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AN EXPERIMENTAL EVALUATION OF METALLIC DIAPHRAGMS FOR POSITIVE FUEL EXPULSION IN THE ATMOSPHERE EXPLORER HYDRAZINE PROPULSION SUBSYSTEM

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16. Abstract

Four Arde conospheroid metallic diaphragms were tested at Goddard Space Flight Center to evaluate their capability for use in the orbit adjust propulsion subsystem (OAPS) of the Atmosphere Explorer spacecraft. The diaphragms will be used for positive propellant expulsion and spacecraft center of mass control. A leak-free cycle life capability of nine reversals was demonstrated. The diaphragms rolled smoothly from ring to ring in a predictable manner on the first reversal. Varying amounts of diaphragm cocking and ring skipping were observed on subsequent reversals. The diaphragm pressure differential did not exceed 7 N/cm^2 (10 psid) during any reversal. Cycle life capability, reversal mode, and pressure differential were not affected by sudden reversals, environmental tests, or 18,000 partial reversals. An expulsion efficiency of approximately 97 percent was demonstrated. The results of these tests show that metallic diaphragms can be used as an effective means of positive fuel expulsion; however, to achieve spacecraft center of mass (c.m.) control, the diaphragm must not be reversed prior to flight.

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AN EXPERIMENTAL EVALUATION OF METALLIC DIAPHRAGMS FOR POSITIVE FUEL EXPULSION IN THE ATMOSPHERE EXPLORER HYDRAZINE PROPULSION SUBSYSTEM

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INTRODUCTION

This paper reports on the results of a series of tests performed to evaluate the capability of Arde conospheroid metallic diaphragms. The tests were conducted at NASA Goddard Space Flight Center (GSFC) during the period of December 1971 through March 1972. The prime objective was to evaluate the use of metallic diaphragms in propellant tanks as a means of achieving spacecraft center of mass (c.m.) control. A secondary objective was to establish the diaphragm cycle life capability and expulsion efficiency. The final objective was to determine the effect of sudden reversals, launch-level environmental conditions, and 18,000 partial reversals on the diaphragm performance.

One of the significant features of the Atmosphere Explorer spacecraft (AE's C, D, and E) is that its c.m. must be maintained in a fixed location ±0.254 cm (±0.100 in.) throughout its life. Because the AE spacecraft weighs approximately 635 kg (1400 lb), of which 168 kg (370 lb) is propellant (hydrazine), the propellant c.m. must be controlled to control the spacecraft c.m. Arde metallic diaphragms rolling from ring to ring in a predictable manner offer a solution to this problem.

The four test diaphragms and the test tank were transferred to NASA/GSFC from NASA Lewis Research Center (LeRC). The diaphragms were designed and fabricated for NASA LeRC by Arde, Inc., of Mahwah, New Jersey, under contract NAS 3-12026. The purpose of that program was to develop high cycle life ring reinforced diaphragms for use in cryogenic systems.[1] At the conclusion of the program, four diaphragms, each with a cone half-angle of 25°, remained untested. The diaphragms were then tested at NASA/GSFC using distilled water as a simulant for the propellant.

TEST PLAN

This test program was carried out in two phases. Phase 1 consisted of repeated reversals of a diaphragm to establish baseline cycle life capability, reversal mode, pressure drop, and

[1] D. Gleich: "Metallic Positive Expulsion Diaphragms." NASA CR-72775. Arde, Inc. Report 46002 (Contract NAS 3-12026), March 1971.

expulsion efficiency. Phase 2 consisted of subjecting three diaphragms to conditions they might encounter in flight or during ground handling (sudden reversals, environmental tests, and 18,000 partial reversals) and determining the effect of these conditions on the diaphragm performance.

TEST HARDWARE AND SETUP

Test Hardware

A photograph and cross-section diagram of the diaphragms are shown in Figures 1 and 2, respectively. The diaphragm has a conospheroid shape with a cone half-angle of 25°. It has an inside diameter of 33 cm (13 in) with a 5-cm (2-in) flange at the girth for mounting the diaphragm in a test tank. It is fabricated with 321 corrosion-resistant steel with a nominal wall thickness of 0.02 cm (0.008 in). Reversal mode control is achieved by 20 equally spaced rings brazed to the pressurant side of the diaphragm. Spacing between rings (centerline to centerline) is 1.067 cm (0.420 in). The rings are made of 308 corrosion-resistant steel wire with a diameter of 0.279 cm (0.110 in). Thirteen rings are on the conical portion, six are on the hemispherical portion, and one is located at the transition from conical to hemispherical. The rings are brazed to the diaphragm shell with a copper braze material. The diaphragms weigh 1.04 kg (2.3 lb) each.

