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NASA TN D-1577

N63-11618
Code 1

NASA TN D-1577

TECHNICAL NOTE

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EFFECT OF THE ACCELERATION DISTURBANCES ENCOUNTERED IN THE MA-7 SPACECRAFT ON THE LIQUID-VAPOR INTERFACE IN A BAFFLED TANK DURING WEIGHTLESSNESS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON January 1963

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EFFECT OF THE ACCELERATION DISTURBANCES ENCOUNTERED IN THE MA-7 SPACECRAFT ON THE LIQUID-VAPOR INTERFACE IN A BAFFLED TANK DURING WEIGHTLESSNESS

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SUMMARY

As a part of the overall study of the problems associated with the behavior of stored propellants in space vehicle tanks during periods of weightlessness, a study was conducted on the effect of the acceleration disturbances encountered in the MA-7 spacecraft on the liquid-vapor interface in a baffled tank.

The zero-gravity steady-state configuration of the liquid-vapor interface observed in the MA-7 test is identical to that observed in previous drop-tower studies and was found to be independent of any initial angular misalinement of the baffle axis with the gravity or thrust vector. The steady-state configuration is one in which the baffle is completely full, and the remaining liquid is uniformly distributed at the base of the baffle.

The acceleration disturbances imposed upon the experimental tank during orientation maneuvers in orbit had no effect on the liquid-vapor interface configuration. Control of the liquid-vapor interface was lost by the surface-tension baffle as the spacecraft passed through 0.30 g during reentry into the Earth's atmosphere.

INTRODUCTION

The effect of weightlessness on the behavior of stored propellants in space-vehicle tanks during coasting periods is currently being investigated by the NASA Lewis Research Center. The behavior of typical wetting and nonwetting liquids in spherical glass tanks has been studied in a drop-tower zero-gravity facility, and the results are presented in reference 1. The results of this investigation indicate that for wetting liquids, which are typical of most common propellants, the location of the spherical liquid-vapor interface in spherical tanks is random because the liquid completely wets the walls of the tank and the vapor bubble is randomly located within the liquid. The effect of internal tank baffling on the position control of the liquid-vapor interface is presented in reference 2. The results of this investigation indicate that the liquid-vapor interface can be positioned in a predictable configuration in the tank by placing a cylindrical surface-tension baffle on the spherical centerline. These two experimental investigations were conducted in a 2.3-second drop tower by procedures that ensured extremely quiescent initial conditions and a gravity level below 10^{-5} g.

In applying the results of references 1 and 2 to the design of tankage for future space vehicles, the effect of acceleration disturbances on the ability of surface-tension baffling to maintain control of the liquid-vapor interface or, in the face of large disturbing forces, to regain control of the interface is still an unknown. Unfortunately, ground-based zero-gravity facilities are so limited in time that experimental data on the effect of acceleration disturbances are extremely difficult to obtain because most disturbances are virtually impossible to simulate. Therefore, in order to investigate this phenomenon, an experimental tank with an internal surface-tension baffle was designed for installation in the MA-7 Mercury spacecraft.

The purpose of this investigation was to study the long-term steady-state configuration of the liquid-vapor interface in the experimental tank and to determine (1) the ability of the surface-tension baffle to control the liquid-vapor interface during spacecraft orientation maneuvers in orbit and (2) the acceleration level at which interface control is lost during spacecraft reentry.

APPARATUS

The experimental tank consisted of a 300-milliliter glass sphere with a cylindrical glass surface-tension baffle fused at one end to the inside surface of the sphere. The baffle extended nominally 0.6 of the sphere diameter into the spherical tank. Three holes were located at the base of the baffle to provide flow passages between the tank and the inside of the baffle. The glass tank was mounted between an aluminum hemisphere and a Lucite hemisphere suitably flanged and hermetically sealed at ambient conditions. The inside of the aluminum hemisphere was painted white to serve as a light reflector. A schematic diagram of the glass tank showing pertinent dimensions is presented in figure 1. A photograph showing all components of the experiment is presented in figure 2.

The experimental tank assembly was mounted in the MA-7 spacecraft slightly above and to the right of the astronaut's head and suitably oriented for good lighting and photography. The location of the experiment with respect to the spacecraft axes is shown in figure 3. Photographic data were obtained throughout the flight with the pilot observer camera. This camera, mounted in the instrument panel, simultaneously photographed the astronaut, the experiment, and a clock that was used to correlate the liquid behavior with spacecraft maneuvers.

The test liquid used in this experimental investigation (as a spacecraft compatibility requirement) was distilled water, and the ullage was essentially air. The distilled water was modified with additives to reduce its surface tension so as to ensure the compatibility of these test results with the results obtained in the drop tower with ethyl alcohol. A detailed description of the test liquid is given in the appendix.

