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FLUERIC NORMAL SHOCK SENSOR

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FLUERIC NORMAL SHOCK SENSOR

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U.S. ARMY MATERIEL COMMAND
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SUMMARY

A flueric circuit for measuring shock location in the divergent section of a jet-engine inlet diffuser has been designed and tested by the Harry Diamond Laboratories. The circuit consists of 12 bistable sensing elements and a fluid logic network. Control signals to the sensors are obtained from static pressure taps located along the diffuser wall. Fluid logic is employed to prevent erroneous signals from affecting the computed shock position.

The circuit was bench-tested over a wide range of pressures to simulate actual operation on an experimental inlet between Mach numbers 1.75 and 3.0. These tests were conducted to establish the static response of the circuit to variations in wall pressure, supply pressure, and ambient pressure. The test results indicate that the circuit operated satisfactorily over its design range.

FOREWORD

This report summarizes the work performed under Order No. A1317A for the National Aeronautics and Space Administration, Ames Research Center, Air Breathing Propulsion Division. This work was conducted under the cognizance of John Gawienowski, Technical Monitor for NASA Ames Research Center.

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ILLUSTRATIONS

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1. INTRODUCTION

In many air breathing supersonic propulsion systems, spike-type inlet diffusers are employed to decelerate the incoming airflow to velocities and pressures compatible with engine requirements. In these diffusers the transition from velocity to pressure occurs through a complex oblique shock-wave pattern that terminates in a normal shock. The location of this normal wave with respect to the inlet throat has a stron effect on pressure recovery and inlet stability (fig. 1).[1] Ideally, optimum pressure recovery is achieved when the normal shock is maintained at a position as close to the throat as possible. However, the closer the shock comes to the throat, the more sensitive the flow becomes to external perturbations such as wind gusts, angle of attack, velocity, and engine pressure fluctuations. Such perturbations as these usually cause the wave to oscillate between the inlet face and the throat (buzz), or cause complete expulsion of the wave (unstart). Since these flow instabilities have been known to cause severe airframe stresses and engine flame-outs and since pressure recovery governs overall propulsion performance, various control concepts have been considered for measuring and positioning the normal wave.

Most current control concepts require the use of electronic sensing and computation networks to provide signals to a network of hydraulic back-pressure bleed doors. In these systems, shock position data are usually derived from pressure ratio computations. Implementation of these concepts is exceedingly complex due to the circuits required to compensate for changes in inlet geometry and flight conditions. The uncertainties in the measurements caused by the sensitivity of electronic systems to temperature, plus the fact that position is derived from computed information, often result in pressure recovery being sacrificed for stability.

The application of flueric technology to normal shock sensing and control appears to offer significant advantages over current electrohydraulic systems. These advantages include the elimination of electrical power supplies, no moving parts except those required for door actuation, elimination of hydraulic interfaces by using amplified air pressure signals to pilot actuation mechanisms, temperature insensitive integrated circuitry that can be located within the inlet, and practically maintenance-free operation. In addition, since fluidic devices are normally powered with air, actuated with air signals and interfaced with air driven piston actuators, significant savings in

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[1] Handbook of Supersonic Aerodynamics, Section 17, Ducts, Nozzles and Diffusers, NAVWEPS Report 1488, Vol 6, 6 Jan 1964.

space and weight might be realized by eliminating the need for electrical and hydraulic power.

A program, sponsored by the National Aeronautics and Space Administration Research Center at Moffet Field, California, was conducted at the Harry Diamond Laboratories in Washington, D. C. to develop a flueric sensing and control circuit for measuring the position of a normal shock wave in an axisymmetric internal-external compression supersonic inlet. To accomplish this, a breadboard circuit was designed, fabricated, and bench-tested under simulated wind-tunnel operating conditions. These conditions required that the circuit be operable over the range of recovered supply, signal, ambient and wall pressures dictated by wind-tunnel tests on an experimental axisymmetric inlet, operating over a Mach number range of 1.75 to 3.0 at various angles of attack and assumed altitudes ranging from 60,000 to 80,000 ft.

The circuit was designed to measure shock position in terms of wall pressure. Twelve digital pressure-sensitive fluid jet amplifiers of the wall-attachment type were employed as sensing elements. In a shock control system, each sensor would be connected to a throat tap and to one of several wall taps located downstream of the throat. Each sensor produces an output when its wall pressure is equal to or greater than the throat pressure. Fluid logic was employed to prevent random signals such as those created by boundary layer effects and oblique shock reflections, from affecting the final output. The output was monitored by a series of on-off pressure actuated switches and a ram piston. The number of actuated switches and/or piston displacement refers to the consecutive number of sensing taps at pressures equal to or greater than the throat pressure and therefore shock position (fig. 1 and 2). Resolution of the position measurements depends upon the spacing of the wall pressure sensing taps.

2. CIRCUIT DESCRIPTION

The circuit shown in figures 2, 3, and 4 is designed to operate with air bled directly from the diffuser. Pressure regulation is not required. Flow is delivered to the system through a tube connecting the subsonic diffuser section to a supply manifold located in the circuit housing. This flow passes through each circuit element into the housing chamber where it generates a back pressure and is discharged through a single constant-area regulating orifice to atmosphere.

Signals are transmitted to the system through a network of pressure taps located in the wall at stations 0 through 12. Station 0 is located at throat of the inlet. Stations 1 through 12 are located in the divergent section immediately downstream of the throat as shown in figure 2.

Station 0 is connected to the reference manifold. Taps 1 through 12 are connected to sensors 1 through 12, which are also located in the housing.

Each sensing element is composed of two input and two outlet ports (fig. 5); one input port is connected to the reference manifold, and the other to a particular wall tap. An output signal pressure is generated when the wall pressure at any particular station is equal to or greater than the reference pressure. When the wall pressure is less than the reference pressure, the flow is vented into the housing chamber. Each output signal is transmitted to the logic circuit. The logic circuit is designed to differentiate between pressure discontinuities upstream of the terminal shock and the actual shock itself.

The logic program was derived on the assumption that three or more consecutive pressure signals downstream of the shock are sufficient to define position. It should be noted that various other programs could have been implemented through simple modifications of the logic circuitry. These programs include combinations such as: four or more consecutive, five or more consecutive, or any other number of consecutive inputs downstream of the shock. In each case, based on an analysis of available wind tunnel data, the solution to each logic equation would have produced the same position data.

3. DESCRIPTION OF COMPONENTS

The sensing element illustrated in figure 5A is a high-input-impedance, wall-attachment, monostable, fluid amplifier. It has both a vent and a signal output and can be switched to the output position only by applying an input pressure that is greater than the reference pressure. When the input pressure drops below that of the reference, the output returns to the vent position.

Internal operation of the sensor occurs in the following manner. In figure 5B, the supply flow divides between the main power stream and the bias slot and discharges through the input and vent. Fluid in the return slot is entrained into both the main power stream and the bias flow, producing a low-pressure region that holds the output in the vent position. The output remains in the vent position as long as the bias flow is allowed to pass freely through the input port. Increasing the pressure in the input channel decreases the flow rate through it, causing the bias flow to back up into the return slot. When input pressure exceeds reference pressure, flow from the return slot switches and holds the flow in the output position (fig. 5C). Reducing the input pressure below the reference level returns the flow to the vented output.

The logic circuit is designed to produce an output when there are three or more consecutive sensor input signals. The "induction" AND, and passive AND unit, is used to implement the circuit because of its relative pressure insensitivity. The "induction" AND unit in figure 6A performs the logic function on two parallel input streams (A and B) by means of the wall attachment effect. When either input stream is present alone (fig. 6B), it attaches to its outer wall by virtue of the bias geometry and entrains fluid through the vent on one side and the interaction chamber on the other. When both streams are present (fig. 6C), air is entrained from the interaction chamber, creating a low pressure in that area. The result is that both streams attach to the walls of the common divider and discharge through the center port as the AND function A·B.