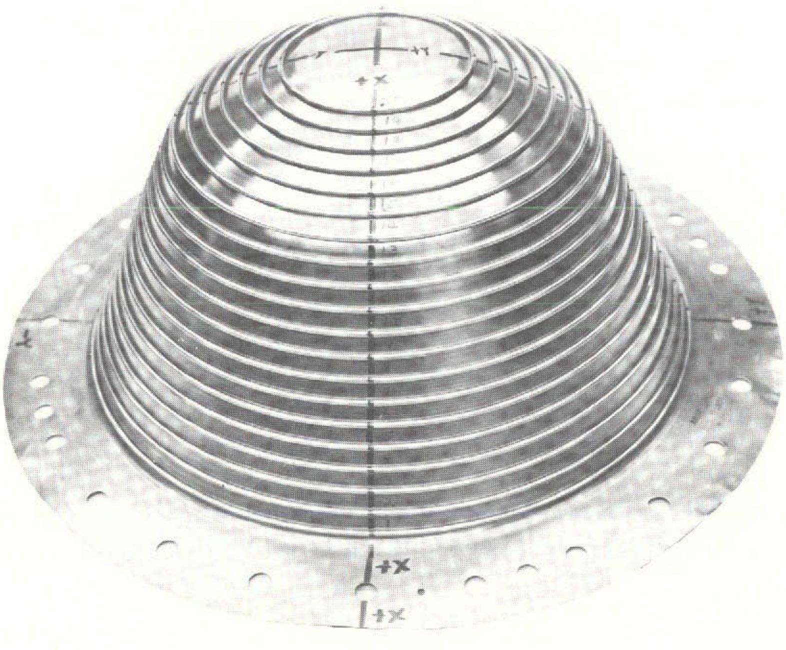

Figure 1. Diaphragm.

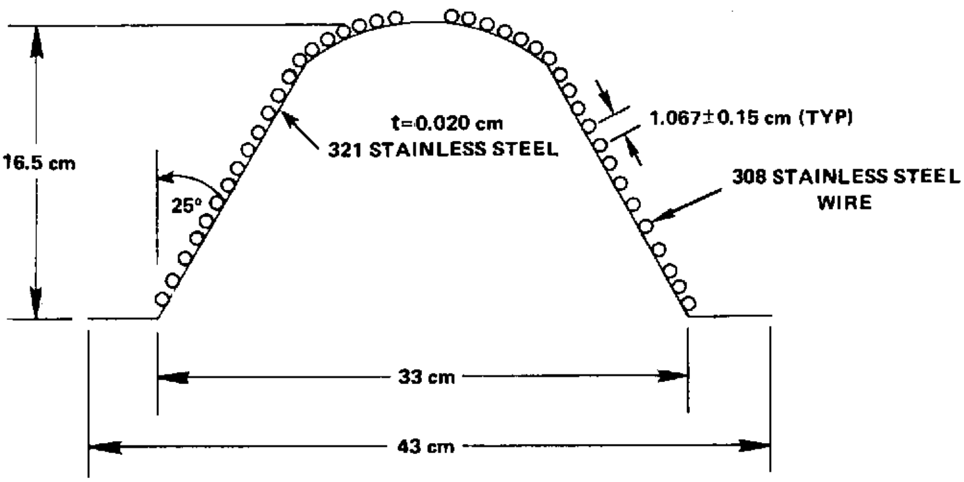

Figure 2. Diaphragm schematic.

Test Setup

A photograph and schematic diagram of the test setup are shown in Figures 3 and 4, respectively. The lower portion of the test tank has a conospheroid shape corresponding to that of the diaphragm. The upper portion is cylindrical with a glass window for viewing and photographing the diaphragm during an expulsion cycle. The diaphragm is sealed in the tank with "O" rings and the window is sealed with gaskets. Provision is made for evacuating or pressurizing either side of the diaphragm, supplying distilled water to the propellant side of the diaphragm, and expelling water through a flowmeter to a scale for weighing. Diaphragm pressure drop was measured during the reversals by means of a Dynasciences differential pressure transducer. Data were recorded on a Honeywell 1508 visicorder.

RESULTS

Phase 1

Diaphragm S/N 5 was reversed repeatedly until a leak developed. The purpose of this test was to establish the diaphragm baseline performance in terms of cycle life, reversal mode, pressure drop, and expulsion efficiency.

