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Technical Report No. 32-875

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W. F. MacGlashan, Jr.

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ABSTRACT

16153

A simple, compact, lightweight valve was developed to satisfy the need for reliable fill valves for the Advanced Liquid Propulsion System (ALPS). Manually operated valves for on–off control of Earth-storable propellants and inert gases were designed, built, and tested.

The preferred valve design consists of a ceramic ball, a screw, and a tank boss. The screw pushes the ball onto a spherically lapped seat in the tank boss. With the ground fitting engaged, the valve can be actuated irrespective of line pressure. Flow can be either around or through the screw.

Several variations of this ball valve are described. Problems encountered, refinements, and test results are discussed.

Author

I. INTRODUCTION

This Report describes several fill valves which have been designed, built, and evaluated as part of the Jet Propulsion Laboratory's Advanced Liquid Propulsion System (ALPS) program. References 1 and 2 describe the ALPS program and some of the other work being done in support of it.

The major activity in this program is the development of a liquid rocket-propulsion system. Four manually operated fill valves are required in this system to fill and drain the fuel, oxidizer, monopropellant generant, and pressurizing gas for the generant. The fuel and oxidizer fill valves are of ½-in. nominal tube size and the other two are of ¼-in. tube size.

The "standard" propellants for the ALPS system are nitrogen tetroxide (N_2O_4) and hydrazine (N_2H_4), but the valves are required to be suitable also for alternative "Earth-storables," such as mixed oxidizers of nitrogen (MON) for the oxidizer and derivatives of hydrazine, e.g., monomethyl hydrazine (MMH), unsymmetrical dimethylhydrazine (UDMH), and various mixtures of these

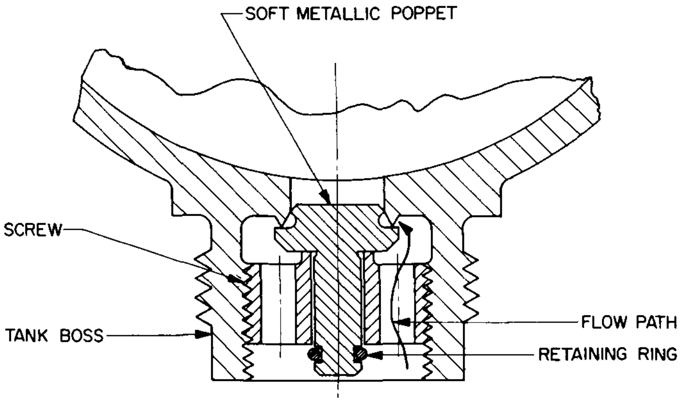

Fig. 1. Knife-edge fill-valve cross section (ground fitting not shown)

Table 1. ALPS fill valve requirements

Valve	Nominal size, in.	Fluid	Maximum pressure during actuation, psi	Maximum pressure during flight, psi	Temperature range,[b] °F	Rated flow vs pressure drop	Allowable leakage (internal and external)
Fuel fill valve	½	N_2H_4 (MMH or UDMH)[a]	100	300	+35 to +300	1 lb/sec at 5-psi ΔP	1 std. cm^3/min N_2 gas at 355 psi or 1 cm^3/year liquid N_2O_4 at 300 psi
Oxidizer fill valve	½	N_2O_4 (MON)[a]	100	300	+35 to +160	1 lb/sec at 5-psi ΔP	1 std. cm^3/min N_2 gas at 355 psi or 1 cm^3/year liquid N_2O_4 at 300 psi
Generant fill valve	¼	N_2H_4	100	1500	+35 to +160	0.2 lb/sec at 5-psi ΔP	1 cm^3/year liquid N_2H_4 at 1500 psi
Generant pressurization valve	¼	N_2 (He)[a]	1500	1500	−50 to +160	0.01 lb/sec at 10-psi ΔP	10 std. cm^3/year He gas at 1500 psi

[a] Possible alternate fluids.

[b] Temperature range with ground fitting engaged is +40 to +100°F.

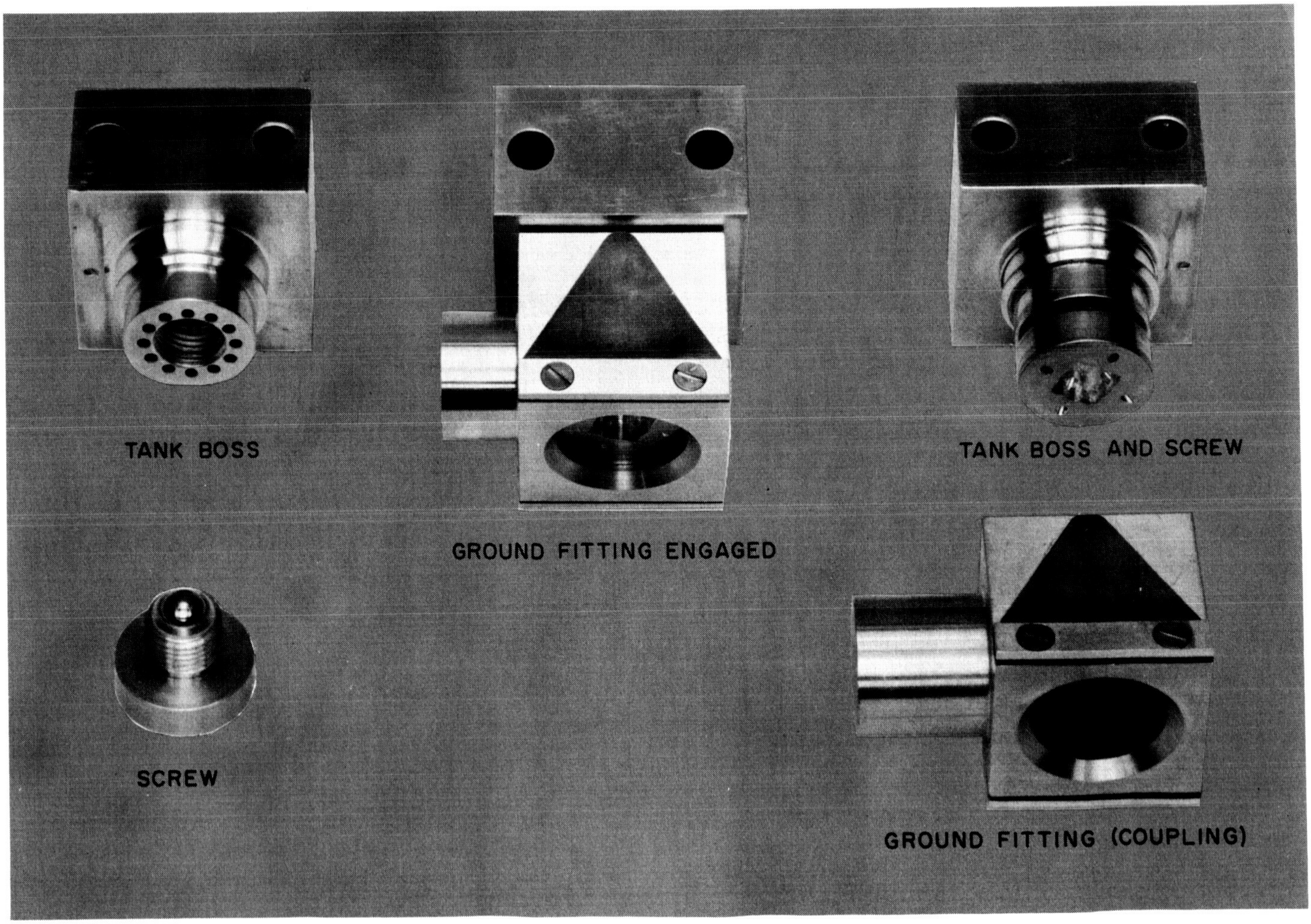

Fig. 2. Ball fill valve (type with flow passage in boss)

fuels. Hydrazine is the monopropellant generant and nitrogen is the pressurizing gas (helium could be a substitute for nitrogen).