The circuit employs 21 AND elements that are fabricated in plastic and cascaded as shown in figure 7. The center output ports of the first stage producing the AND function A·B are used as the inputs to the next stage of the logic module. The completed module is connected to pressure switches as shown (fig. 7).

To isolate the system from atmosphere, the flueric components are enclosed in a housing chamber. Supply flow, reference pressure, and input and output signal pressures are transmitted through ports located in the housing wall (fig. 2). A constant ratio is maintained between supply pressure and chamber pressure by discharging the flow through a single choked orifice to atmosphere. This orifice is used to isolate the flueric components and the chamber pressure from variations in ambient pressure. This is achieved as follows: (a) air is supplied to the flueric elements at P_1 and discharged into the chamber at P_2; (b) the chamber pressure P_2 is discharged to ambient pressure P_∞ through the regulating orifice. The flueric components are designed to operate at a pressure ratio P_1/P_2 approximately equal to 2/1. The regulating orifice functions at pressure ratios, for which P_2/P_∞ is $\geqq$ 2/1. Since the pressure ratio across the system (P_1/P_∞) ranges between 5/1 and 30/1, it is possible — through the proper selection of regulating orifice discharge area — to maintain the required relationships between P_1, P_2, and P_∞, and to isolate the system from atmosphere.

4. DESCRIPTION OF TESTS

4.1 Test Setup

The test setup shown in figure 8 was designed to simulate the static pressure conditions that exist in an actual inlet. The setup provides the capability of subjecting the circuit components to various combinations of signal, reference, supply and ambient pressure. This circuit is manually controlled. All pressure conditions and output states are displayed on the control panel shown in figure 9.

High-pressure ejector pumps were used to provide the low pressures required to simulate high-altitude operating conditions. Supply pressure to the pumps ranged from 300 to 500 psi, producing output pressures ranging from .50 to 14 psia. One pump was connected to the output of the regulating orifice located on the housing chamber and was used to simulate ambient pressure. The second pump was used to generate signal pressures between 5.0 and 14.0 psia.

A network of three-way manually operated solenoid valves were employed to transmit various signal pressure combinations to the sensing elements. Pressures corresponding to the upstream pressure (P_X) or downstream pressure (P_Y) were controlled by each valve and monitored by gauges. The state of each valve was monitored on a series of panel lights. Values of throat reference pressure (P*) were also controlled and monitored. The output of the system was monitored with electro-pneumatic pressure switches. The outputs of the switches were connected to an electro-pneumatic piston and simultaneously displayed by a row of panel lights as shown in figures 9 & 10. The system was subjected to various combinations of pressure, approximating those derived from the wind-tunnel test data. All data were recorded manually.

4.2 Operation

Figures 11 through 13 are included to illustrate the type of wall pressure data that can be handled. The computed location of the terminal shock wave, as defined by the logic equations, is indicated. The wind-tunnel data shown in figures 11 through 13 represents various centerbody wall pressure distributions for the conditions stated. The data supplied by the Ames Research Center (NASA) are for a 20-in capture diameter model of a mixed-compression axisymmetric inlet.

The following example is included to illustrate how the circuit would function under a given set of conditions.

Example I. - Wind-tunnel tests on an axisymmetric inlet operating at M=3.0 and zero angle of attack produced the center body pressure distribution illustrated in figure 11. This distribution shows a discontinuity between stations 2 and 4. It is assumed that this discontinuity is caused by boundary layer interaction and that the maximum downstream position of the wave is between stations 4 and 5.

Solution. - Each sensor transmits information when the wall pressure P is greater than the throat pressure P*. Therefore, signals are transmitted from sensors 3 and 5 through 12, and the remaining sensors are vented. Since the logic circuit transmits an output only when three or more consecutive inputs are present, outputs at 5 through 12 are generated. This indicates that the normal shock is located downstream of station 4 and upstream of station 5.

4.3 Summary and Test Results and Conclusions

Tests were conducted to determine the static response characteristics of a flueric circuit designed to measure normal shock location in a supersonic diffuser. Static pressure signals were supplied to the sensor amplifier through solenoid valves connected to pressure manifolds. Diffuser static pressure profiles were simulated over an inlet Mach number range from 1.75 to 3.0 and between altitudes of 60,000 to 80,000 ft. The output signal from the circuit was used to position an electropneumatic piston, thus providing a visual indication of the calculated normal shock location.

The sensors and logic circuit performed as programed over the entire range of simulated diffuser operating conditions. Although the system was thoroughly tested only for static performance, it was noticed that its response was sluggish when the pressure profile was changed. The use of cascaded passive AND elements in a logic circuit results in low fluid velocities through the elements, suggesting that system response could be significantly improved by using active logic elements.

SYMBOLS

A^* = Throat Area

M = Local Mach number

P = Pressure

P_∞ = Ambient pressure

P_R = Recovered pressure

P_1 = Supply pressure

P_2 = Chamber pressure

P_x = Pressure upstream of shock

P_y = Pressure downstream of shock

N = Sensing station number

P^* = Throat reference pressure

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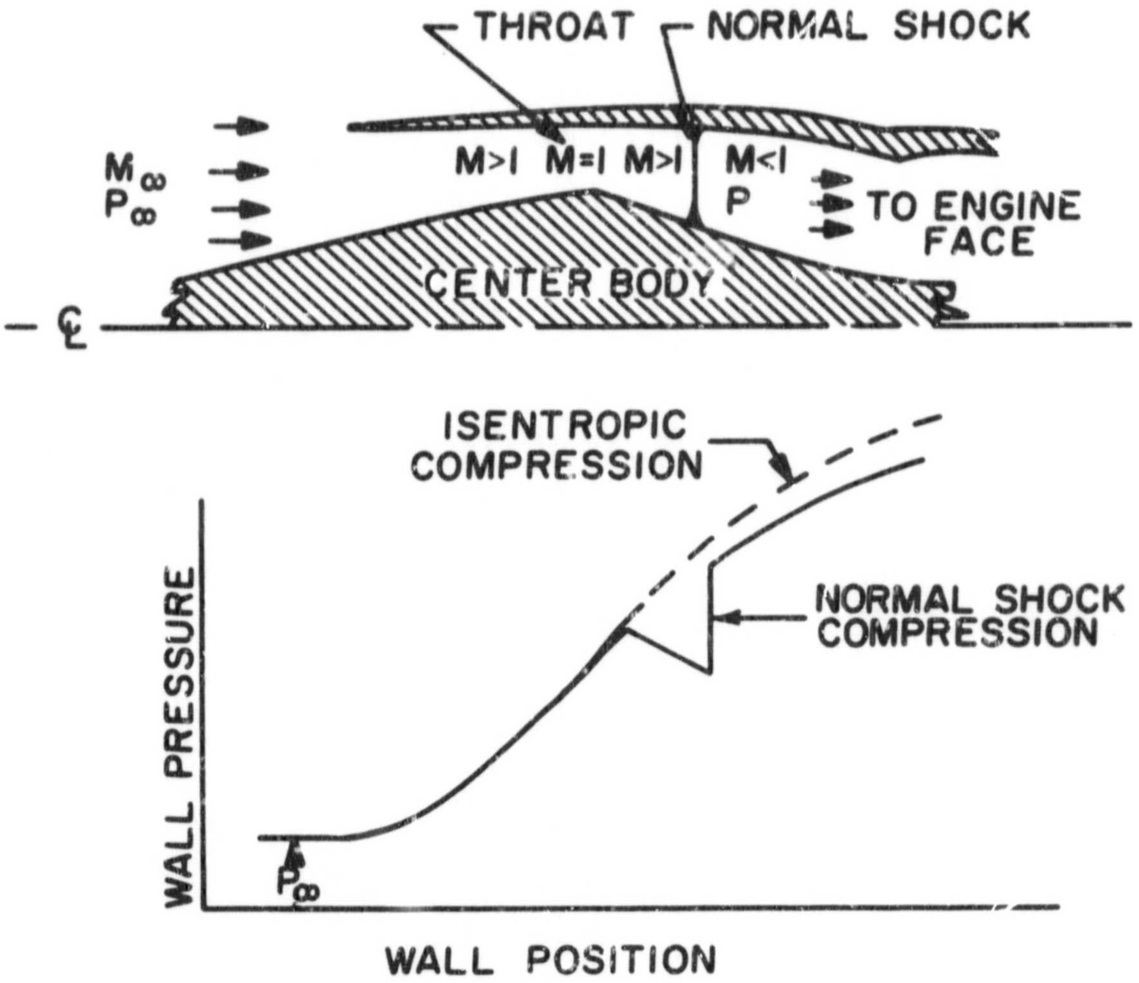