The diaphragm rings were numbered sequentially from 1 to 20 starting with the ring nearest the girth. Gaseous nitrogen pressurized to 34 N/cm^2 (50 psia) was used as the pressurant. The water flowrate was adjusted to 6.8 g/s (0.015 lb/s) to simulate the nominal propellant flowrate in the spacecraft. Approximately 50 min were required to complete each odd-number reversal (1, 3, 5, and so on). The diaphragm was restored to its initial condition, on the even-number reversals (2, 4, 6, and so on) by the introduction of water into the propellant side of the diaphragm at 34 N/cm^2 (50 psia). Because the even number reversals do not represent a propellant expulsion cycle, they will not be discussed further in this document.

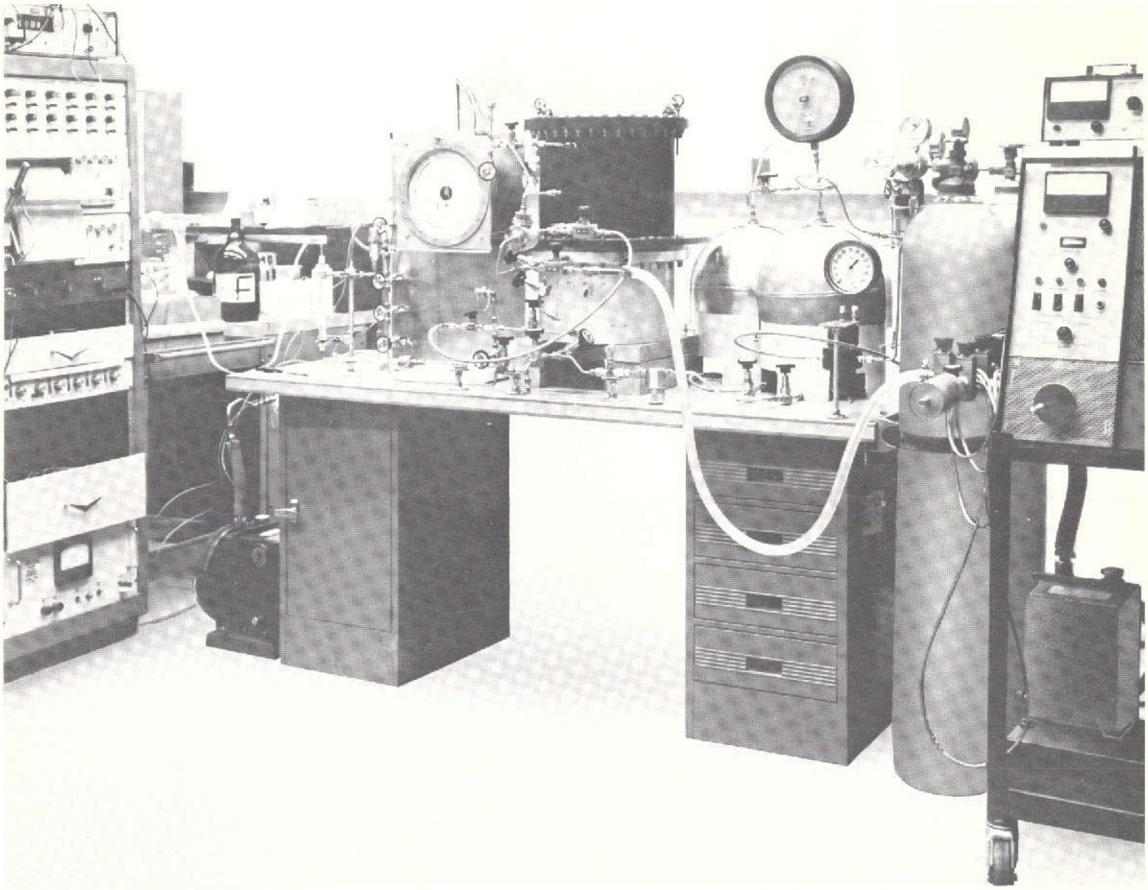

Figure 3. Test equipment.

Reversal number 1 was accomplished without incident. The reversal began at the girth, next to ring number 1, and rolled smoothly from ring to ring, expelling water in a predictable manner. In general, the odd-number reversals begin at the girth and the even-number reversals begin at the apex. The diaphragm pressure drop was less than 7 N/cm^2 (10 psid) until it was fully reversed. At the end of the reversal, the pressure differential was allowed to increase to 24 N/cm^2 (35 psid). A portion of a typical data trace is shown in Figure 5.

The third reversal began at the girth and reversed smoothly through ring number 7. At that point the dome (the small region above ring 20) reversed. The reversal continued at ring 8 and reversed normally to ring 14. At that point, the diaphragm stopped reversing on one side but continued to reverse to ring 16 on the other side, causing the diaphragm to cock. At this point the reversal stopped at ring 16 while the other side reversed to ring 16, straightening out the diaphragm. From that time the reversal was accomplished without cocking. Similar reversal patterns were obtained on the other odd-number reversals.