The maximum propellant-tank pressure is less than 300 psi and the maximum generant-tank pressure is 1500 psi. Since the propellants are Earth-storables, the nominal temperature range at which the system is stored is +35 to +120°F; the extremes of temperature at the valves during or after firing periods are not expected to exceed −50°F at the generant pressurizing valve and +300°F at the fuel fill valve. Table 1 defines the operating temperatures for each valve.

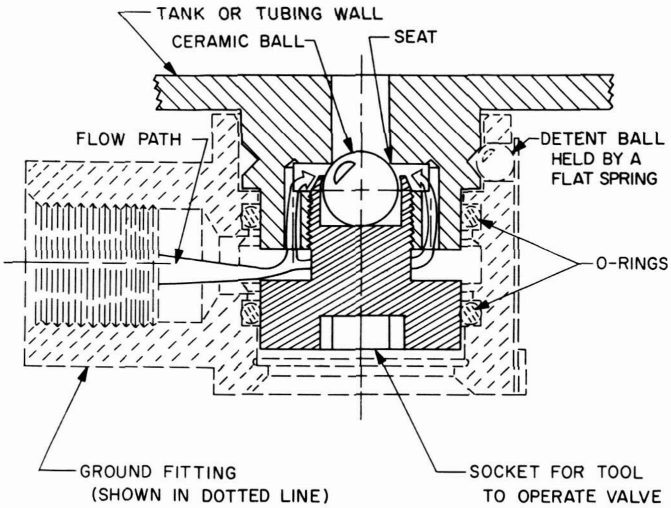

Fig. 3. Ball fill-valve cross section (type with flow passage in boss)

Flow coefficients and permissible leakage rates were established by ALPS system requirements. These and some of the other factors affecting the design of the valves are also summarized in Table 1.

Several types of valves were designed. One knife-edge fill valve (Fig. 1) and three ball-type valves are described in this Report, in the chronological order of development. Each valve represents an improvement over its predecessor. The first ball fill valve is the type with the flow passage in the boss (Figs. 2–4); the second is the type with the flow passage in the screw (Figs. 5–6), and the third type is the type with the headless screw (Figs. 7–8).

Each valve assembly consists of a flight portion, which contains the valve mechanism, and a ground fitting portion which engages the flight valve during loading and unloading of the fluids.

Table 2 gives a comparison of the physical features of the four ¼-in. valve designs. Some ½-in. line size valves were also built; these were a direct 2-to-1 scale-up of the ¼-in. size valves. However, only the ¼-in. valves were tested because of the urgent need to complete the development of the ¼-in. size for the *Mariner Mars* spacecraft midcourse propulsion system (Ref. 3). These valves were the first ALPS components to be flown as part of a spacecraft.

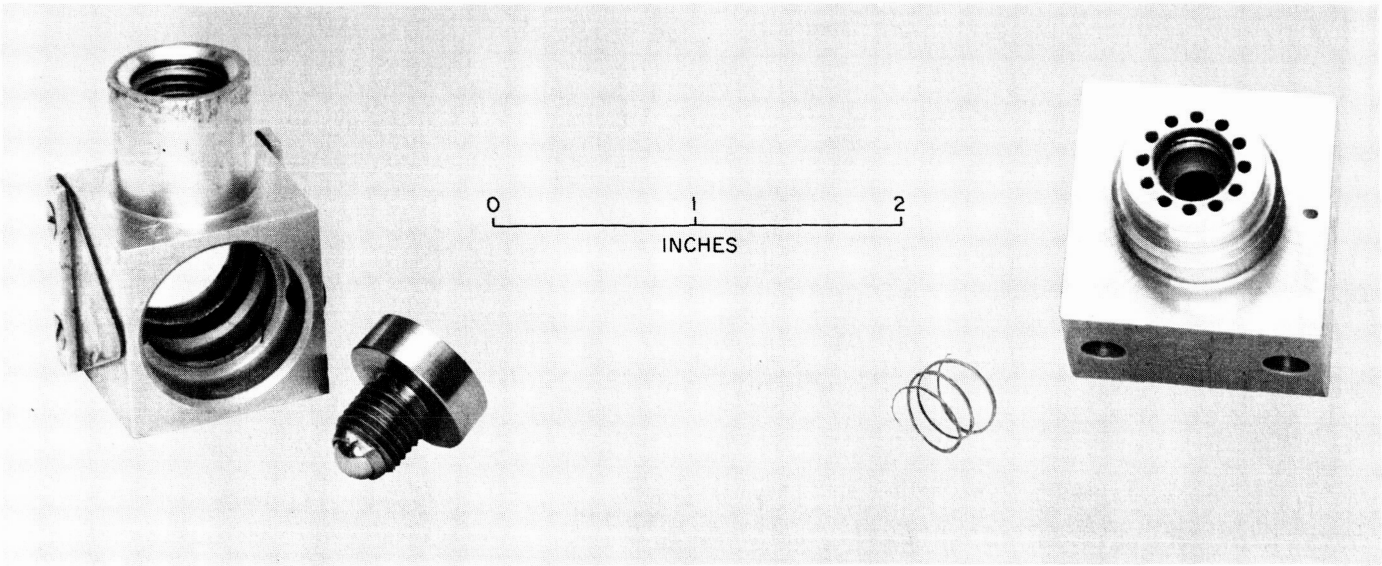

Fig. 4. Ball fill-valve thread failure at 7200 psi during burst test with ground fitting engaged

