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DEVELOPMENT OF A FLUERIC EXPLOSIVE INITIATOR FOR FAE WEAPONS

JOHN R. MASLY

OCTOBER 1972

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DEVELOPMENT OF A FLUERIC EXPLOSIVE INITIATOR FOR FAE WEAPONS

FOREWORD

This report documents work performed during the period 14 April 1971 through 14 May 1972 by Picatinny Arsenal, Dover, New Jersey, under Project Order ATO-100-1-0060, Air Force Armament Laboratory, Eglin Air Force Base, Florida. The program was funded under Armament Laboratory LDF Project 71/7. Mr. Gary H. Parsons (DLIF) monitored the program for the Armament Laboratory.

This report has been reviewed and is approved.

FRANKLIN C. DAVIES, Colonel, USAF
Chief, Flame, Incendiary, and Explosives Division

ABSTRACT

A flueric second event initiator for Fuel Air Explosives has been designed and tested. It consists of an ignitor incorporating a gas supply bottle and a modified Flueric Explosive Initiator which ignites an explosive through resonance heating. The main feature of the initiator is that it is capable of achieving repeatable time delays of 10 to 1000ms with no moving parts. Time delay mechanization is accomplished by preventing resonance heating at high gas supply pressures and allowing the gas supply pressure to bleed down to the operating point of the ignitor. The characteristic time delay of the discharging supply bottle is therefore the time delay of the ignitor. It was shown how the characteristic time delay of the supply bottle could be made insensitive to the ambient temperature of the gas. Time delay ignitions of KDNBF explosive of 1000ms were obtained with a 170cm^3 gas supply bottle initially charged to 1000 psig.

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I. INTRODUCTION

Due to recent advances in Fuel-Air Explosive (FAE) technology, it is now possible to deliver the FAE weapon and generate the desired detonable cloud at high impact velocities. This delivery capability has necessitated the development of a detonator that can be delivered to points within the FAE cloud to initiate detonation of the cloud. During the past several years, Picatinny Arsenal has been developing a new type of detonator that fluerically (pneumatically) initiates an explosive charge. This initiator has several desirable features such as small size, simplicity, and potential high reliability. Consequently, it appears to offer a second event detonator system incorporating the above advantages while minimizing the disadvantages. This report discusses the development of this device for application to an FAE weapons system.

II. HISTORICAL BACKGROUND

The flueric initiator is based upon resonance tube phenomenon which is a means of converting gaseous flow energy directly into thermal energy. The resonance tube phenomenon is not a recent discovery, but was first described in 1919 by Professor Julian Hartmann. The first systematic experimental investigation of the heating effects of resonance tubes was reported by H. S. Sprenger in 1954. After Sprenger's work there was a period of considerable experimentation and theoretical investigation that has brought the resonance tube to its current status.

The flueric initiator, often called the Pneumatic Match, consists of three basic components: a nozzle, resonance tube, and explosive cup (Fig 1). The gas used to power the device flows through the nozzle where it is accelerated to supersonic velocity. The gas exits the nozzle under-expanded, and the external flow from the nozzle tends to readjust itself through a series of shock and rarefication waves that produce the characteristic diamond shaped Mach cells (Fig 2). It can also be seen from Figure 2 that the static pressure decreases in the first and rises in the second half of the cell, with a minimum value occurring at the intersection of the shock waves. Observed areas of instability (represented by the dashed lines in Fig 2) occur between the cell midpoint and the end of the cell. Hartmann observed that if the opening of a cavity was placed in such a region of instability, a self-sustaining system of oscillations would be created by driving the gas trapped in the cavity into resonance. Even though there is a continuous flow of gas into and out of the resonating cavity, a small percentage of the gas remains trapped at the closed end of the cavity. This trapped gas, because of its driven resonance, undergoes repeated cycles of compression and rarefaction that produces an irreversible temperature increase which can be several times the value of the initial abiabatic temperature head. The thermal energy generated in this manner is concentrated at the closed end of the cavity and can be utilized to ignite an explosive train.

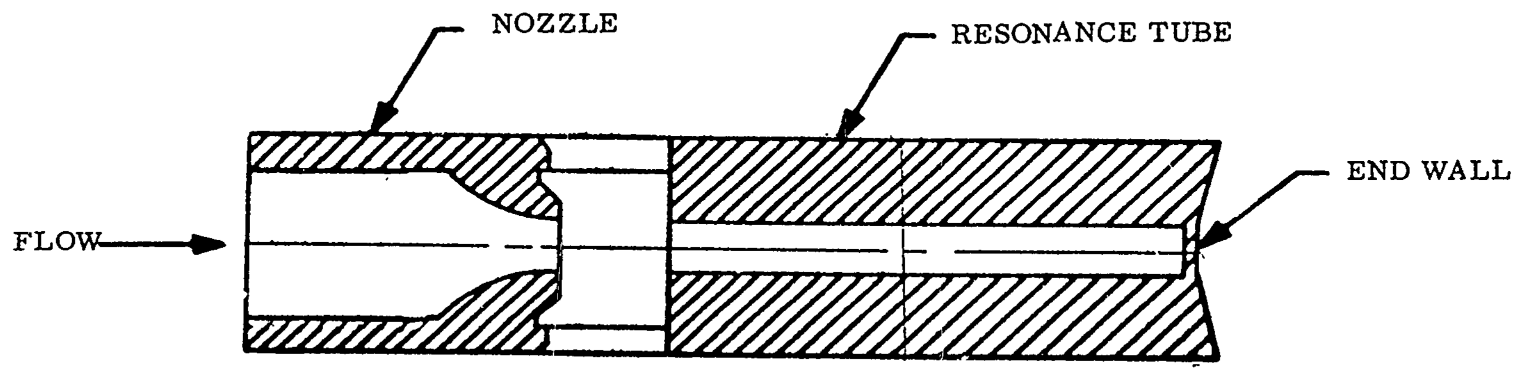


FIGURE 1 SCHEMATIC OF PNEUMATIC MATCH CONFIGURATION

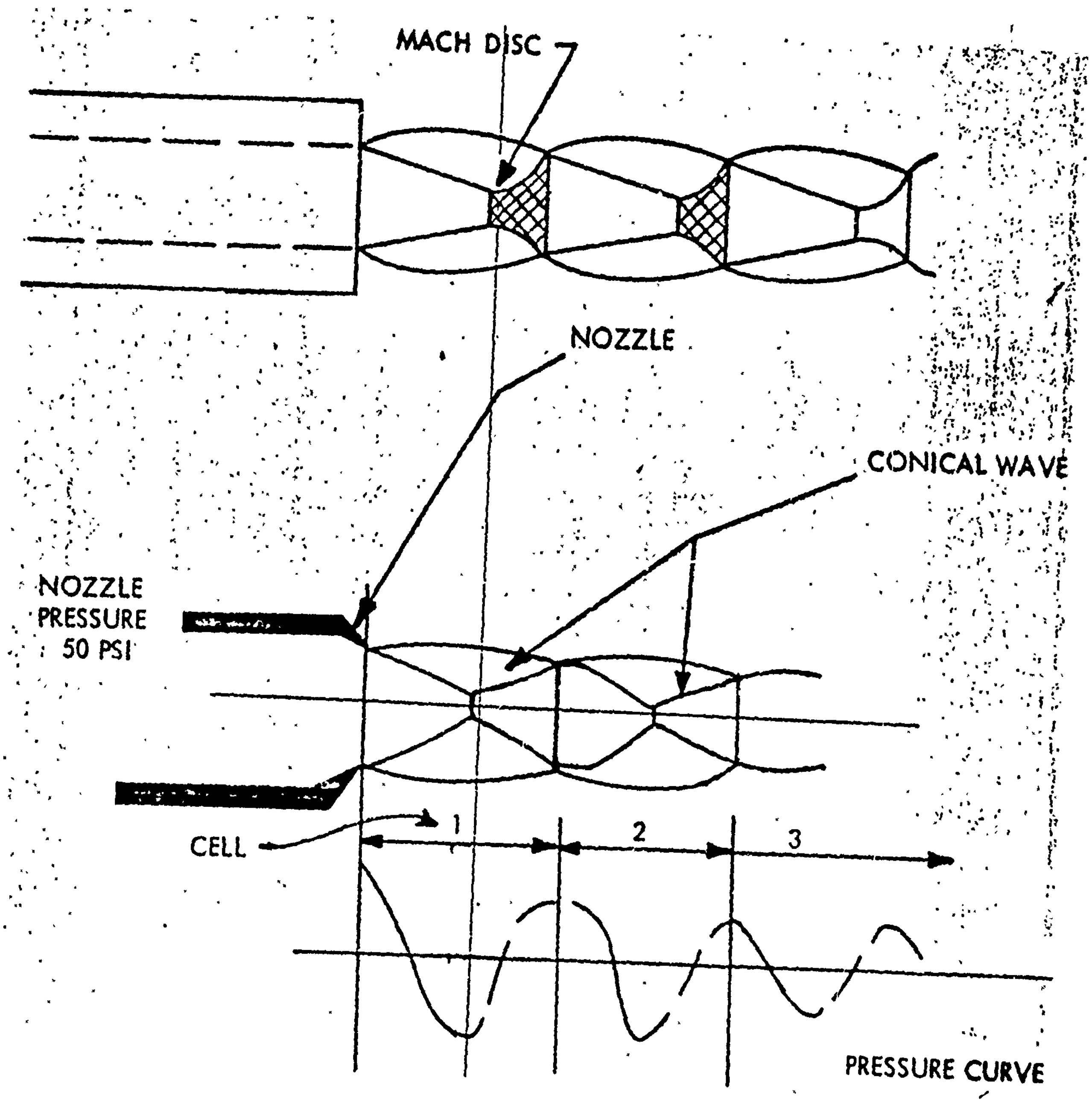


FIGURE 2 NOZZLE SHOCK AND PRESSURE CHARACTERISTICS

III. DEVICE DEVELOPMENT

The Air Force Armament Laboratory (AFATL) requirements for the Flueric Explosive Initiator (FEI) for FAE weapon applications are presented in Appendix A.

Throughout the early states of development, the FEI had been tested only in the static mode. Figure 3 presents the standard static test setup for this device. The apparatus consists of a gas supply, lecture bottle, solenoid valve, and initiator holding assembly interconnected as shown. For testing, the lecture bottle was charged to a predetermined pressure, and the shut-off valve was closed. A match assembly, consisting of a plastic nozzle, resonance tube, and explosive cup, was inserted into the holder and clamped in place. The match fired as soon as the solenoid valve opened. Since, in this configuration, the vents in the chamber between the nozzle and the resonance tube were always open, the chamber pressure and, hence, the pressure acting through the resonance tube on the explosive cup, was never more than a few pounds per square inch (psig) above ambient conditions.

