NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-682

Explosive-Actuated Valve Design Concept That Eliminates Blow-By

Ray Hagler, Jr.

(NASA-CR-138769) EXPLOSIVE-ACTUATED VALVE DESIGN CONCEPT THAT ELIMINATES BLOW-BY (Jet Propulsion Lab.) 34 p HC $4.75 CSCL 13K G3/15 N74-27908 Unclas 42573

JET PROPULSION LABORATORY
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PREFACE

The work described in this report was performed by the Propulsion Division of the Jet Propulsion Laboratory.

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ABSTRACT

This report presents the JPL method of evaluating the normally open and normally closed, explosive - actuated valves that were selected for use in the trajectory correction propulsion subsystem of the Thermoelectric Outer Planet Spacecraft (TOPS) Program. The design philosophy which determined the requirements for highly reliable valves that could provide the performance capability during long-duration (10-year) missions to the outer planets is discussed. The techniques that were used to fabricate the valves and manifold 10 valves into an assembly with the capability of five propellant-flow initiation/isolation sequences are described. The test program, which was conducted to verify valve design requirements, is outlined and the more significant results are shown.

I. INTRODUCTION

The baseline Thermoelectric Outer Planet Spacecraft (TOPS) design incorporates a single monopropellant hydrazine thruster to provide the required changes in velocity for correction of the spacecraft trajectory. The trajectory correction propulsion subsystem (TCPS) uses solenoid-actuated valves for primary hydrazine flow control during trajectory correction maneuvers. Redundant explosive-actuated valves are provided for isolating the hydrazine in the supply tank during periods of inactivity and opening the hydrazine feedline when thruster operation is required.

The TCPS incorporates five normally closed (NC) and five normally open (NO) explosive-actuated valves that will be used during four trajectory correction maneuvers, with one of each type of valve available as a spare. The valves are manifolded into a "ladder" arrangement (Fig. 1) that permits the next valve in sequence to perform the opening or closing of the hydrazine feedline should one of the valves fail to perform the commanded function. One method of physically manifolding the 10 valves is shown in Fig. 2. This manifolded valve assembly has been tested in a TCPS feasibility demonstration module.

II. BACKGROUND

Explosive-actuated devices have achieved widespread acceptance as a highly reliable method for accomplishing a nonrepetitive control function. When the required number of functions is small, explosive-actuated devices can be used for primary control. When the number of functions becomes prohibitively large, a less reliable device can be used for primary control, with the explosive-actuated device performing a redundant control function at the usual high confidence level that the commanded function will occur when needed.

Critical interactions and interfaces between the propellant control valves, the thrusters, and the other components in the propellant feed system impose stringent requirements on the design for propellant control valves. The following problem areas must be considered when explosive-actuated valves are used for propellant control:

(1) Compatibility of the materials of construction: the valve design must provide compatibility with the propellant. All surfaces that contact the propellant should be a compatible metal that has been cleaned and processed to maximize resistance to corrosion and minimize decomposition of the propellant.

(2) Leakage: parent-metal membranes should contain the propellant prior to actuating the valve. Metal-to-metal seals should prevent propellant leakage after actuation. All external leak paths should be sealed by welding.

(3) Shock loads during actuation: the effects of these loads can be minimized by mounting the valves away from critical components or isolating the shock with dampeners.

(4) Metal fragments: a minimum number of fragments should be generated by valve actuation. Shearing rather than cutting is the preferred method for piercing the parent-metal membranes.

(5) Pressure-drop at rated flow: the valve design should minimize restrictions to propellant flow.

(6) Propellant pressure surges: valve actuation should not cause large pressure surges in the propellant feedlines.

(7) Combustion products: the combustion products from the explosive actuator should be prevented from entering the propellant feedlines.

JPL has achieved satisfactory solutions for the first six problem areas by utilizing explosive-actuated valves similar to those shown in Figs. 3 and 4. Valves with these design features[1] have provided satisfactory performance during the Mariner Mars missions in 1964, 1969, and 1971 and the Mariner

[1] Patented by Pyronetics Incorporated, Santa Fe Springs, California.

Venus mission in 1967, but squib combustion products can "blow by" and enter the propellant feedline if the Teflon seal on the ram should leak during valve actuation.

The closure of the TCPS normally open valve will entrap a volume of hydrazine in the feedline between the explosive-actuated valve manifold and the solenoid-actuated valves. Any combustion products that enter this volume could generate undesirable pressures by either decomposing or reacting with the hydrazine. Since the TCPS is programmed to be "locked up" during the lengthy coast periods between encounters, any blow-by of combustion products could present serious problems.

Under a JPL contract, some effort was performed by the Thiokol Corporation during FY 1970 to create an explosive-actuated valve design that would eliminate the blow-by problem. The Thiokol design used a rolling diaphragm (ROLLDEX) to preclude blow-by, but the design evaluation was discontinued before the concept could be reduced to practice. Results of this program are contained in Ref. 1.

III. INDUSTRY SEARCH

On May 22, 1970, a JPL Source Information Request was sent to all known manufacturers of explosive-actuated valves to assess industry capability to supply valves that would meet TOPS TCPS requirements (Table 1). The specified requirements stated that all combustion products must be contained within the squib cavity and that a metal barrier between the combustion products and the propellant (hydrazine) was desirable.

Responses were received from 10 of the 13 manufacturers that were contacted. Seven of the 10 vendors submitted valve designs for consideration. A detailed evaluation of the responses showed that:

(1) Three of the submitted designs could have been used for initial feasibility demonstrations but these designs had limited potential for upgrading to flight hardware.

(2) Only one vendor, Pyronetics, submitted designs that were suitable for TOPS TCPS flight hardware (Fig. 5). A metal bellows was

utilized to prevent the squib combustion products from entering the propellant feedline.

A cost comparison of two alternatives for the TCPS feasibility demonstration module valves showed that the cost savings associated with using "off-the-shelf" valves did not offset the benefits of early experience with flight-type hardware. On March 17, 1971, JPL directed Pyronetics to manufacture and deliver six normally open valves, P/N 1399 (Ref. 4), and six normally closed valves, P/N 1400 (Ref. 5). These valves incorporate 6061-T6 aluminum bodies and nipples. The rams and the actuator assemblies are corrosion-resistant steel (CRES). The contract specified that the delivered valves must meet all the requirements listed in Table 2 and delineated acceptance and lot-sampling criteria for verification of the valve performance (Table 3).

IV. DEVELOPMENT

No problems were encountered during the fabrication and testing of one each normally open and normally closed, engineering-prototype valves (Figs. 6 and 7). The design drawings were approved, and production lots of nine each normally open and normally closed valves were fabricated. Three each normally open and normally closed valves were randomly selected from the production lots for evaluation testing per Table 3. Detailed results of the evaluation testing were reported by Pyronetics for the normally open valve (Ref. 6) and the normally closed valve (Ref. 7). The evaluation test data indicate that the performance of both valves met or exceeded all specified requirements. Only one discrepancy was discovered during testing; the ram on the second normally closed valve in the evaluation program underactuated, leaving the flow passage through the valve partially obstructed (approximately 25%). Although the valve performance was satisfactory during postactuation tests, the balance of the normally closed valve testing was suspended until the valve had been disassembled and the cause of the underactuation determined.

Inspection showed that the leading edge of the ram had cut into the body taper and formed a ledge which stopped the ram prematurely. Two conditions caused the underactuation:

(1) The OD of the ram was on the high side of allowable tolerance providing a ram/body clearance that was 25 to 38 μm (0.0010 to 0.0015 in.) smaller than the two valves that were previously actuated.

(2) The radius on the ram leading edge was the minimum allowable and did not blend smoothly with the ram taper.