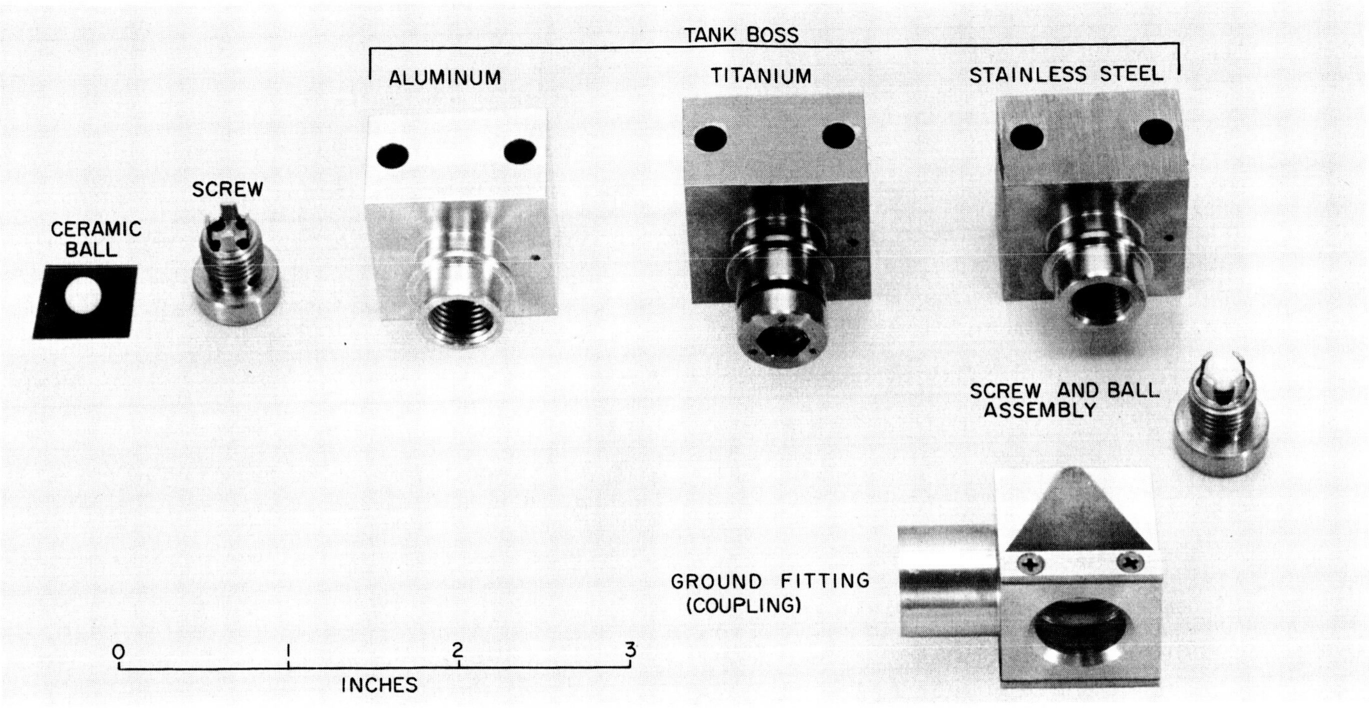

Fig. 5. Ball fill valve (type with flow passage in screw)

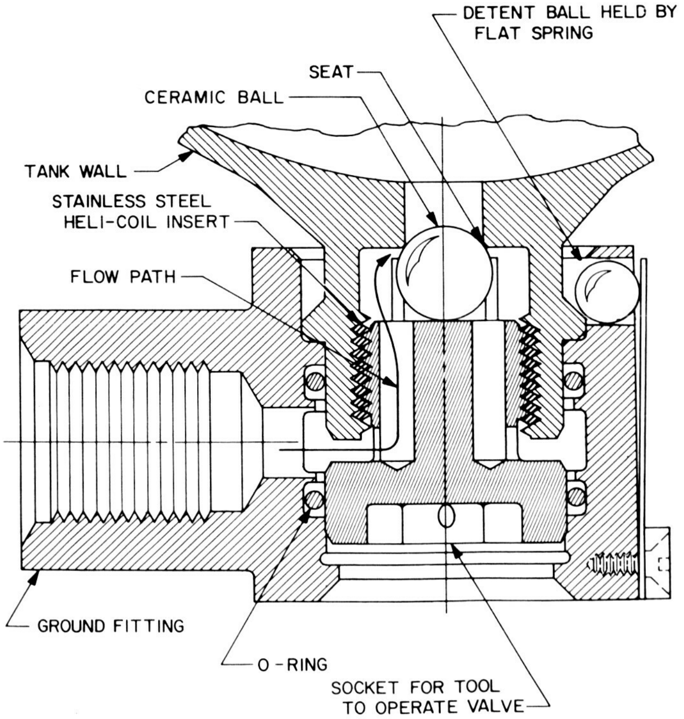

Fig. 6. Ball fill-valve cross section (type with flow passage in screw)

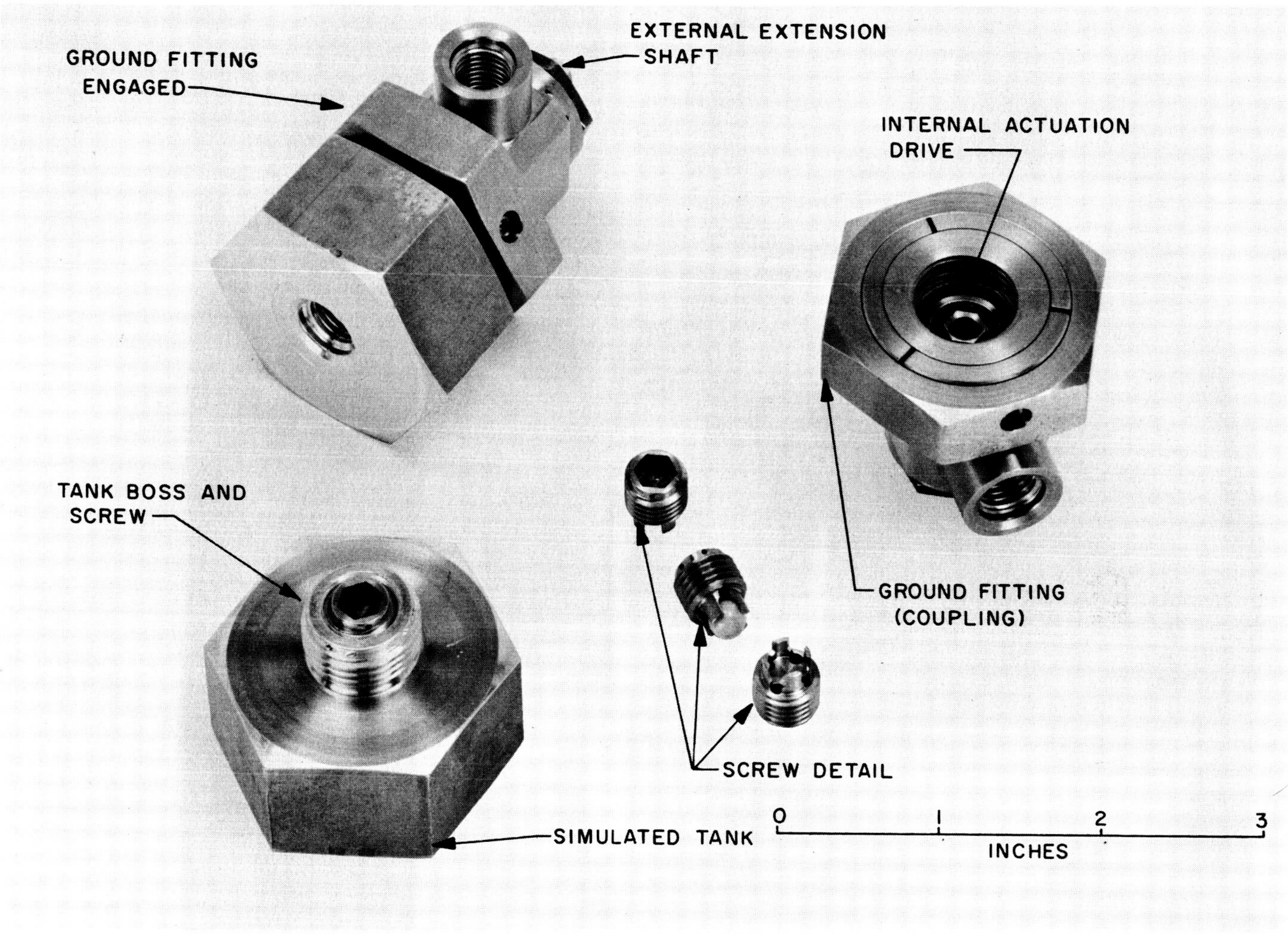

Fig. 7. Ball fill valve (type with headless screw)

Table 2. Comparison of valve types

Fill valve type		Figure No. in this Report	Seat diameter, in.	Seat ball, in.	Increase in axial seat screw load from line pressure during fill	Seat screw thread	Pressure-balanced coupling	Screw head diameter, in.[a]	Contact angle between ball and seat, deg[b]
Knife edge[c]		1	5/32	—	No	1/2-20	No	—	—
Ball seat	Flow passage in boss[d]	2, 3, 4	3/16	1/4	Yes	3/8-24	Yes	11/16	106
	Flow passage in screw[e]	5, 6	6/32	1/4	Yes	7/16-20	Yes	5/8	80
	Headless screw[f]	7, 8	5/32	1/4	No	7/16-20	No	—	80

[a] Coupling seals on this diameter. Line pressure acting on this diameter is transferred to seat screw thread.