Initially, the entire match assembly was fabricated from injection molded plastic components. This rationale was based on the fact that the plastic exhibited very low thermal conductivity (thus reducing heat loss from the resonance tube) and would be inexpensive to produce. Since the plastic lent itself to injection molding techniques, all three components of the match were fabricated simultaneously in one set of molding dies. In order to increase the efficiency of heat transfer between the resonance tube output (closed end of tube) and the explosive, a 0.001-inch stainless steel disk was incorporated into the explosive cup (Fig 4). This disk also provided protection for the explosive from disruption by the hot resonating gases. Since components fabricated in this manner performed satisfactorily in the static tests, no further consideration was given at the time to enhancing the structural characteristics of the device.

The FEI was originally envisioned as being utilized in squib switches and explosive logic devices on Army munition systems; hence, it was designed to have the shortest delay time possible from the initiation of gas flow to the initiation of the explosive. The AFATL requirements for the FAE igniter included a time delay function ranging from 150 milliseconds to 800 milliseconds. Since this time delay was two orders of magnitude

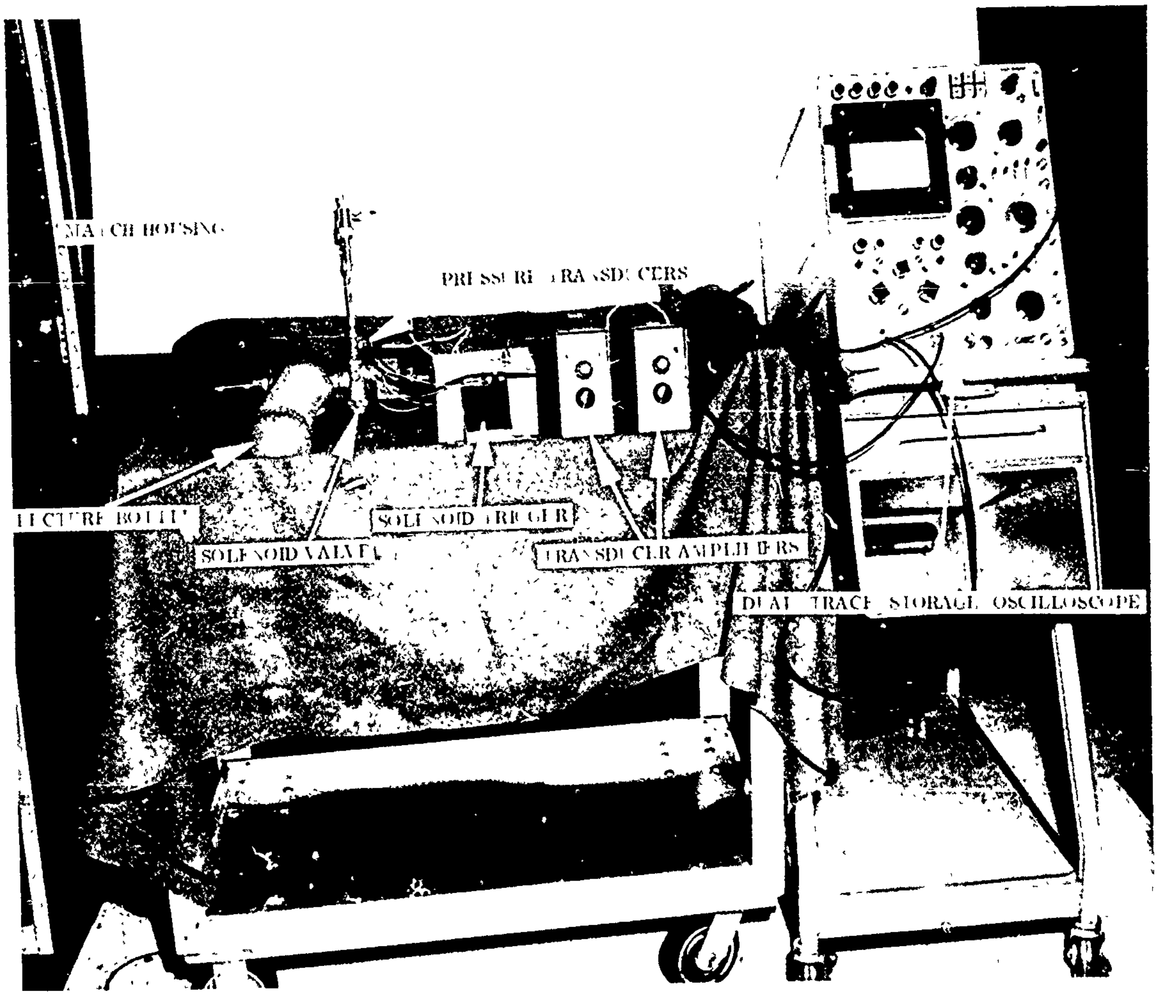


Figure 3. Static Test Apparatus

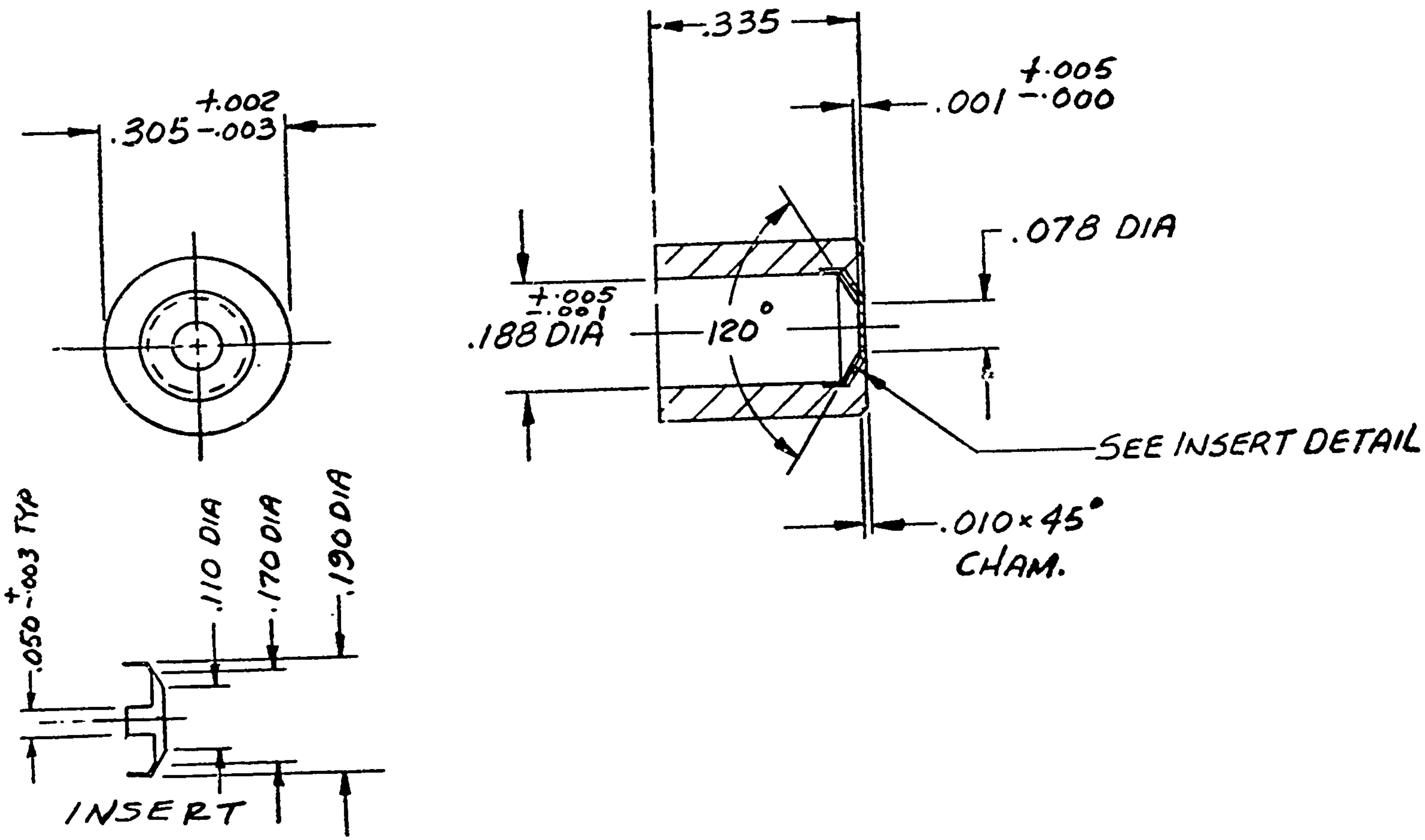


FIGURE 4 EXPLOSIVE CUP CONFIGURATION

longer than the standard pneumatic igniter delay, effort was expended in the initial phases of FAE igniter development toward meeting this requirement. Several alternate methods were proposed, and included:

1. Variation of the resonance tube internal shape/configuration.

2. Changes in the explosive cup disc thickness.

3. Blowndown from a nonresonant high pressure condition.

4. Variation of operating pressure.

5. Changes in the working gas.

Although it was possible to obtain the required time delays utilizing any one of the above procedures, all of them except the blowdown from a nonresonant high pressure condition would require extensive redesign and/or modification of the nozzle, resonance tube, or explosive cup. Another prime consideration was that the thermal generation, once started, should be extremely rapid (steep positive slope) to ensure repeatable detonation times within the specified tolerance. Consequently, the high pressure blowdown method was selected for development as the FAE igniter.

The blowdown principle depends solely upon the operating characteristics of the resonance tube. Since optimum resonance heating is obtained when the opening of the resonance tube lies in the region of instability within the first Mach cell, and since this condition can be met only over a relatively small range of nozzle pressure ratios, the resonance tube will not generate heat until the bottle pressure has dropped and the minimum pressure ratio is attained.

At nozzle pressure ratios higher than those in this range, the resonance tube opening lies well forward of the first instability region and no heating is experienced. At nozzle pressure ratios lower than those in the operating range, but still supersonic, the resonance tube opening may or may not lie in the region of instability of a Mach cell (other than the first); however, due to the energy-dissipating viscous effects introduced by repeated shock compression and expansion, the temperature response of the resonance tube becomes orders of magnitude slower.