Ram drawings were revised to ensure adequate ram/body clearance and to increase the radius on the ram leading edge. A requirement for blending the leading-edge radius with the ram taper was specified on the drawing. For additional margin, the ram slot (flow passage) was lengthened 5.1×10^{-4}m (0.020 in.) to increase the tolerance on ram travel.

The rams for all normally closed valves were reworked to the new configuration and the third valve in the evaluation program was actuated with a special squib that provided only 75% of the nominal output pressure. Actuation of the reworked valve was satisfactory, and the production lots of normally open and normally closed valves were accepted.

Valve weight with the squib installed is 0.32 kg (0.71 lb) for both the normally open and normally closed designs.

V. MANIFOLDING

A design study was conducted to determine the desired configuration for the explosive-actuated valve assembly that would be used on the TCPS feasibility demonstration module. The resultant manifolded assembly of five each normally open and normally closed valves is shown in Ref. 8. An analysis of the fabrication processes and a comparison of the costs of two alternative plans for manifolding the valves at either JPL or Pyronetics showed a significant advantage in having Pyronetics manifold the valves in conjunction with the routine fabrication and processing of the valves.

(1) Costs for manifold fittings and the mounting bracket were equivalent in both plans.

(2) Heat-treating to return the 6061 aluminum to the T6 condition after welding could be performed by Pyronetics on the complete welded assembly at the same point in the manufacturing sequence that the valve nipple-to-body welds were programmed for heat treatment. Manifolding at JPL would have required a second heat-treat to condition the manifold welds.

(3) Heat treatment at JPL would have required disassembly, retest, recleaning, and reassembly of the valves.

Following this analysis, Pyronetics was directed to fabricate the detail parts, to weld the manifolded assembly of five each normally open and normally closed valves, and to test, clean, and deliver the explosive-actuated valve assembly (Fig. 2) to JPL. The remaining valves, one each normally open and normally closed, were delivered as spares and ultimately used for verification of valve capability to withstand exposure to vibration and shock environments.

The manifolded assembly, Pyronetics P/N 1411 (Ref. 9), with squibs installed weighs 3.95 kg (8.7 lb).

VI. FEASIBILITY DEMONSTRATION

The explosive-actuated valve assembly, Pyronetics P/N 1411, was integrated into the TCPS feasibility demonstration module and utilized during a test series that duplicated anticipated TCPS sequencing. Valve performance was satisfactory. Detailed results of the feasibility demonstration were published in the final report on the TOPS program (Ref.10).

VII. VALVE TEST PROGRAM

The two valves that were delivered as spares were used to evaluate the capability of the designs to withstand vibration and shock environments. The valves were modified by welding adapters to the inlet and outlet tubes (Fig. 8). These adapters were used to simulate normal installation and to provide a means for pressurization and leakage detection.

The valves were tested as described in Ref. 11. The complete test program is listed in paragraph 3.9 of Ref. 11. The major tests and operations were conducted in the following sequence:

(1) Disassembly

(2) Modification

Proof pressure

Leakage

(3) Cleaning and assembly

(4) Squib installation

(5) Vibration

(6) Shock

(7) Disassembly and inspection

Proof pressure

Leakage

(8) Cleaning and assembly

(9) Squib installation

(10) Actuation with hydrazine flow

(11) Disassembly and inspection

Proof pressure

Leakage

(12) Burst pressure

Details of the test conditions and operation instructions are given in Ref. 11. The valves were disassembled in a clean area, and the actuator assemblies and rams were bagged to protect cleanliness. Mounting adapters were welded to the tube stubs, and the entire modified body assembly was heat-treated to achieve the T6 condition for the 6061 aluminum.

After modification, the valve bodies were proof-pressure tested with GN_2 at 6.89×10^6 N/m^2 (1000 psig). After proof testing, leakage through the valve nipples and from the valve body and mounting adapter welds was measured with a mass spectrometer type leak detector. Total leakage, while pressurized with helium of 3.45×10^6 N/m^2 (500 psig), was less than the specified maximum allowable (1×10^{-6} scc/s).

The valve bodies were cleaned and the rams and actuator assemblies were installed. The inlet and outlet ports were capped to protect valve cleanliness and the squibs were installed. This valve design allows the squibs to be installed and removed in areas where environmental conditions are uncontrolled without affecting the cleanliness level of the valve interior. This feature also minimizes handling hazards and cost since the squibs do not require precision cleaning prior to installation into the valve.

The valves were mounted on a flat plate as shown in Fig. 9 and sequentially exposed to vibration and shock as specified in Ref. 12. Vibration and shock environments were:

(1) A 9.8-m/s^2 (1-g) sinusoidal sweep from 5 to 2000 Hz to map resonant frequencies.

(2) Sinusoidal vibration at a sweep rate of 2 octaves per minute:

Frequency, Hz	Amplitude, m/s^2 (g) peak
5 to 10	2.02×10^{-2} m (0.8 in.) DA
10 to 30	39.2 (4.0)
30 to 2000	98.2 (10.0)

(3) Random vibration for 300 s in each of three mutually perpendicular axes with a spectrum as shown in Fig. 10.

(4) Five shocks (Fig. 11) in each of three mutually perpendicular axes.

Test results are shown in Ref. 13. Visual inspection after exposure did not disclose any damage to the valves. Relatively large (as high as 58 to 1) amplification ratios in the response peaks (Table 4) indicate that supports at the squib end of the valve will be required when this mounting method is used. An alternate mounting method with valve mounting points at or near the center of gravity should also be considered.

Following vibration and shock exposure, the squibs were removed and the valves were disassembled. Thorough visual inspection did not disclose any damage to detail parts. All details were proof-pressure tested and leakage was measured. No damage was detected, and measured leakage was less than 1×10^{-6} scc/s of helium. The squib bridgewire resistances were satisfactory.

All detail parts were cleaned and the valves were reassembled. The squibs were installed and the valves were transferred to the test facility for actuation tests with hydrazine as the test fluid.

The valves were installed in a test setup and tested per paragraph 4.9 of Ref. 11. The valve actuation tests were conducted with the hydrazine feed system that was used to evaluate TCPS thrusters. The test valves were installed downstream of the facility solenoid-actuated valve that controls hydrazine flow. A Millipore filter with a 5-μm absolute Mitex element was installed just downstream of the test valve to catch any metal particles generated during actuation.

The normally open valve was actuated first. Nominal flowrate through the valve was established at a test pressure of 2.76×10^6 N/m^2 (400 psig) by throttling with a manual valve downstream of the Millipore filter. GN_2 was used to purge residual hydrazine from the test setup after actuation. A second Millipore filter was used when the normally closed valve was actuated. Both actuations were normal and the amount of generated particles was small. Particle size distribution by valve type is shown in the following table:

Particle size, μm	Number		
	NO		NC
Under 25		Not counted	
26 to 50	9		202
51 to 100	3		80
101 to 150	2		34
Over 150	0		10

This number of particles would not overload the system filter which is used to protect downstream components. The larger number of particles released by the normally closed valve can be attributed to the fluid flow which, after actuation, flushes generated particles into the Millipore filter. Examination of the filter element during counting of the particles did not disclose any particle-impact damage to the Mitex element.

After actuation, the squib-gas pressure was released and the valves were disassembled. No discrepancies were apparent. The bellows were intact, and there was no evidence of hydrazine leakage past the rams or squib-gas leakage from the actuator assembly. The valve detail parts were proof-pressure tested. Leakage was measured with helium at 3.45×10^6 N/m^2 (500 psig), and the leakage from the bellows, the welds, and the metal-to-metal seals between the rams and the valve bodies was less than 1×10^{-6} scc/s of helium.