Figure 1. Flow diagram and theoretical pressure plot showing the Mach number variations and pressure levels along the wall of an internal compression diffuser for a constant set of input conditions and for an isentropic compression and a normal shock compression.

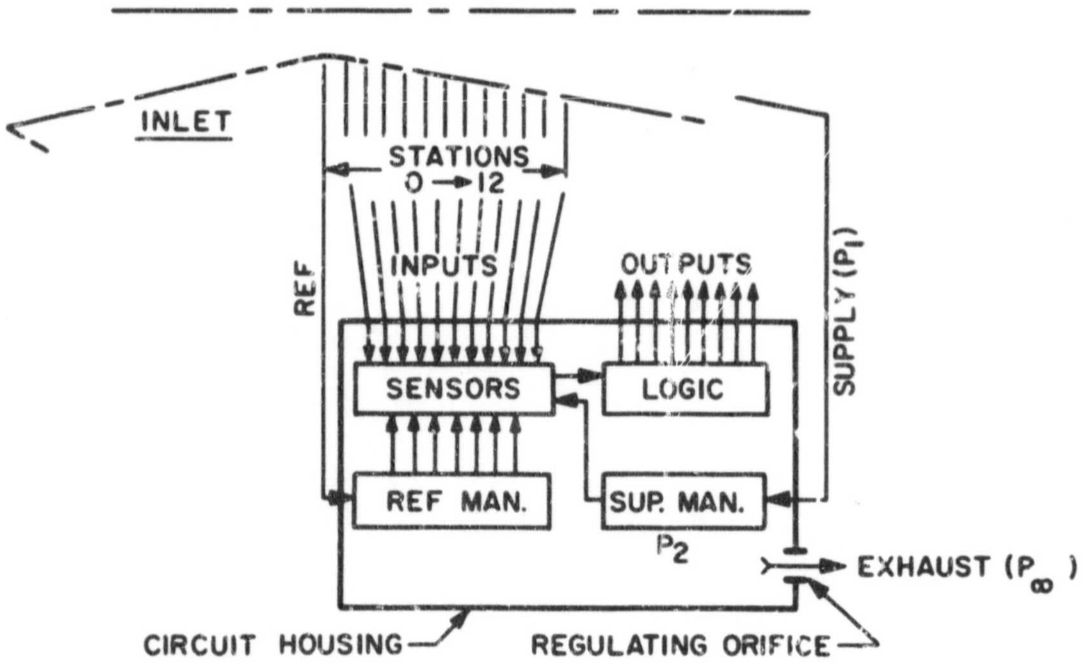

Figure 2. Shock sensor diagram showing sensor stations, manifold connections, and exhaust orifice.

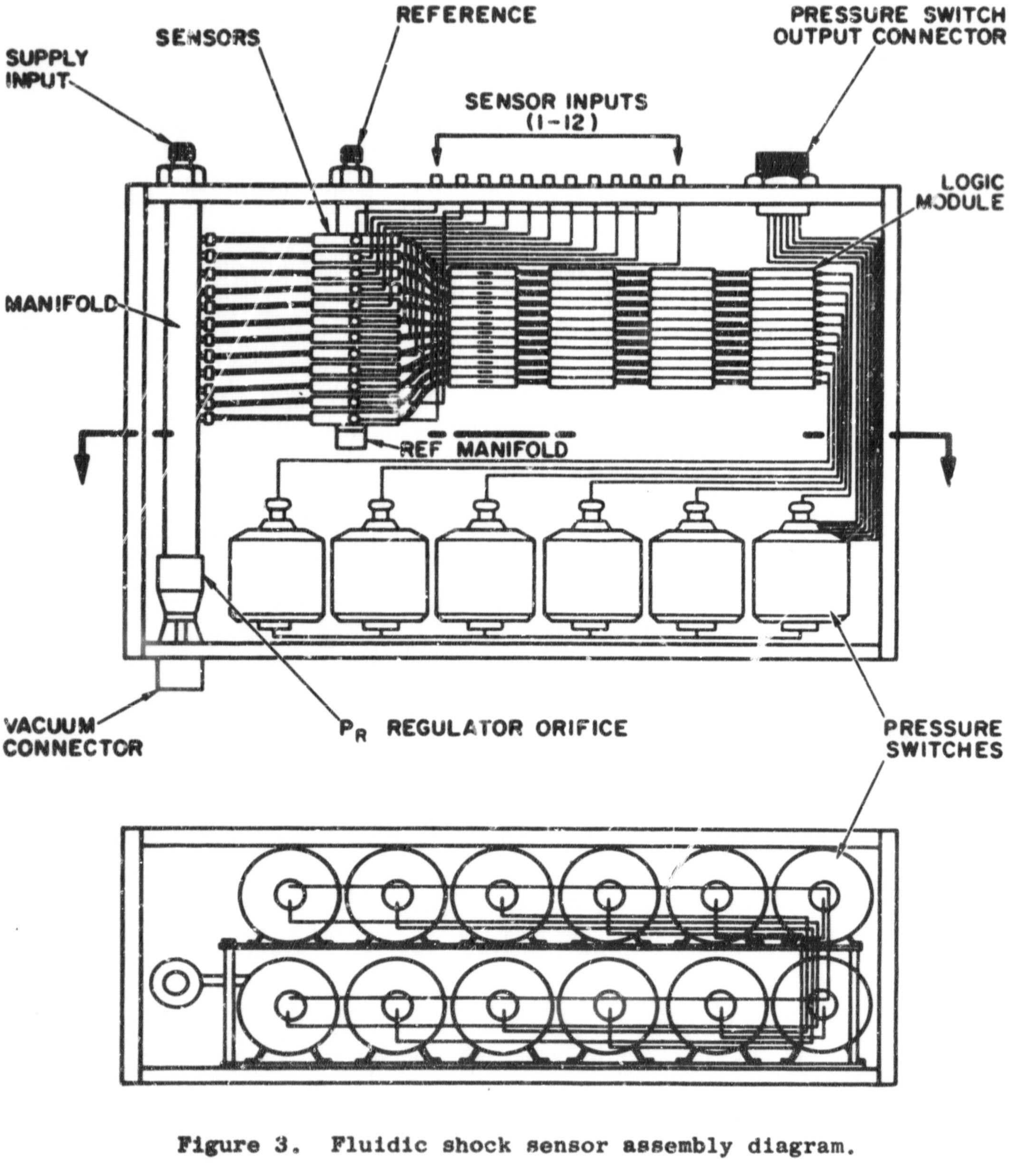

Figure 3. Fluidic shock sensor assembly diagram.

