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TECHNIQUES FOR IMPROVING THE OPENING OF THE MAIN DIAPHRAGM IN A LARGE COMBUSTION DRIVER

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TECHNIQUES FOR IMPROVING THE OPENING OF THE MAIN DIAPHRAGM IN A LARGE COMBUSTION DRIVER

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SUMMARY

Refinements in operating techniques to improve the piercing process and the lobe formation of the main diaphragm in a large combustion driver are described. Problems associated with time variations in the driver combustion process as they affect the form of the diaphragm petalling are discussed. The use of a Pierce Analog System (PAS) to actuate the diaphragm punch is shown to be beneficial from the standpoint of (1) diaphragm lobe shaping, (2) full utilization of the combustion energy, and (3) reduction in the scatter in the run-to-run primary shock velocity. Consistent opening of a diaphragm into four triangular-shaped lobes is shown to be attained with the use of a properly designed piercing head.

INTRODUCTION

The Ames 1-foot shock tunnel is a combustion-driven gasdynamic testing facility which operates at Mach numbers from 10 to 15 with air, CO_2, and other gas mixtures. The operating principle of the facility is described in references 1 and 2. Its basic components include a large combustion or driver chamber (24-ft by 27-in. I.D.), a driven or shock-tube section (40-ft by 6.2-in. I.D.), a conical nozzle, a test section 1-foot square, and a vacuum chamber. A rupturable diaphragm separates the driver- and driven-tube sections as shown in figure 1. The diaphragm is opened by means of a squib-powered piercing mechanism.

The 100-cu ft driver with throttle plates at the entrance to the driven tube (and the large driver-driven tube area ratio) is designed to give a particular tailored-interface mode of operation. A reservoir enthalpy of about 5000 Btu per pound is produced with air as the driven gas. To obtain this reservoir enthalpy, the helium driver gas is heated by the combustion of oxygen and hydrogen to a temperature of 4000° F and to a pressure of about 5200 psia from an initial pressure of 750 psia. The use of the large combustion chamber created certain unique problems. One problem arose because although the combustion process is generally consistent and the peak pressures are reproducible, the time from ignition to the peak value varies considerably from run to run. It is essential for efficient and safe operation to contain the gases in the chamber until the mixture can burn completely.

This paper discusses some of the problems associated with time variations in the driver-combustion process as they affect both diaphragm petalling and the primary-shock strength in the driven tube. Techniques are described which provide consistent diaphragm petalling and permit timed piercing to occur concurrently with the attainment of peak pressure in the driver chamber (completion of combustion).

DIAPHRAGM DESIGN

Hemispherical diaphragms only have been used between the driver- and driven-tube sections in the arrangement shown in figure 1. The dome shape of the diaphragm was determined initially by nonrupture tests in which the driver was operated as a constant-volume combustion chamber. The diaphragms are cold die formed. They are shaped and stressed so that they do not bulge from their shape during normal combustion in the driver. This is an essential point since it permits the spacing between the pierce tip and the inner surface of the apex of the dome portion to be preset accurately. If the spacing is too close, the pierce cannot penetrate the diaphragm; if it is too great, the pierce attains such a high momentum that it damages the mechanism at the end of its stroke. Downstream of the diaphragm, a section of the driven tube has been cut out to provide space for the lobes to fold into when the diaphragm opens.

The choice of material from which the diaphragm is fabricated was found to be important. Initially, warehouse stocks of class 18-8 stainless steels were used. Through trial and error, it was found that a particular steel of this class, a Jones and Laughlin type 321 stainless with a D finish, produced the most consistent lobe formation without fragmenting. It has a tensile strength of 86,000 psi, a yield strength of 39,600 psi, and elongation of 52 percent and can be bent 180° in a radius equal to the sheet thickness. The thickness at the apex of the dome of a diaphragm formed from a 0.125-in.-thick sheet is reduced in the drawing process to 0.100 ±0.002 in. The thickness distributions along four mutually perpendicular rays are measured and all units falling outside certain tolerance limits are discarded. This procedure provides some assurance that upon rupturing, the diaphragm tears uniformly. A crimp ring in the flange both positions and helps hold the diaphragm in place between the clamping rings.

DIAPHRAGM PETALLING

A mechanical piercing system, with a four-sided punch head driven by an explosive cartridge, is used to initiate diaphragm opening. To eliminate the chance of the diaphragm's opening before the combustion process was completed, the pierce system was originally programmed to pierce at a fixed time after the initiation of combustion. The time selected was that which corresponded to the longest time necessary to allow the gas mixture to burn completely. Operating experience showed this time to be 710 msec. At the preset time, the punch head pierces the diaphragm and forms a four-sided hole. The hot, high-pressure gases in the driver then cause the diaphragm to tear, forming petals or lobes which fold back against the sides of the driven tube. Photographs of typical lobe openings are shown in figures 2 and 3.

While four-lobe openings are desired, operating experience showed that in some instances the diaphragm, although pierced with a four-sided punch, opened into three lobes as shown in figure 2(c). With a three-lobe opening, the tear line between adjacent lobes has a tendency to curl rather than to terminate in a sharp notch (compare figs. 2(a) and 2(c)). This curl has the effect of lifting a portion of the opened lobe off the wall and into the hot gas stream. When this occurs, the lobe is heated and becomes weakened. If the action of the gases causes the piece of lobe to break off, it is picked up and accelerated by the high velocity of the stream and can be damaging to tunnel components.

Statistically it was noted that the loss of portions of diaphragm lobes (from a three-lobe opening) was associated with rapid combustion times. The time required for the pressure in the combustion chamber to rise from its initial value to the maximum varies considerably from run to run. With normal, smooth combustion, the time required can be as short as 400 msec or as long as 700 msec. The variation in the pressure-time histories of the driver chamber that occurs for normal combustion is shown in figure 4. The causes of these differences in the time to reach peak pressure are difficult to delineate and are probably associated with minute changes in the combustion environment. With the "fixed-time" pierce and with an early pressure peak (point a, fig. 4), the gas pressure in the driver was reduced as the gas cooled. Consequently, the measured shock velocity in the driven tube with diaphragm opening corresponding to point b was 9,600 fps as compared to 10,050 fps for point c.