These operational characteristics can be utilized for the FAE igniter to obtain the desired time delay. By connecting the FEI to a supply bottle containing gas at a pressure higher than that required for operation and allowing the bottle to bleed back down to ambient conditions through the nozzle, the operational time delay can be set as the time it takes for the bottle pressure to drop from its initial value to the value required for FEI operation.

Initial testing of the FAE igniter was conducted utilizing a resonance tube defined as "S_8" (Fig 5) and nitrogen as the working gas. The standard pneumatic match static-test fixture (Fig 3) was utilized for these tests and a memory oscilloscope was used to document the function time of the delay igniter. The trigger-on signal for the oscilloscope was produced by opening the solenoid valve between the supply volume and the match-holding fixture. The trigger-off signal for the oscilloscope was the pressure pulse produced by the detonation of 25 milligrams of KDNBF consolidated at 35,000 psig in the plastic explosive cups. The results of this testing are shown in Table I. Similar data were obtained with a resonance tube which was drilled out so that the resonance cavity was a cylinder 0.080 inch in diameter. This data is shown in Table II. As can be seen from Tables I and II, results obtained were erratic and nonrepeatable.

In order to better understand the pressure dependent time delay, a number of tests were performed to define the supply bottle pressure delay characteristic. Experimental pressure delay curves were obtained by monitoring the supply bottle pressure continuously after the bottle was permitted to blow down through a nozzle to ambient conditions after opening of the solenoid valve. The results of some of these tests are shown in Figure 6. It should be noted that the apparent disparity between the charging pressure and the initial nozzle pressure was due to the pressure drop in the solenoid valve. From the data presented and from the known operating characteristics of the pneumatic match, it can be seen that by varying the nozzle size, supply pressure, and supply volume, the solution to the time delay problem can be realized.

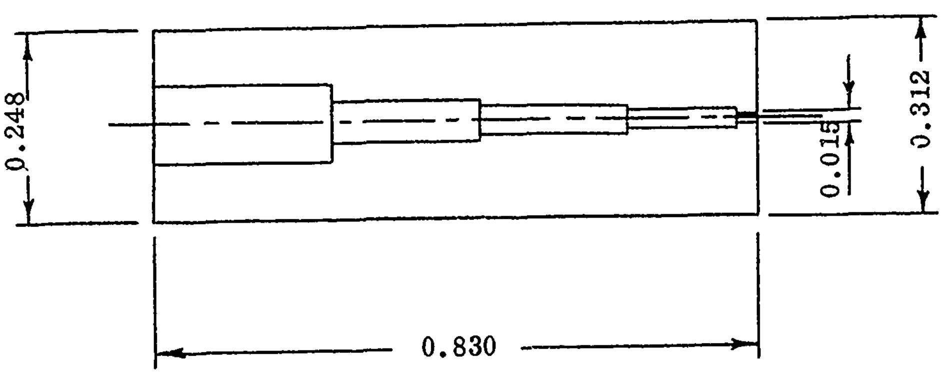


FIGURE 5 S_8 RESONANCE TUBE CONFIGURATION

TABLE I

S_8 RESONANCE TUBE TEST FIRING RESULTS

Run No.	Supply Pressure (psig)	Delay Time (ms)
1	200	400
2	250	500
3	260	150
4	255	150
5	250	350
6	240	180
7	220	No trigger
8	220	180
9	200	260
10	180	350
11	160	540
12	140	860
13	140	900
14	300	10
15	295	145
16	285	160
17	300	5
18	300	6
19	295	136
20	300	132
21	295	168
22	290	900

TABLE II

CYLINDRICAL RESONANCE TUBE (S_8 TUBE MODIFIED)
TEST FIRING RESULTS

Run No.	Supply Pressure (psig)	Delay Time (ms)
1	270	100
2	260	No trigger
3	255	180
4	240	200
5	220	240
6	200	260
7	180	320
8	180	880

1. The flow through the nozzle is assumed to be ideal and the gas in the supply bottle expands isentropically.

2. The pressure in the supply bottle decays in an exponential manner and is a function of temperature, initial pressure, initial volume, and molecular weight of the gas.

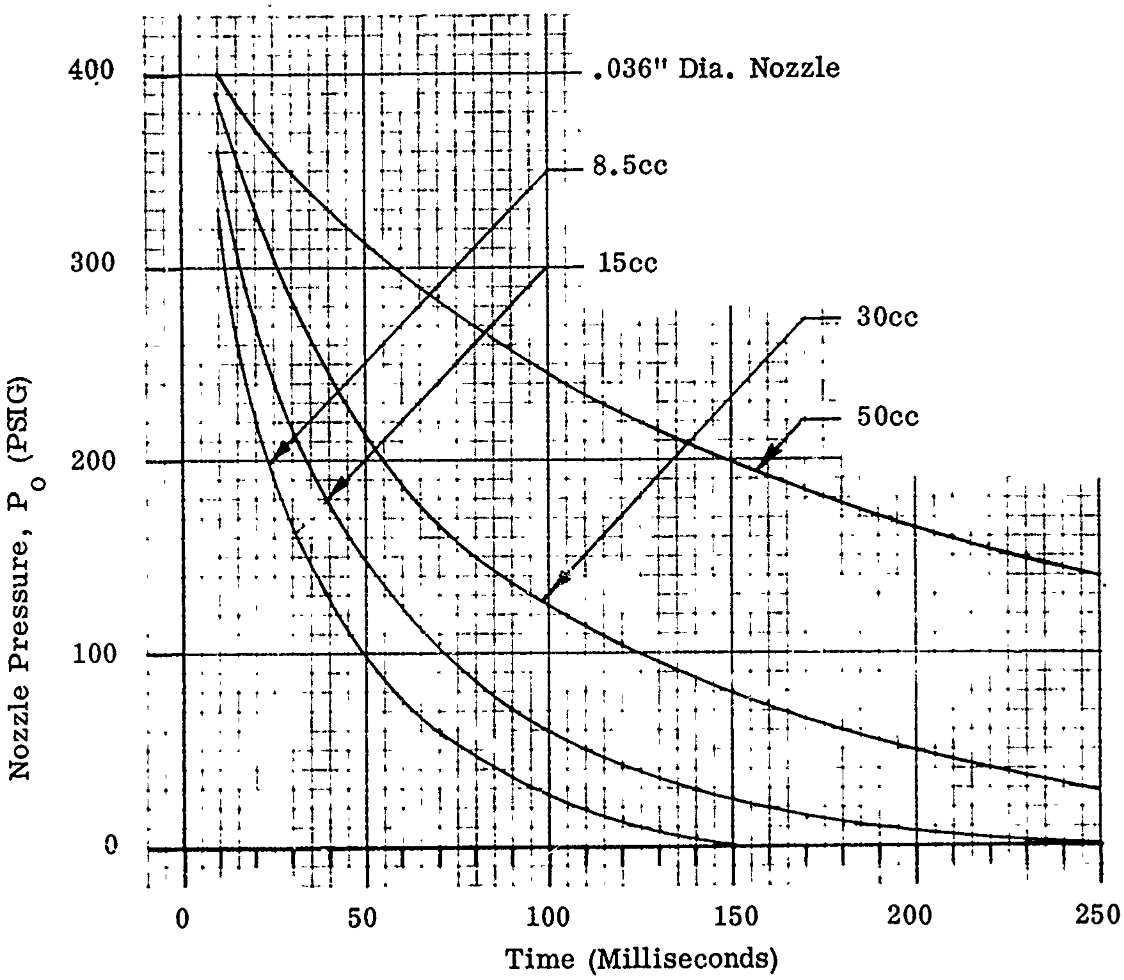


FIGURE 6 PRESSURE/TIME PROFILES FOR VARIOUS SUPPLY VOLUMES

In order to predict the correct nozzle size and supply pressure, a computer simulation of the pneumatic match flow system was evolved. Two separate analyses were considered: Isentropic pressure blowdown and exponential pressure blowdown.

Solutions to both analyses were obtained and are plotted for the given conditions in Figures 7 and 8. Both methods closely approach the experimentally determined pressure delay; however, the exponential analysis is closer to the experimental data in the region of greatest concern (i.e., the pneumatic match operational pressure range). For this reason, it was decided to use the exponential pressure delay in the design of the FAE igniter system.

The equation governing the exponential pressure decay is

$$P = P_o e^{-\theta t}$$

where

$$\theta = \frac{A\, A_s \left[\left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma+1}{\gamma-1}} \right]^{1/2}}{V_o}$$

P_o = Initial Supply Pressure (psig)

A = Nozzle Area (ft^2)

A_s = Speed of Sound = $\frac{R\, T_o}{M}$

γ = Ratio of specific heats (49,700 ft^2/mole °F sec^2)

R = Molecular weight of the gas

T_o = Initial temperature (°R)

A computer program was written to solve this equation for various values of temperature, nozzle size, volume supply, and initial pressure. A source listing of the program is presented in Figures 9 and 10. After it was determined that the program was running correctly, the parameters were varied and a number of pressure-versus-time plots were obtained. These plots are presented in Figures 11 through 18.