The valve bodies were pressurized with water to the minimum burst pressure of 1.38×10^7 N/m^2 (2000 psig). No distortion or leakage was evident. The water pressure was increased until the valves ruptured or an upper limit of 6.89×10^7 N/m^2 (10,000 psig) was reached. The normally open valve did not rupture, but one nipple-to-body weld on the normally closed valve broke at 5.95×10^7 N/m^2 (8600 psig). Since all other valves had withstood 6.89×10^7 N/m^2 (10,000 psig) without rupture, an investigation was made to determine weld quality. Enlarged photographs of the weld showed some porosity, but the cause of the reduced strength was insufficient penetration. Since the rupture occurred at 4 times the design burst pressure, no redesign was necessary; however, the vendor was cautioned to improve cleanliness during welding to decrease the porosity and to revise weld schedules to ensure adequate penetration.

VIII. CONCLUSIONS

The Pyronetics P/Ns 1399 and 1400 explosive-actuated valves met or exceeded all requirements. The valves, as designed, would provide satisfactory flight hardware for an aluminum, propellant-feed system. Two changes should be made to optimize the envelope and decrease the high amplitude responses during vibration exposure:

(1) The squib, JPL P/N 10028049, should be replaced with another squib having identical output pressure but enveloped within a 1/2 - 20 thread instead of the 7/8 - 14 thread. This would allow the size of the actuator to be reduced.

(2) Mounting provisions should be redesigned to locate mounts nearer the center of gravity or to provide supports at the squib end of the valve.

The performance of the manifolded assembly of five each normally open and normally closed valves verified the design concept of Ref. 9. Manifold parts were cleaned prior to welding and heat-treating and, after processing, the manifolded assembly was recleaned to level D2 of Ref. 14.

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Table 1. TOPS explosive-actuated valve requirements

General
a. Materials and processing shall be compatible with hydrazine. Use of magnetic materials shall be minimized.
b. External leakage shall be less than 10^{-6} scc/s of helium when pressurized at 5.5×10^{6} N/m^2 (800 psig). Welding is the preferred process for fabricating the valve bodies.
c. Valve actuation shall not introduce metal fragments into the propellant passage.
d. All products of combustion shall be contained in the cavity between the explosive actuator (squib) and the ram. A metal barrier between the products of combustion and the propellant is desirable.
e. Explosive actuators must be removable.
f. Envelope, weight, and pressure drop at rated flow should all be minimized within the constraints of the valve designs.
g. Pressures: Operating 0 to 2.75×10^{6} N/m^2 (0 to 400 psig) Proof 5.5×10^{6} N/m^2 (800 psig) (minimum) Burst 1.1×10^{7} N/m^2 (1600 psig)(minimum)
h. Temperature: -17.8 to +37.8°C (0 to +100°F)
i. Flowrate: 0.113 kg/s (0.25 lb/s) hydrazine (maximum)
j. One normally closed and one normally open valve may be manifolded or fabricated from a single housing. MS 33656-4 fittings shall be provided for installing valves in test setups and systems. Mounting provisions are optional.
Normally closed valve
a. Prior to actuation, inlet and outlet ports shall be sealed with parent-metal membranes that will withstand the specified proof pressure without leakage into the ram cavity.
b. Subsequent to actuation, the valve shall provide a "straight-through" flow path with a minimum pressure drop at rated flow, and withstand proof pressure without retraction of the ram or leakage into the squib cavity.
c. Opening of the valve shall be accomplished by shearing rather than cutting the parent-metal membranes.

Table 1 (contd)

d. A plug shall be provided to properly position the ram and prevent foreign materials from entering the squib installation port when the squib is not installed.
Normally open valve a. Prior to actuation, the valve shall provide a "straight-through" flow path with a minimum pressure drop at rated flow, and withstand proof pressure without retraction of the ram or leakage into the squib cavity. b. Actuation shall not cause large pressure transients in the propellant supply lines. c. After closing, the valves shall withstand proof pressure without leakage through the valve or into the cavity between the squib and the ram. d. A plug shall be provided to properly position the ram and prevent foreign materials from entering the squib installation port when the squib is not installed.
Squib The JPL standard squib as defined by Refs. 2 and 3 is the preferred squib for use in all valves. In the event that a proposed valve design requires or is presently qualified with a different squib, that squib shall be described as completely as possible including a graph of output pressure versus time and a qualification history.

Table 2. TOPS explosive-actuated valve performance and design criteria[a]

Valve	Characteristic	Dimension	Requirement
Both	Pressure, operating proof burst	N/m^2 (psig)	0 to 3.45×10^6 (0 to 500) 6.89×10^6 (1000) (minimum) 1.38×10^7 (2000) (minimum)
Both	Leakage, external (He)[b]	scc/s	10^{-6}(maximum) from 0 to 6.89×10^6 N/m^2 (0 to 1000 psig) (before and after actuation)
1399 (NO)	Leakage, internal (He)[b]	scc/s	10^{-6} (maximum) from 0 to 3.45×10^6 N/m^2 (0 to 500 psig) (after actuation)
1400 (NC)	Leakage, internal (He)[b]	scc/s	10^{-6} (maximum) from 0 to 3.45×10^6 N/m^2 (0 to 500 psig) (before actuation)
1399	Flowrate (N_2H_4)	kg/s (lb/s)	0.068 (0.15) (before actuation)
1400	Flowrate (N_2H_4)	kg/s (lb/s)	0.068 (0.15) (after actuation)
Both	Pressure drop at 0.068kg/s (0.15 lb/s) (N_2H_4)	N/m^2 (psid)	3.44×10^4 (5) (maximum)
Both	Temperature, operating	°C (°F)	+4.4 to +71.1 (+40 to +160)
Both	Line size (nominal ID)	m (in.)	4.37×10^{-3} (0.172) dia.
Both	Ports (nominal OD) (nominal length)	m (in.)	1.07×10^{-2} (0.420) dia. 5.08×10^{-2} (2.0) from ℄ of valve
Both	Mounting brackets	—	None (tube mounted)
Both	Flow media	—	N_2H_4, isopropyl alcohol, water, helium, and GN_2
Both	Metals	—	6061-T6 aluminum bodies and nipples; CRES acceptable for balance
Both	Elastomers	—	EPR (Parker E515-8 or equivalent)
Both	Fabrication	—	Welding for nipple-to-body joints
Both	Weld rod	—	4043 aluminum
Both	Products of combustion	—	Contained within a metal barrier between the squib cavity and the valve body cavity
Both	Metal fragments	TBD	A minimum amount shall be introduced into the propellant passage during actuation
Both	Squib (JPL furnished)	—	JPL Standard P/N 10028049; Spec ES504522
Both	Plug	—	Close squib boss when the squib is not installed
Both	Cleanliness	—	Level D2 of JPL Spec FS504574

[a]These criteria are the requirements specified for Refs. 4 and 5.

[b]Leakage shall be measured with a mass spectrometer type leakage detector, and the recorded value shall be the largest rate indicated during a test period of at least 30 min.

Table 3. TOPS explosive-actuated valve test requirements

Test	Acceptance		Evaluation	
	1399 (NO)	1400 (NC)	1399 (NO)	1400 (NC)
Before Assembly				
Proof pressure	X	X	X	X
Body and nipples at 6.89×10^6 N/m^2 (1000 psig) (He)[a]				
Bellows at 3.45×10^6 N/m^2 (500 psig) (He)				
Leakage	X	X	X	X
Body and nipples at 6.89×10^6 N/m^2 (1000 psig) (He)[a]				
Bellows after proof with He[a]				
After Assembly				
Examination of product	X	X	X	X
Cleanliness	X	X	X	X
Actuation with H_2O			X	X
Ram stroke			–	X
Proof pressure at 6.89×10^6 N/m^2 (1000 psig)			X	X
Internal leakage at 6.89×10^6 N/m^2 (1000 psig) (He)[a]			X	–
Pressure drop at rated flow (H_2O)			–	X
After Disassembly				
Leakage at 6.89×10^6 N/m^2 (1000 psig)(He)[a]			X	X
Body, nipples, and ram				
Bellows				
Burst pressure [to rupture or 6.89×10^7 N/m^2 (10,000 psig)] H_2O			X	X

[a]See footnote b in Table 2.