It was noticed that when the combustion pressure peaked at about 650 to 700 msec, the diaphragm generally lobed evenly with no tendency for a lobe to fold over (see fig. 2(c)). If the combustion pressure peaked early at about 400 msec, the diaphragms generally lost portions of their lobes (fig. 3(c)). Examination of the records of 59 consecutive diaphragm openings indicates the following breakdown between four- and three-lobe types (driver-driven conditions remained unchanged):

four-lobe (similar fig. 2(a))	42 percent
four-lobe (similar fig. 2(b))	6 percent
three-lobe (similar fig. 2(c))	11 percent
three-lobe (similar fig. 3(a))	23 percent
three-lobe (similar fig. 3(b))	6 percent
three-lobe (similar fig. 3(c))	12 percent

There was no instance in which a petal of a four-lobe opening showed a tendency to fold over.

It is believed that two factors contribute to the poor diaphragm operation noted with a three-lobe opening and an early peak combustion cycle (for a fixed pierce time). First, with the longer time interval between peak pressure and pierce, the diaphragm absorbs a greater amount of heat with an attendant loss in its mechanical strength properties. Second, the large lobe base (compared to a 4-petal lobe) tends to position the effective neutral axis of the individual lobe well away from the plane of the metal. This causes a greater deformation at the base of a lobe and induces a crack to propagate normal to the main parting line to relieve the stress distribution along the circumference of the lobe. (Compare fig. 2(a) with figs. 2(c) and 3.)

It was apparent that better control of the pierce time relative to the peak combustion pressure would be required if consistent diaphragm petalling were to be achieved.

PIERCE ANALOG SYSTEM

To compensate for the variation in the pressure rise time of the combustion process in the driver, a Pierce Analog System (PAS) was installed in the facility. The PAS was designed to differentiate a pressure signal from the driver with respect to time and, at the time the derivative becomes zero (at peak pressure), initiate piercing of the diaphragm. This system takes the place of the original pierce timing control which was based on a fixed time interval. A block diagram of the PAS is shown in figure 5. There are three input signals: an analog signal from a pressure transducer located in a port in the combustion chamber, a pulse signal from a pressure switch (located in the same port), and a pulse signal from the discharge of the capacitor bank network (to the ignition wires within the combustion chamber). With the PAS, the time from peak pressure in the combustion chamber to pierce can be programmed. Typical pierce times used with the PAS are indicated by the solid symbols on the curves of figure 4.

The operation of the PAS is as follows: The system is started into operation for a GO situation by a pulse signal from the discharge of the capacitance network into the wire ignition system (initiation of combustion). The timer t_1 (fig. 5) switches Gate No. 1 into the pressure transducer signal circuit. The pressure switch signal opens Gate No. 2. As the rate of change from the pressure transducer signal passes through zero, a pulse (Schmitt trigger) is produced that triggers the thyratron tube circuit. The thyratron pulse is sent to the pierce circuit and through a time-delay circuit to the nozzle closing mechanism. While it is not pertinent to the diaphragm operation, the requirement for a nozzle closing device influenced the design of the PAS and will be discussed later. Certain protective or NO-GO arrangements were also incorporated in the design as follows: If the pressure transducer signal reaches 3800 psi before time t_1, the pressure switch signal is sent to Gate No. 3 to trigger a thyratron pulse to the nozzle valve system. Also, if the pressure transducer signal does not reach 3800 psi before time t_2, a thyratron pulse triggered from time-delay unit t_2 is sent to the nozzle valve system. Both actions will abort the shot and immediately close the nozzle valve, to protect the tunnel structure downstream of the nozzle and the models in the test section, in case of a detonation or a very slow combustion.

In either case, the initial shock-wave velocity within the driven tube would not be that required to establish the tailored interface condition in the test-gas reservoir.

A total of 41 diaphragm openings were made with the PAS in operation. The lobe formations were as follows (driver-driven conditions and punch shape remained unchanged).

four-lobe (similar fig. 2(a))	34 percent
four-lobe (similar fig. 2(b))	2 percent
three-lobe (similar fig. 2(c))	39 percent
three-lobe (similar fig. 3(a))	18 percent
three-lobe (similar fig. 3(b))	5 percent
three-lobe (similar fig. 3(c))	2 percent

A comparison of this and the preceding tabulation shows that the PAS improved the number of satisfactory diaphragm openings (typified by fig. 2) from 59 to 75 percent.

In addition to improving diaphragm petalling, the PAS serves another equally important function. It assures that the diaphragm opens near maximum combustion chamber pressure and temperature. For the curve in figure 4, with pierce following point a, the measured shock velocity was 10,200 fps (as compared to 9,600 fps for point b). The PAS has reduced scatter in the primary shock velocity, in the driven tube, from about 7 percent to 1.5 percent at a nominal velocity of 10,100 fps. In turn, this has improved the run-to-run repeatability of conditions in the test-gas reservoir.

CONCAVE-SURFACE PUNCH

With the Pierce Analog System in operation, the number of three-lobe diaphragm openings was still too large to be considered satisfactory. Considerable thought was given to the remaining variables that could affect punch entry and diaphragm tearing. A review of the early developmental work that resulted in the use of the particular four-sided shape illustrated in figure 6(a) showed the following: In the initial shakedown testing of the facility, a conical shape had been tried first without success. Even with different cone angles, the punch generally pierced without inducing lobing. A pyramid shaped punch with flat sides and with a slightly flattened tip was tried, which apparently produced successful diaphragm openings into both three- and four-lobed flares. At this time in the development of the facility many other problems were limiting operation. As a result, further punch development was deferred. It was not until the refinements of the PAS and the consistent attainment of smooth combustion in the driver that it became increasingly evident that the pierce shape was a contributing factor to the type of lobe formation.