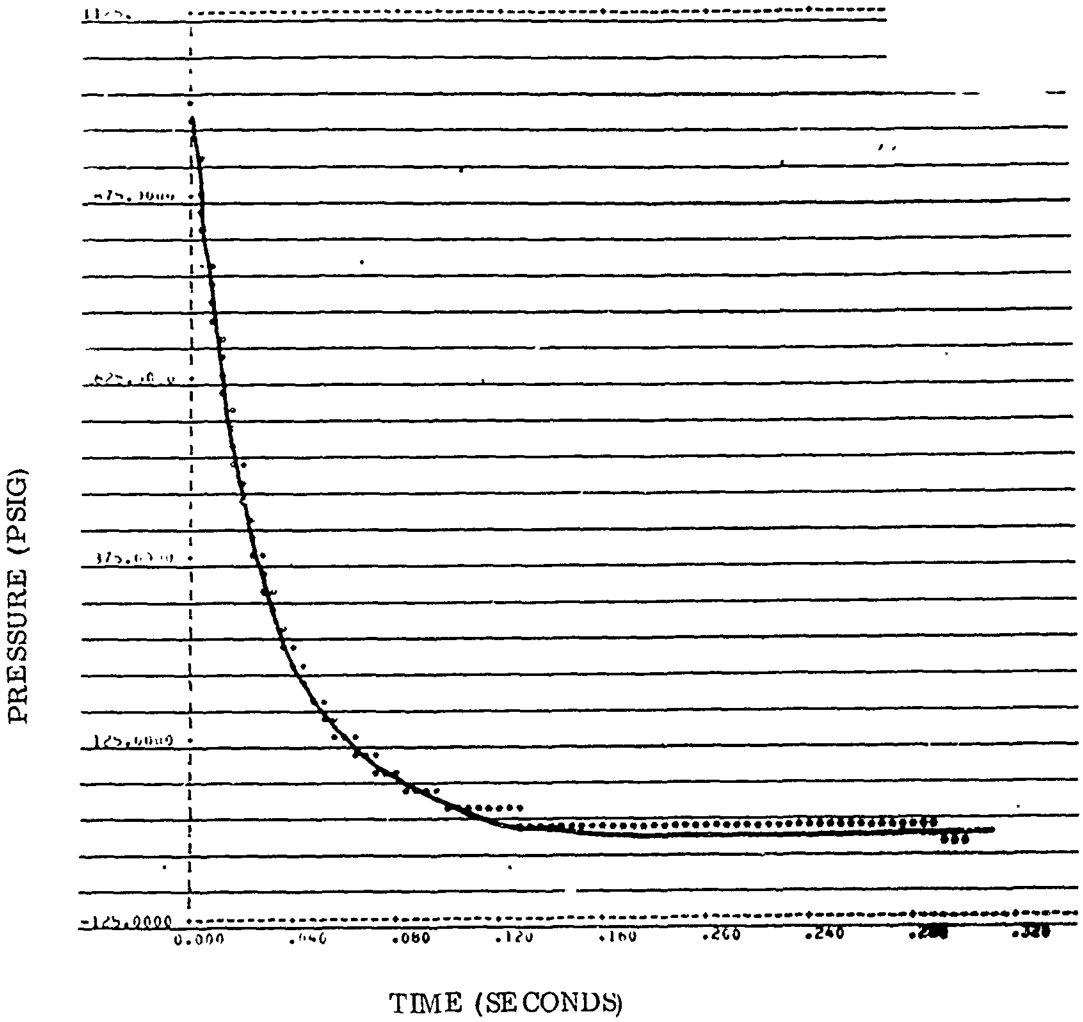


FIGURE 7 Isentropic Pressure Decay Curve

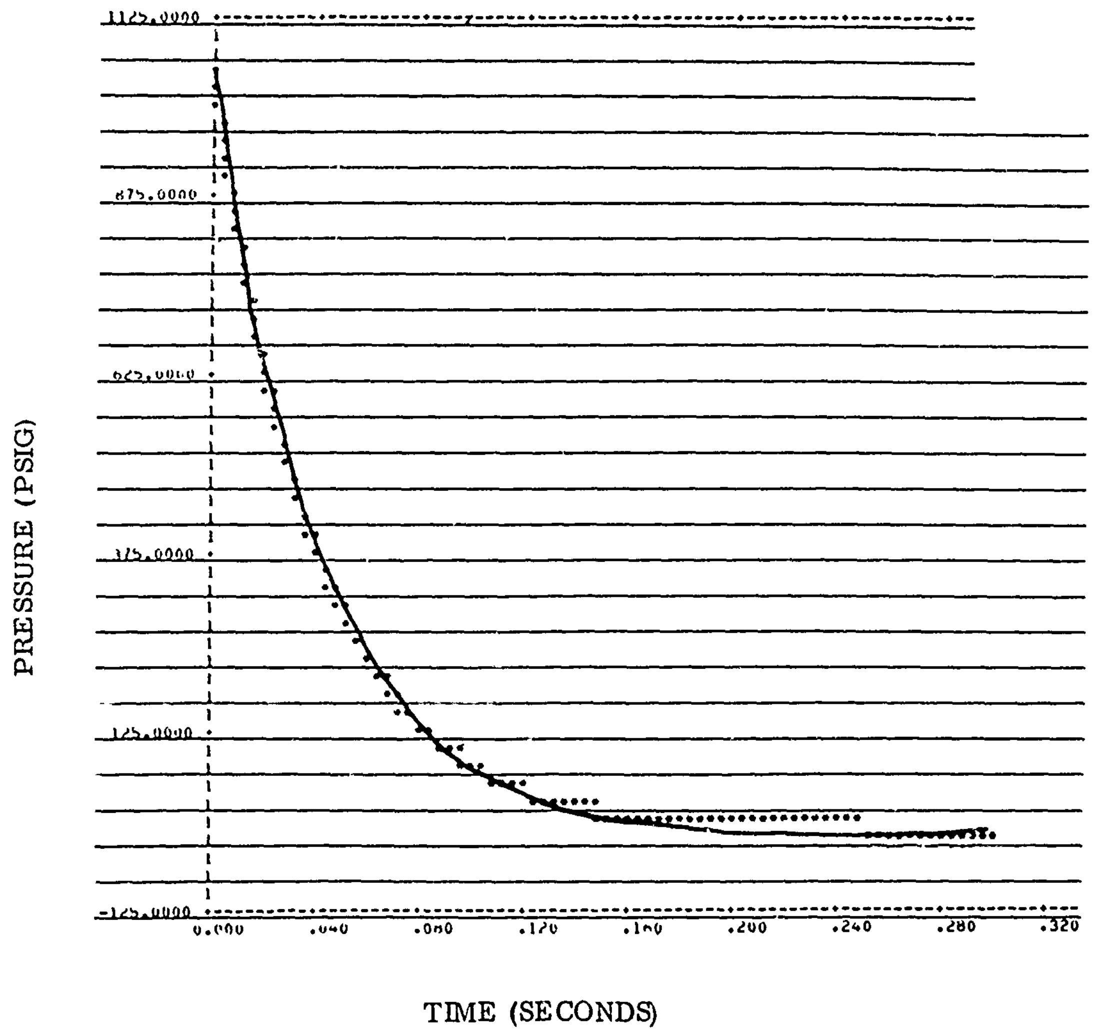


FIGURE 8 Exponential Pressure Decay Curve

```
BOTTLES,CM60000,T25.
COMMENT.(880-880.02805E).MASLY
FTN.
MAP(OFF)
REWIND(OUTPUT)
ATTACH(NAN,NANCY,CY=1,SD=16)
LOAD(NAN)
LGO.
0000000000000000000000
      PROGRAM BOTTLES(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
      DIMENSION T1(500),T2(500),T3(500),P1(500),P2(500),
     +          P3(500),V(20),R(20),TO(20),P(500),T(500),
     +          PO(20)
C
C
C  THIS IS A PROGRAM TO CALCULATE AND THEN PLOT THE PRESSURE
C  DECAY IN A SMALL GAS BOTTLE.IN ORDER TO DETERMINE THE
C  DECAY IT WAS ASSUMED THAT IT OCCURRED EXPONENTIALLY
C
C  THE FOLLOWING IS A LIST OF SYMBOLS USED IN THE PROGRAM
C
C     AS....THE SPEED OF SOUND IN THE WORKING FLUID AT
C           TEMPERATURE TO (FEET PER SECOND)
C     AT....THE THROAT AREA OF THE NOZZLE USED (FEET SQUARED)
C     E.....THE GAS CONSTANT FOR THE WORKING FLUID (FEET
C           SQUARED PER MOLE PER DEGREE RANKINE PER SECOND
C           SQUARED)
C     GAM...THE RATIO OF SPECIFIC HEATS OF THE WORKING FLUID
C     IRUN..THE NUMBER OF SAMPLES TO BE PLOTTED ON EACH GRAPH
C           IN THIS PROGRAM IRUN=3
C     P.....THE BOTTLE PRESSURE (PSIG)
C     PO....THE INITIAL BOTTLE PRESSURE (PSIG)
C     P1....DUMMY PRESSURE USED TO SAVE THE VALUES OF P
C     P2....DUMMY PRESSURE USED TO SAVE THE VALUES OF P
C     P3....DUMMY PRESSURE USED TO SAVE THE VALUES OF P
C     R.....THE NOZZLE DIAMETER (INCHES)
C     RAD...THE NOZZLE RADIUS (FEET)
C     RMOL..THE MOLECULAR WEIGHT OF THE WORKING FLUID
C     T.....THE TIME (SECONDS)
C     TO....THE INITIAL TEMPERATURE (DEGREES RANKINE)
C     T1....DUMMY TEMPERATURES USED TO SAVE THE VALUES OF T
C     T2....DUMMY TEMPERATURES USED TO SAVE THE VALUES OF T
C     T3....DUMMY TEMPERATURES USED TO SAVE THE VALUES OF T
C     THETA.THE EXPONENT IN THE DECAY EQUATION
C     V.....THE BOTTLE VOLUME (CENTIMETERS CUBED)
```

Figure 9 Source Listing of Pressure Decay Computer Program Page 1

```
C     VO....THE BOTTLE VOLUME (FEET CUBED)
C
C
      GAM=1.67
      E=49700.
      RMOL=4.
      IRUN=1
    5 READ(5,10) (V(I),R(I),TO(I),PO(I),I=1,3)
   10 FORMAT(F10.0,F10.3,F10.0,F10.0)
      IF(TO(IRUN).EQ.520.) GO TO 99
      PO(IRUN)=PO(IRUN)*TO(IRUN)/520.
   99 DO 9 J=1,3
      AS=SQRT(GAM*E*TO(J)/RMOL)
      VO=V(J)*3.531E-05
      RAD=R(J)/24.
      AT=3.1417*(RAD*RAD)
      THETA=AS*.5623*AT/VO*(-1.)
      DO 1 I=1,31
      T(I)=(I-1.)/100.
    1 P(I)=PO(J)*EXP(THETA*T(I))
      IF(J.EQ.1) GO TO 100
      IF(J.EQ.2) GO TO 101
      GO TO 102
  100 DO 2 IN=1,31
      T1(IN)=T(IN)
    2 P1(IN)=P(IN)
  101 DO 3 IN=1,31
      T2(IN)=T(IN)
    3 P2(IN)=P(IN)
      GO TO 9
    9 CONTINUE
  102 DO 4 IN=1,31
      T3(IN)=T(IN)
    4 P3(IN)=P(IN)
      CALL NEWCHAR(1,1HA)
      CALL NEWCHAR(2,1HB)
      CALL NEWCHAR(3,1HC)
      CALL NANCY3(T1,P1,31,T2,P2,31,T3,P3,31,.2,.08,400.00,
     + 0.,2,1)
      CALL LABEL (4HTIME,6H(SECS),8HPRESSURE,6H(PSIG),1)
      CALL TITLE (8HGAS BLOW,5H DOWN)
      IRUN=IRUN+1
      IF(IRUN.LT.4) GO TO 5
      STOP
      END
```