Table 4. Peak response points

Frequency, Hz	Input level (G peak)	Response level (G peak)	Valve		Response axis
			NO	NC	
		X-axis			
800	1.0	100	X		X
		3	X		Y
		45	X		Z
		120		X	X
		3		X	Y
		40		X	Z
794	10.0	490		X	X
		9		X	Y
		156		X	Z
877	10.0	580	X		X
		12	X		Y
		100	X		Z
		Y-axis			
491	1.0	2	X		X
		92	X		Y
		10	X		Z
		1		X	X
		64		X	Y
		4		X	Z
491	10	330		X	Y
		14		X	Z
530	10	325	X		Y
		15	X		Z
806	10	6		X	X
820	10	14	X		X
		Z-axis			
830	1.0	3	X		X
		2	X		Z
		3.5		X	X
		2		X	Z
853	10	38	X		X
		17	X		Z
800	10	40		X	X
		20		X	Z
530	10	31	X		Y
500	10	35		X	Y

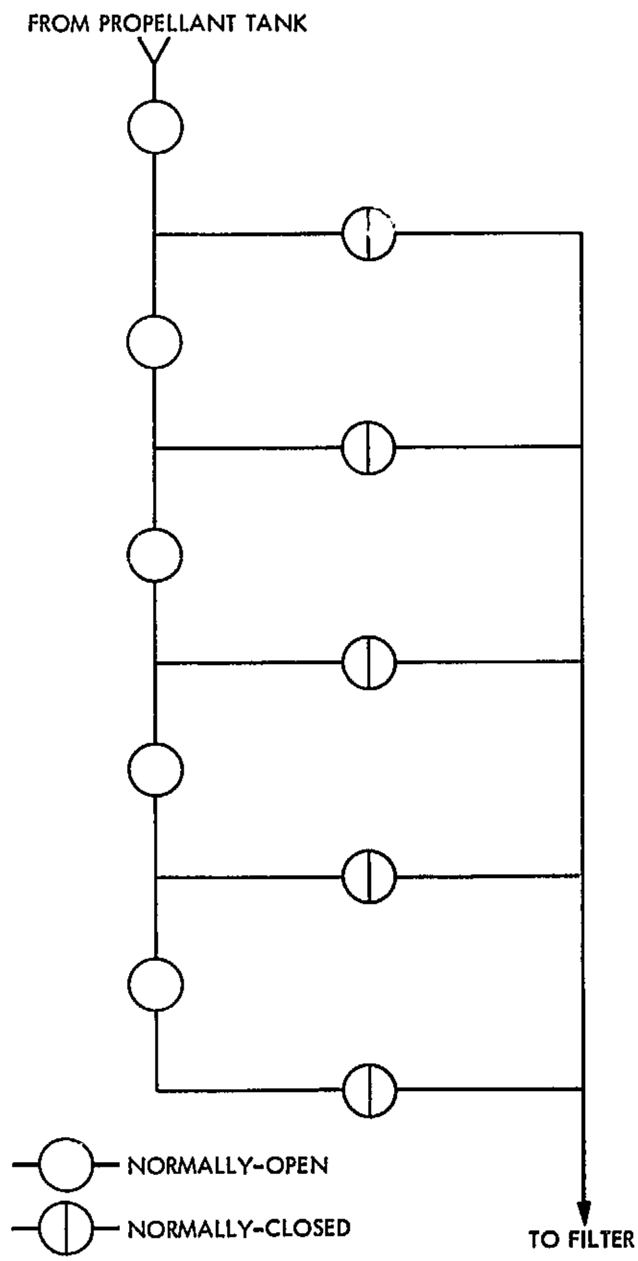


Fig. 1. TCPS explosive-actuated valves

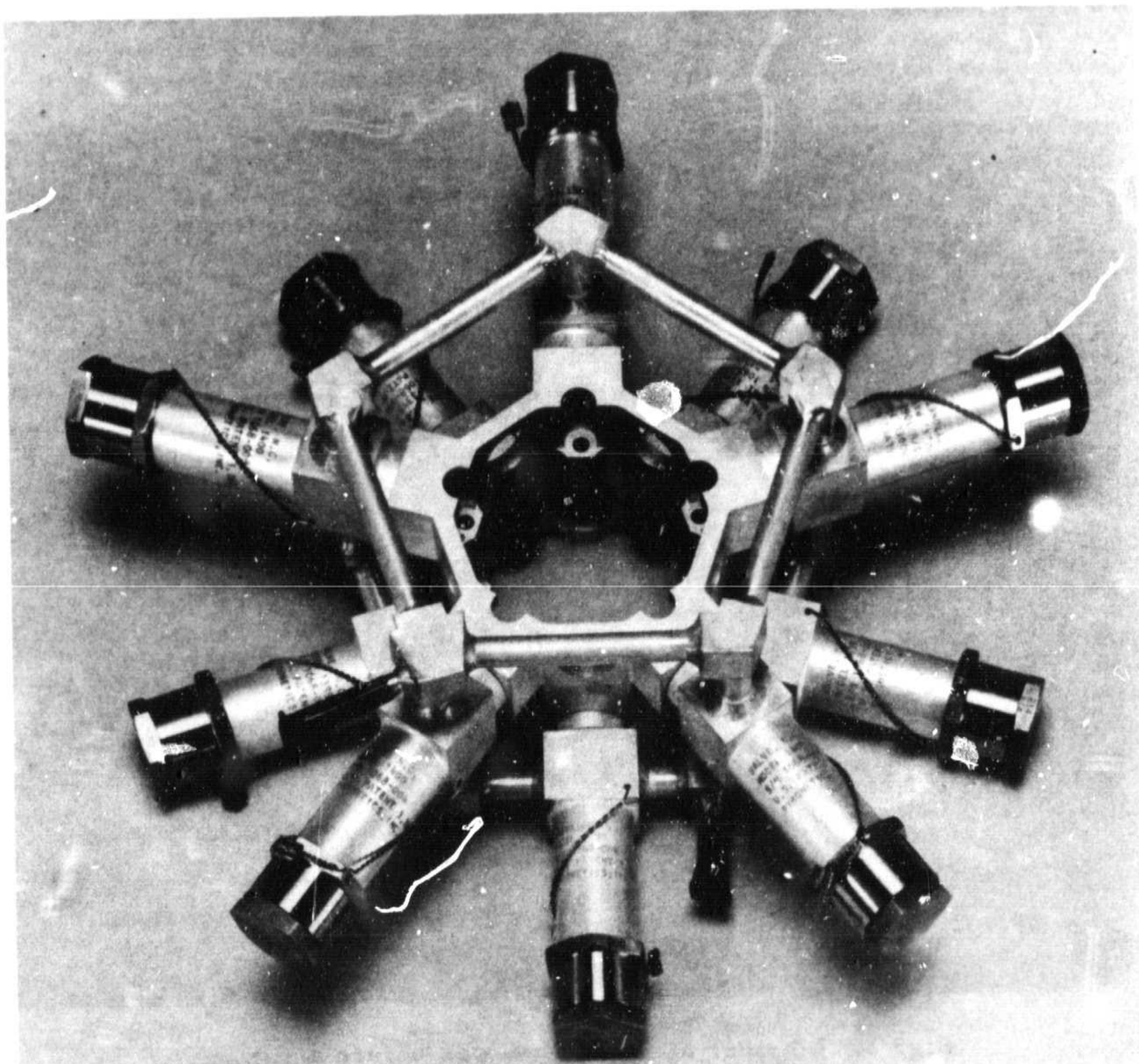