EXPERIMENTAL PROCEDURES

MA-7 Disturbance Spectrum

Acceleration disturbances during orbit. - During the orbital period of the flight of MA-7, the only significant acceleration disturbances imparted to the experimental tank resulted from spacecraft orientation maneuvers. These maneuvers were accomplished by the activation of the hydrogen peroxide orientation control thrusters. To accomplish pitch and yaw maneuvers 1- or 24-pound thrusters can be used, and for roll maneuvers 1- or 6-pound thrusters are available. Short-term activation of the 24-pound thrusters in pitch and yaw directions resulted in tangential acceleration disturbances on the experiment of 0.011 and 0.005 g, respectively. The 6-pound roll thruster imparted 0.003 g of acceleration disturbance on the experiment.

Acceleration disturbance during reentry. - After the retrorockets have fired and the liquid has again assumed its zero-gravity steady-state configuration, a gradual buildup of gravity forces will occur as a result of the spacecraft entering the Earth's atmosphere. During this period, the experiment will be subjected to an increasing acceleration disturbance along an axis nearly perpendicular (70°) to the centerline of the surface-tension baffle. The magnitude of this acceleration disturbance increases from essentially zero to several g's during peak spacecraft deceleration. A postflight analysis of radar tracking data during reentry was made, and the results are presented in figure 4.

Preliminary Drop-Tower Studies

The tank geometry used in this investigation was based on the results of the experimental study presented in reference 2. These results indicated that a cylindrical surface-tension baffle was effective in locating the liquid-vapor interface. Although it is recognized that other geometries may also be suitable, the cylindrical baffle is a simple geometry that illustrates the principles involved. For the MA-7 test, the relative height of the baffle was reduced as compared with that used in the investigation of reference 2 to avoid some of the difficulties encountered with the high standpipe (ref. 2). The amount of liquid (20 percent of the total tank volume) was chosen so that, when the baffle was full of liquid, the liquid remaining in the tank proper would not obscure the action of the liquid in the baffle during the acceleration disturbances.

Because of the orientation of the surface-tension baffle with respect to the thrust axis (see fig. 3), a preliminary experimental study was conducted in the NASA Lewis 100-foot drop tower to determine the steady-state configuration of the liquid-vapor interface when the major axis of the baffle was misalined with the gravity vector (thrust axis) before entering weightlessness. The study was conducted by using a scale model of the MA-7 experimental tank that was designed for compatability with the time limitation imposed by the drop tower. The model was a 100-milliliter glass tank with a baffle of the same relative dimensions as used in the MA-7 test. The photographic results of the investigation are presented in figure 5. These photographs from the motion pictures taken during the test drops present the zero-gravity steady-state configuration of the liquid-vapor interface for mounting angles of 0° (axis of baffle parallel to gravity vector), 45°, 75°, and 90°. It should be noted that at 90° the axis of the baffle is perpendicular to the gravity vector and that the baffle was not in contact with the liquid prior to entering zero gravity. The results of these tests indicate that the zero-gravity steady-state configuration of the liquid-vapor interface is identical for large initial angular misalinement of the axis of the surface-tension baffle with the gravity vector or thrust axis.

MA-7 RESULTS

The photographs were, as mentioned previously, obtained by the use of the pilot observer camera. Selected frames from the motion-picture film at relevant times during the flight are presented in figure 6. The zero-gravity experiment is seen in the upper left corner of each photograph, and the clock is visible in the upper right corner. It should be mentioned that the motion-picture film was damaged by salt water; however, the quality is satisfactory for analysis of the liquid behavior. As an aid to the reader, a small schematic diagram showing the location of the liquid-vapor interface is presented with each photograph.

Table I lists times and events pertinent to the zero-gravity experiment. It should be noted that no photographic data could be obtained during the periods of darkness during the flight.

DISCUSSION OF RESULTS

Steady-State Configuration

The steady-state configuration of the liquid-vapor interface observed in the experimental tank in the MA-7 spacecraft remained unchanged during the entire flight and was identical to that observed in the preliminary drop-tower tests (compare figs. 5 and 6). The configuration is one in which the baffle is completely full and the remaining liquid is uniformly distributed at the base of the baffle. Hence, it can be concluded that, although drop towers yield relatively short periods of weightlessness, the time is sufficient for determining the steady-state liquid configuration in model tanks.

Time Response

The time required for the liquid transition from the thrust configuration to the zero-gravity configuration was of the order of 12 seconds both at initial entry into zero gravity and after retrofire (see table I). This period of time is longer than that observed in the models studied in the drop tower (ref. 2) and is attributed to the fact that the tank was larger and the holes at the base of the surface-tension baffle were comparatively smaller and limited the flow.

Effect of Acceleration Disturbances

Disturbances during orbit. - At no time during the orbital flight of the MA-7 spacecraft did the acceleration disturbances, arising from orientation maneuvers, significantly affect the liquid-vapor interface configuration. From 0:05:26, when the surface-tension baffle filled with liquid, until 4:33:09, when the retrorockets were fired, the baffle remained full and the base of the baffle, where a pump inlet might be located, was covered with liquid. The only effect of the orientation maneuvers was an occasional slosh of the liquid outside the base of the standpipe during pitch maneuvers, which apply the largest disturbance on the experiment (0.011 g).