Figure 10 Source Listing of Pressure Decay Computer Program Page 2

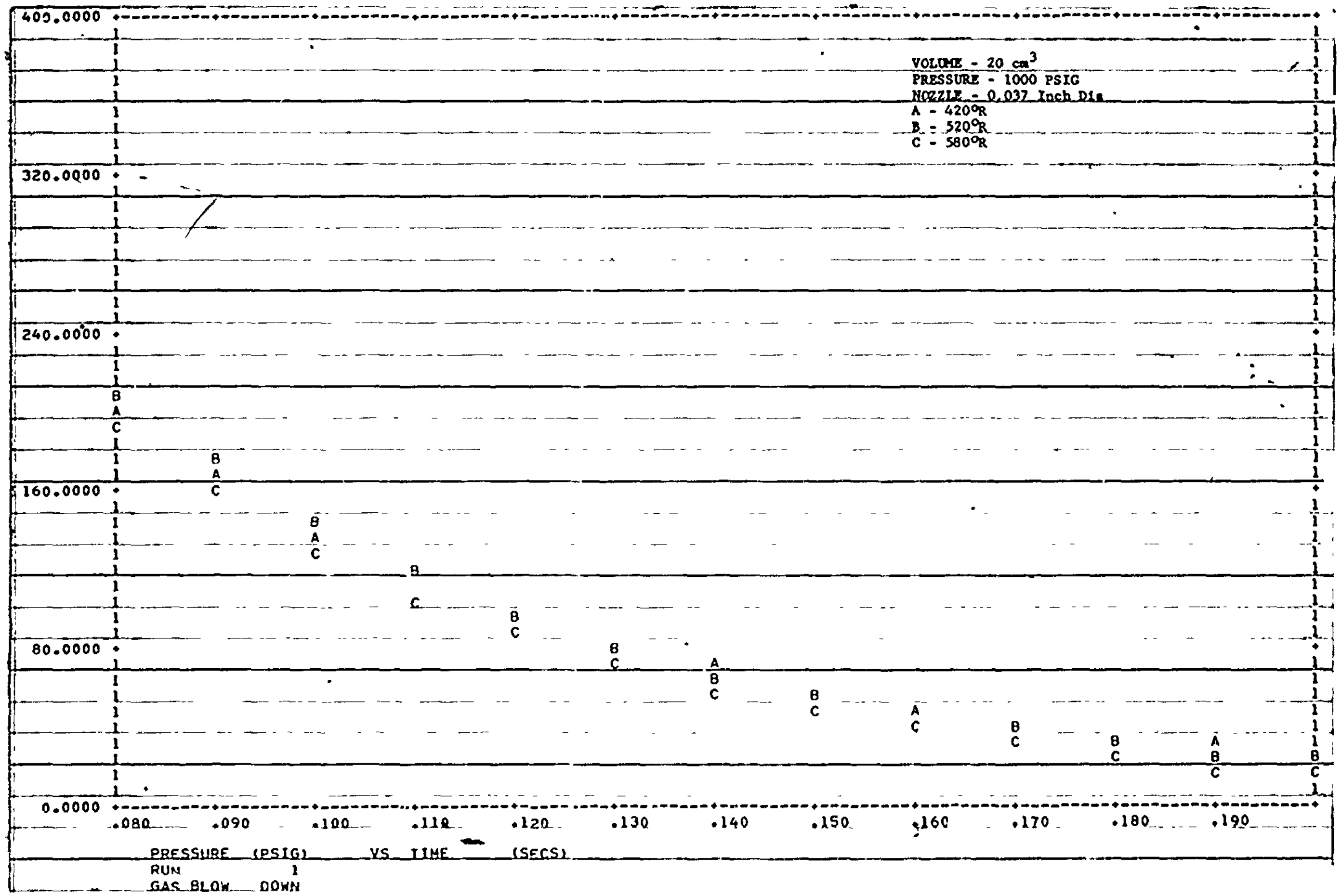


FIGURE 11 PRESSURE DECAY PLOT - 20 cm^3, 1000 PSIG, 0.037 INCH DIA NOZZLE

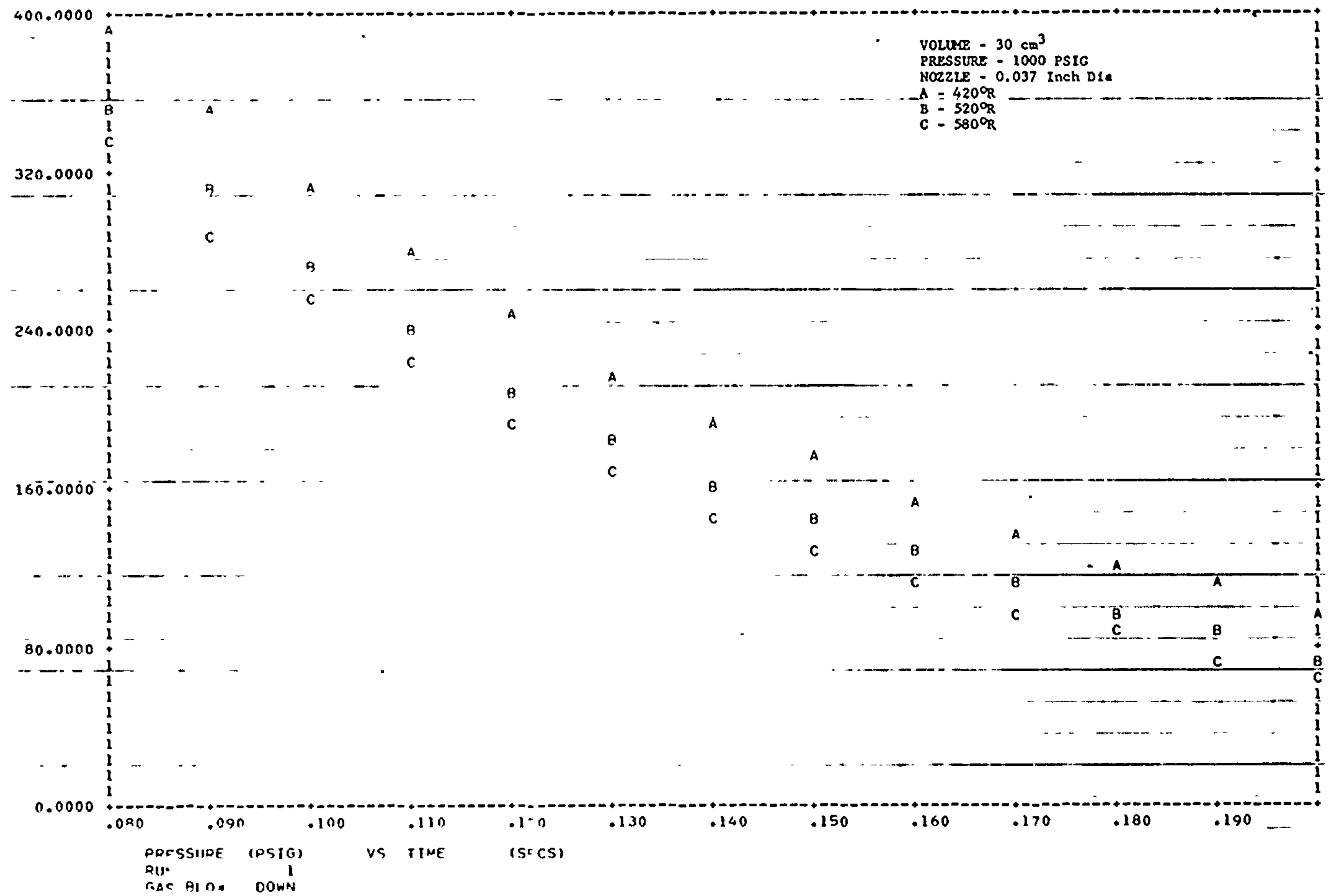


FIGURE 12 PRESSURE DECAY PLOT - 30 cm^3, 1000 PSIG, 0.037 DIA NOZZLE

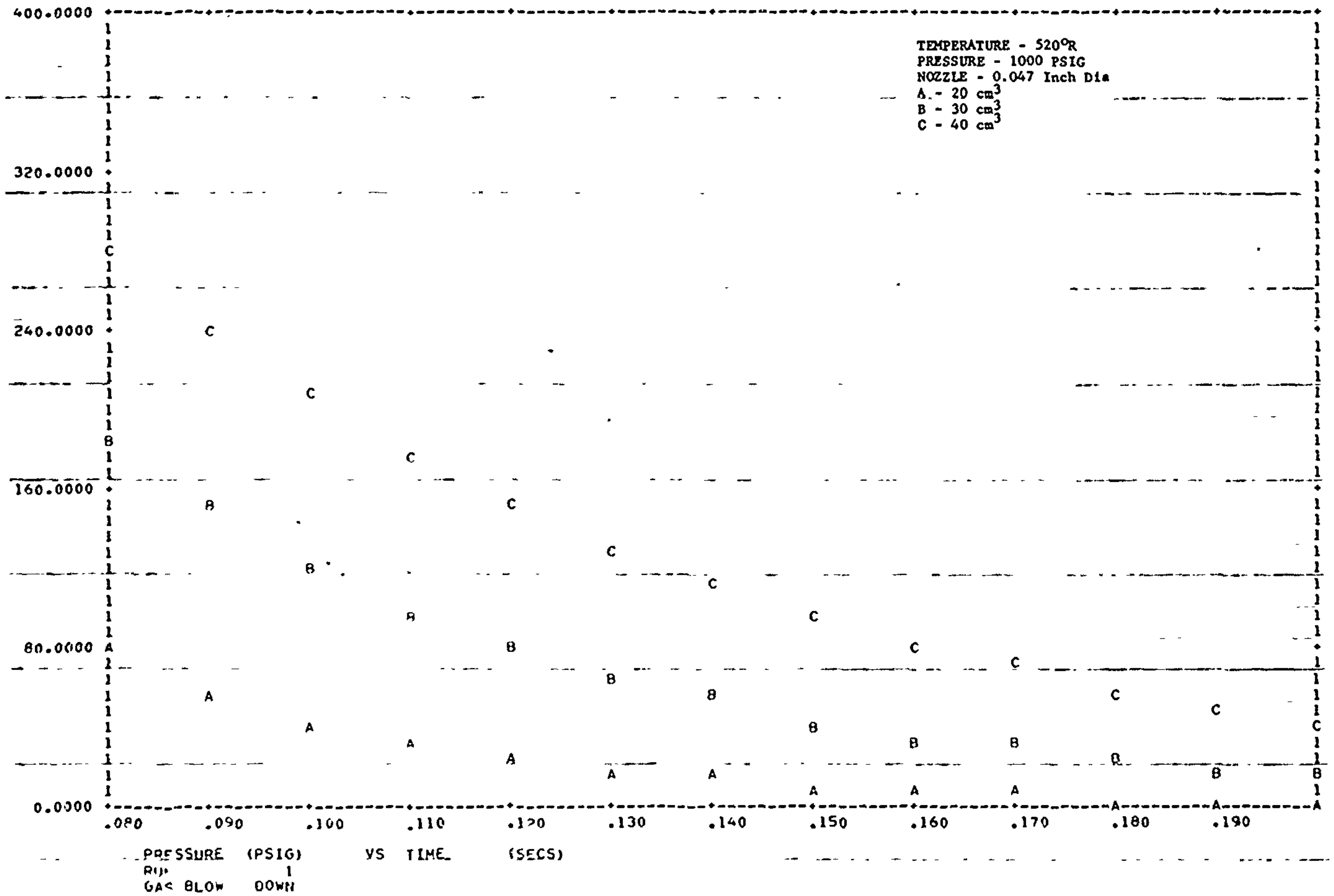


FIGURE 13 PRESSURE DECAY PLOT - 520°R, 1000 PSIG, 0.047 INCH DIA NOZZLE

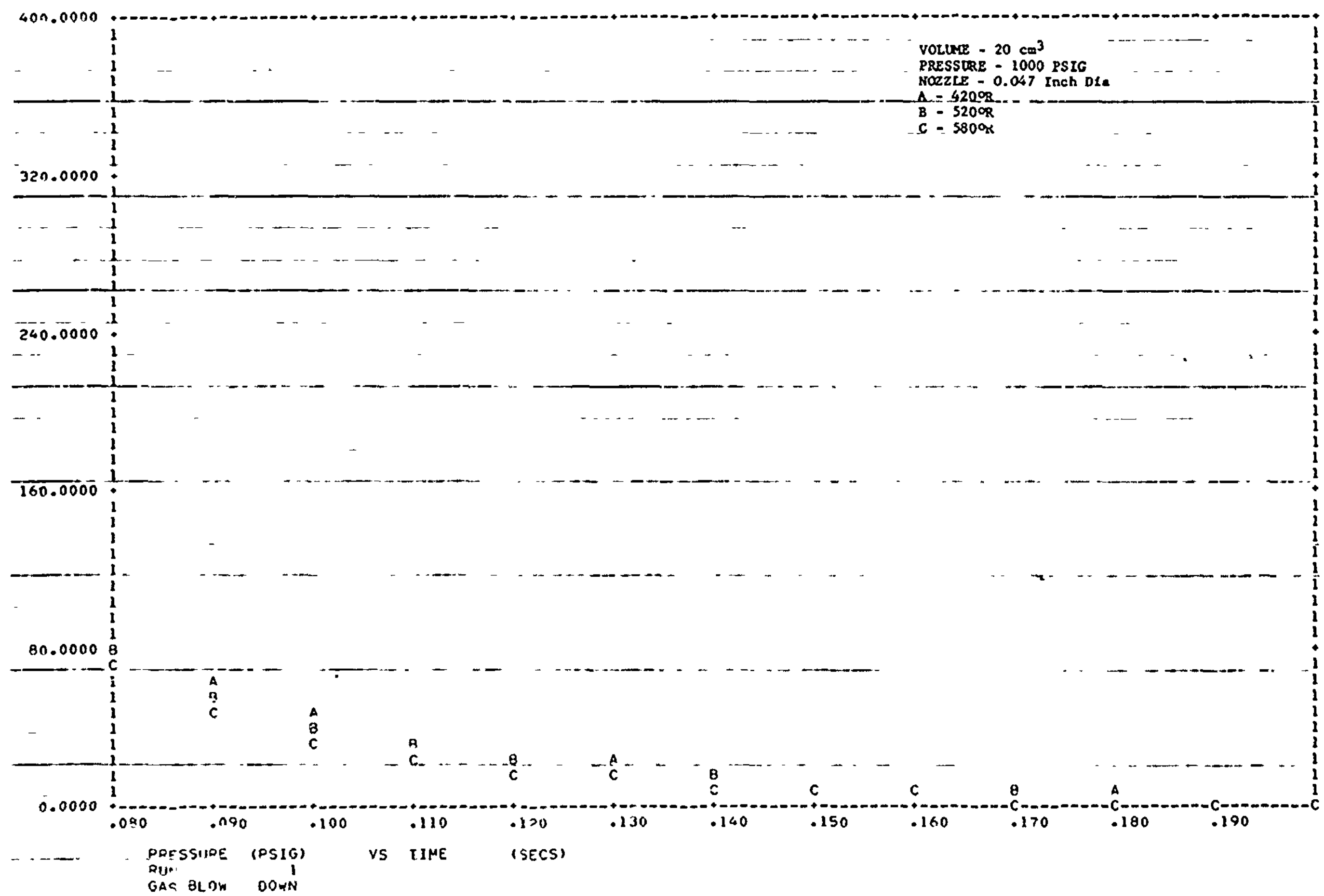


FIGURE 14 PRESSURE DECAY PLOT - 20 cm^3, 1000 PSIG, 0.047 INCH DIA NOZZLE