Fig. 2. Feasibility demonstration manifold

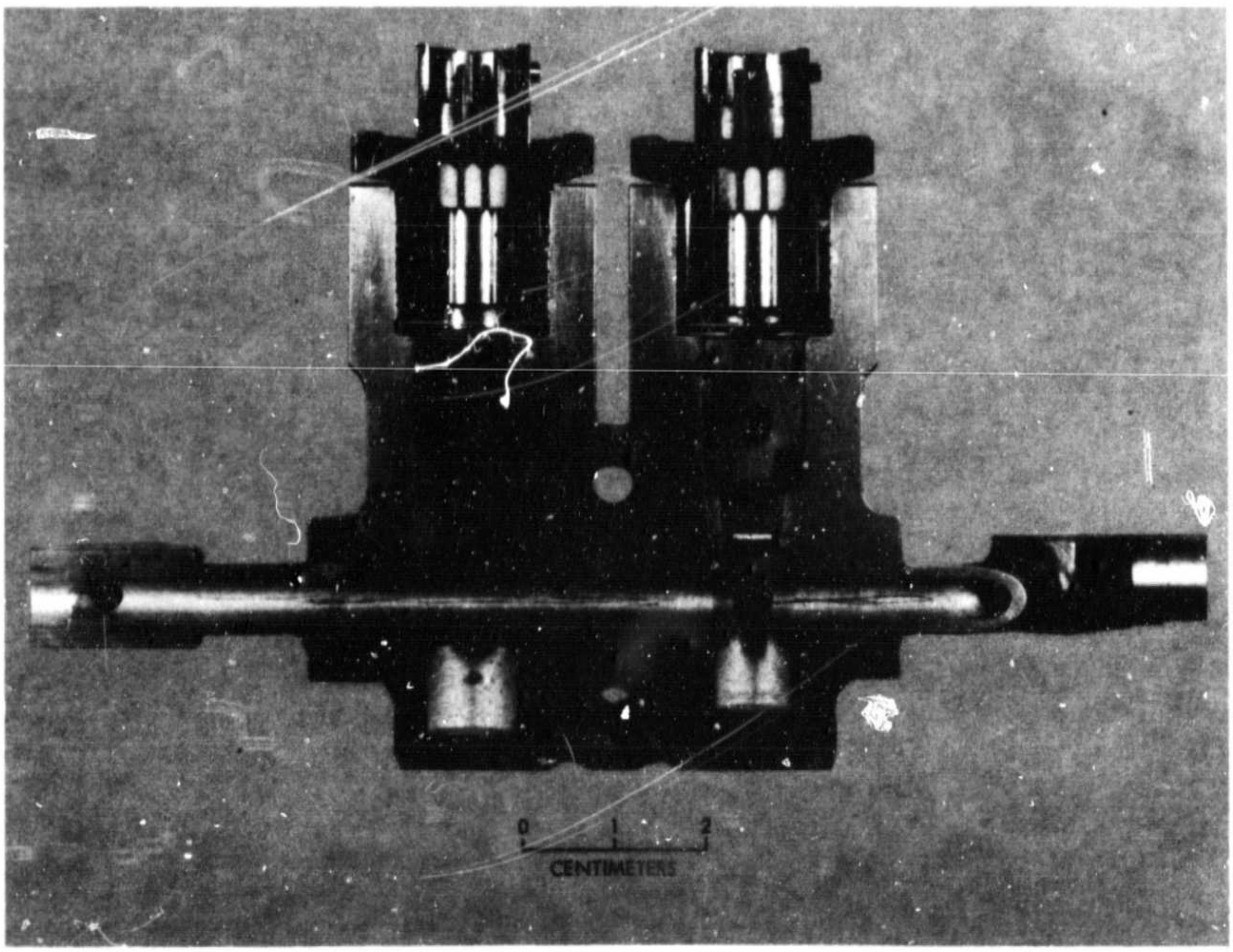


Fig. 3. Mariner Mars 1969 valves before actuation

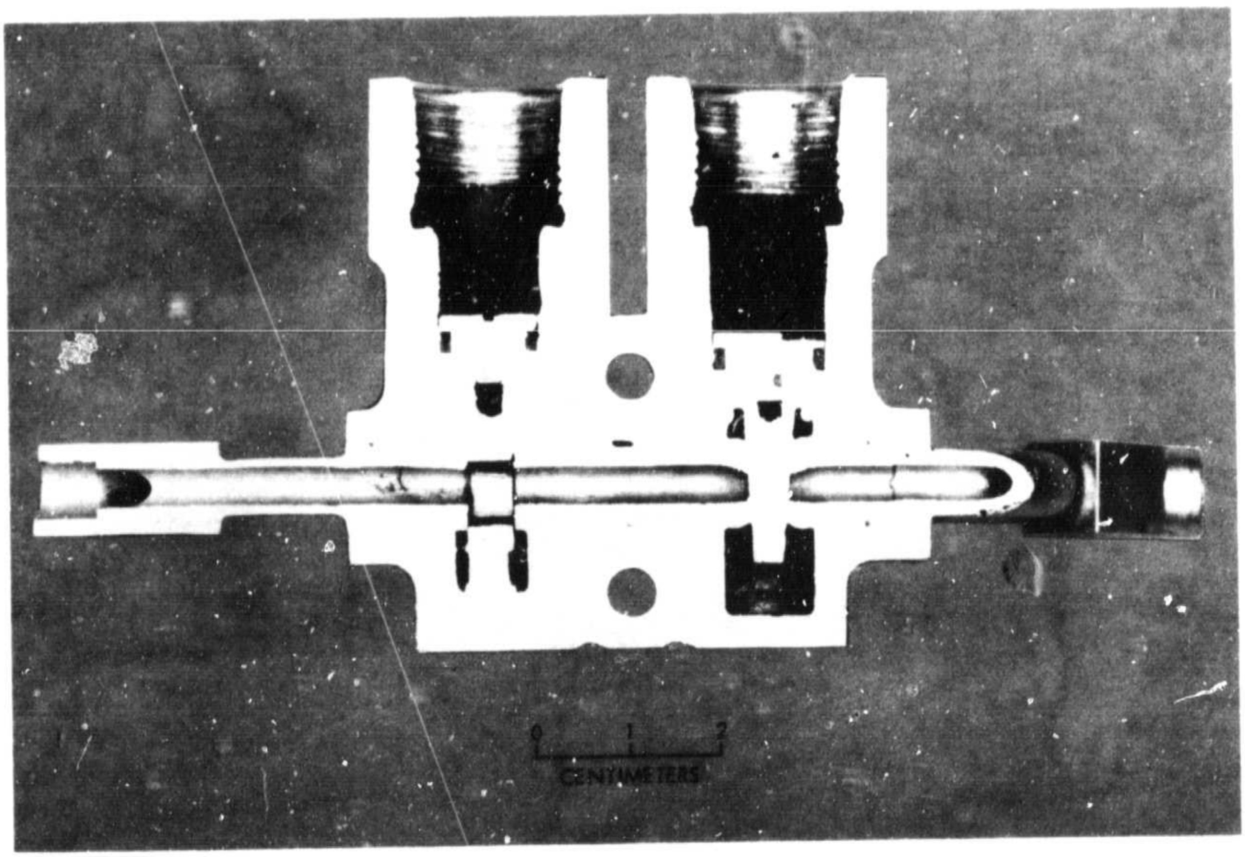


Fig. 4. Mariner Mars 1969 valves after actuation

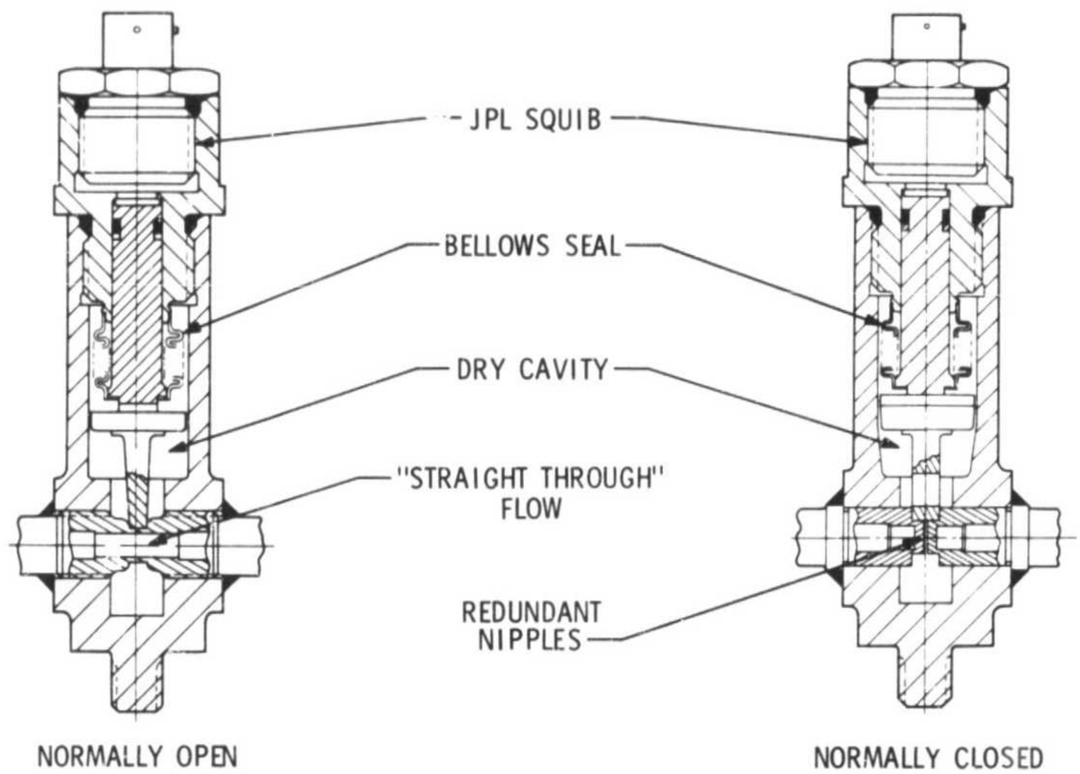


Fig. 5. Explosive-actuated valves

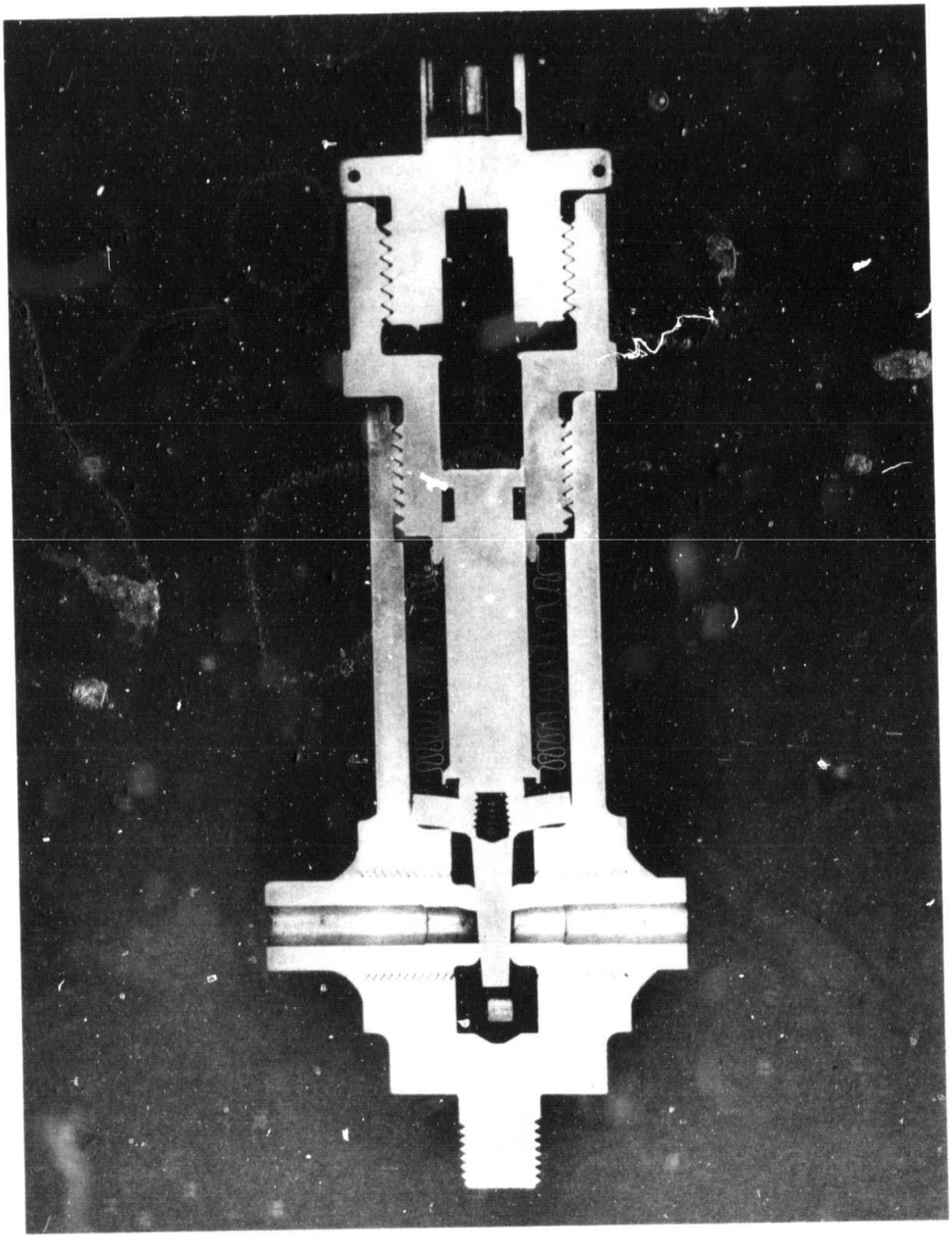