[b] Or included angle from center of ball to seat diameter.

[c] JPL drawing No. C9116072.

[d] JPL drawing No. 62 × 09500.

[e] JPL drawing No. 63 × 06302-4.

[f] JPL drawing No. J9116559.

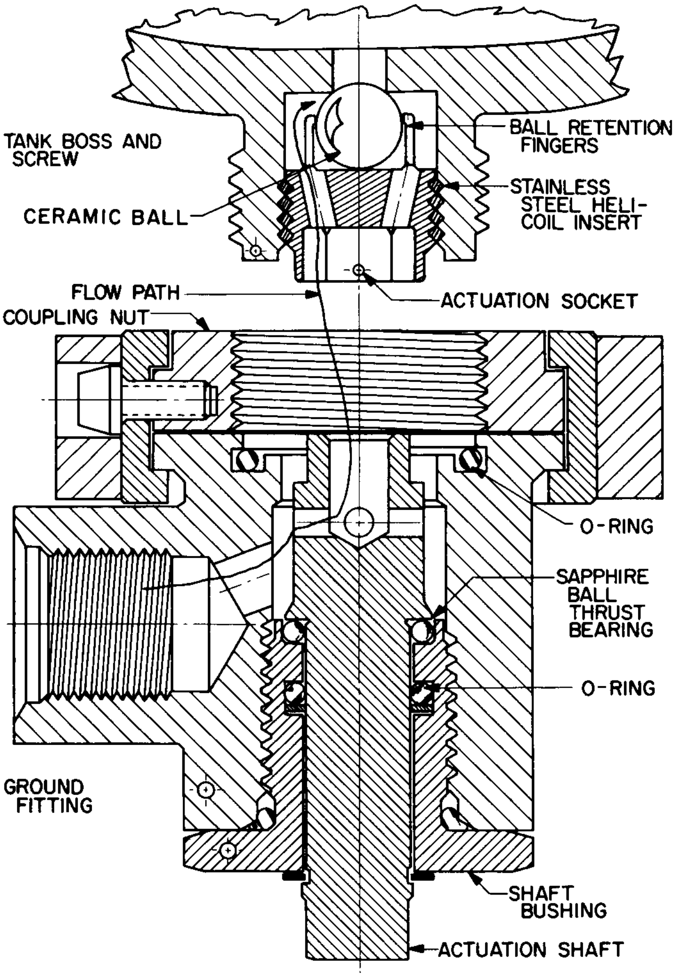

Fig. 8. Ball fill-valve cross section (type with headless screw)

II. FUNCTION AND WORKING PARTS OF THE FILL VALVE

The function of the fill valve is to provide a closable path through which the fluids may be transmitted into or out of the propulsion-system tankage. It is essentially a coupling consisting of a flight component, which can tightly seal off the fill port, and a ground component, which can be locked in engagement with the flight component for the purpose of connecting a fluid transfer conduit (tube or hose) to the propulsion system.

The flight portion consists of a boss containing a seat, a shutoff mechanism, and a means for manual actuation of the mechanism. It is shaped so as to fit into the ground-half.

The ground fitting is basically a housing, to be attached to the end of a fluid transfer line, which slips over the flight-half to permit sealing to and securely anchoring to the boss of the flight-half. Since the ground fitting contains no shutoff valve, a conventional valve must be installed in the transfer line to control the flow through the line.

If the ground fitting is pressure-balanced (such as in the designs shown in Figs. 3 and 6), the ground fitting may be retained in the coupled position by a simple detent. (The ground fitting is pressure-balanced if, under all conditions, line pressure does not exert a force tending to move the fitting relative to the flight component). If not pressure-balanced (Figs. 1 and 3), the ground fitting must have provision for positively retaining it in engagement with the flight-half of the valve.

III. EVALUATION PROCEDURES

Most of the tests used to evaluate the fill-valve designs consisted of determining the torque required for bubble-tight shutoff, frictional torque during actuation at various line pressures with ground fitting engaged, and leak rates. In addition to the proof and leak tests, the valves were subjected to conventional handling shock, low temperature and low humidity, high temperature and high humidity, vibration, and salt fog tests.

The maximum required line pressure during actuation with the ground fitting engaged is 100 psi for nitrogen tetroxide and hydrazine service and 1500 psi for nitrogen service. These values are ALPS system requirements and appear in Table 1. Endurance testing with the ground fitting engaged was conducted primarily to determine O-ring and screw thread durability. During the cycling tests, the valve was fully opened each time (1½ turns) while the fluids (hydrazine, nitrogen tetroxide, and nitrogen gas) were trapped in the valve at maximum pressure. Pressure is trapped in the valve by capping the port of the ground-fitting portion and by maintaining fluid pressure on the tank side of the flight portion. Thus the valve can be opened and closed while under pressure without causing flow. Line pressure exerts an axial force on the threads equal to the product of the screw-head area and the unit fluid pressure. Line pressure also increases the rotary friction between the ground fitting O-ring and the screw head against which the O-ring seals. The sum of the actuation torques caused by the above-mentioned thread and O-ring friction plus the seat-tightening or net torque is defined as the *gross closing torque*. Because of the added valve wear induced by the line pressure, the cycling with the ground fitting engaged was limited to 100 cycles.

Endurance testing without the ground fitting was conducted with 1700-psi nitrogen gas applied to the tank side of the flight valve. The valve was cycled 1000 times by opening the seat (only slightly so as to minimize gas usage). The purpose of this test was to determine the durability of the seat.

Originally 10 in.-lb was the nominal net torque applied during cycling. The torque was increased up to 20 in.-lb when necessary to obtain bubble-tight shutoff. The seat was considered to have failed if leakage occurred at 20 in.-lb torque. Since a new seat seals at 2 in.-lb, more torque than necessary was applied during the early cycles. Therefore, the procedure was changed so that only sufficient torque was used to cause bubble-tight shutoff. At intervals during the cycling, the torque necessary for shutoff was determined. (For cycle-testing purposes, bubble-tight shutoff is defined as a shutoff which

Table 3. Typical relationship between closing torque and leak rate after 100 cycles in hydrazine at 100 psi (valve type with flow passage in boss; see Fig. 3)

Closure torque, in.-lb	Leak test media	Leak test method	Leak rate
15	1700-psi N_2	Bubble in alcohol	1 bubble in 4 min[a]
17	1700-psi-N_2	Bubble in alcohol	No bubble detectable
20	1700-psi He	Mass spectrometer	0.7 std. cm^3/year[b]

[a] Approximately equivalent to 0.1 std. cm^3/hr (Basic assumption: 150 bubbles $\cong 1$ cm^3.)

[b] Approximately equivalent to 2 bubbles/week. (Basic assumption: 150 bubbles $\cong 1$ cm^3.)

permits formation of no more than 1 bubble in 15 sec.) This new torque value was then used until the next check point. The seat was considered to be good if the net torque did not exceed 60 in.-lb in meeting the seat leakage requirements.

Bubble leak tests were conducted by running a stainless steel capillary tube (1/16-in. OD × 0.015-in.-thick wall) from the valve being tested to a glass graduate inverted over a bath of alcohol. The tube outlet was made flush with the surface of the alcohol to maintain zero head pressure in the tube. Thus individual bubbles could be counted or allowed to accumulate by displacement in the graduate.*

For more precise leak checks, the helium leak rate was determined by using a mass spectrometer. Because of the additional time required, the mass spectrometer is used only at intervals, usually at the conclusion of a series of tests. Table 3 shows the typical relationship between closing torque, leak rate, and leak detection methods.