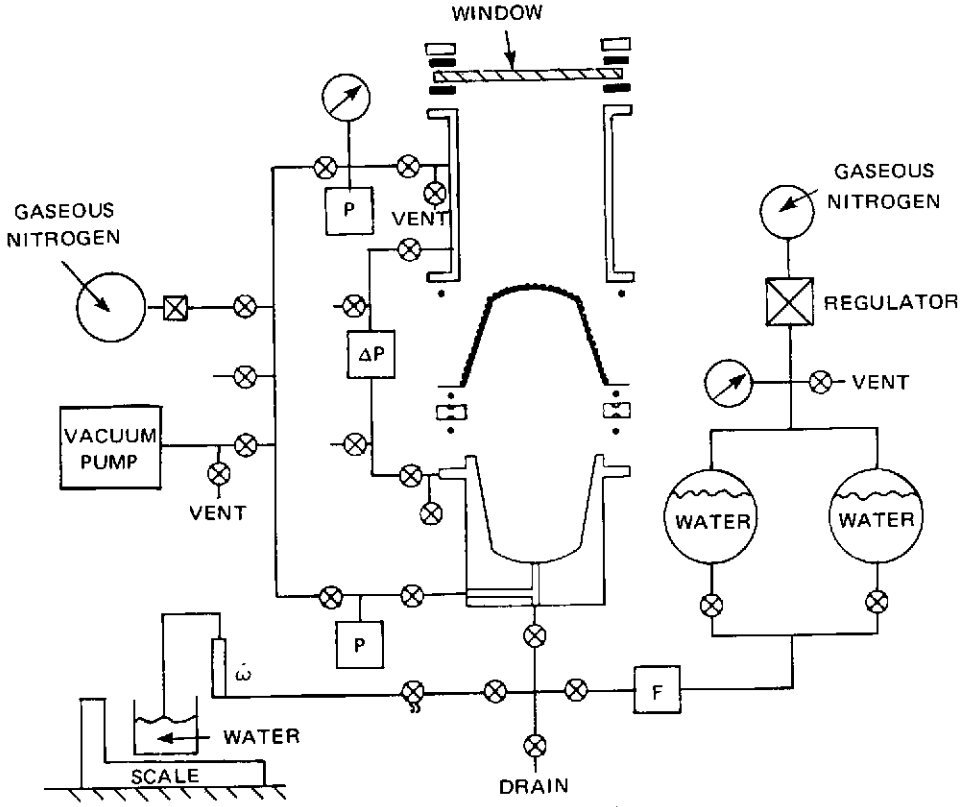

Figure 4. Exploded schematic of diaphragm test equipment.

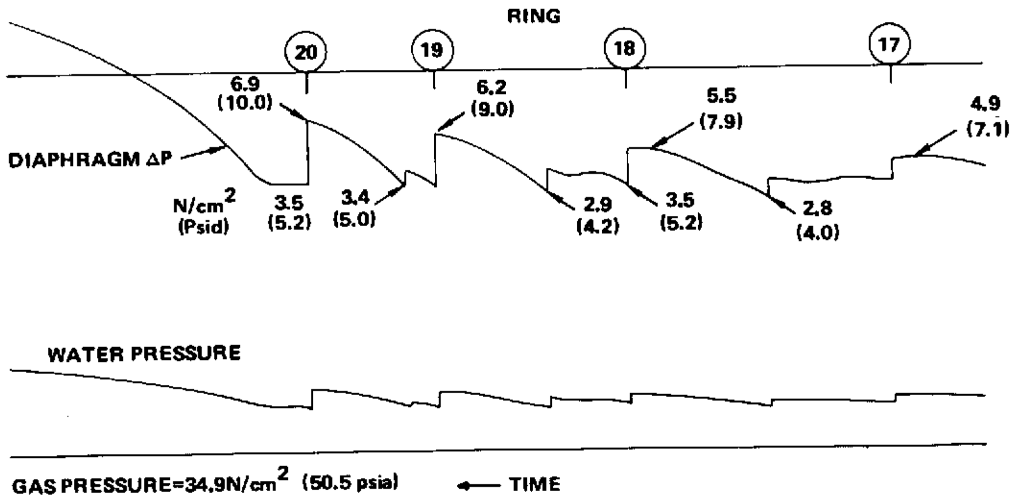

Figure 5. Typical diaphragm data trace.