Disturbances during reentry. - As would be expected, the firing of the retrorockets caused the liquid to leave the surface-tension baffle. Upon reentering zero gravity at 4:33:39 the liquid again assumed the steady-state configuration. The liquid remained in that configuration until 4:45:53, when the gravity forces caused by the spacecraft entering the Earth's atmosphere became large enough to overcome the surface-tension forces and caused the liquid to spill from the baffle. Analysis of radar tracking data indicates that the acceleration level at this time was 0.30 g (see fig. 4).

SUMMARY OF RESULTS

An experimental study during weightlessness of the effect of the acceleration disturbances encountered in the MA-7 spacecraft on the liquid-vapor interface in a baffled tank yielded the following results:

1. The zero-gravity steady-state configuration of the liquid-vapor interface observed in the MA-7 test remained unchanged during the entire flight and was identical to that observed in drop-tower studies.

2. The liquid-vapor interface configuration was not affected by the level of the accelerations imposed by the spacecraft orientation maneuvers during orbit.

3. The surface-tension baffle lost control of the liquid-vapor interface as the spacecraft passed through 0.30 g during reentry.

4. From the preliminary drop-tower studies it was found that the zero-gravity steady-state configuration of the liquid-vapor interface is identical for initial angular misalinements of the axis of the surface-tension baffle with the gravity vector or thrust axis.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, September 21, 1962

APPENDIX - COMPOSITION OF TEST LIQUID

A sample of liquid was prepared for use in the experimental tank of the MA-7 zero-gravity experiment by adding various amounts of the following solutions to 1000 milliliters of distilled water:

(1) A dark solution of green dye was made by dissolving 0.1347 gram of green dye in 100 milliliters of distilled water (20 ml added).

(2) A dark solution of yellow dye was made by dissolving 0.1444 gram of yellow dye in 100 milliliters of distilled water (20 ml added).

(3) A supersaturated aerosol solution of 30 grams of aerosol dissolved in 70 milliliters of ethyl alcohol was made to serve as a surface-tension reducer (2 ml added).

(4) A suspension of 1.70 grams of silicone dispersed in 20 milliliters of distilled water was made to depress foaming (1 ml added).

The surface tension of the distilled water after addition of the above solutions was reduced to 34.0 dynes per centimeter, and the density of the water was essentially unchanged.

REFERENCES

1. Petrash, Donald A., Zappa, Robert F., and Otto, Edward W.: Experimental Study of the Effects of Weightlessness on the Configuration of Mercury and Alcohol in Spherical Tanks. NASA TN D-1197, 1962.

2. Petrash, Donald A., Nelson, Thomas M., and Otto, Edward W.: A Study of the Effect of Surface Energy on the Liquid-Vapor Interface Configuration During Weightlessness. NASA TN D-1582, 1962.

TABLE I. - SEQUENCE OF EVENTS DURING MA-7 FLIGHT

Flight time, hr:min:sec	Clock time, hr:min:sec	Event	Liquid configuration
0:00:00	12:45:17	Lift-off	Liquid in pool at 70° to baffle axis
0:05:14	12:50:31	Enter zero gravity	Liquid begins to assume steady-state configuration
0:05:26	12:50:43		Steady-state configuration attained; surface-tension baffle full of liquid
0:45	1:30	Begin darkness	Configuration unchanged
1:25	2:10	Begin daylight	Configuration unchanged
2:20	3:05	Begin darkness	Configuration unchanged
2:50	3:35	Begin daylight	Configuration unchanged
3:20	4:05	Astronaut observes experiment	Configuration unchanged
3:50	4:35	Begin darkness	Configuration unchanged
4:22	5:07	Begin daylight	Configuration unchanged
4:33:09	5:18:26	Retrofire	Liquid leaves baffle and collects in a pool at 70° to the baffle axis
4:33:39	5:18:56	Reenter zero gravity	Liquid begins to assume steady-state configuration
4:33:51	5:19:08		Steady-state configuration attained
4:44:44	5:30:01	Spacecraft passes through 0.05 g	Configuration unchanged
4:45:53	5:31:10	Spacecraft passes through 0.30 g	Liquid-vapor interface control is lost; liquid leaves surface-tension baffle