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*Basic assumption: 150 bubbles $\cong$ 1 cm^3.

IV. KNIFE-EDGE FILL VALVE

A. Description

This valve was developed to overcome a disadvantage inherent in the conventional needle valve, which is that the pintle rotates on the seat during closure.

The flight portion of this improved valve (Fig. 1) consists of three pieces: the boss into which the knife-edge seat is machined, a soft-metal poppet, and a screw to advance the poppet onto the seat. The poppet is free to swivel in the screw and, since the contact diameter of screw and poppet is smaller than the seat diameter, there is no rotary motion between the seat and poppet during closure. This freedom from rotation at the seat reduces galling tendencies and results in longer seat life. A pilot on the poppet assures repeated concentric seating. No ground fitting was built.

Two valves were built and tested. Both poppets were made from 1100-0 aluminum and both screws from Type 303 stainless steel. One boss was made from 6061-T6 aluminum alloy and the other from 6-Al-4V titanium alloy.

B. Performance

The valve with the aluminum boss was cycled 100 times, then pressurized with 1700-psi helium and subjected to thermal shock by immersion in liquid nitrogen, temperature conditioning to 250°F in an oven, and vibration testing. There were no leaks.

The valve with the titanium boss passed the liquid-nitrogen test but developed a leak while returning to ambient from the 250°F oven test. The probable cause of failure was the almost 3-to-1 thermal expansion ratio (aluminum-vs-titanium), which was too great to allow a seal to be maintained over the extreme temperature range.

V. BALL FILL VALVE—TYPE WITH FLOW PASSAGE IN BOSS

A. Description

A simple form of valve consists of a screw which presses a ball against a central hole in an internally threaded tank boss. This is the approach which was followed in designing the ball fill valve (Figs. 2–3, Ref. 4).

It is desirable to have the tank or flight portion compact, lightweight, reliable, and simple. Complexity can be tolerated in the ground fitting since it is not a flight item.

The ground fitting, screw, and boss are machined from 6061-T6 aluminum alloy. A stainless steel ball is inserted into a flat-bottomed bore in one end of the screw and is retained by spinning the bore edge. The ball is kept radially loose so as to self-align on the seat. The OD of the head on the other end of the screw is the same as the OD of the boss. These outside diameters are sealed by O-rings contained in the ground fitting and the flow from the ground fitting to the flight fitting is fed through the annulus between the two O-rings. Since these diameters are equal, line pressure does not tend to disengage the ground fitting. With the ground fitting engaged, line pressure axially loads the threads with a force equal to the product of the line pressure and the area of the head diameter. The pressure-balanced ground fitting is attached to the boss and held in place by two stainless steel ball detents during filling and draining operations. The balls are held in place with flat phosphor-bronze springs which are bolted to opposite sides of the ground fitting. A square-edged seat and female threads with a relief at the bottom are machined in the boss. Outside the threads, in a circular pattern, axial holes are drilled from the boss face into the thread relief. These holes carry the flow around the threads from the annulus between the O-rings to the ball seat cavity.

The valve is opened by backing the ball off the seat. This is done by turning the screw with a square or hexagonal drive tool. The valve is closed by screwing the valve shut so that the ball is seated. During the time the ball is in contact with the seat, there is no scrubbing or relative motion between the ball and seat because the ball pivots on the flat bearing surface on the screw. This is important since it minimizes scratching, galling, and wear. To facilitate the cleaning of the pilot cavity between the ball and screw, two axial vent holes are drilled in the ball socket bottom to intersect corresponding radial holes in the screw thread relief.

B. Performance

The original ³⁄₁₆-in.-diam. seat edge was machined square and the ¼-in. stainless steel ball, during seating, formed the square edge to the spherical contour of the ball. The excessive torque required for seating resulted in thread galling and metal pickup on the ball from the seat and pivot. Substitution of a ceramic ball produced a slight improvement. For equal shutoff, the ceramic ball required less torque with use while the opposite was true for the stainless steel ball. Because metal pickup could be more readily removed from the ceramic ball, it was used in all future tests.

To reduce the torque required for bubble-tight shutoff, a 0.006-in.-land spherical seat was diamond-lapped to the ball contour. Metal pickup from the seat and pivot was still experienced in fewer than 100 closing cycles at 10 in.-lb torque. Silicone grease applied to the seat did not diminish the metal pickup.

Substituting a Type 303 stainless steel screw for the aluminum screw greatly reduced the thread galling and the metal pickup on the ceramic ball at the pivot point. Burnishing the ball and seat with Teflon resulted in a satisfactory seat after 500 cycles at 10 in.-lb torque. At 12 in.-lb torque the seat was bubble-tight and at 15 in.-lb torque the leakage with 1500-psi helium was less than 1 std. cm^3/year.

A new valve with a Teflon-burnished seat and ball was cycled 1000 times with nitrogen gas. At the end of the test, the leak rate, as checked on a mass spectrometer, was less than 1 std. cm^3/year with 1500-psi helium. The shutoff torque increased from 3 in.-lb at the start to 20 in.-lb at the finish because of progressive metal pickup from the aluminum seat to the ceramic ball.

Extensive cycling yields a wider seat land, which results in a lower unit contact pressure between seat and ball. To maintain the unit pressure, the seating torque must be increased as the cycling progresses.

Temperature cycling tests indicated a tendency toward lower torque at high temperature (135°F) and higher torque at low temperature (20°F) than is required for shutoff at ambient conditions.

A valve, without a ground fitting, was cycled 100 times with 10 in.-lb torque while the lapped aluminum seat was submerged in hydrazine (N_2H_4) at atmospheric pressure. An untreated ¼-in. ceramic ball was used on the untreated 3/16-in.-diam. seat. There was no metal transfer from seat to ball. The test was repeated using an untreated sapphire ball and the result was the same.

A valve, with a ground fitting engaged and capped, was cycled 100 times with 10 in.-lb net closing torque. The valve was fully opened (1½ turns) each time while 100-psi N_2H_4 was applied to the open port. Acid Safe Lubricant No. 2031 had been applied to the threads and the ground fitting O-rings. The frictional torque to bring the ball to the seat remained at 10 in.-lb throughout the test (20 in.-lb total closing torque). The net closing torque for bubble-tight shutoff was 8 in.-lb at the start of the test and 15 in.-lb at the finish.

The above test was repeated except that the pressurized fluid was nitrogen tetroxide (N_2O_4) and the lubricant was a mixture of 70% (by weight) DC-11 silicone grease and 30% Molykote Z (MoS_2). The seat failed before completing 100 cycles, partially because of seat contamination from Molykote particles released when the DC-11 was dissolved in the N_2O_4.

A failed seat was restored by applying a Rulon* Spray coating. Rulon Spray contains DuPont 5-μ Vydax (fluorocarbon) dispersed in freon with a binder. While the binder is not resistant to N_2O_4 or N_2H_4, the consensus is that the quantity of binder is so minute that no problem of propellant contamination should result. This coating restored the seat to satisfactory operation for 5000 additional cycles with nitrogen gas.

Additional cycling tests (100 cycles each) with pressurized N_2O_4 and Teflon-burnished and Rulon-sprayed seats were conducted. At the conclusion of the tests, the net closing torque was 19 in.-lb for the Teflon-burnished seat and 8 in.-lb for the Rulon-sprayed seat. The torque to bring the ball to the seat was 5 in.-lb for both.