To evaluate the opening formed by a pierce head, several flat-sided punches were fired into diaphragms. Typical results are shown in figure 7.

Although a square hole was formed in each case, as shown in figure 7(b), a careful examination of the corners of the holes indicated that many did not show a crack emanating from the corner into the metal. Thus, there probably was not an adequate crack or notch in each corner to induce the stress concentration believed necessary to start a tear along each of the hoped-for paths (i.e., four mutually perpendicular paths radiating from the corners of the pierce). In fact, as can be noted in figure 7(a), the axis of the tear into one corner (lower right in figure) is almost parallel to the plane of the metal rather than perpendicular to the metal.

In an effort to improve the piercing characteristics, the punch shape was notched; that is, metal was removed between adjacent edges as shown in figure 6(b) to obtain a better cutting action in each corner of the opening. Several diaphragm openings were made with the notched-surface piercing heads. Although satisfactory lobes were formed in all cases, the ratio of three-lobe to four-lobe openings was about even. The hole formed in the diaphragm was essentially the same as that noted for the flat surface punch as shown in figure 7.

To increase the cutting action at pierce, a punch shape was designed with hollow ground surfaces and with thin, concave edges, as illustrated in figure 6(c). Also, the tip of the pierce head had a smaller entry angle, as compared to the straight-sided units. Figure 8 shows the pierce in a diaphragm obtained with a concave-surface piercing head. A distinct vee-notch is formed in which the thickness of the uncut metal along a notch is tapered from that of the parent metal (0.1 in.), at the edge away from the hole, to a paper-like thickness as the notch fairs into the pierced hole. This arrangement provides for the formation of localized high-stress concentrations to induce four well-formed tear paths.

The diaphragm openings obtained with a concave-surface pierce head and the PAS have all been satisfactory. This shape is in daily use in the facility and in 73 firings, 71 openings were into four-lobe types similar to that noted in figure 2(a). The other two openings were into three-lobe types (fig. 2(c)). In all cases, the diaphragm weight measured before and after each test indicated no loss in material.

NOZZLE CLOSING MECHANISM

A quick closing mechanical nozzle valve has been designed, constructed, and employed in conjunction with the PAS. One necessity for this device arises from the fact that a large volume of hot, high-pressure driver gas remains in the driver and driven chambers at the completion of the test period. Since their combined volume is about 110 cu ft, the remaining gas (at about 4000 psi and 2000° R) would continue to flow through the nozzle and test section for several minutes. Thin-skinned models would be heated above the melting point, and fast-response pressure or force transducers mounted therein would be lost. Since the models and instruments are used for further tests, it is necessary that they be exposed to the hypersonic test gas for only the minimum time required for a specific experiment.

The assembly and details of the squib-operated nozzle closing mechanism are shown in figure 9. The valve was designed as part of the nozzle housing. A rectangular piece of copper is guided by a slot in the retaining block and has an open position and a closed position. In the open position, the hole through the copper block is concentric with the opening in the section of the upstream portion of the nozzle orifice. In the closed position, the passageway is blocked by the solid portion of the block. The weight of the moving parts, as shown in the right-hand side of figure 9, totals about 4 pounds. The mechanism is actuated by two explosive squibs which pressurize the cylinder chamber to approximately 6000 psi. Measurements have shown that the time from the instant the signal is sent to the primer circuit until the pressure starts to rise in the cylinder is about 10 to 15 msec. During this period the piston does not move. Coincident with the pressure rise, the piston starts in motion and travels its full distance (1-3/8 in.) in less than 2 msec.

CONCLUDING REMARKS

The present paper has summarized the recent experience with diaphragm operation in the Ames 1-foot shock tunnel. The modification of several components of the diaphragm piercing system has resulted in a substantial improvement in the repeatability of the primary shock-wave velocity and has virtually eliminated diaphragm lobe failure. It has been demonstrated that a pierce analog system can be used to open a diaphragm at the optimum time, regardless of the length of a normal combustion process in the driver section.

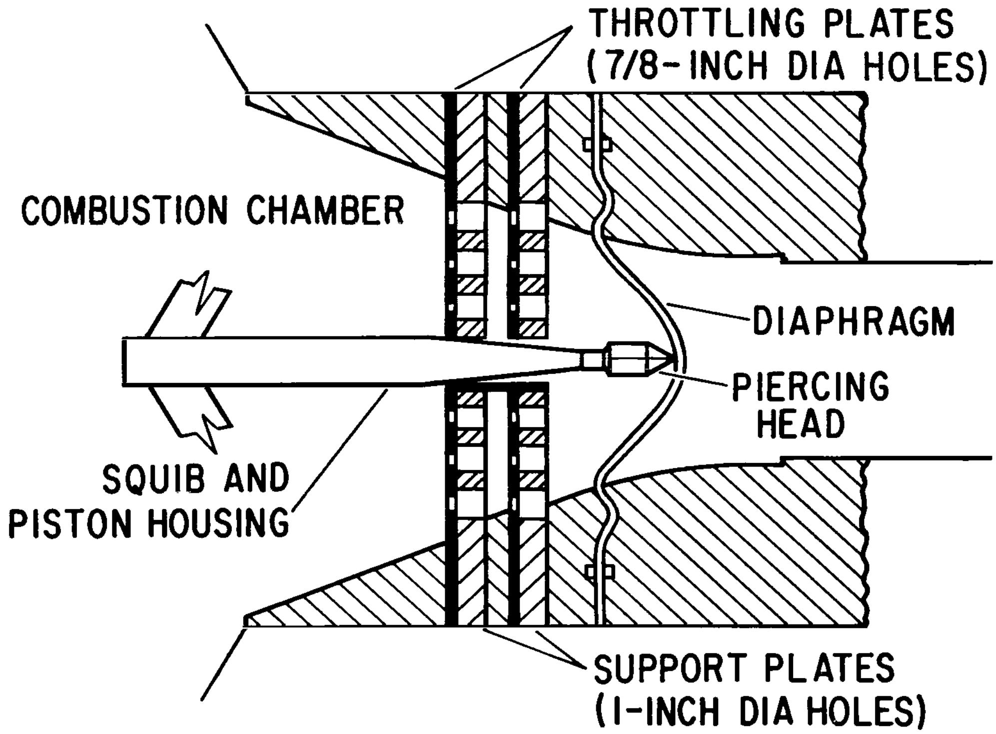
The pierce control circuit also serves to integrate the operation of a nozzle closing valve into the operating cycle of the facility, such that test models are protected from damage in the event of an abnormal functioning of the combustion-heated driver. If the pierce head is properly designed, the diaphragm can be consistently opened into a four-lobed configuration with no loss of material.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Jan. 7, 1965