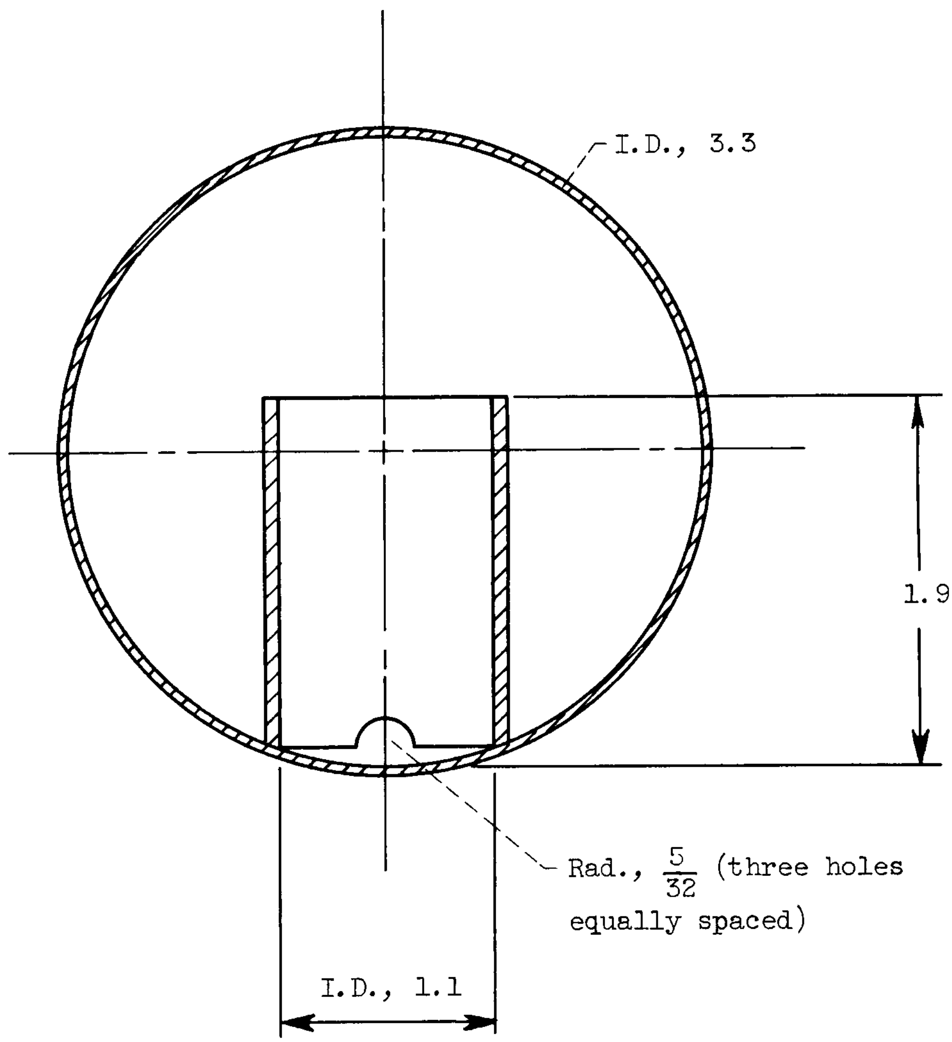
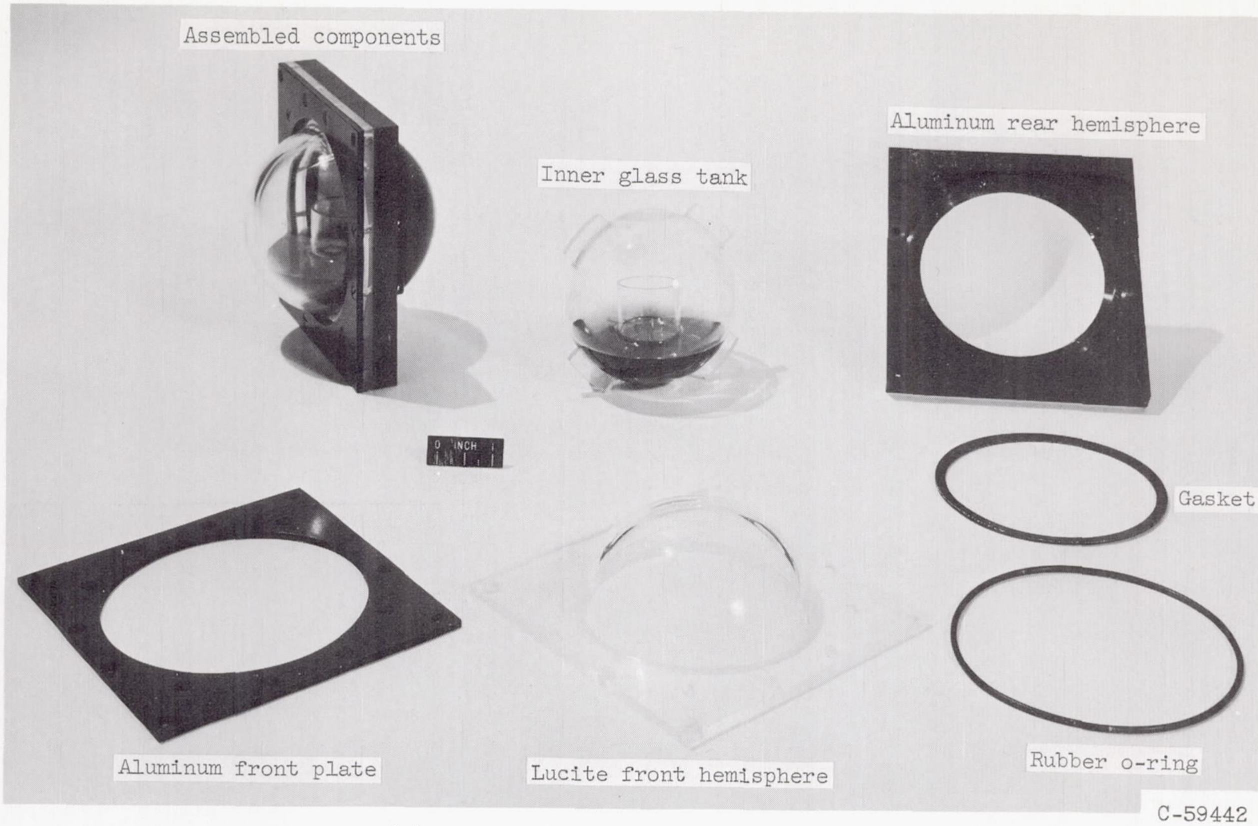