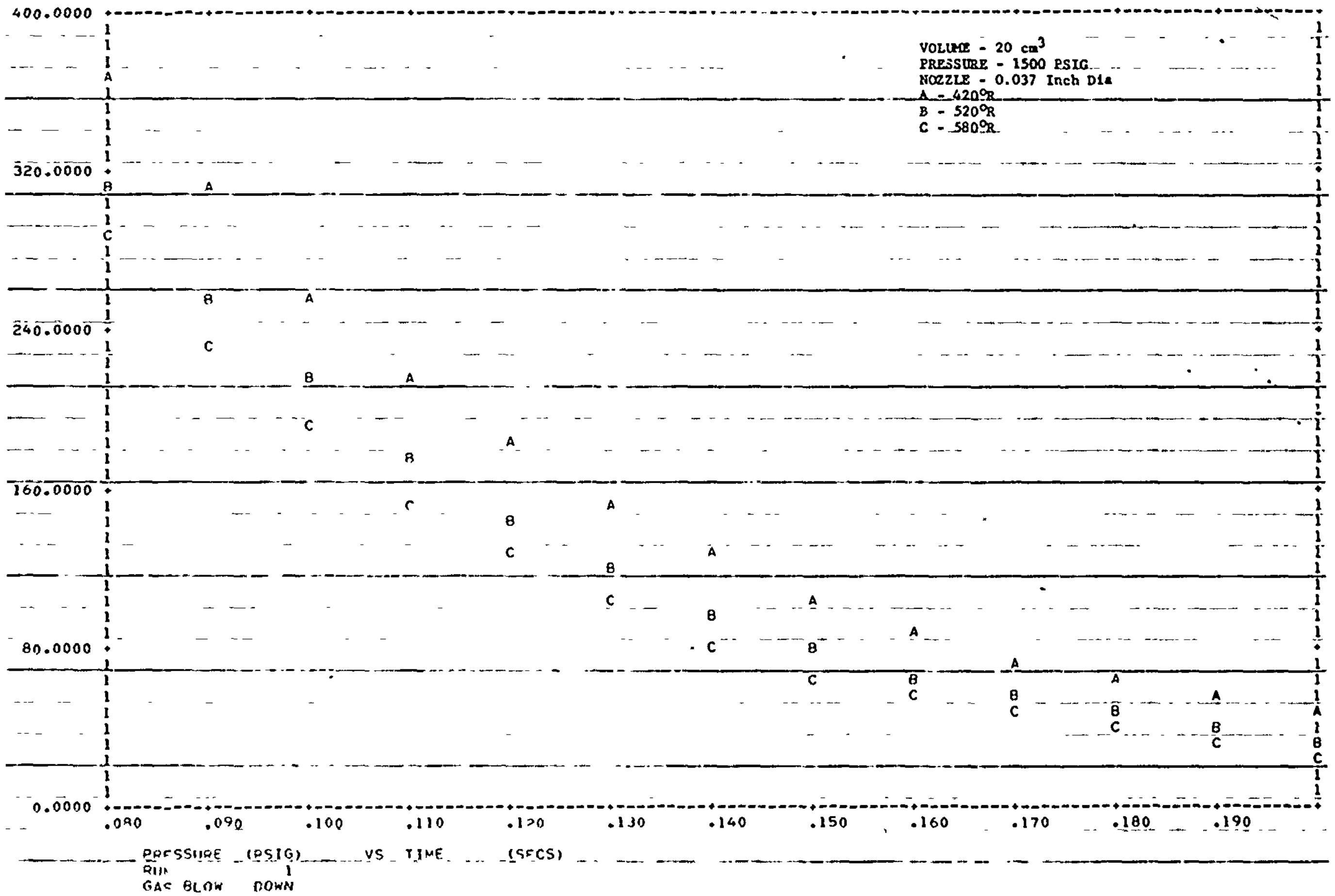


FIGURE 15 PRESSURE DECAY PLOT - 20 cm^3, 1500 PSIG, 0.037 INCH DIA NOZZLE

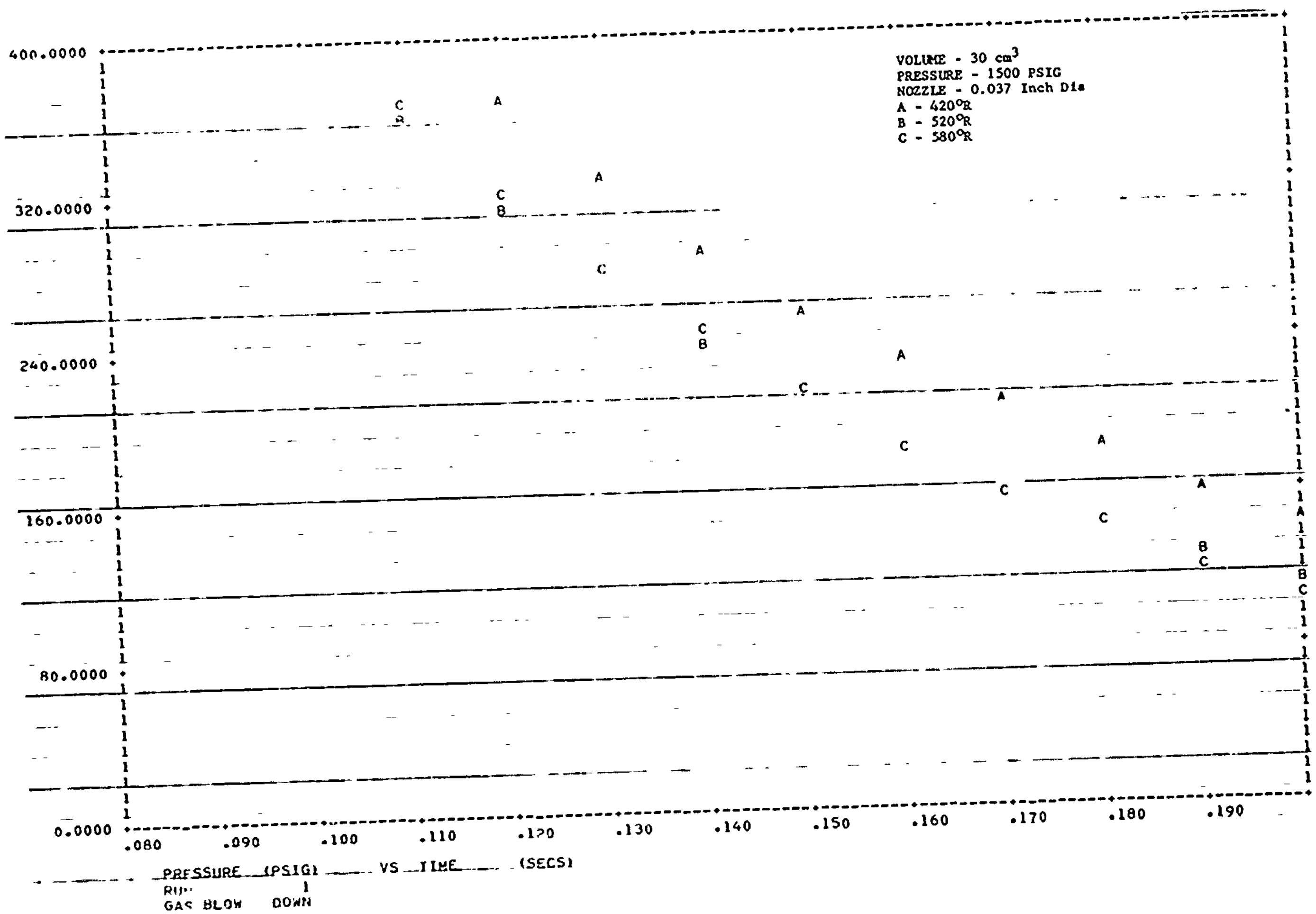


FIGURE 16 PRESSURE DECAY PLOT 30cm^3, 1500 PSIG, 0.037 INCH DIA NOZZLE

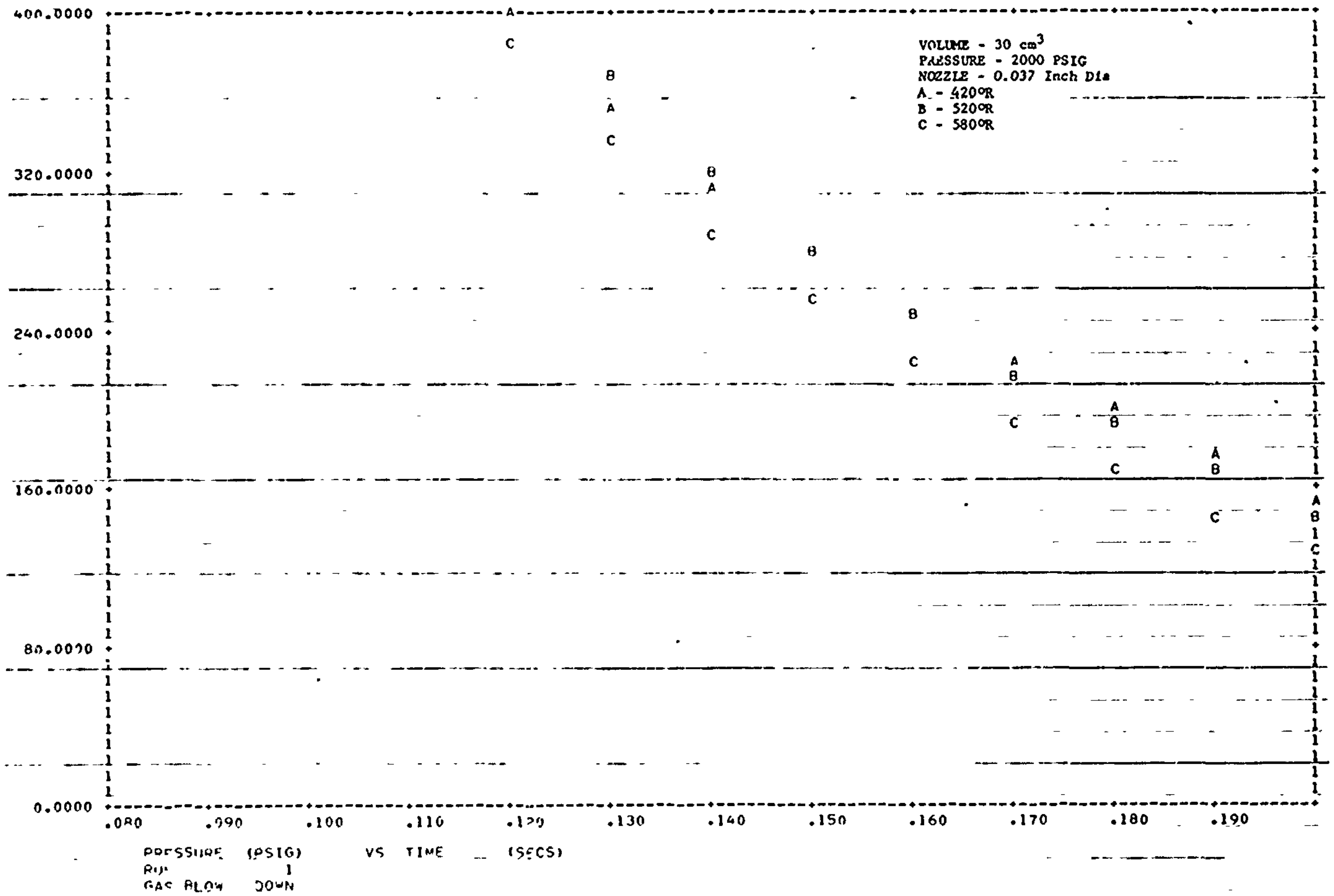


FIGURE 17 PRESSURE DECAY PLOT - 30 cm^3, 2000 PSIG, 0.037 INCH DIA NOZZLE

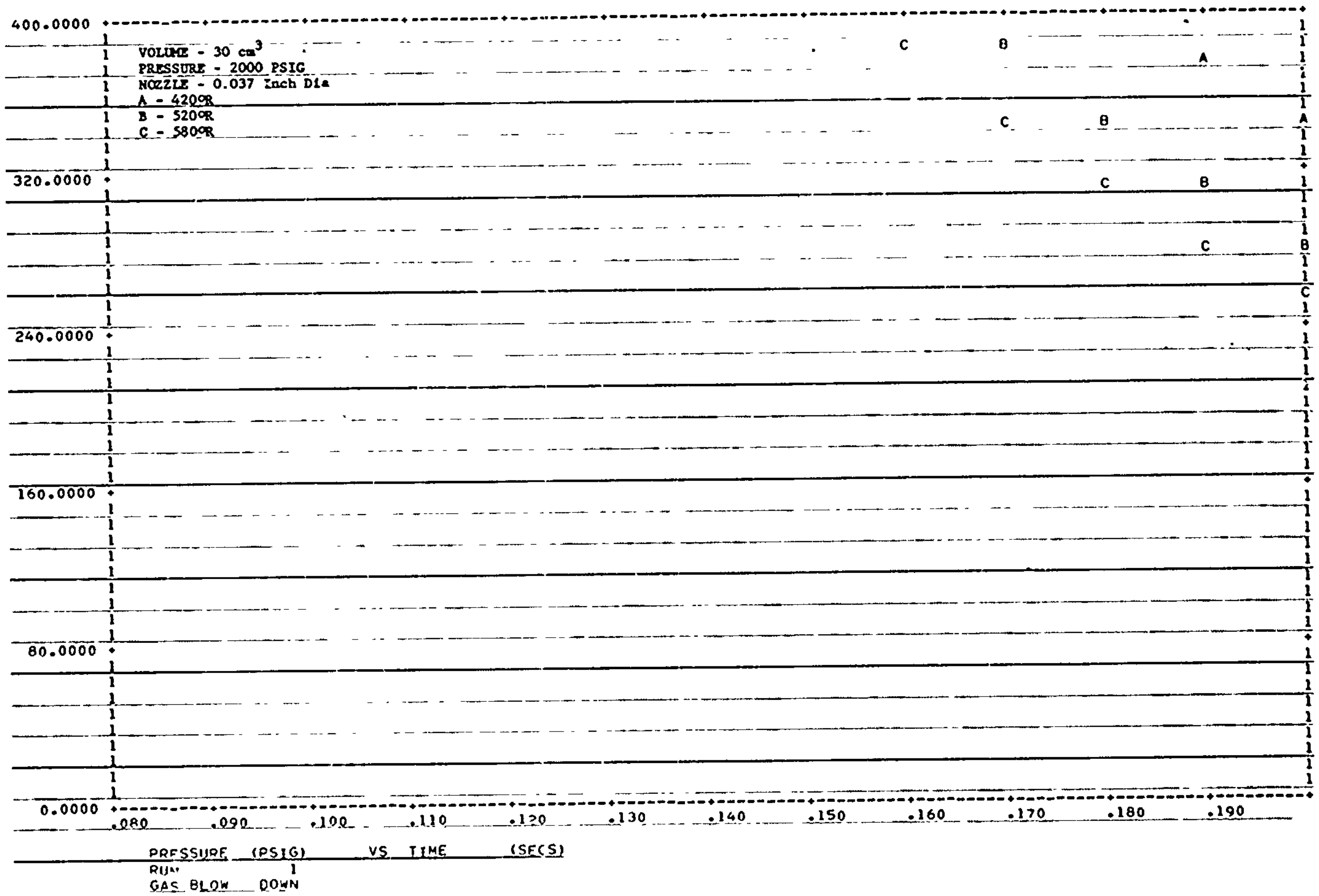


FIGURE 18 PRESSURE DECAY PLOT - 40 cm^3, 2000 PSIG, 0.037 INCH DIA NOZZLE

It can be seen from these plots that for a constant volume and nozzle size the change in supply pressure, due to a change in temperature, can have a significant effect on the time required to reach resonance pressure. In some cases, the curves remained very close together and at times even intersected. This condition is desired, since the intersection of the curves for standard, high, and low temperature at a single point which lies within the desired time delay range and at the proper operating pressure would indicate that the igniter design was temperature insensitive.