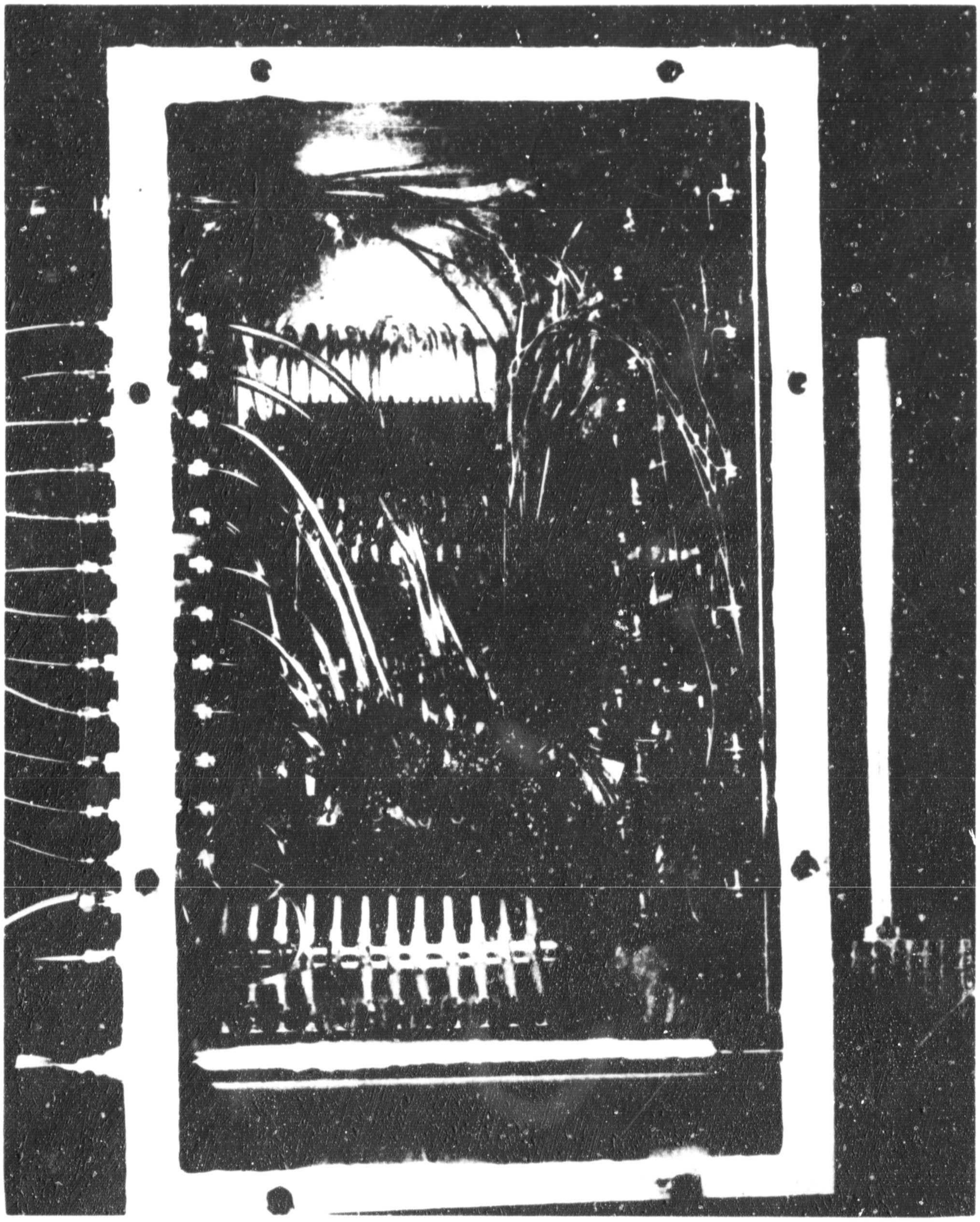

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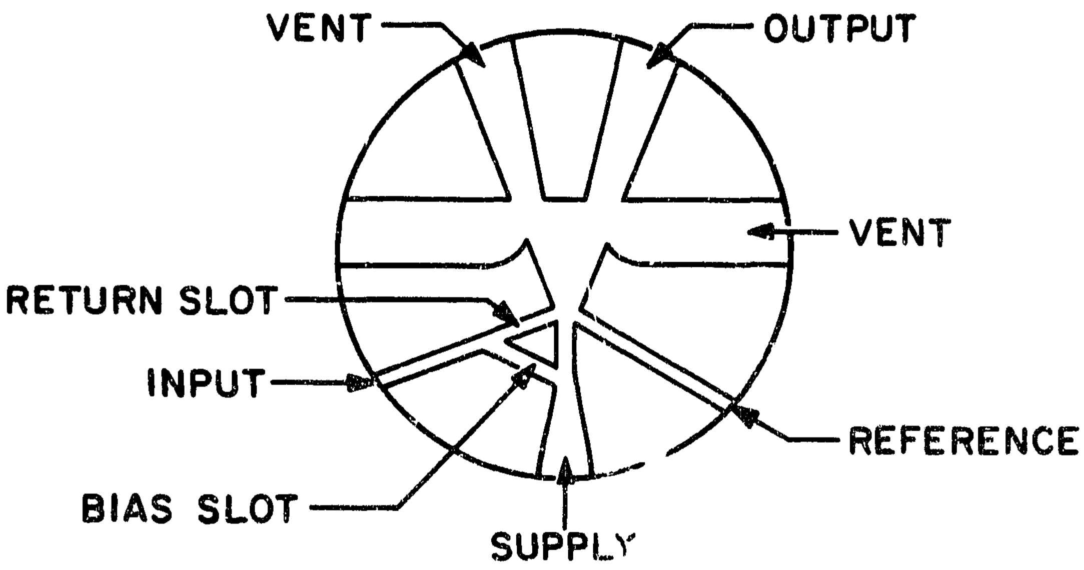
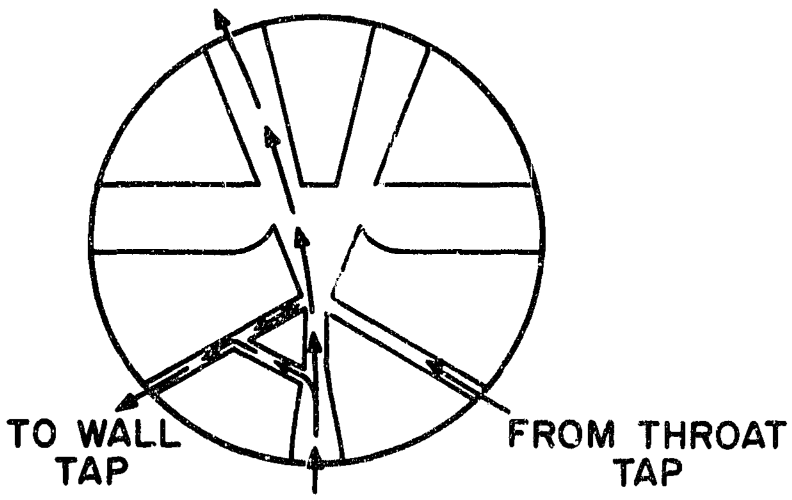
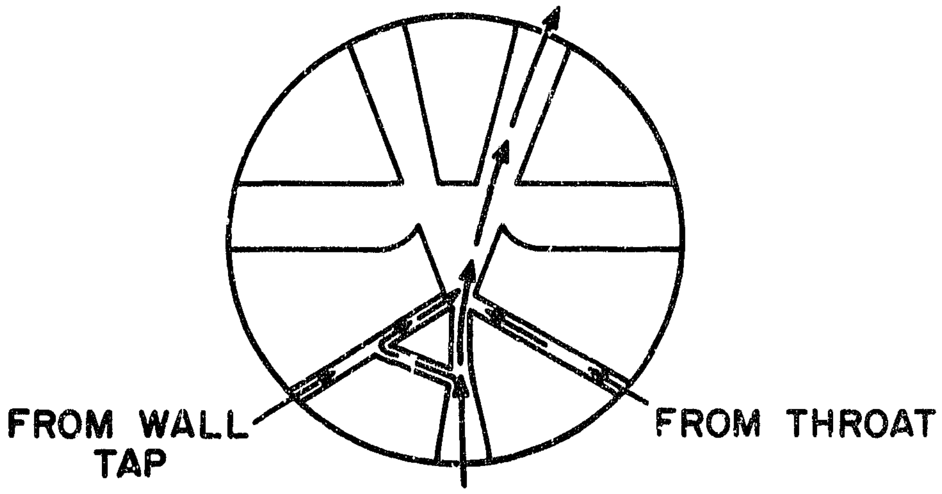
Figure 4. Flueric shock sensor assembly and ejector.