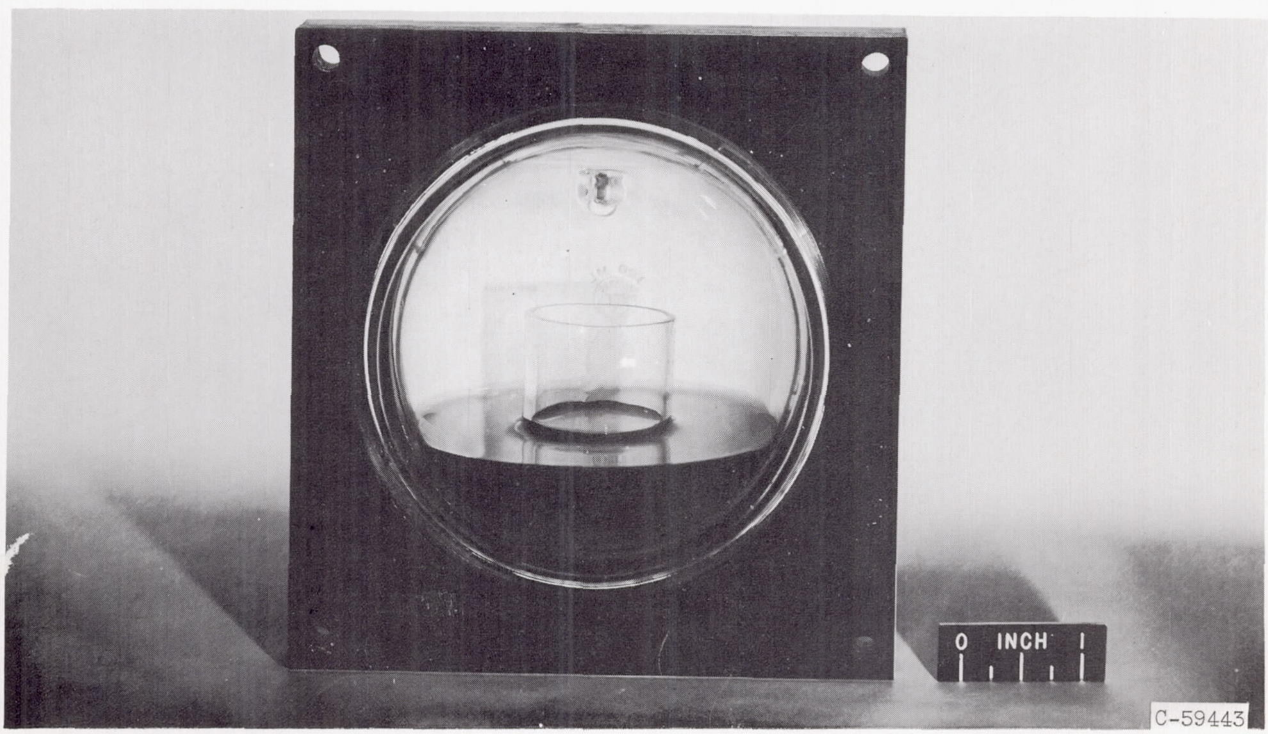