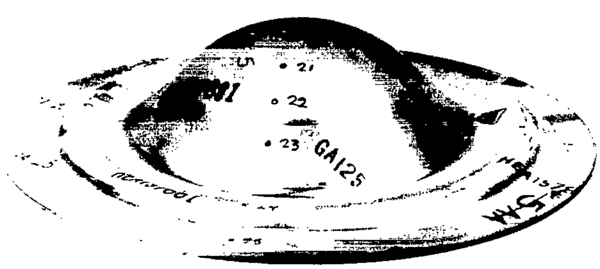
REFERENCES

1. Cunningham, Bernard E.; and Kraus, Samuel: A 1-Foot Hypervelocity Shock Tunnel in Which High-Enthalpy, Real-Gas Air Flows Can be Generated With Flow Times of About 180 Milliseconds. NASA TN D-1428, 1962.

2. Loubsky, William J.; Hiers, Robert S.; and Stewart, David A.: Performance of a Combustion Driven Shock Tunnel With Application to the Tailored-Interface Operating Conditions. Paper presented at Third Conference on Performance of High Temperature Systems, Pasadena, Dec. 7-9, 1964.



(a) Schematic detail of punch, throttling plates, and diaphragm.



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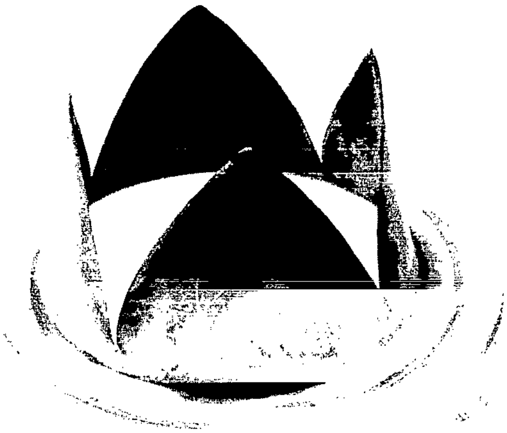
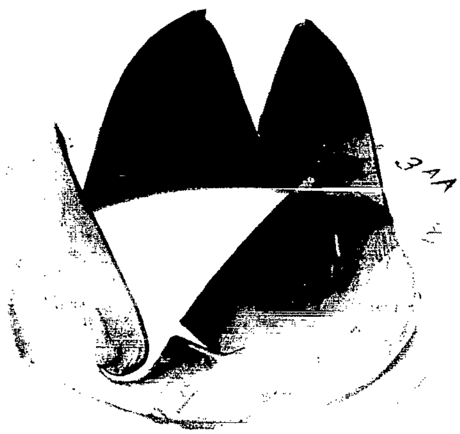
(b) Shape of diaphragm before rupture.

Figure 1.- Arrangement of driver-driven diaphragm section of the Ames 1-Foot Shock Tunnel.



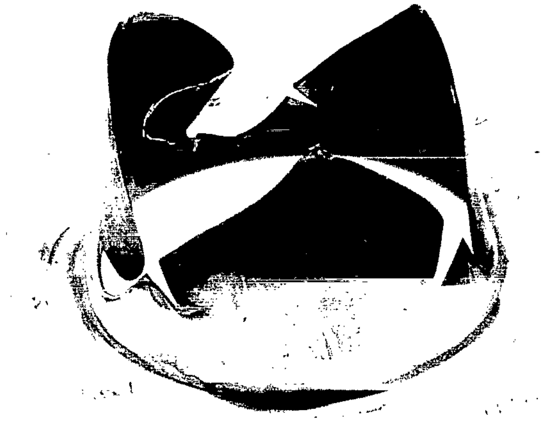
(a) Four-lobe, normal, even.



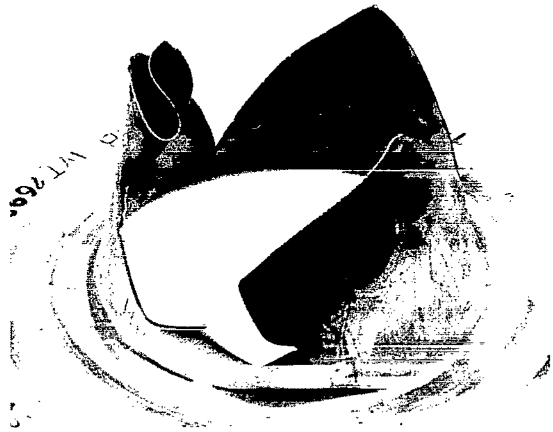
(b) Four-lobe, uneven.

(c) Three-lobe, normal.

Figure 2.- Lobe formation of diaphragm openings considered to be satisfactory.



(a) Three-lobe, small fold.



(b) Three-lobe, fold and tear.

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(c) Three-lobe, lost metal.

Figure 3.- Lobe formation of diaphragm openings considered to be unsatisfactory.