(A) SENSOR CONFIGURATION

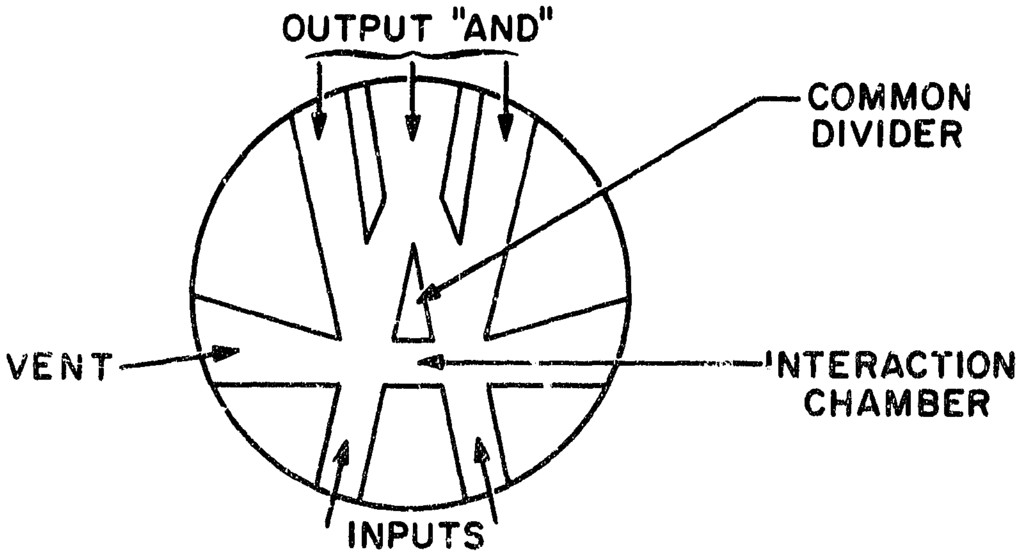


(B) INPUT PRESSURE LESS THAN REFERENCE

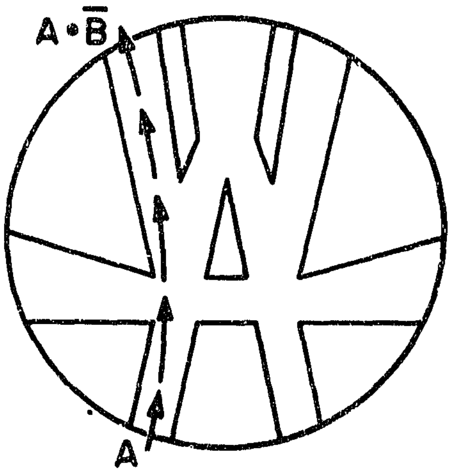


(C) INPUT PRESSURE GREATER THAN REFERENCE

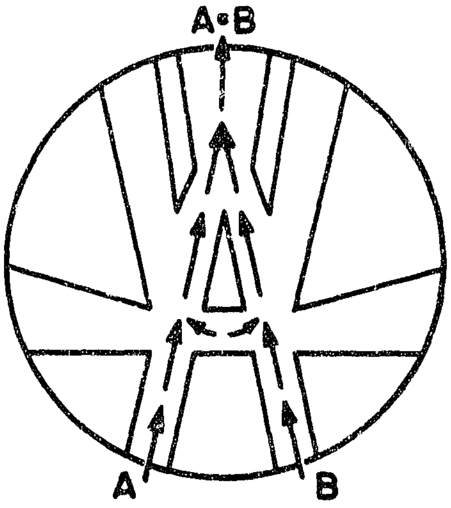
Figure 5. Flueric sensing element operation.



(A) "AND" UNIT CONFIGURATION



(B) INPUT "A" ON, "B" OFF



(C) INPUTS "A" AND "B" ON

Figure 6. Flueric AND unit operation.

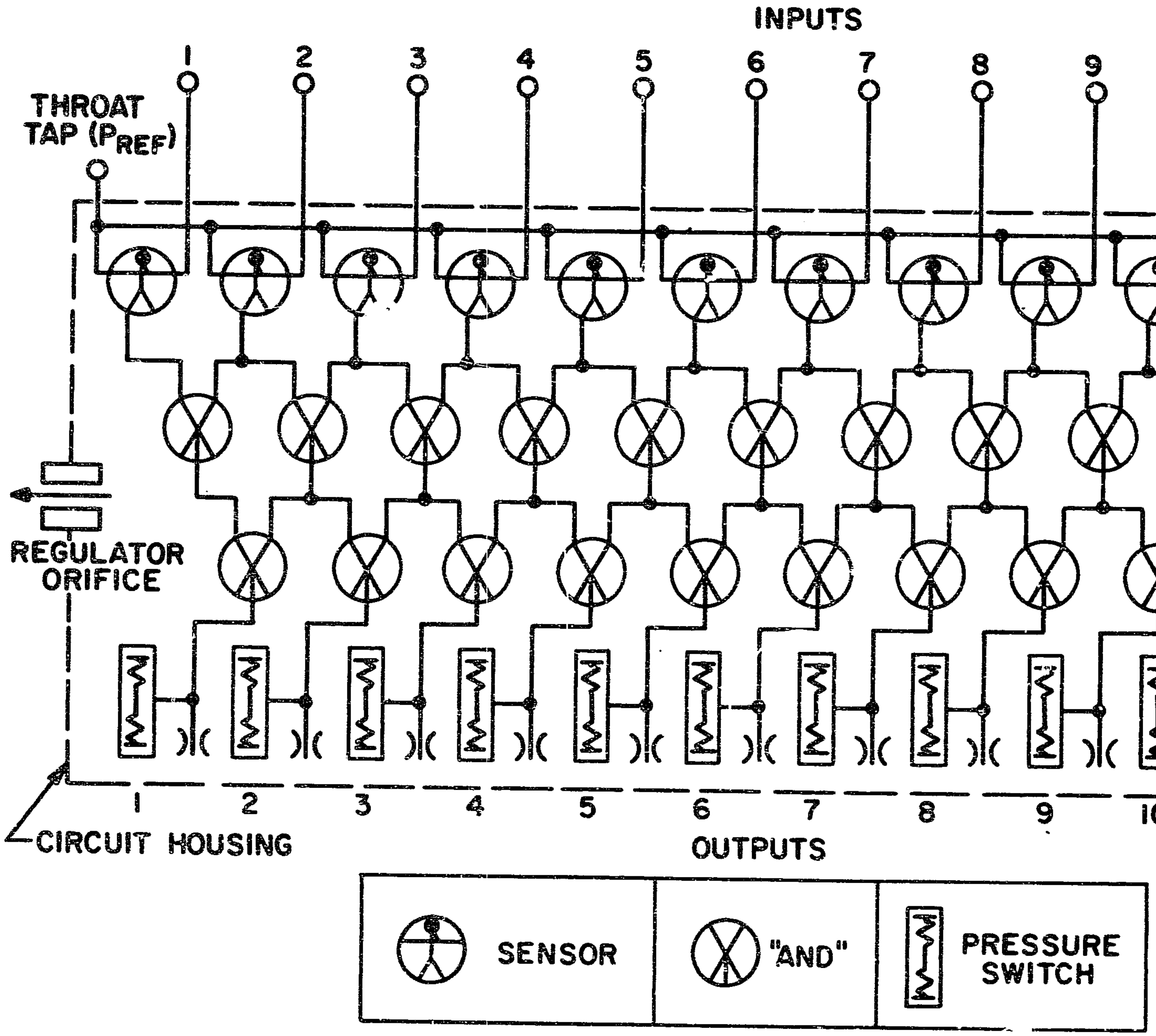


Figure 7. Sensing and logic circuit—schematic diagram.