Two valves with Rulon Spray on ball and seat, and Acid Safe Lubricant No. 2031 on threads, were cycled 100 times in 100-psi N_2H_4. One had no leak with 19 in.-lb closing torque while the other leaked 7200 std. cm^3/hr N_2 with 20 in.-lb closing torque. The leak test pressure was 1700 psi. During closed-circuit cycling in N_2H_4, a 40-psi pressure buildup indicated a chemical reaction. A black scale-like deposit, which ultrasonic cleaning would not remove, was noticed on the valve seat.

The above test was repeated using two valves with triple-lapped seats and Teflon-burnished balls and seats. Pressure buildup was noticed in the valve lubricated with Acid Safe Lubricant No. 2031 and the leak rate was 5400 std. cm^3/hr. The other valve was operated without lubrication except for a contamination of the ground fitting O-rings with DC-11 silicone grease to facilitate assembly. No pressure buildup was experienced and the leak rate was 0.6 std. cm^3/hr. There was slight metal pickup on the ceramic balls of both valves.

The triple-lapped seat (Ref. 5) consists of a seat lapped to the ball contour and then thinned at the OD and ID by lapping with a 1/32-in. oversize and a 1/32-in. undersize ball, respectively. Since the triple seat indicated an increased tendency toward metal pickup, it was suspected that the change in the contact angle between the ball and seat was responsible. This angle change from approximately 106 deg to 116 deg would increase the smearing action of the ball on the seat.

The effects of burnishing ceramic balls with Molykote Microsize (1-μ molybdenum disulfide, MoS_2) and the reduction of the contact angle (Fig. 9) of the ball with the seat were tested and the results are shown in Table 4. The seat was lapped before each of the tabulated tests. The Molykote Microsize-burnished ball picked up metal from the 106-deg contact-angle seat (¼-in. ball on 3/16-in.-diam. seat) after 1500 cycles. With the 80-deg contact-angle seat (¼-in. ball on 5/32-in.-diam. seat), both the untreated and the Teflon-burnished ball picked up metal after 700 cycles, but the MoS_2-burnished ball was still uncontaminated after 2700 cycles. From this test it was concluded that the MoS_2 surface treatment for the ball and the reduction of the ball and seat contact angle were both very effective in reducing metal pickup, which is the main cause of seat failure.

Table 4. Effect of ball contact angle and surface treatment on metal pickup

Ball contact angle[a]	Ball surface treatment	Valve actuation cycles	Metal pickup on ball
106 deg	MoS_2-burnished	1500	Yes
80 deg	None	700	Yes
	Teflon-burnished	700	Yes
	MoS_2-burnished	2700	No

[a] See Fig. 9.

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*Product of Connecticut Hard Rubber Co., New Haven, Conn.

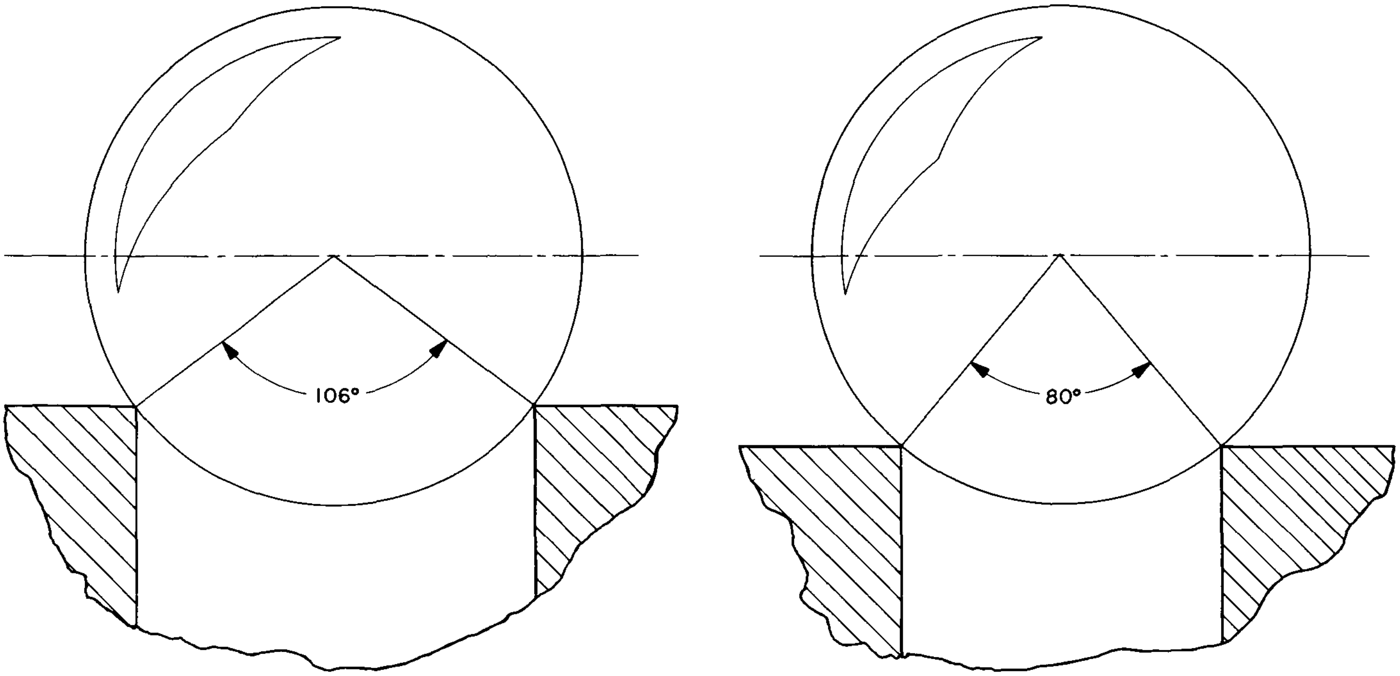

Fig. 9. Contact angles of the ball with the seat

Molykote Microsize-burnished ceramic balls were proved to be effective in preventing metal pickup when the valve was cycled in nitrogen tetroxide, hydrazine, and nitrogen gas. Although Molykote Microsize is not compatible with hydrazine, no difficulty was experienced because of the minute amount of MoS_2 involved. Molykote Microsize-burnished sapphire balls were tested in hydrazine, but no improvement over ceramic balls was indicated.

The abrasion of metal chips from the aluminum female threads during cycling in N_2H_4 and N_2O_4 was a cause of seat damage. Heli-coil thread inserts of 18-8 stainless steel were effective in reducing the formation of metal chips during cycling. Apiezon L grease was found to be an excellent lubricant for nitrogen and N_2H_4 service.

Use of Acid Safe Lubricant No. 2031 was discontinued because hydrazine dissolves the silicone and petroleum constituents and leaves a hard graphite residue that cannot be removed by either solvents or ultrasonic cleaning. It is possible that the pressure buildup during cycling in N_2H_4 (previously reported) was caused by the excessive formation of aluminum chips, which chemically reacted with the hydrazine and which were caused by the abrasive action of the graphite residue on the threads. Finely divided aluminum particles abraded from the threads are believed to be the cause of the pressure buildup during closed-circuit cycling in hydrazine because the Heli-coil insert in the boss eliminated the pressure buildup when the test was repeated. Although a few stainless steel wear particles were generated, they appeared to be magnetically retained in the lubricated thread area. The seat ball was perfectly clean at the conclusion of the test. Prior to the use of the Heli-coil insert, examination after test always revealed migration of grease and aluminum particles to the ball and seat.