Figure 1. - Schematic diagram of experimental glass tank. (Dimensions in inches.)



(a) Components of experimental tank.



(b) Complete assembly.

Figure 2. - Experimental apparatus.

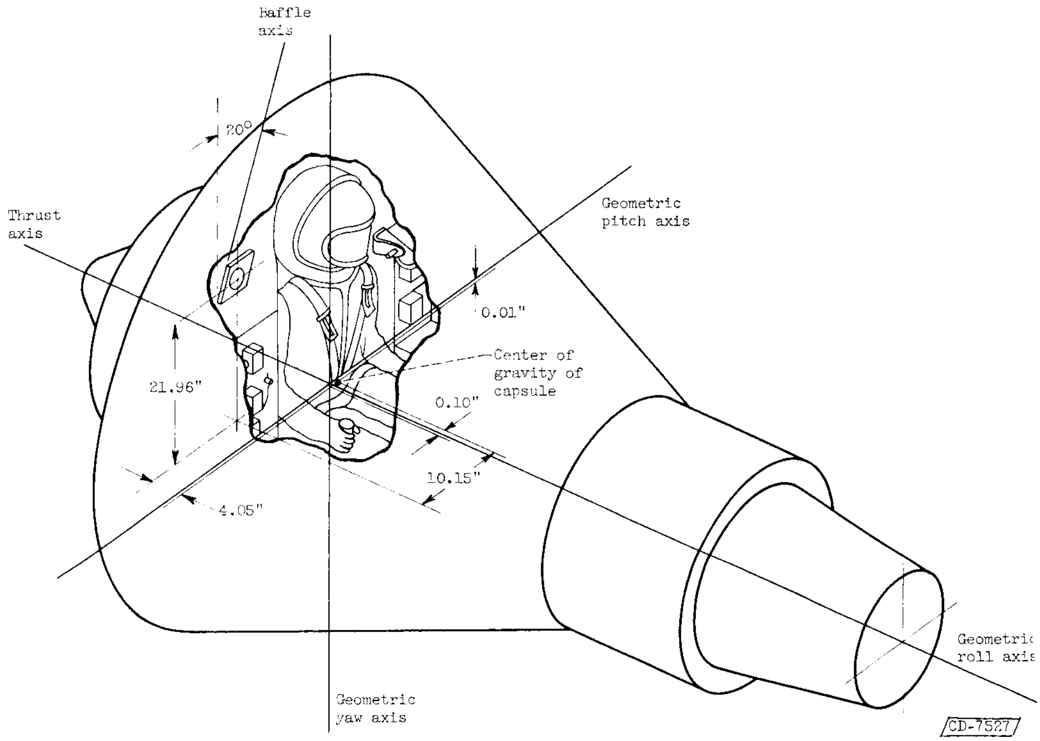


Figure 3. - Schematic diagram showing location of experiment mounted in MA-7 spacecraft.

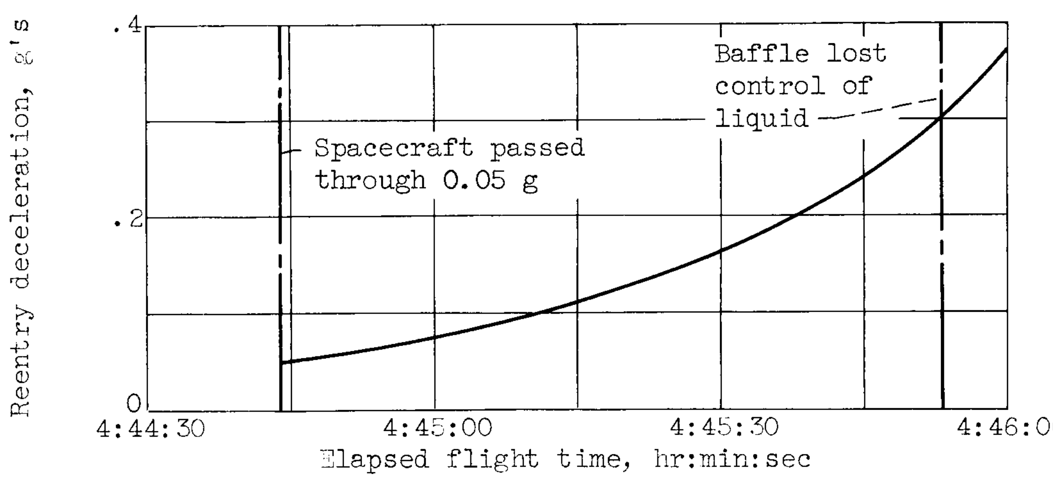
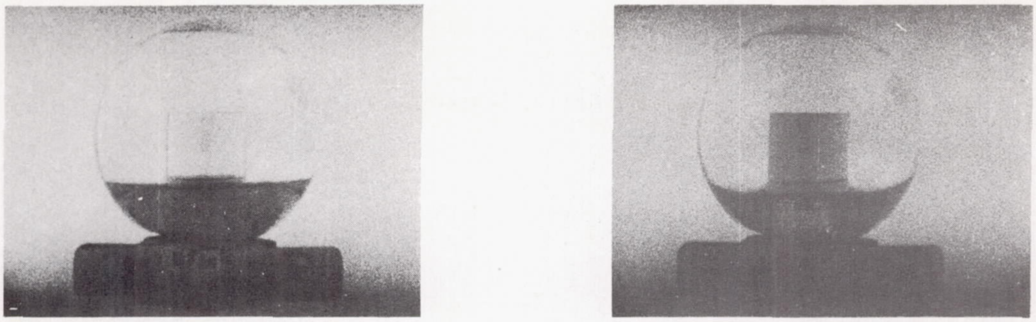