Fig. 6. Actuated normally open valve

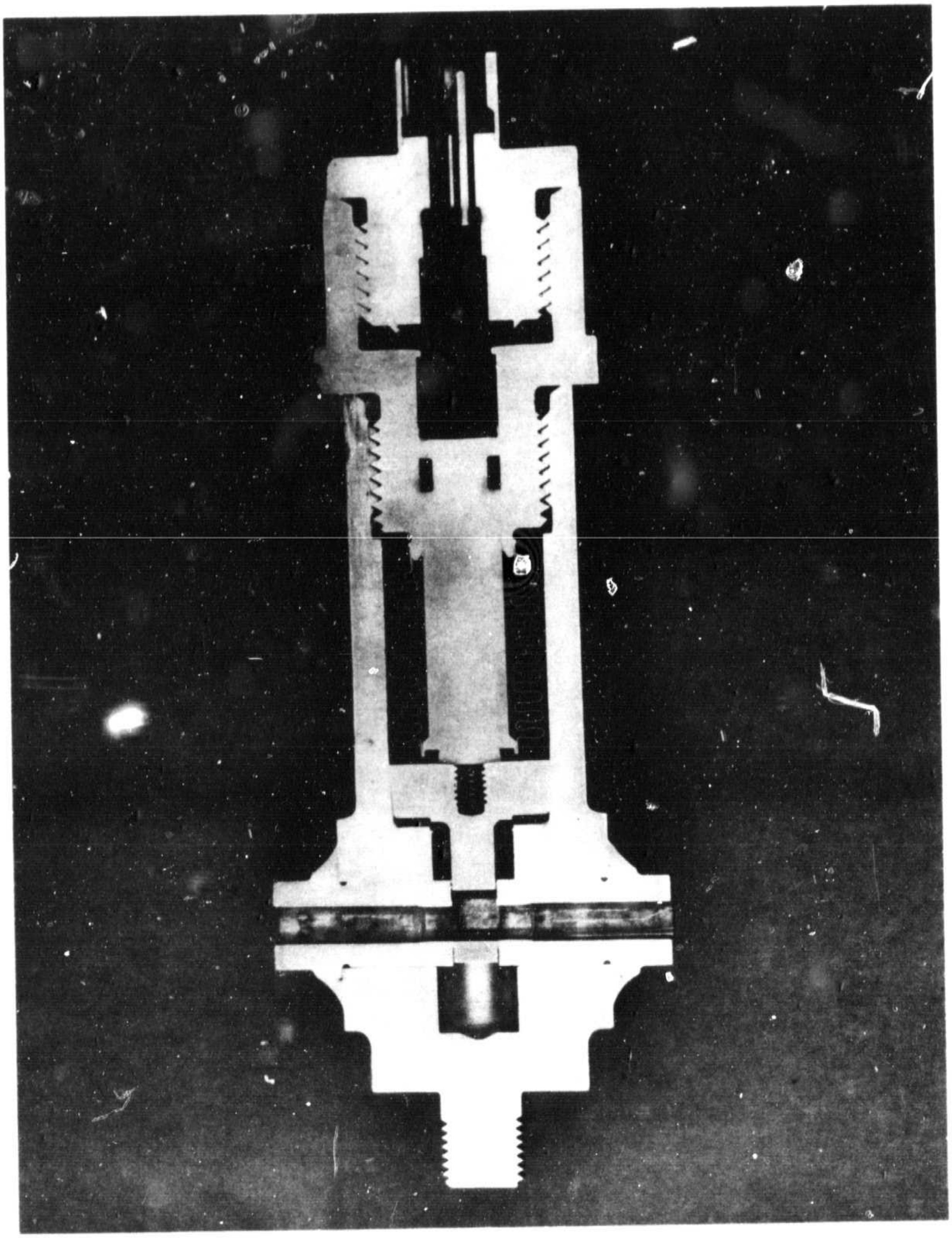


Fig. 7. Actuated normally closed valve

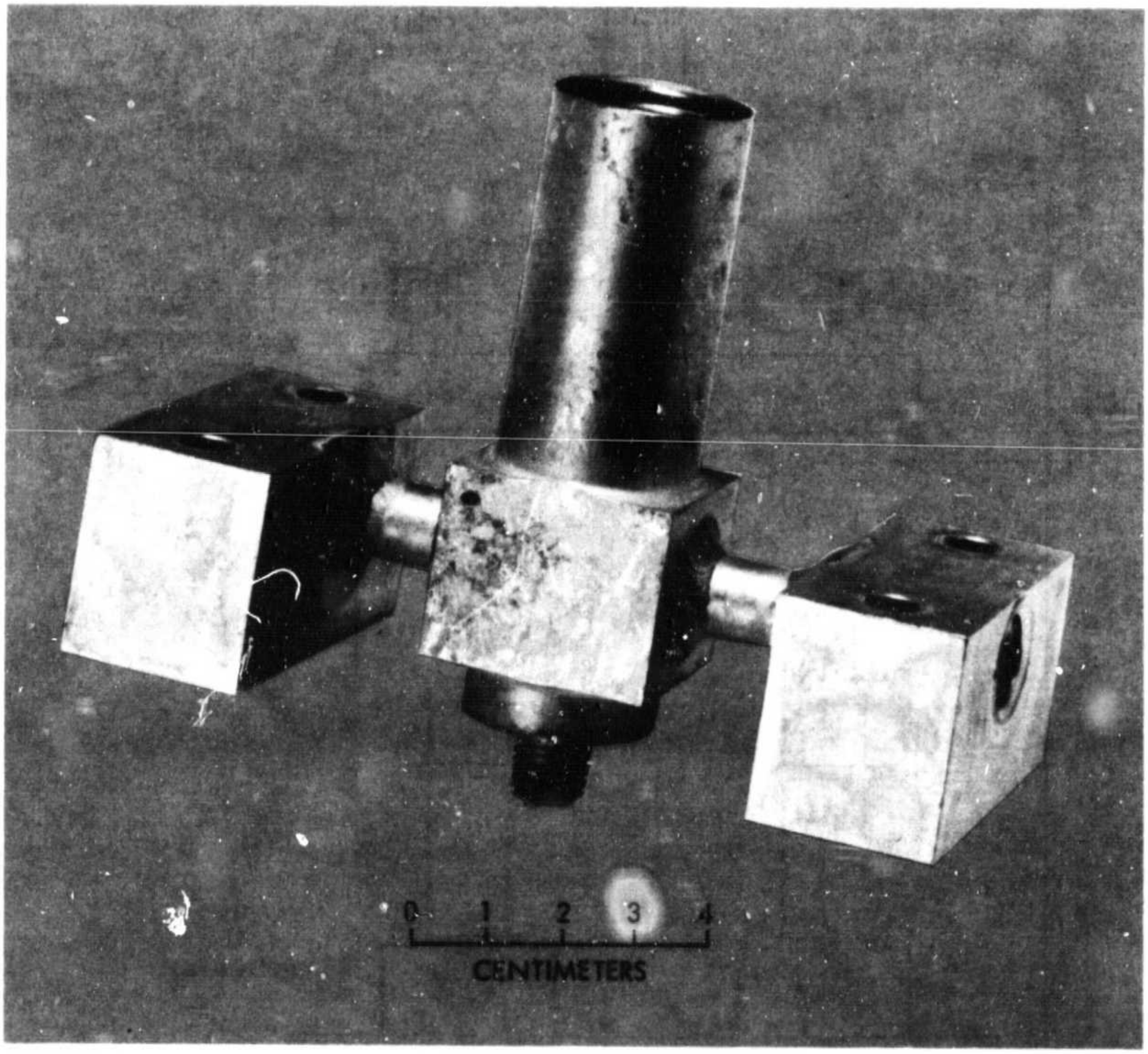


Fig. 8. Modified body assembly

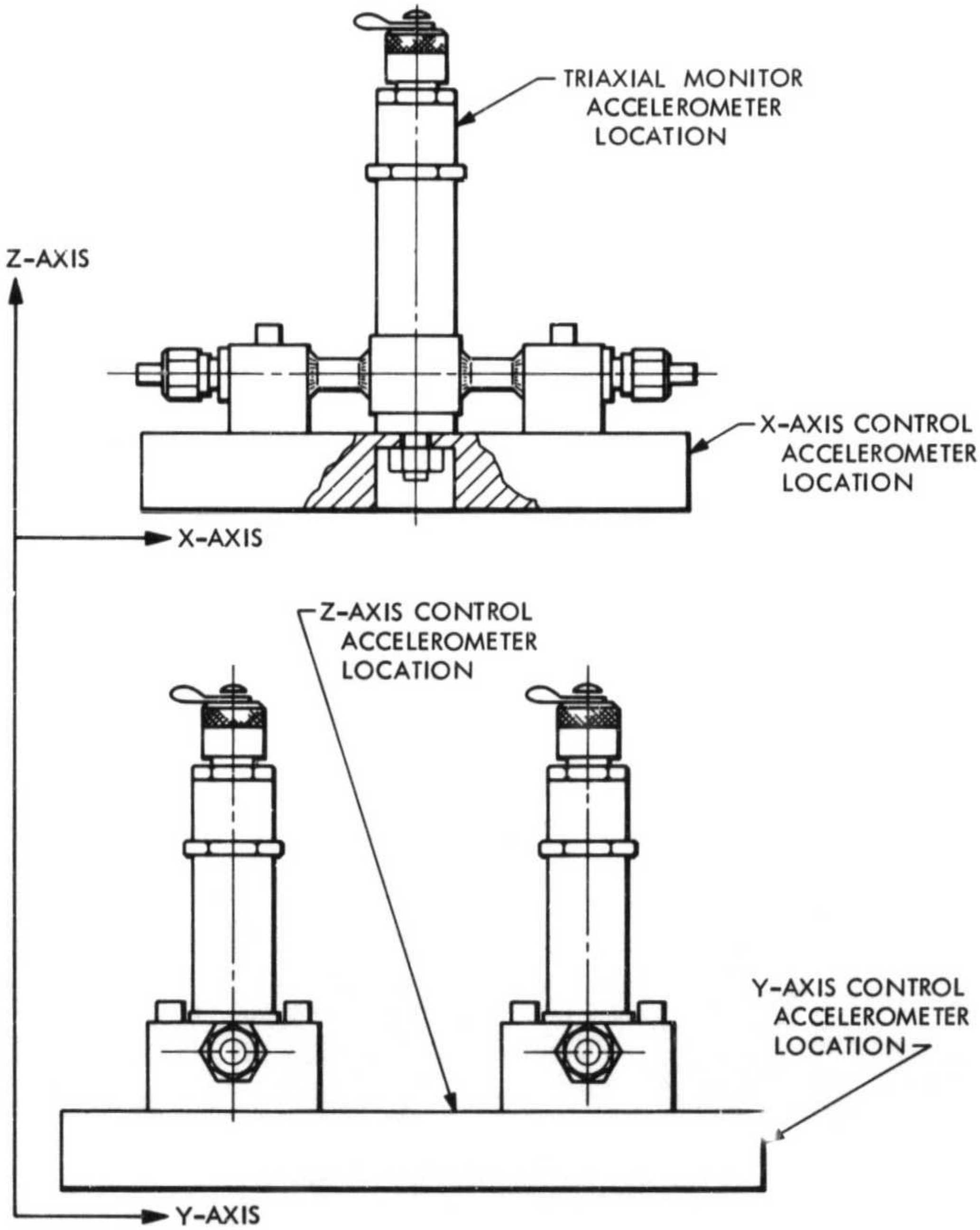


Fig. 9. Test configuration and axes definition

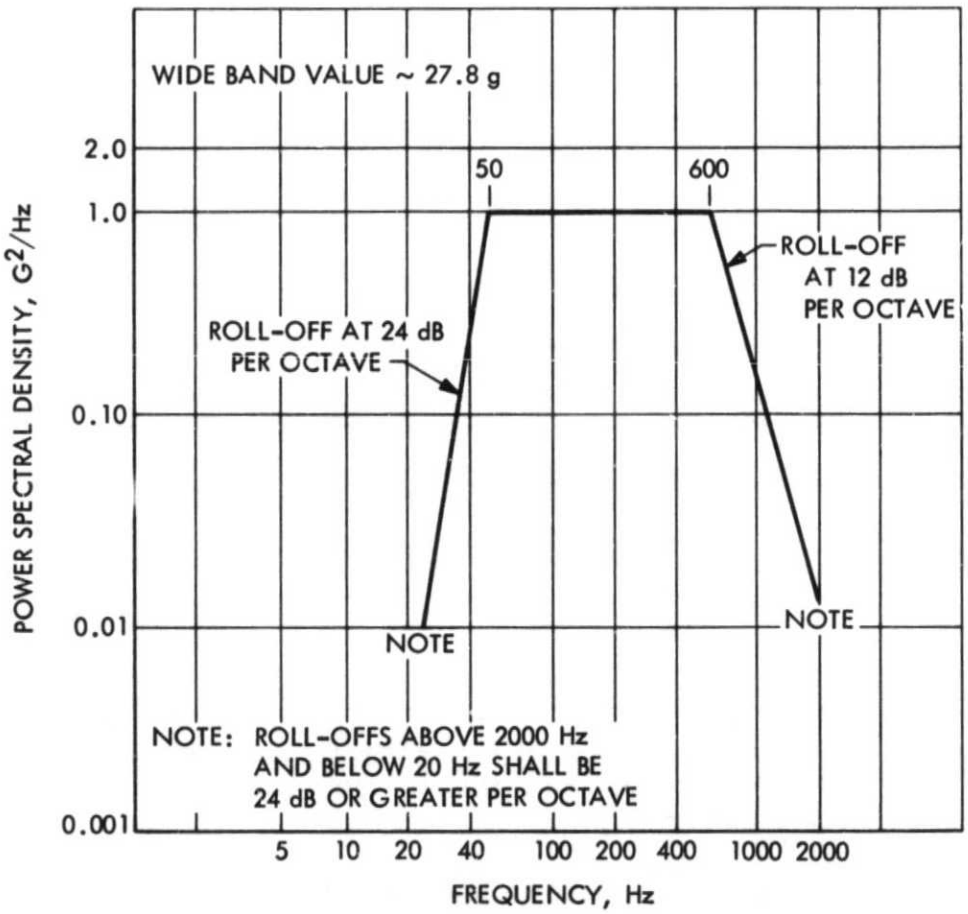