The typical relationship between closing torque and leak rate is shown in Table 3. This valve had a Molykote Microsize-burnished ceramic ball, a Heli-coil insert, Apiezon L lubricated threads, and ground fitting O-rings; the valve was cycled 100 times in 100-psi hydrazine with the ground fitting engaged. Although ball surface treatment is not necessary when the ball is submerged in liquid, the Molykote Microsize-burnished ball offers protection prior to the introduction of the liquid. The leakage rates in Table 3 are for the same valve at different closure torques. At closure torques of 15 and 17 in.-lb with 1700-psi nitrogen gas applied, the bubble-in-alcohol leak rates were respectively, 1 bubble in 4 min and no detectable leak. At 20 in.-lb torque, the leak rate with 1700-psi helium applied was 0.7 std. cm^3/year or approximately 2 bubbles/week. This latter leak rate was determined with a mass spectrometer which is used to detect very small helium leaks.

Figure 4 shows a spiral of aluminum thread which was sheared from the boss as a result of a burst test. Failure occurred at 7200 psi with the ground fitting attached and with the seat opened 1½ turns. This test was conducted before Heli-coil inserts were used for this application.

VI. BALL FILL VALVE—TYPE WITH FLOW PASSAGE IN SCREW

A. Description

This fill valve (Figs. 5–6, Ref. 6) is similar to the fill valve described in Section V but with several improvements. The axial holes in the boss for conducting the flow were transferred to the screw in the new design. This enabled the screw thread to be increased from ⅜ in. to 7/16 in. and the OD of the boss and the screw head to be reduced from 11/16 in. to ⅝ in. The smaller screw-head diameter reduces the line pressure load on the threads when the ground coupling is engaged. Instead of swaging the seat ball in a socket, the new design retains the ball on the end of the screw with four spring fingers which are integral with the screw. This enables the ball to be readily removable for cleaning, burnishing, or replacement. Initially, in this new design, Heli-coil inserts were installed in the aluminum bosses only, but later were added to all bosses because of the desirable magnetic chip-retention feature previously described. The detent balls, for retaining the ground fitting in engagement, were changed from steel to sapphire or ceramic to eliminate the galvanic corrosion which froze the steel balls in their sockets. The spherically lapped seat land was reduced from 0.006 in. to 0.002 in. so as to give greater unit seat loading with less torque. The design of the ground fitting was unchanged.

Table 5 summarizes the lubricants and O-ring materials that were used with the various fluid test media. The wide-open valve pressure drop at rated flow is recorded in the last column of Table 5.

B. Performance

Fill valves with bosses made from aluminum (with Heli-coil insert), titanium, and stainless steel were tested to determine if there is a thread galling danger when the cycling valve is 1½ turns open with the ground fitting engaged and pressurized with nitrogen. The screw in each valve was made of Type 303 stainless steel. Each valve was cycled 100 times while 100-psi N_2 was applied to the engaged ground fitting. Threads and O-rings were lubricated with Kel-F No. 90 grease. The tests were repeated using Apiezon L grease. The torque to bring the ball to the seat was about 4 in.-lb. All tests were satisfactory.

When the N_2 pressure was raised to 1500 psi, the torque to bring the ball to the seat increased after five actuations from an initial 22 in.-lb to 60 in.-lb. Each actuation produced a circumferential cut on the screw-head sealing O-ring. There was no improvement when Rulon Spray Dry Lube was applied to the O-ring. The cycling was successfully completed after installing a Teflon O-ring replacement. Results of the tests using Apiezon L grease are shown in Table 6. The torque to

Table 6. Results of actuating valves at high pressure (valve type with flow passage in screw; see Fig. 6)

Boss material	Actuation torque, in.-lb			Remarks[b]
	Zero N_2 pressure	1500-psi N_2		
		Initial	Final[a]	
6061-T6 aluminum (Heli-coil insert)	5	25	30	Screw burnished by insert; minimum of abraded metal in grease
Titanium (6A14V alloy)	5	45	60	Heating apparent; grease blackened
Stainless steel (Type 347)	5	45	55	Heating apparent; metal chips prevented free removal of screw

[a] After cycling to 1 turn open for 100 times in N_2 gas at 1500 psi.

[b] In all cases the Type 303 stainless steel screw was lubricated with Apiezon L grease.

Table 5. Valve summary for nitrogen tetroxide, hydrazine, and nitrogen test media (valve type with flow passage in screw; see Fig. 6); valve line size, ¼ in.; seat diameter, 5/32 in.; ball diameter, ¼ in.

Fill valve name	Test fluid	Lubricant	Ground fitting O-ring material	ΔP (valve fully open)
Generant fill valve	Nitrogen tetroxide[a] (N_2O_4) Hydrazine (N_2H_4)	Kel-F No. 90 grease	Silastic LS-53 Butyl	30 psi (50 psi H_2O at 0.2 lb/sec flow)
Generant pressurization valve	Hydrazine (N_2H_4) Nitrogen gas (N_2)	Apiezon L grease	Butyl Teflon[b]	2 psi (300 psi N_2 at 0.01 lb/sec flow)

[a] In the ALPS system, the ¼-in. valve is not used with N_2O_4. Tests using N_2O_4 were conducted with the ¼-in. valve on the assumption that data obtained would be applicable to the ½-in. valve which is used with N_2O_4.

[b] Teflon was used to withstand the rotary friction between the screw head OD and the ground fitting O-ring ID during actuation when pressurized to 1500 psi.

bring the ball to the seat with zero line pressure was 5 in.-lb. With 1500-psi line pressure, the torque ranged from 25 to 30 in.-lb for the aluminum valve with the Heli-coil insert and from 45 to 60 in.-lb torque for the titanium and stainless steel valves. Since the O-ring friction is constant for all three valves, the high torque for the latter two valves reflects the high thread friction and the accompanying heating. All tests were satisfactory since any abraded chips were retained in the thread lubricant. The screws used in the titanium and stainless steel valves showed signs of thread wear but the screw used with the Helicoil was in excellent condition.

This type valve with aluminum boss and Heli-coil thread insert was used for type-approval testing. Some external leakage was experienced because the Teflon O-ring was deliberately sliced through to facilitate assembly into the one-piece ground fitting. A two-piece construction to allow the O-ring to be installed without distortion should solve the leakage problem.

VII. BALL FILL VALVE—TYPE WITH HEADLESS SCREW

This valve (Figs. 7–8) represents an effort to provide a flight portion that is more reliable, more compact, and simpler than previous units. To accomplish this, a more complicated ground fitting is required. If the ground fitting is reliable, other conditions such as size, weight, and simplicity are not too important.

The flight valve is similar to the flight valve described in Section VI, except that the screw head has been removed and external threads have been added to the tank boss. A hexagonal drive shaft mounted in the ground fitting engages a socket in the screw when the ground fitting is attached to the tank boss by means of the swivel coupling nut which engages the boss threads. An O-ring in the ground fitting seals on the boss face when boss and fitting are fully engaged. This fill fitting is not pressure-balanced. Line pressure separation force is sustained by the coupling nut threads. The actuation shaft is O-ring-sealed and extends outside the fill coupling to receive the torque for opening and closing the valve seat. Line-pressure thrust on the actuation shaft is carried by a full complement of sapphire balls nested between the actuation shaft and the shaft bushing. Shaft and bushing are made from 17-4 PH CRES and hardened. When the ball is off the seat, line pressure exerts no load on the threads of the ball screw. This elimination of load on the Heli-coil insert should minimize the formation of thread chips. The ball screw bottoms on the face of the actuation shaft when the seat is fully open. Flow is through radial holes to a central bore in the shaft, then through axial holes in the ball screw to the seat.