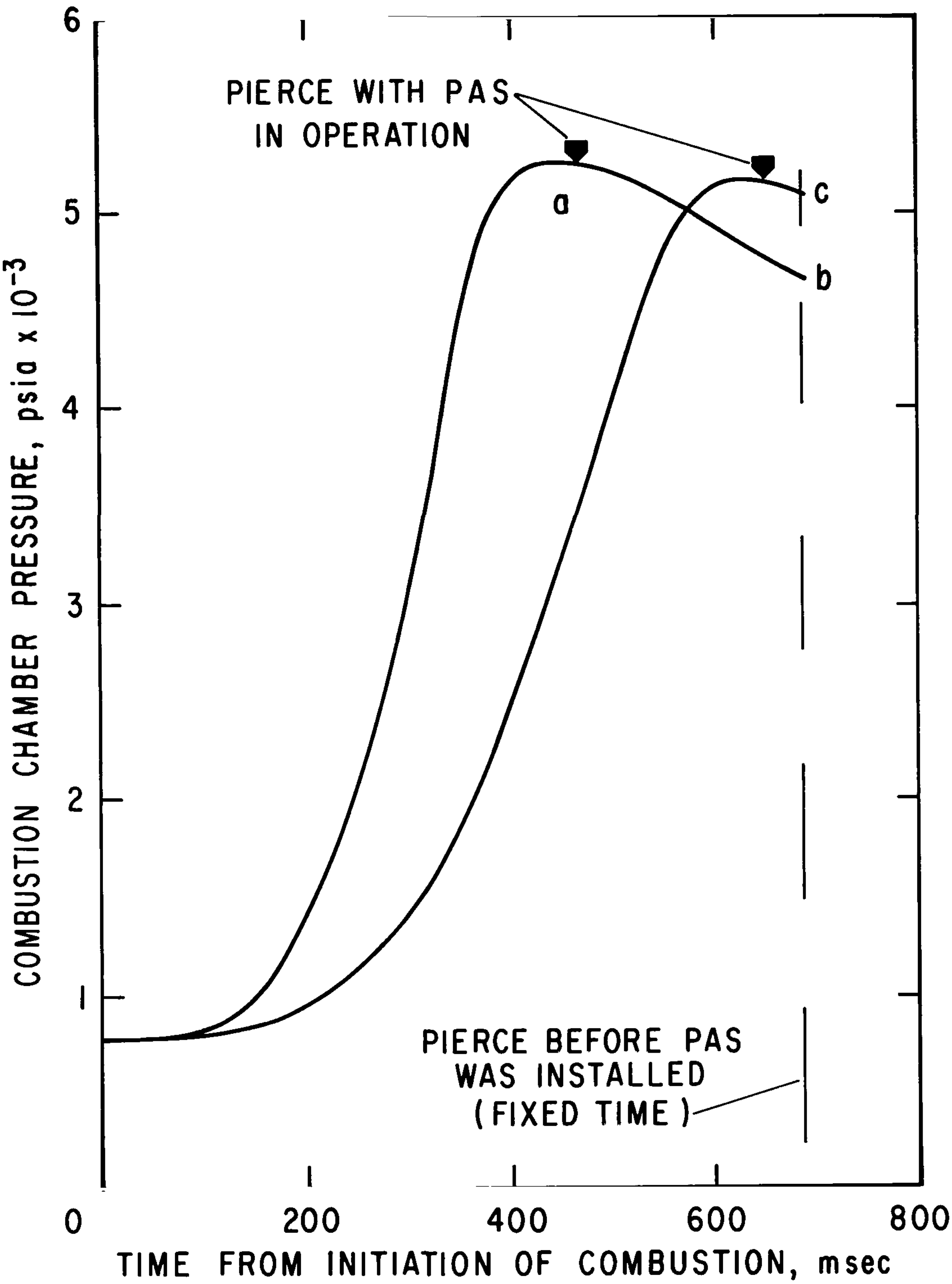


Figure 4.- Representative records of the fastest and slowest pressure-time variations indicative of normal combustion in the driver of the Ames 1-Foot Shock Tunnel.

