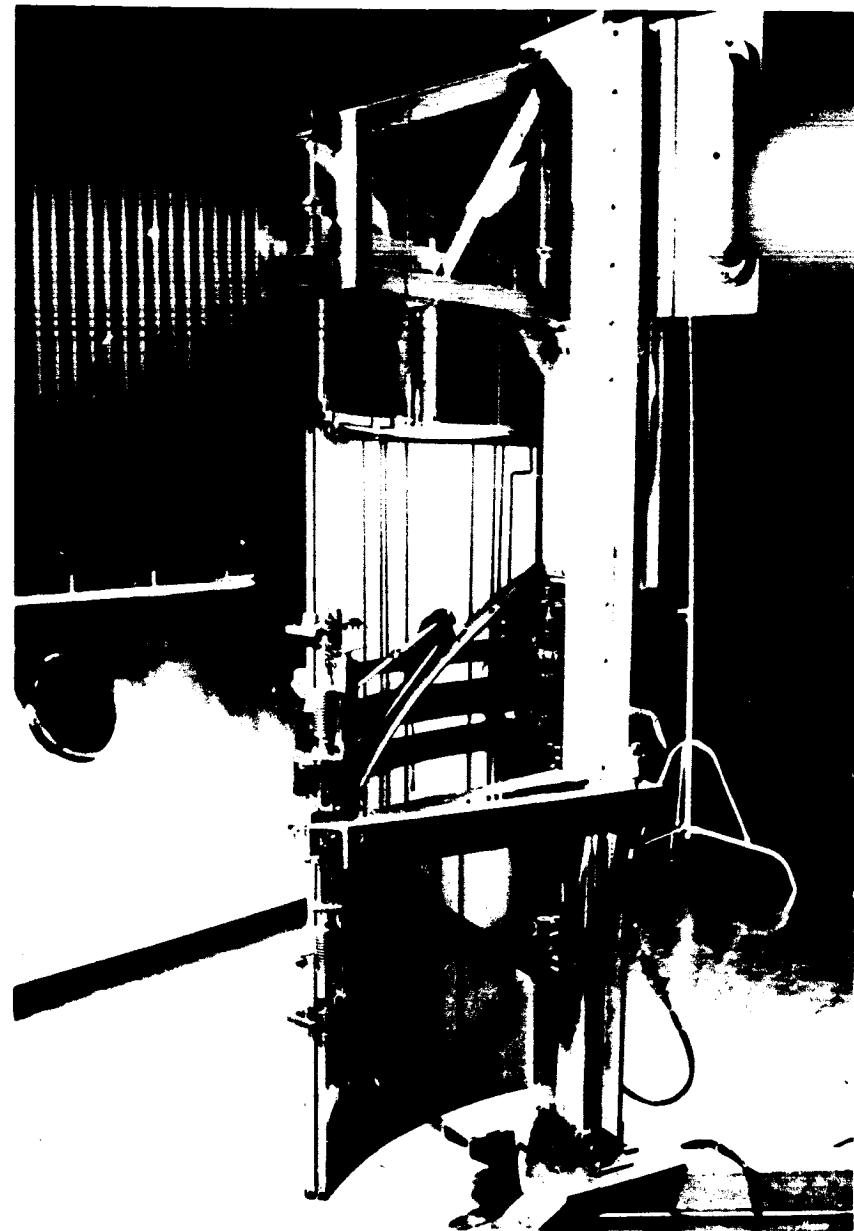


Figure 1. Stowed Solar Array Module in Ground Deployment Fixture

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