A discussion of this valve and others described in this Report was included in Ref. 7.

Two complete valves have been built and assembled but no testing has been done as of this writing.

VIII. VALVE BALL

A. Material

Balls of stainless steel, sapphire, and ceramic were tested in the fill valves. Steel balls were ruled out for this service because of their susceptibility to surface scratching and galvanic corrosion. Sapphire and ceramic are almost identical chemically (aluminum oxide). Either sapphire or ceramic balls are satisfactory from a standpoint of corrosion-resistant properties (Ref. 8), surface hardness and finish, light weight, and accuracy. Ceramic balls are preferred because of better response to surface treatment, availability in larger sizes, and nominal cost.

B. Accuracy

The ceramic balls used in these valves are spherically accurate within 0.000025 in., which is more than adequate for this application because sufficient force from the torque is available to elastically deform the seat to the ball contour. The surface finish is 2 μin. rms or better.

C. Cleaning Method

1. Removal of Metal Pickup

The ceramic ball is prepared for service by rubbing the ball on a rubber mat with a block of micarta. The micarta is dimpled to retain the ball and silver polish is applied to the mat. This scrubbing action cleans the ball and removes any metal pickup that might be galled on the surface.

2. Lint Removal

Lint can be removed after cleaning or surface treatment by dipping in an ultrasonic water bath which contains a nonionic-type detergent, such as Tween 20 (polyoxyethylene sorbitan monolaurate). Surface treatments, such as Molykote Microsize-burnishing, are not removed by this detergent bath.

Cleanliness to the extent of lint removal is not absolutely necessary for the seat ball application because ample seating force is available from the torque.

D. Surface Treatment

Two types of burnished surface treatments for ceramic balls have been used to reduce metal pickup from seat to ball. The first is Teflon-burnishing. The second, which is far more effective, is burnishing with Molykote Microsize (1-μ molybdenum disulfide powder).

The ball is Teflon-burnished by rubbing the ball on a sheet of paper with a block of Teflon which has a dimple to receive the ball. The ball should roll on the paper and slide in the Teflon socket. To obtain better traction between ball and paper, the paper should be placed on a sheet of rubber. The block and ball should be rotated in a circular path until the paper shows evidence of being polished by the transfer of Teflon from block to paper via the ball. Rotation should be in both directions with moderate pressure at the start and light pressure at the finish.

The Molykote Microsize-burnishing process is identical to that for Teflon-burnishing except that a little Molykote-Microsize powder (MoS_2) is sprinkled on the ball path on the paper. Proper application of the coating can be determined visually because the originally milk-white color of the ceramic ball will become a uniform light-amber color.

IX. VALVE SEAT

A. Spherical Lapping

The seat is machined with a square edge which is free from nicks. The square edge is then spherically lapped to form a 0.002-in.-wide land. Special laps are used which are steel balls (same diameter as the seat ball) each of which is soft-soldered to a brass rod. Diamond compound is impregnated into the ball surface by rolling the ball between sintered-carbide plates. The diamond size for the roughing lap is 15 μ and for the finishing lap is 1 μ. The seat is generated by hand-rotating the kerosene-lubricated lap slowly (less than 50 rpm) and with light pressure (less than 2 oz).

B. Surface Treatment

Several treatments can be applied to the lapped seat to retard metal pickup from seat to ball. These treatments listed below can be used with or without similar treatments to the ball surface.

(1) A light coat of Rulon can be sprayed on the seat. This is also effective in restoring a damaged seat in lieu of relapping.

(2) A mixture of Molykote Microsize and isopropyl alcohol blended for 15 min in a "Wig-L-Bug" dental amalgamator can be applied to the seat.

(3) A thin film of Apiezon L grease applied to a seat ball cemented to a rod handle can be used to contact-transfer a light grease film to the seat.

(4) While not as effective as the above lubricants, flooding the contact surfaces with alcohol reduces the likelihood of metal pickup.

(5) A Teflon stick with a spherical end, which is the same size as the seat ball, can be rotated on the seat.

X. THREAD INSERT

Some thread galling problems were experienced when using the Type 303 CRES screw in a Type 347 CRES boss. To circumvent this problem, a stainless steel Heli-coil thread insert was used. This insert is made from AMS 7245 (18-8) hard-drawn CRES and burnishes the screw without any tendency toward galling and also makes possible uniform thread reliability regardless of the boss material. In addition, the insert serves as a magnetic collector by retaining, in the thread lubricant, any metal particles generated in the thread area.

XI. LUBRICANTS*

During the program, six lubricants were considered. Their respective compatibilities are as follows:

A. Acid Safe Lubricant No. 2031

This lubricant is a compound of silicones, hydrocarbons, and graphite. It should not be used in contact with hydrazine because the silicone and petroleum constituents go into solution and leave a hard graphite residue which cannot be removed by either solvents or ultrasonic cleaning.

This lubricant should not be used submerged in nitrogen tetroxide because the chemical reaction with the hydrocarbons forms shock-sensitive compounds.

B. Grease (70% by weight DC-11 silicone grease plus 30% Molykote Z)

This grease is not suitable for direct contact with either hydrazine or nitrogen tetroxide.

Molykote is not compatible with hydrazine. Nitrogen tetroxide dissolves the DC-11, thus leaving the free Molykote particles (0–62-μ size) which might damage the seat.

C. Flurocarbon Lubricant No. 95-1

Hydrazine was discolored by contact with this grease. This indicates a chemical reaction with constituents leached from the grease which was opaque white before contact.

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*See Appendix for lubricant manufacturers.

D. *Insoluble Pump and Packing Lubricant No. 1A*

This vegetable-based, honey-consistency lubricant went into solution with hydrazine and therefore is unsuitable for direct contact.

E. *Apiezon L Grease*

By far the best lubricant for use with hydrazine and nitrogen, of all those tested, was Apiezon L grease.

Apiezon L is neither dissolved nor discolored by hydrazine.

Because of its high film strength, Apiezon L is an excellent grease for the nitrogen fill valve.

F. *Kel-F No. 90 Grease*

At present, this grease is considered the best for direct contact with nitrogen tetroxide.

XII. STERILIZATION

Although tests to determine the compatibility of these valves with the various procedures for sterilization have not been performed to date, they will be conducted during the next phase of this program.

Heat or chemical sterilization is required for spacecraft components to eliminate the transport of microorganisms into deep space. The preliminary sterilization requirement consists of raising the temperature of the valve from ambient to 300°F and holding at 300°F for 36 hr before returning to ambient. The cycle is repeated for a total of six consecutive cycles.

XIII. CONCLUSIONS

Six of the fill valves described in Section V were successfully used in the midcourse propulsion system of the *Mariner Mars* spacecraft. The nitrogen fill pressure was 3000 psi. One of the valves was actuated nine times during the system checkout.

With all the improvements and additional test data described in Sections VI and VII, an advanced flight fill valve could be supplied that would reflect a high degree of development.

APPENDIX

Manufacturers of Lubricants

Acid Safe Lubricant No. 2031
Hercules Powder Company
Hercules, California

DC-11 Silicone Grease
Dow Corning Corporation
Midland, Michigan

Molykote
The Alpha–Molykote Corporation
Stamford, Connecticut

Flurocarbon Lubricant No. 95-1
Dixon Corporation
Bristol, Rhode Island

Insoluble Pump & Packing Lubricant No. 1A
Crane Packing Company
Morton Grove, Illinois

Apiezon L Grease
James G. Biddle Company
Philadelphia, Pennsylvania

Kel-F No. 90 Grease
Minnesota Mining & Manufacturing Company
St. Paul, Minnesota

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