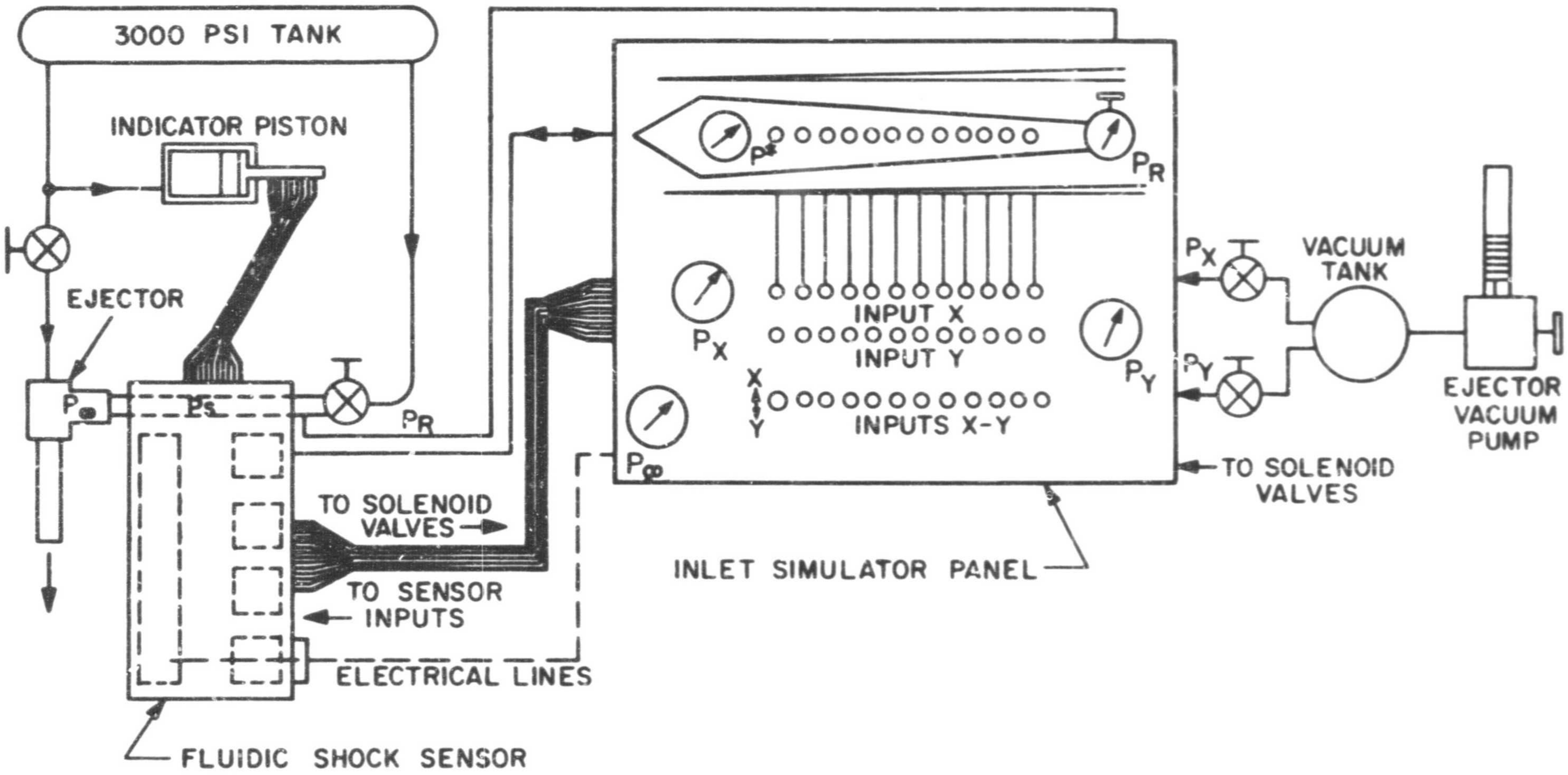


Figure 8. Bench test circuit.