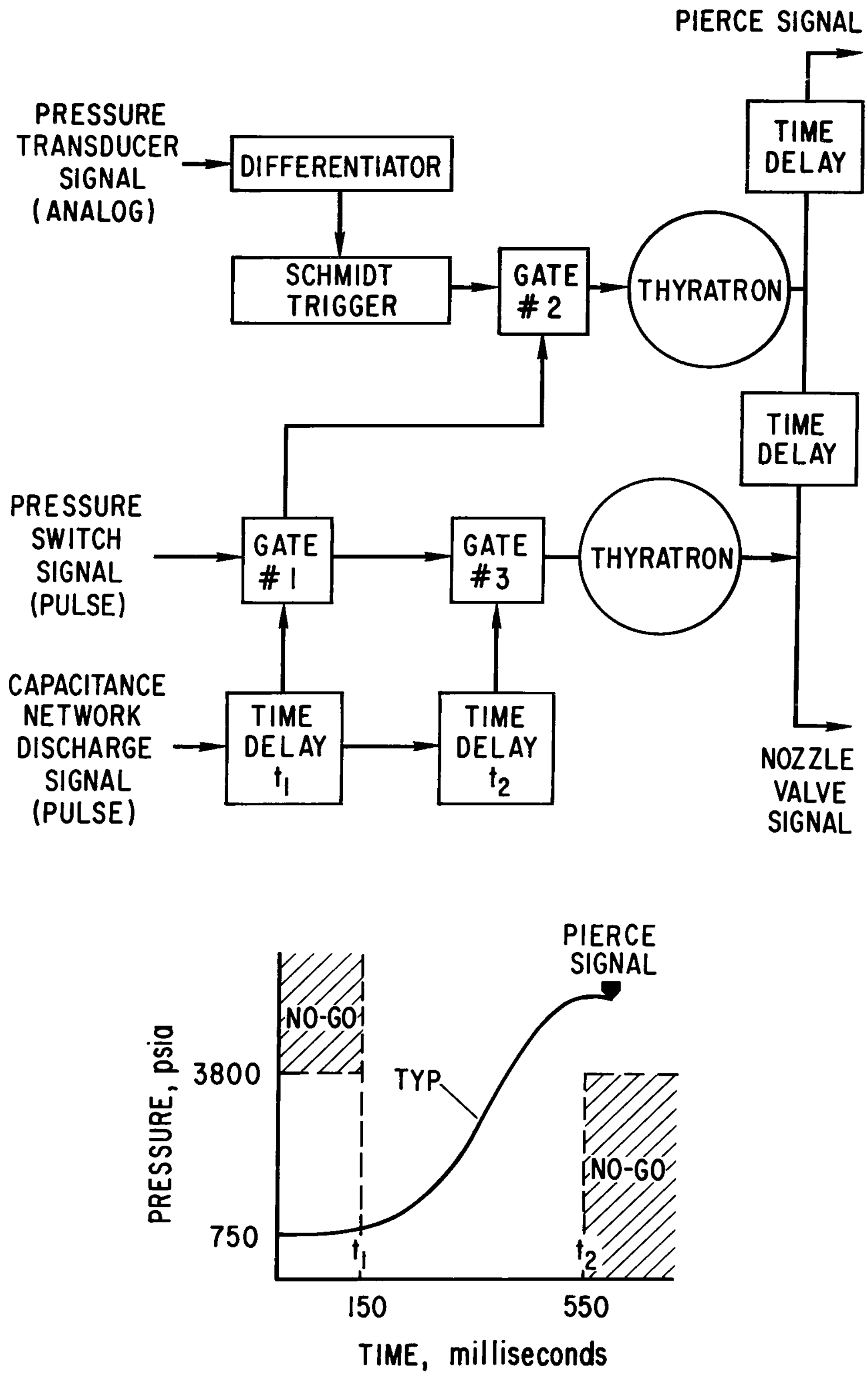


Figure 5.- Block diagram of Pierce Analog System (PAS).

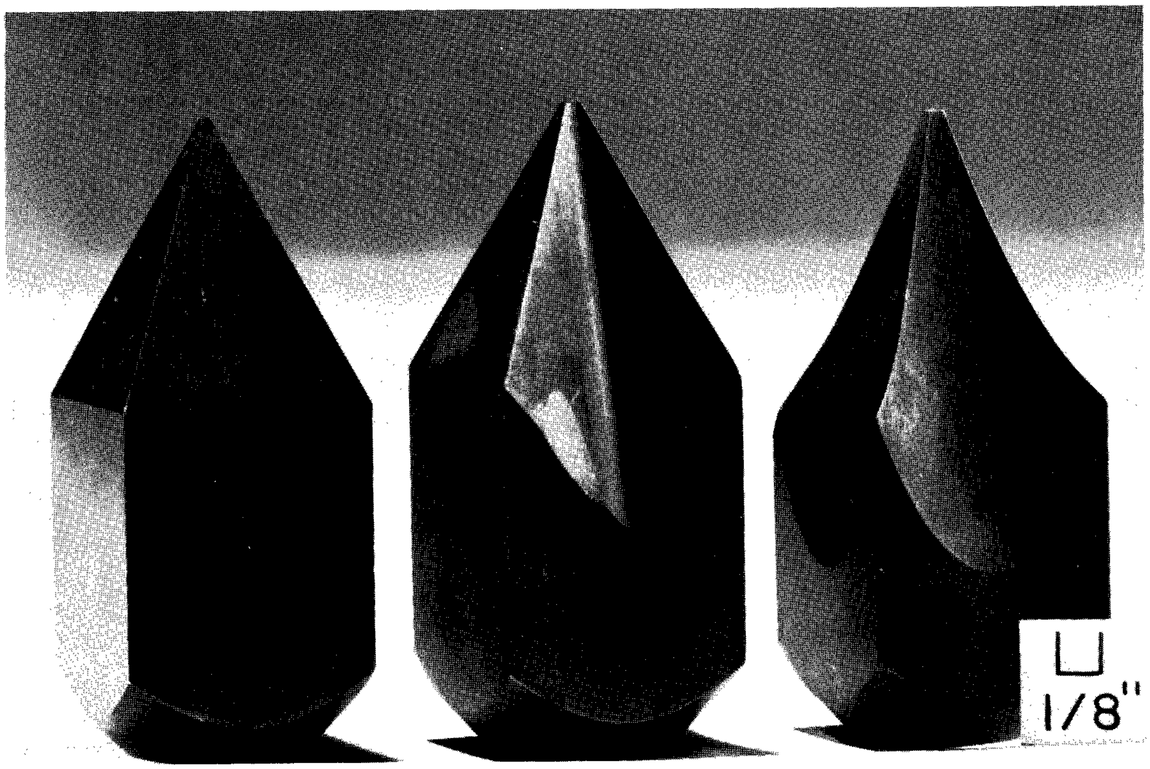
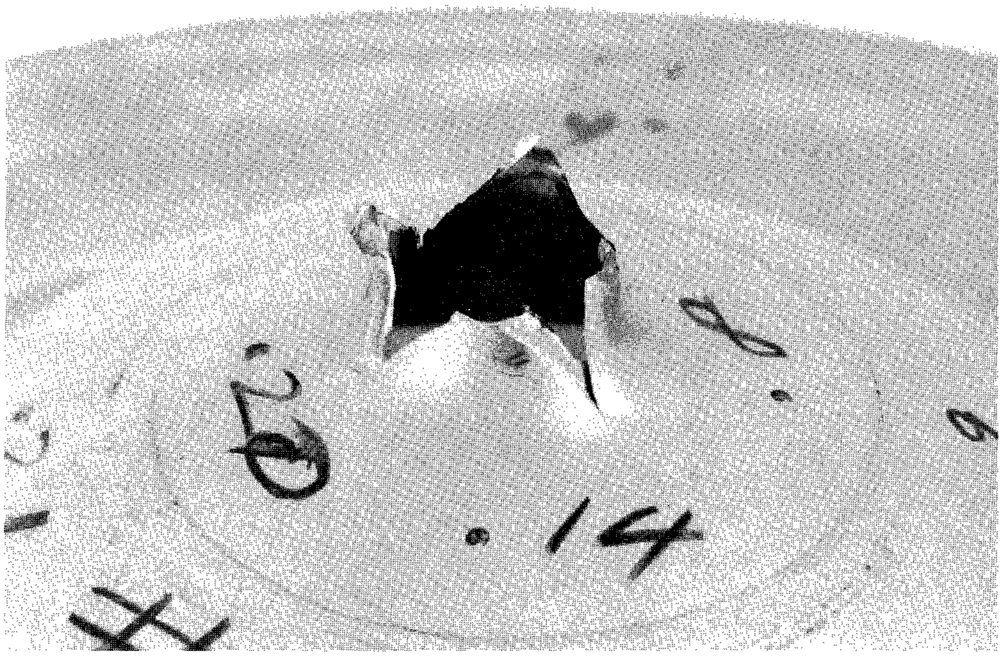