A leak rate of 5.5×10^{-5} cubic centimeters of gaseous helium per second was measured with a CEC leak detector at the end of reversal number 8. This leak rate increased to 1.9 cm^3 of gaseous nitrogen per second at the end of reversal number 9. This pinhole leak grew to a crack 0.79 cm (5/16 of an inch) in length during reversal number 10. The leak occurred next to ring 3. Approximately 16.7 kg (36.9 lb) of water was expelled during the reversals, and an additional 0.41 kg (0.9 lb) was drained from the tank, yielding an expulsion efficiency of 97.6 percent.

Phase 2

Sudden Reversals

Diaphragms in the AE propellant tanks will not be cycled prior to flight unless an accident occurs during ground handling that results in a partial or full reversal. The procedure for loading fluids (propellant or simulant) in the tanks is to evacuate the pressurant side and then the propellant side and then to slowly add the propellant. In this state, if the vacuum is lost on the pressurant side, the diaphragm will experience a sudden reversal. The purpose of this test was to determine the effects of two sudden reversals upon diaphragm cycle life capability, reversal mode, pressure drop, and expulsion efficiency.

Diaphragm S/N 4 was used for the sudden reversal tests. The procedure was to evacuate the pressurant side of the diaphragm to 0.14 N/cm^2 (0.2 psia) and then the propellant side to 0.14 N/cm^2 (0.2 psia). At this point a hand valve was opened as rapidly as possible, venting the pressurant side to atmospheric pressure. The reversal was completed in 20.5 s. The diaphragm reversed in a series of six steps, each step consisting of three to four rings. When the pressure increased to 3.2 N/cm^2 (4.7 psia) (in approximately 6 s), the diaphragm rapidly reversed through the first step and the pressure dropped to 1.7 N/cm^2 (2.5 psia). When the pressure increased to 3.4 N/cm^2 (5.0 psia), the diaphragm reversed through the next step, and so on. The second sudden reversal was completed in 17 s. Diaphragm cocking did not occur during the sudden reversals.

Following the sudden reversals, the diaphragm was subjected to cycle life tests. Diaphragm cocking and ring skipping were observed during these reversals. A pinhole leak was observed between rings 3 and 4 during reversal 10. The pressure drop across the diaphragm and the expulsion efficiency were approximately the same value as obtained with diaphragm S/N 5.

Environmental Tests

Arde tank/metallic diaphragm interfaces are designed such that the diaphragm stiffener rings bottom against the tank shell when the tank is fully loaded with propellant. This means that the pressurant would normally be stored in external tanks. However, because of space and weight limitations on the AE spacecraft, it is desirable to store the pressurant in the propellant tanks. To accomplish this the diaphragm must be partially reversed, providing the required ullage volume on the pressurant side of the diaphragm. In the case of the AE spacecraft, the propellant tanks have a total volume of 33,600 cm^3 (2050 in^3) with an ullage volume of 5,735 cm^3 (350 in^3). This means that the diaphragm is reversed about 17 percent prior to flight. One of the concerns was that it might be damaged or distorted during launch-level vibration and acceleration because it is partially reversed and tilted relative to the launch vehicle thrust axis; as a result, the diaphragm must support part of the propellant during launch (See Figure 6). The purpose of the following tests was to determine whether the diaphragm could withstand vibration and acceleration forces and still perform as required after orbit is achieved.