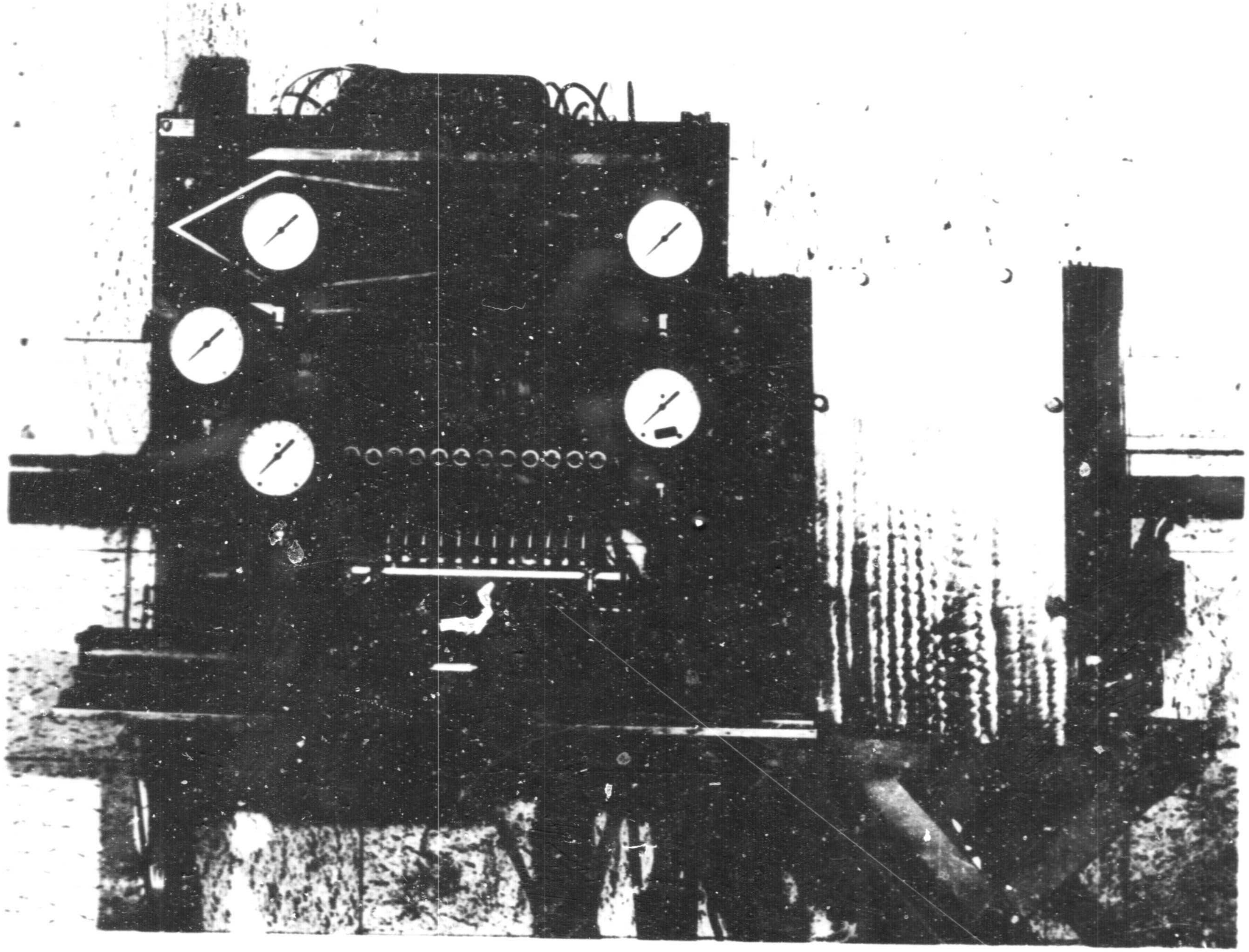
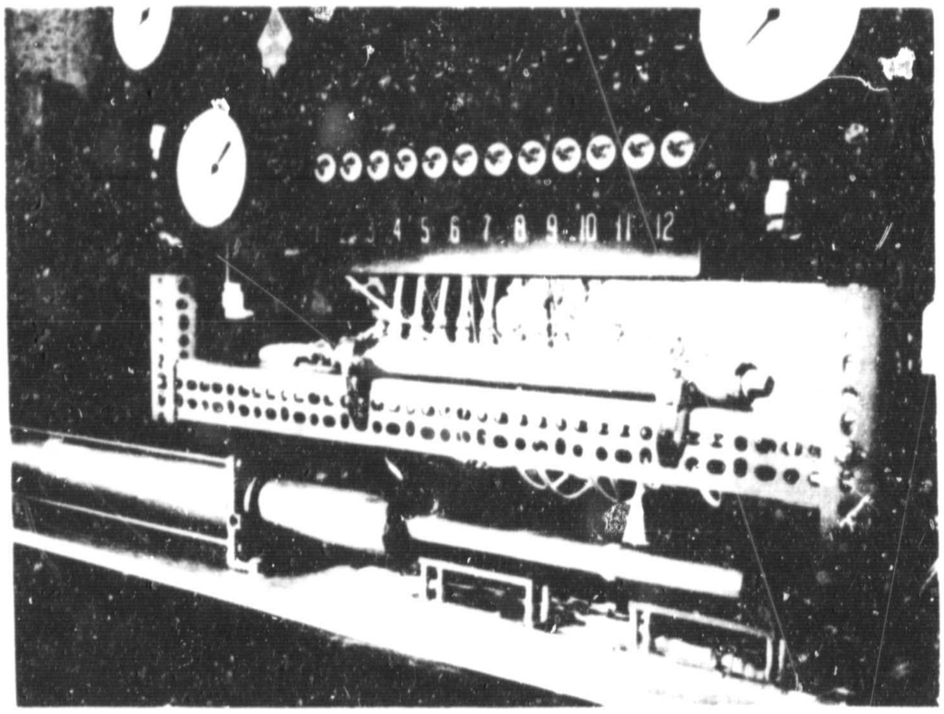
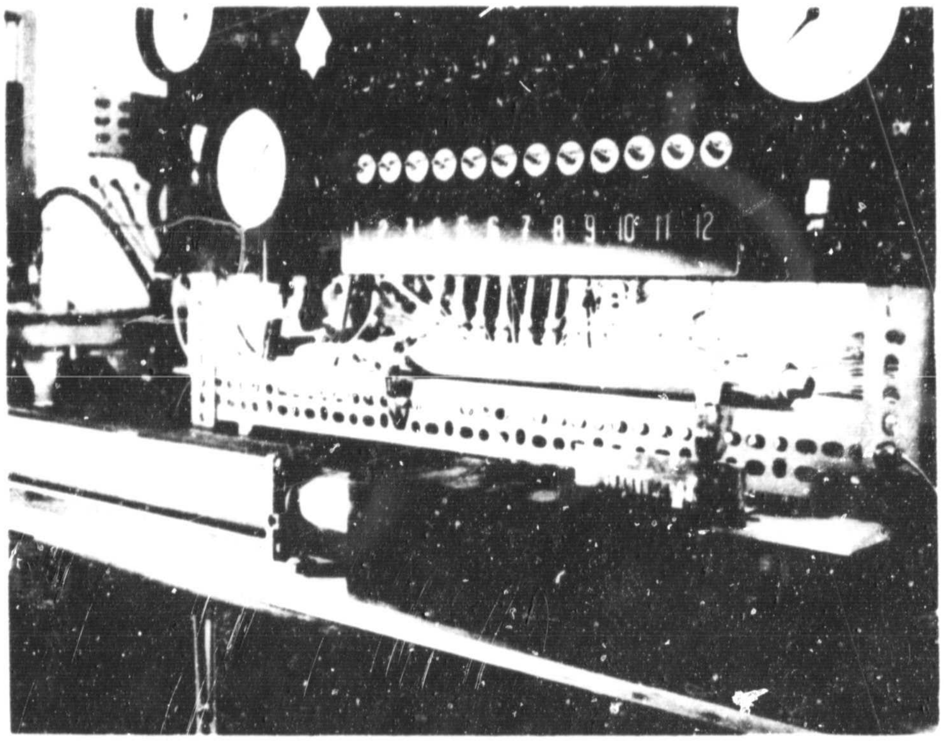


Figure 9. Inlet simulator control panel and shock sensor assembly.



(A) LIMIT-SWITCH ASSEMBLY



(B) POSITION INDICATOR

Figure 10. Electro-pneumatic ram assembly.