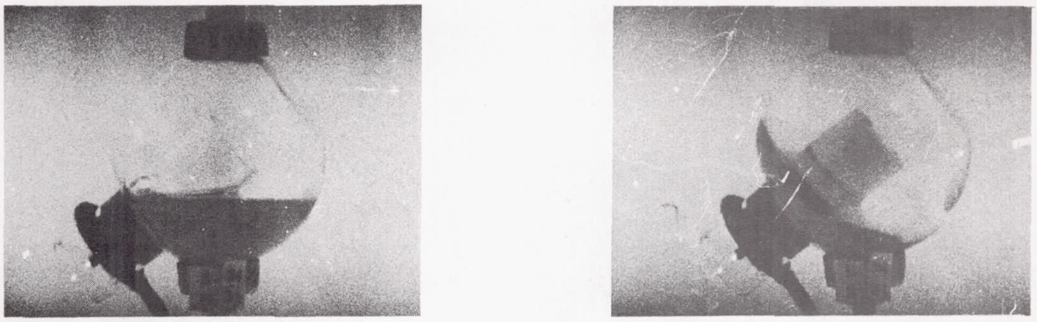
Figure 4. - Results of analysis of radar tracking data during spacecraft reentry.



1-g configuration

Zero-g configuration

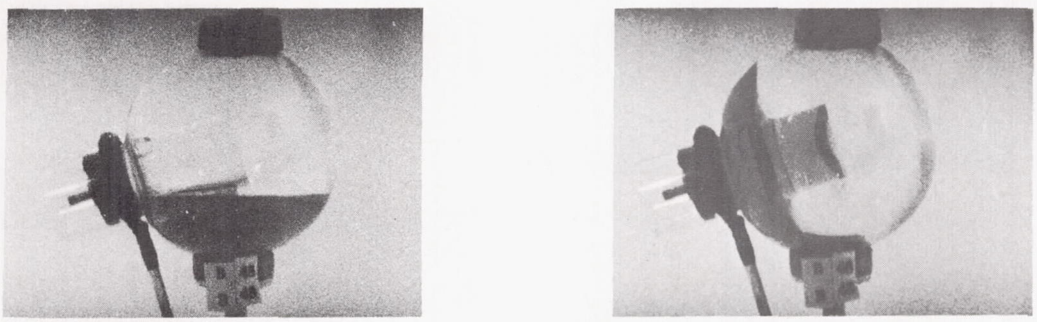
(a) Initial mounting angle, 0°.



1-g configuration

Zero-g configuration

(b) Initial mounting angle, 45°.



1-g configuration

Zero-g configuration

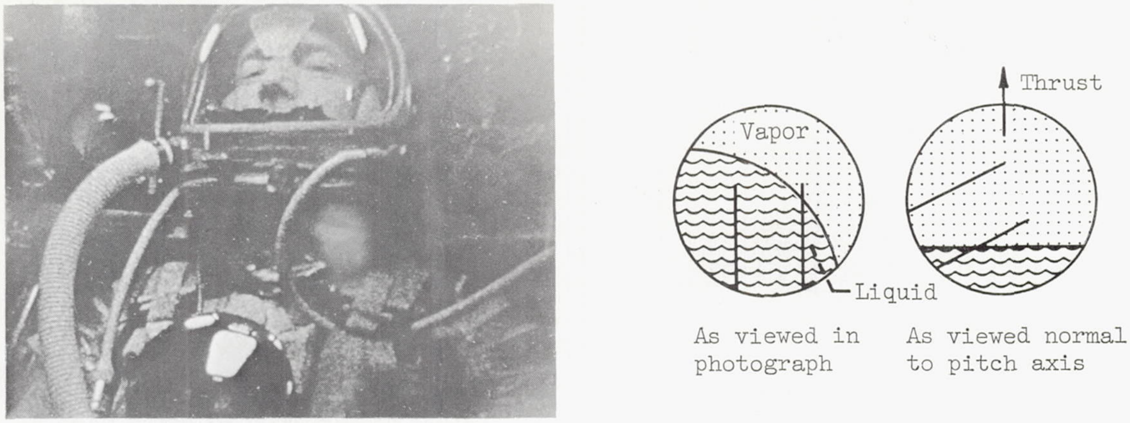
(c) Initial mounting angle, 75°.

1-g configuration

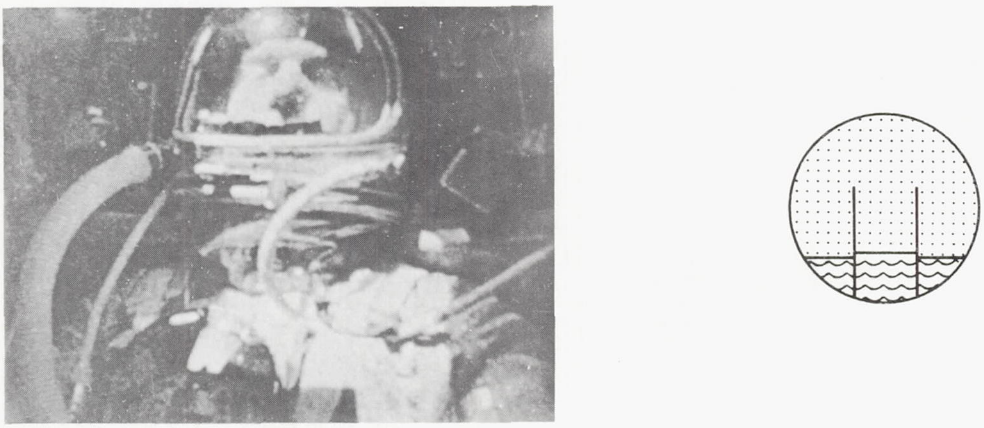
Approaching steady-state zero-g configuration