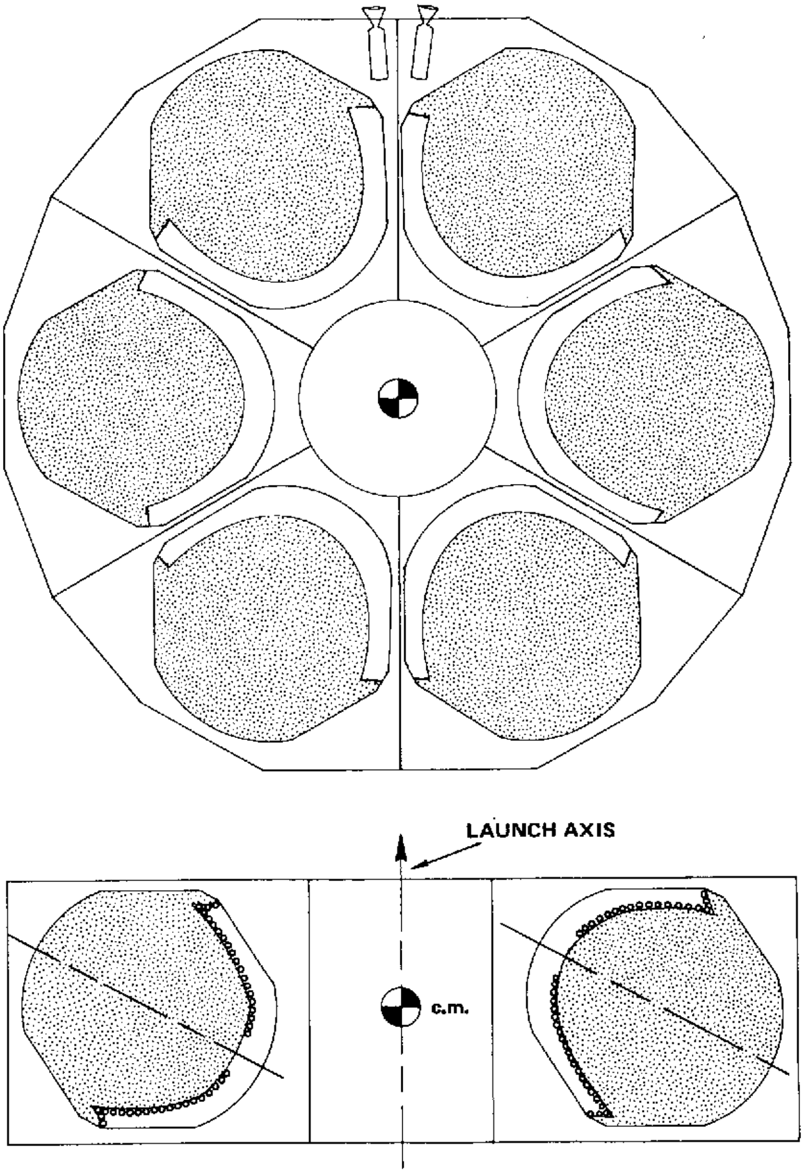

Figure 6. Schematic diagram of orbit adjust propulsion system.

Diaphragm S/N 3 was used for the vibration and acceleration tests. It was installed in the test tank, loaded with 17.25 kg (38 lb) of distilled water, and pressurized to 34 N/cm^2 (50 psia). To simulate the partially reversed AE diaphragm, 2.90 kg (6.4 lb) of water was expelled from the tank, reversing the diaphragm about 17 percent. This reversed the diaphragm to ring 2.

Vibration tests were conducted on the NASA/GSFC Test and Evaluation Division C-210 shaker table, which has a total capacity of 135,000 N (30,000 lb). The test tank was attached to the shaker table via a tilt fixture that was required during the acceleration tests. Thrust axis tests were conducted first. Initially, a low level (1/2g) sinusoidal sweep 5 to 200 Hz) was made as a workmanship check. This was followed by 1-1/2g and 2-1/2g sinusoidal sweeps from 10 to 200 Hz. The two-stage Delta qualification level sinusoidal vibration level is 2-1/2g from 20 to 200 Hz at a sweep rate of two octaves per minute. The random vibration input was 0.09 g^2/Hz (12.8g's rms). This level was maintained for 4 min over the frequency range from 20 to 2000 Hz. Lateral axis vibration tests included sweeps at 1/2g, 1-1/2g, and 8-1/2g. The AE component vibration qualification level is 10g from 20 to 2000 Hz. This level could not be achieved because the shaker table was drawing too much current due to a heavy test fixture. Random vibration test levels were the same as for the thrust axis. Examination of the diaphragm after each test showed no damage.

Acceleration tests were conducted on the NASA/GSFC Test and Evaluation Division launch phase simulator and are summarized in Figure 7. Three acceleration tests were conducted. The first two tests were at the two-stage Delta qualification level and the third was at the AE qualification level. The diaphragm was tilted at a 45° angle during the first test such that the diaphragm was supported by the propellant. (Distilled water was used as propellant simulant.) An acceleration level of 15-1/2g was applied for a duration of 1 min. During the next test the test tank was inverted so that the diaphragm supported the propellant simulant. This test was also conducted at 15-1/2g for 1 min. The final test consisted of having the diaphragm tilted at a 30° angle with the propellant supporting the diaphragm. An acceleration level of 24g was applied for 3 min. This acceleration level and diaphragm orientation simulates the AE configuration while the spacecraft is being spin-balanced at 150 rpm. Examination of the diaphragm after each acceleration test showed no diaphragm damage and no apparent diaphragm movement.

Following completion of the environmental tests, the diaphragm was subjected to cycle life testing to determine if the cycle life capability, reversal mode, pressure drop, and expulsion efficiency were adversely affected by environmental testing. In summary, the diaphragm reversed smoothly from ring to ring without cocking on the first and second reversals. Diaphragm cocking and ring skipping occurred on subsequent reversals. The diaphragm developed a pinhole leak near ring 2 on the 10th reversal. The pressure drop and expulsion efficiency were about the same level as obtained with the other diaphragms.