Figure 6.- Piercing-head punch shapes: (a) left - flat surface; (b) center - notched surface; (c) right - concave surface.



(a) Outer side.

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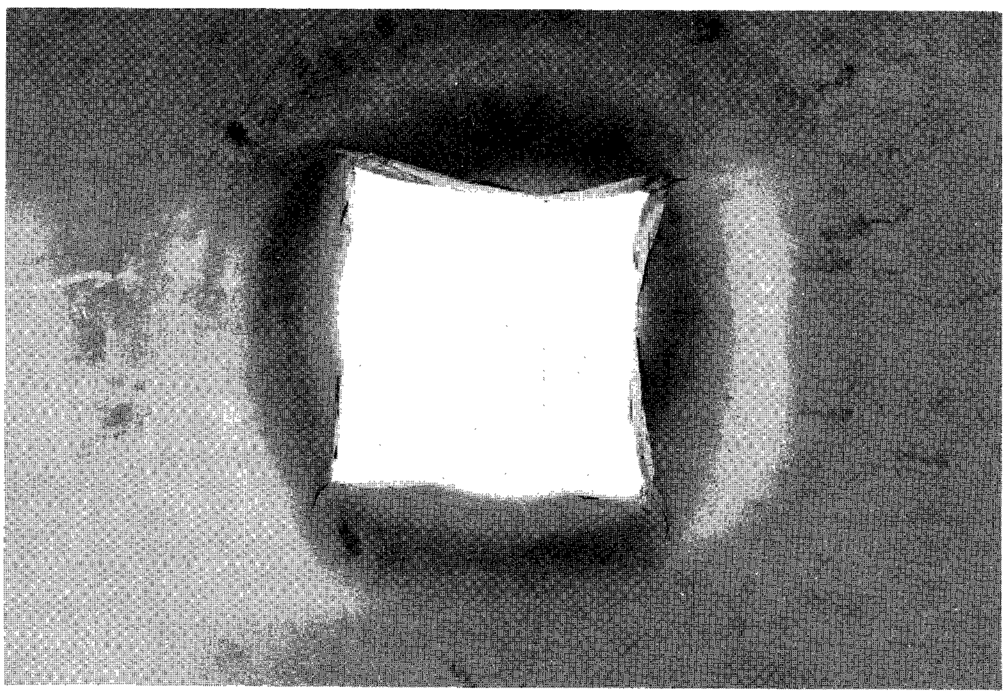

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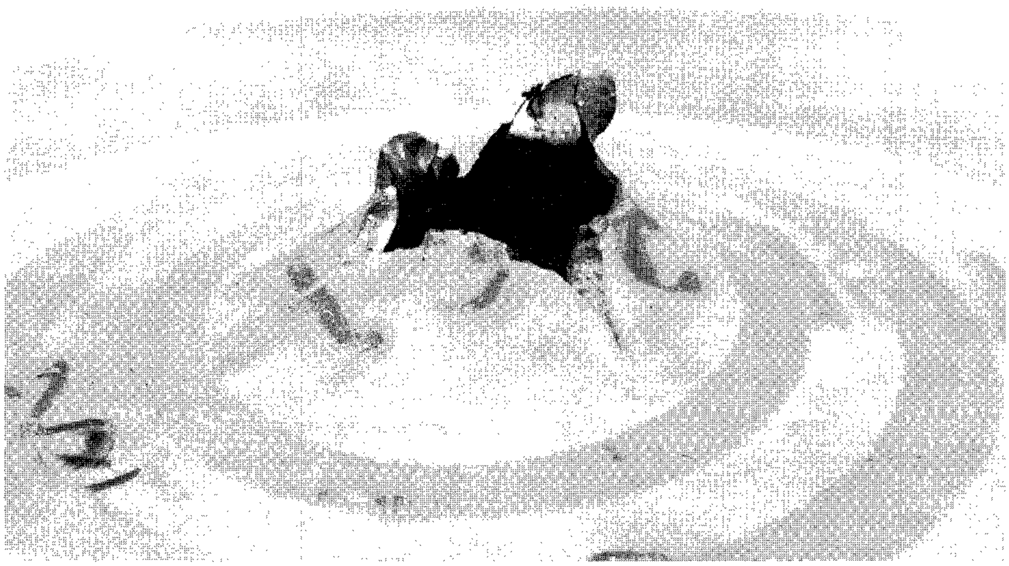
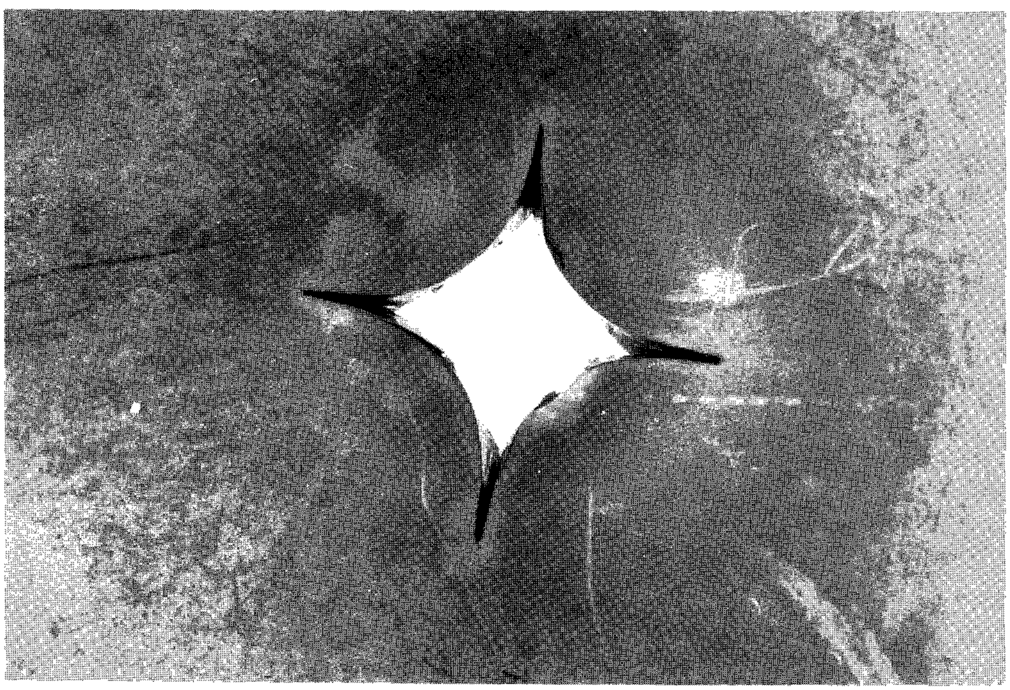
(b) Inner side.