(d) Initial mounting angle, 90°.

Figure 5. - Photographs from preliminary drop-tower tests for range on initial mounting angles.



(a) Configuration during boost. (Time, hr:min:sec, 0 to 0:05:14.)



(b) Configuration during transition from thrust configuration to zero-gravity steady-state configuration. (Time, 0:05:18.)

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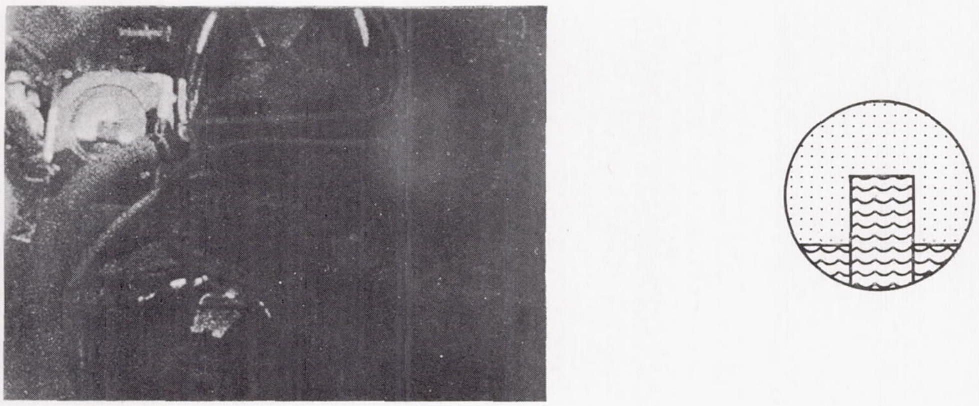
(c) Zero-gravity steady-state configuration. (Time, 0:05:26.)

Figure 6. - Frames from motion pictures taken by pilot observer camera in MA-7 spacecraft.

(d) Zero-gravity configuration during first daylight period. (Time, 0:05:26 to 0:45.)



(e) Zero-gravity configuration during second daylight period. (Time, 1:25 to 2:20.)

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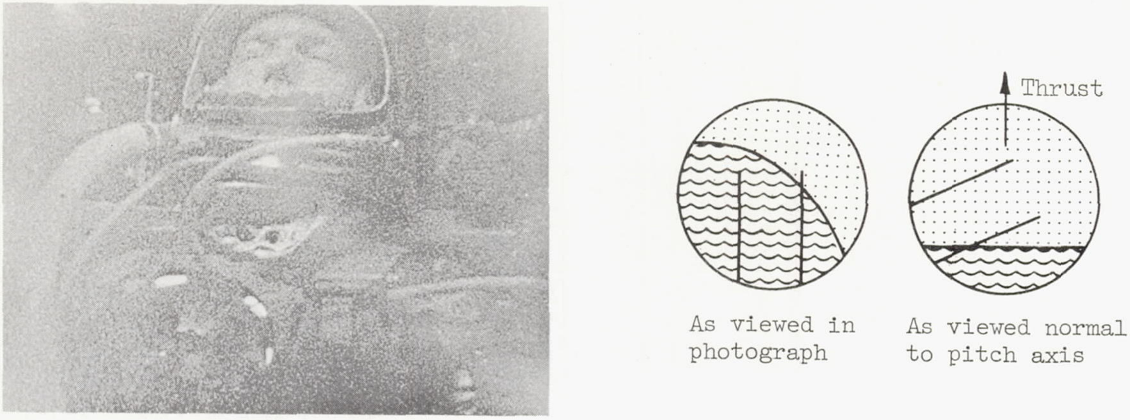
(f) Zero-gravity configuration during third daylight period. (Time, 2:50 to 3:50.)

Figure 6. - Continued. Frames from motion pictures taken by pilot observer camera in MA-7 spacecraft.



(g) Configuration during retrofire. (Time, 4:33:09 to 4:33:39.)

(h) Configuration during transition from retrothrust configuration to zero-gravity steady-state configuration. (Time, 4:33:39 to 4:33:51.)

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(i) Zero-gravity configuration after retrofire. (Time, 4:33:51 to 4:45:53.)

Figure 6. - Concluded. Frames from motion pictures taken by pilot observer camera in MA-7 spacecraft.

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