Partial Reversals

The propellant temperature in the AE spacecraft is expected to vary ±0.56° K(±1° F) from orbit to orbit. Because hydrazine density is a function of temperature, the volume occupied by the propellant in each tank will vary approximately 41 cm^3 (2.5 in^3) during each 2-hr orbital period. This means 4380 partial cycles of the diaphragm (8760 partial reversals) in a 1-yr spacecraft life. Diaphragm S/N 3 was subjected to 18,000 partial

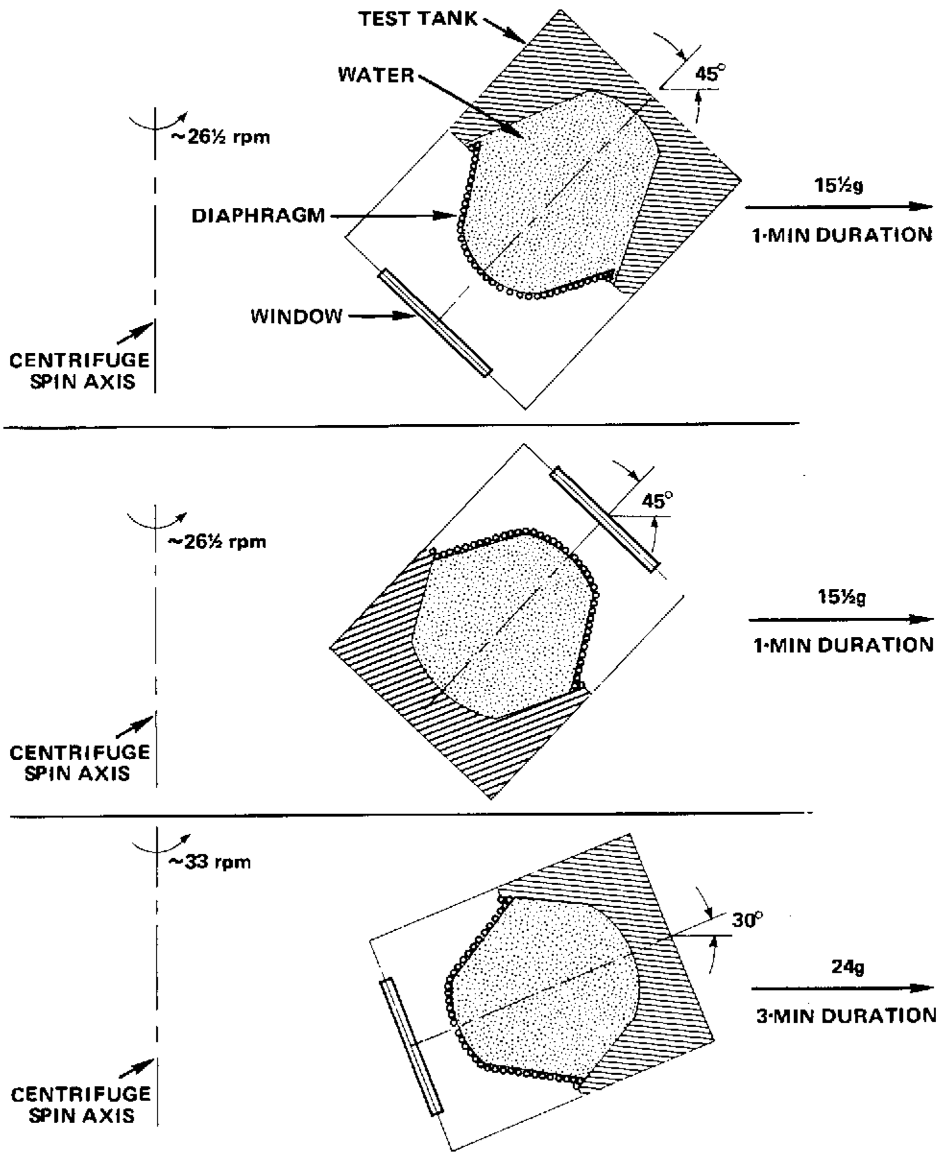

Figure 7. Diaphragm orientation during three acceleration tests.

reversals (approximately twice the number that would be seen in flight); cycle life tests were also performed. Figure 8 shows the setup for these tests. The density change was simulated by alternately expelling and injecting 41 cm^3 (2.5 in^3) of water by means of a hydraulic cylinder. First the diaphragm was subjected to two complete reversals; then it was reversed to the 17.0-percent point that it would be at during launch. At that point the diaphragm was partially reversed 18,000 times, at the rate of 1 cycle per 15 s. Thus all of the partial reversals were put on the diaphragm at one point (worst case). This condition would be encountered in the event a tank outlet valve failed to open during the mission. Following those tests the diaphragm was subjected to cycle life tests. A diaphragm leak was observed between rings 3 and 4 at the end of the 10th reversal. Cocking and ring skipping were observed during the cycle tests. The expulsion efficiency and maximum pressure drop were 97 percent and 7 N/cm^2 (10 psid), respectively.