Figure 7.- Typical pierce formed by four-sided flat-surface punch (without pressure in combustion chamber).



(a) Outer side. A-32777



(b) Inner side. A-32778

Figure 8.- Typical pierce formed by four-sided concave-surface punch (without pressure in combustion chamber).

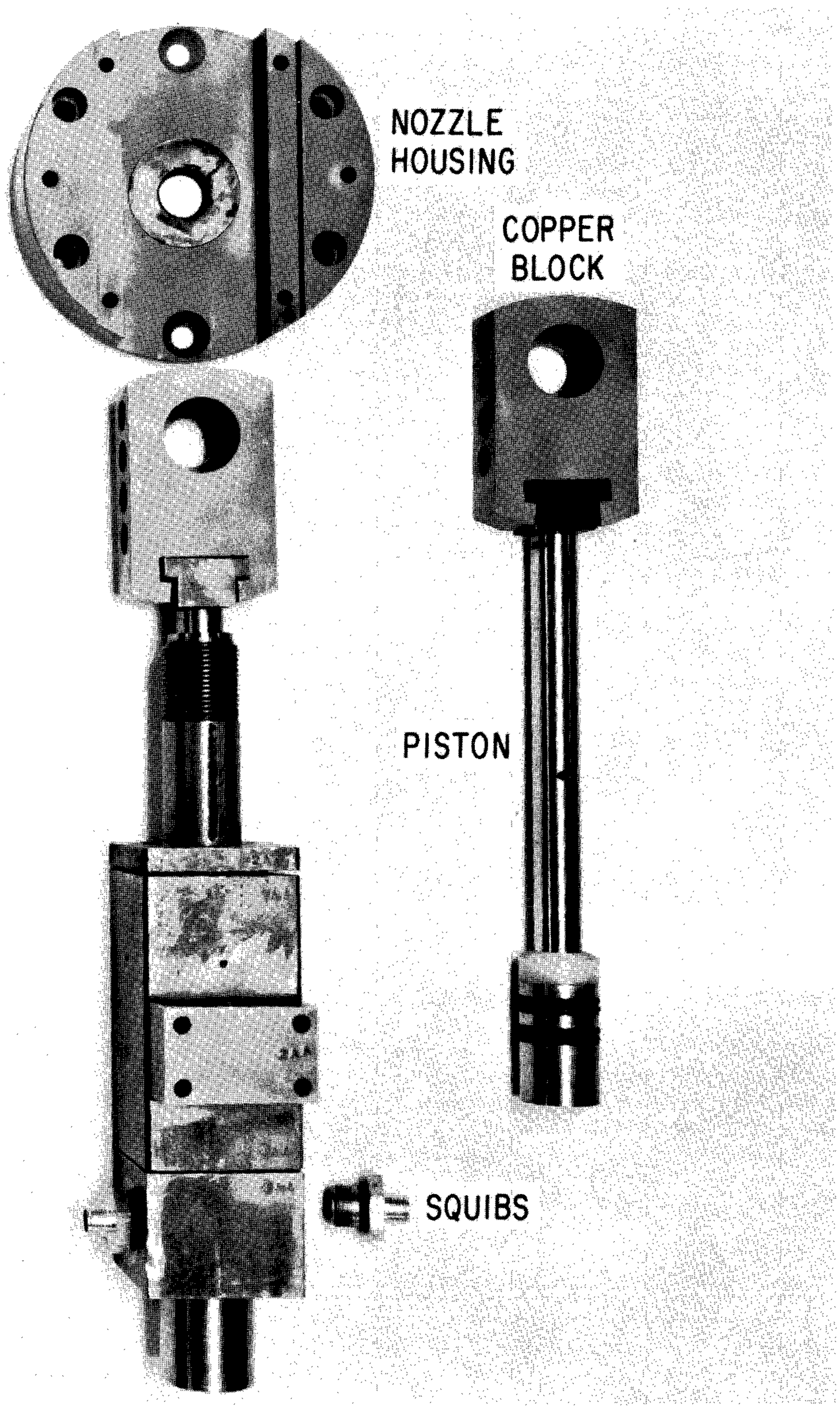


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Figure 9.- Squib actuated nozzle closing mechanism.

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