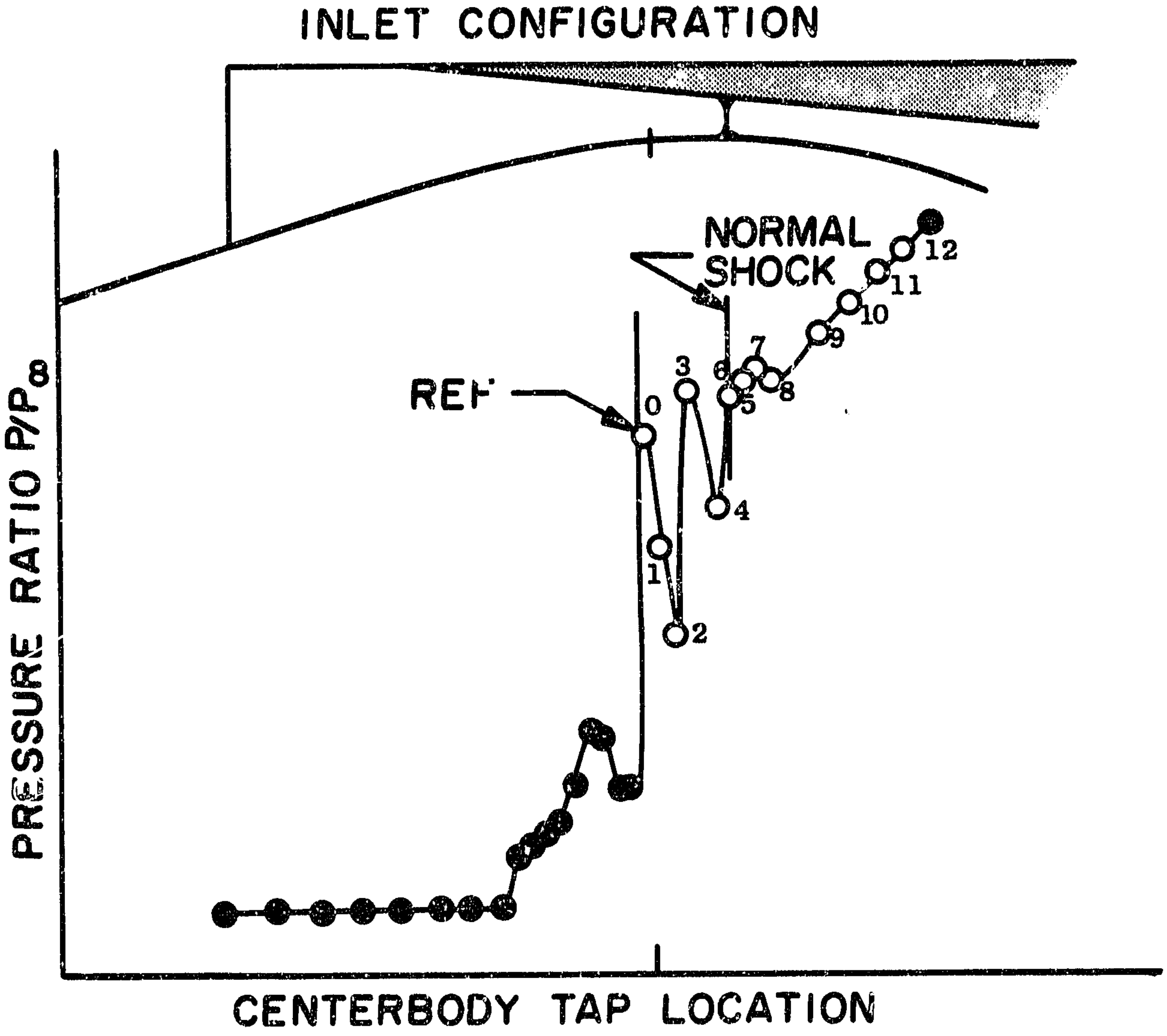


Figure 11. Wall pressure distribution, showing computed normal shock position for $M_\infty = 3.0$. (Pressure distribution taken from NASA report TND-4557, fig. 20, "Investigation of a Nearly Isentropic Mixed Compression Axisymmetric Inlet System at Mach Numbers 0.6 to 3.2," by Smeltzer, Donald B., et al.)

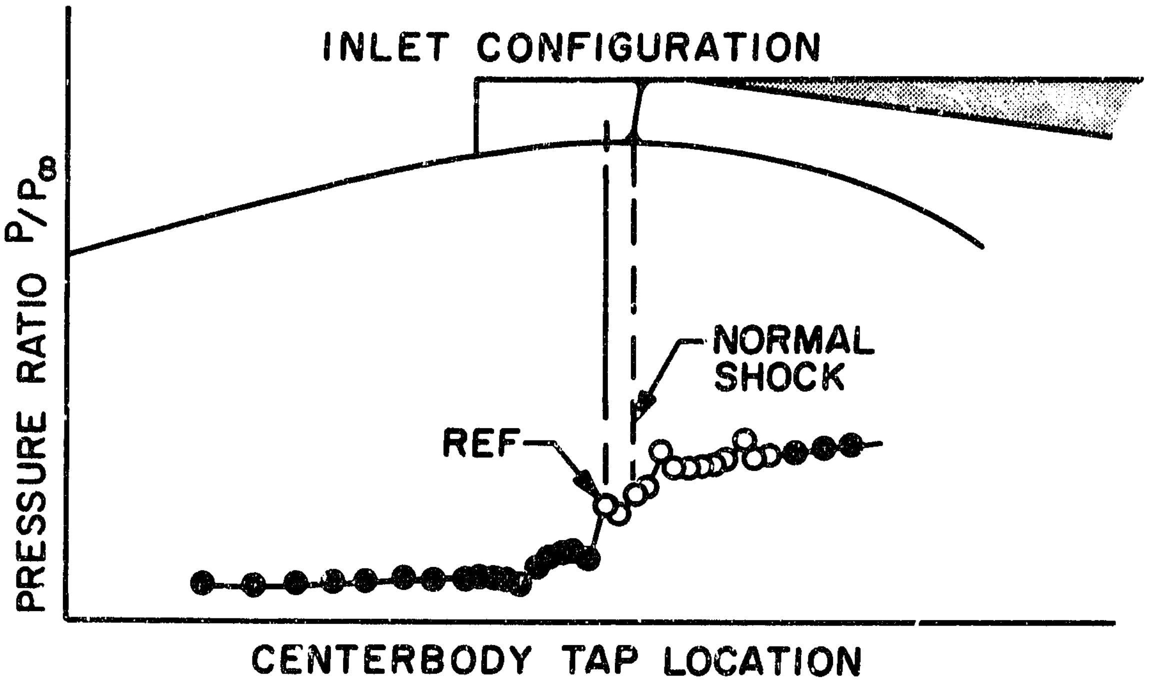


Figure 12. Wall pressure distribution, showing computed shock position for $M_\infty = 2.25$. (Pressure distribution taken from fig. 25, "Investigation of a Nearly Isentropic Mixed Compression Axisymmetric Inlet System at Mach Numbers 0.6 to 3.2," by Smeltzer, Donald B., et al.)

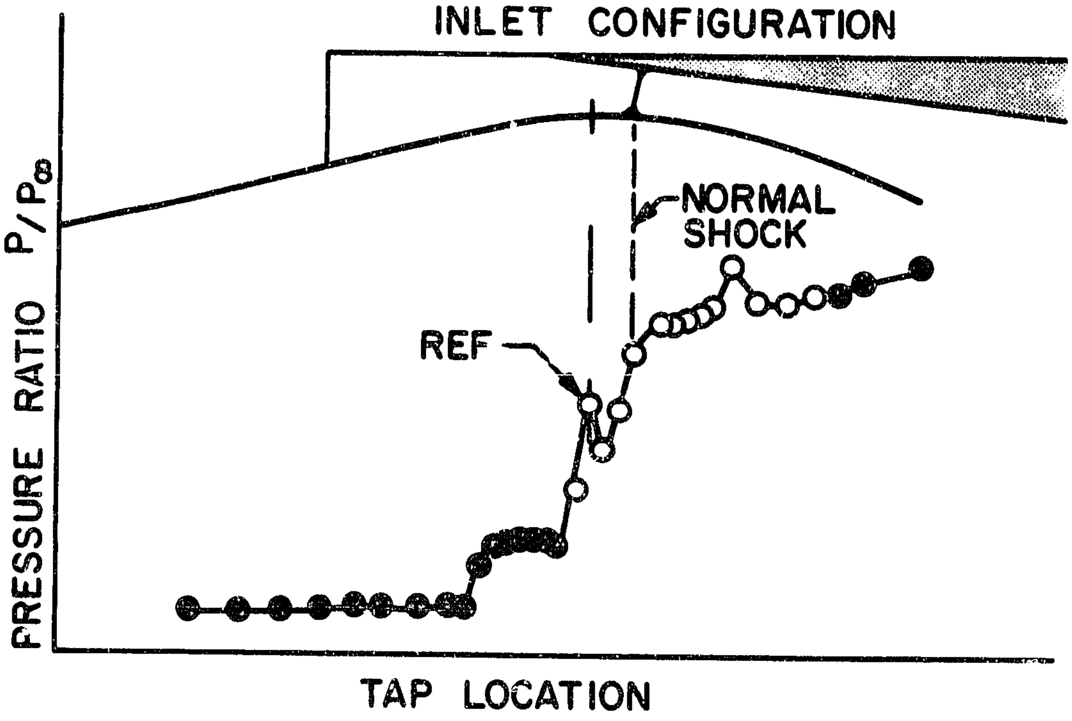


Figure 13. Wall pressure distribution, showing computed normal shock position for $M_\infty = 2.5$. (Pressure distribution taken from NASA report TND-4557, fig. 23, "Investigation of a Nearly Isentropic Mixed Compression Axisymmetric Inlet System at Mach Numbers 0.6 to 3.2," by Smeltzer, Donald B., et al.)

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13. ABSTRACT

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14. KEY WORDS	LINK A		LINK B		LINK C	
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