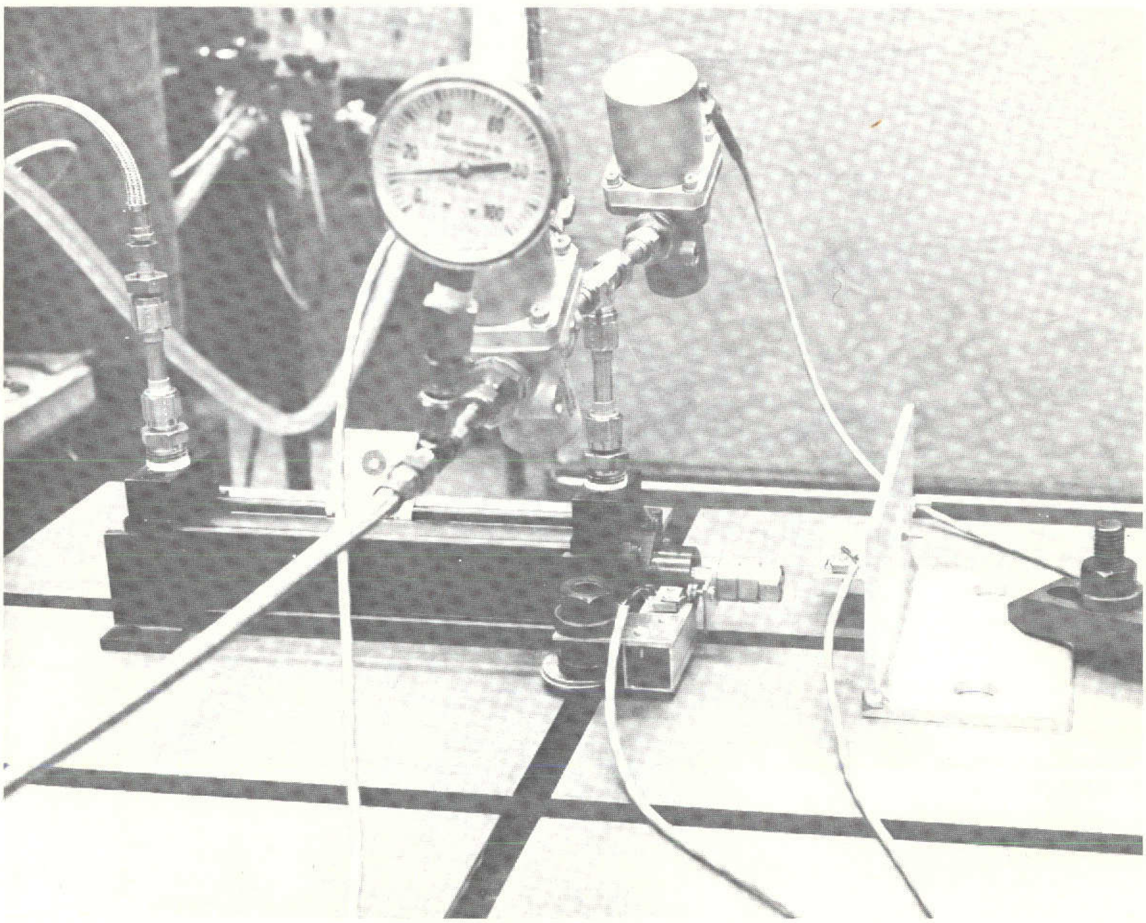

Figure 8. Experimental array for partial reversals.

CONCLUSION

Arde metallic diaphragms reverse smoothly from ring to ring in a predictable manner on the first reversal, but experience various amounts of cocking and ring skipping on subsequent reversals. The pressure drop across the diaphragm remained below 7 N/cm^2 (10 psid) until the diaphragm was fully reversed. A cycle life capability of at least nine reversals was demonstrated. The expulsion efficiency was in excess of 97 percent for all reversals. The diaphragm performance was not adversely affected by sudden reversals, environmental tests, or partial reversals. In conclusion, these diaphragms can be used as an effective means for propellant expulsion, but must not be reversed prior to flight if c.m. control is a spacecraft requirement.

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