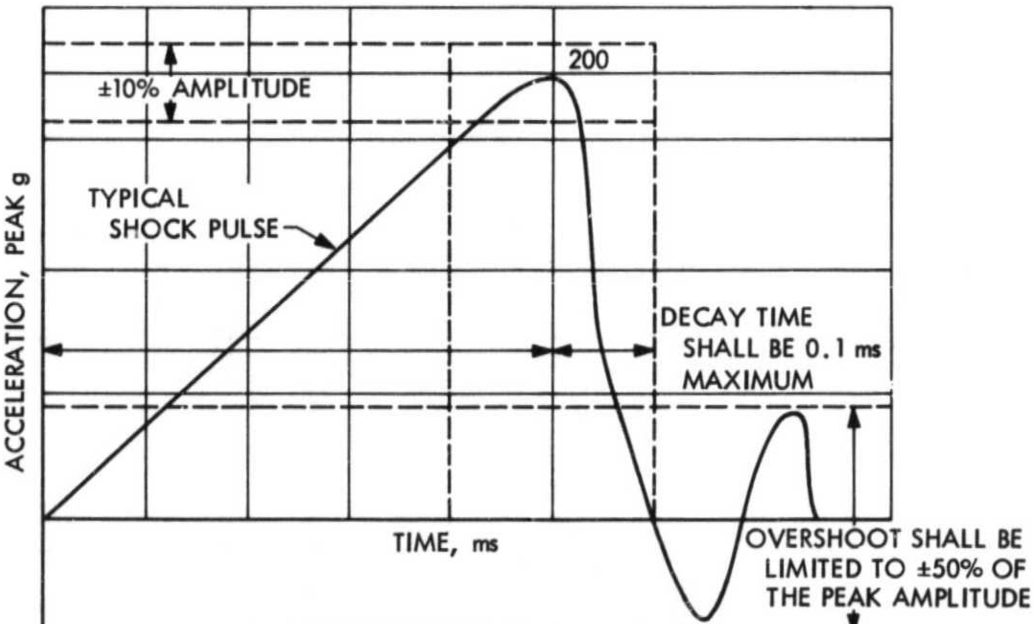


Fig. 10. Random vibration spectrum



NOTE: SOME LATITUDE IS ALLOWABLE FOR THE WAVE SHAPE OF THE SHOCK PULSE. HOWEVER, IT IS DESIRABLE THAT THE SHAPE CONFORM TO THAT OF A TERMINAL PEAK SAWTOOTH AS NEAR AS PRACTICAL.

Fig. 11. Shock pulse

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