An analysis of the ambient temperature effects was then conducted in order to determine the operational parameters which would minimize these effects. The nozzle supply volume and initial pressure must be sized such that at the desired time delay the required gas pressure is obtained, regardless of the ambient gas temperature. The pressure at any time after the vents open is given by:

$$P = P_i e^{-\alpha\sqrt{T}\,t}$$

where α is a function of the nozzle throat area and the supply volume.

If a closed container originally filled to P_i is cooled to a temperature $\bar{T}$ the pressure, P_i, drops to

$$P_i \left[\frac{\bar{T}}{T}\right]$$

It is required that the pressure at some desired time P_D be the same for both conditions, hence,

$$P_i e^{\alpha\sqrt{T}t} = P_i \frac{\bar{T}}{T} e^{-\alpha\sqrt{\bar{T}}\,t}$$

which yields

$$\alpha \sqrt{T}\, t = \ln \left[\frac{\bar{T}}{T} \right] + \alpha \sqrt{\bar{T}}\, t$$

$$\alpha t = \frac{\ln \left[\frac{\bar{T}}{T} \right]}{\sqrt{T} - \sqrt{\bar{T}}}$$

For design purposes the ambient temperature is used, with θ defined as $\theta = \alpha \sqrt{T_{amb}}$. A reasonable range of operating temperature is -50 to + 140°F which gives $\theta t = 2.0448$ as the value which insures that the pressure at any time t will be independent of the temperature. If, for example, the temperature range were -40 to +120° then $\theta t = 2.050$. Figure 19 plots the relationship $\theta t = 2.0448$. The value of θ is found for the desired time delay and then either the nozzle diameter or supply volume is adjusted according to the following equation:

$$\text{Noz dia (in.)} = \sqrt{(3.5 \times 10^{-6}) \text{ Vol } (\text{cm}^3)\ (\theta)}$$

Since $\theta t = 2.05$, the choice of initial pressures is not arbitrary, if temperature insensitivity is necessary.

$$P = P_i e^{-\theta t} = P_i e^{-2.05} = \frac{P_i}{7.7}$$

Thus, if the desired operating pressure is 150 psi, then the initial pressure must be 1,150 psi no matter how the volume and the nozzle size is varied.

Concurrently, tests were performed to define the temperature versus time profiles that could be expected from the igniter by utilizing small supply bottle volumes charged to moderate pressures. The results of this testing are presented in Figure 20. These results indicate that sufficient temperature rises can be obtained for explosive initiation by utilizing the small-volume, moderate-pressure blowdown configuration.

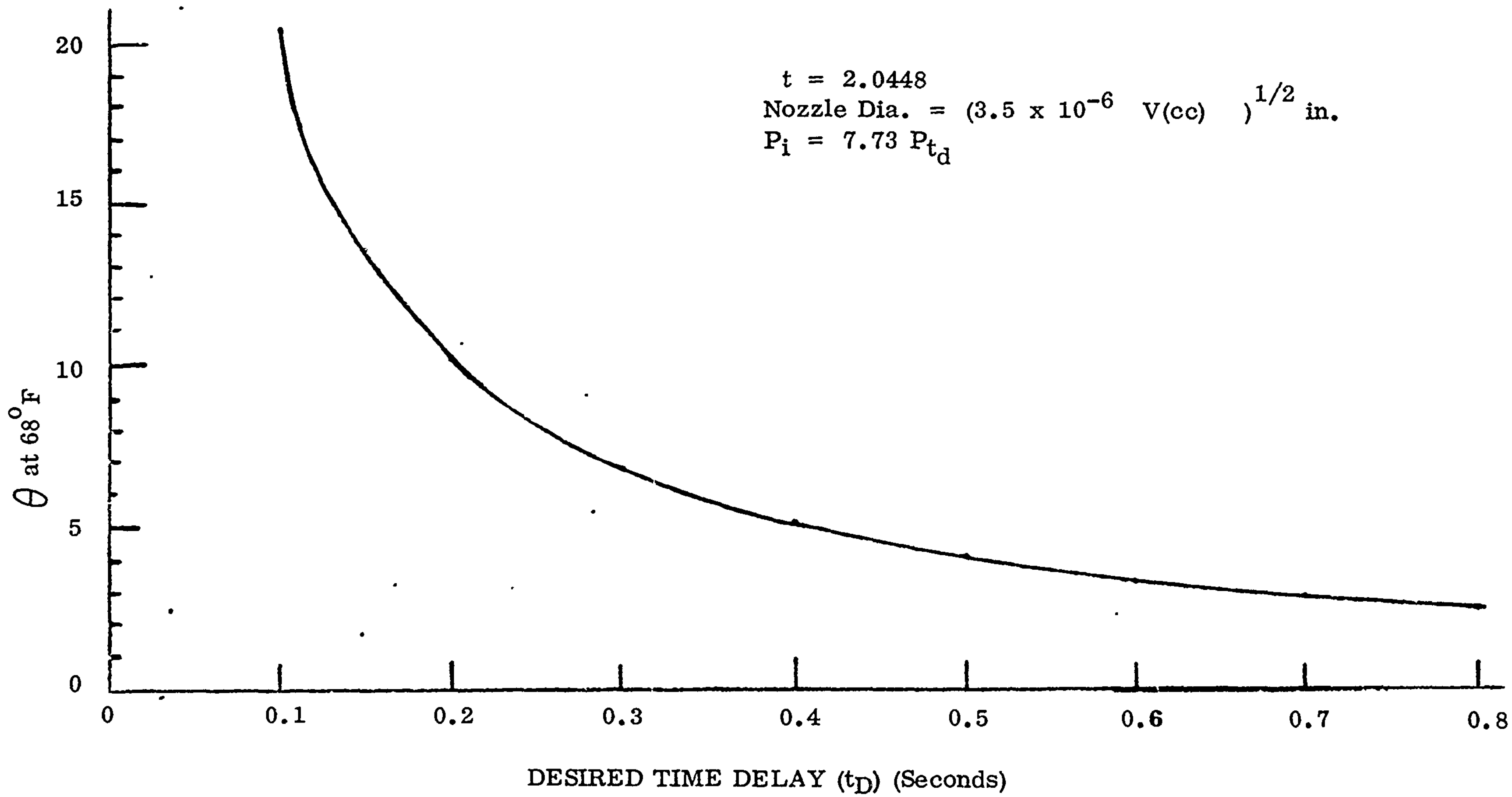


FIGURE 19 PLOT OF θ t FUNCTION

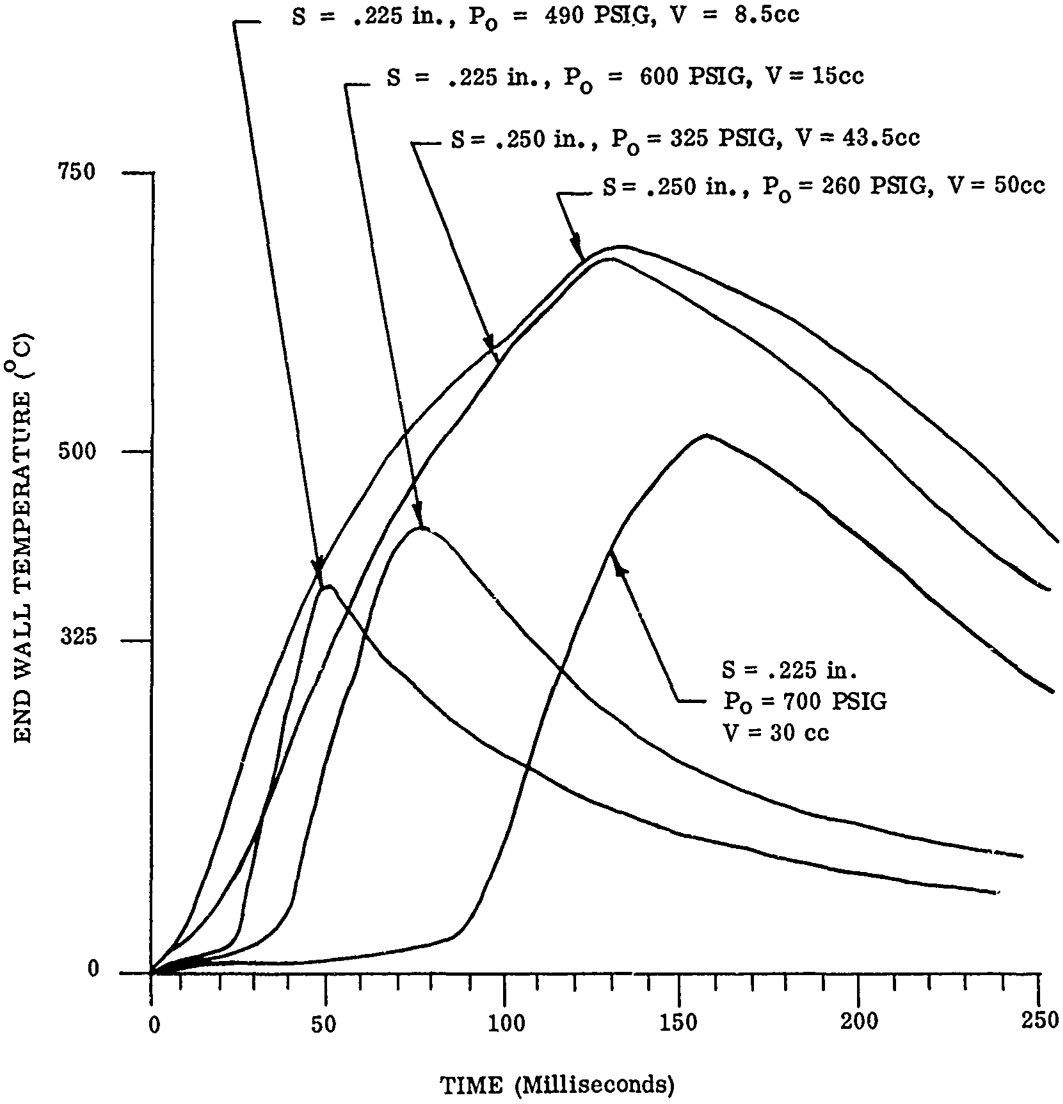


FIGURE 20 TEMPERATURE/TIME PROFILES FOR SMALL VOLUMES - MODERATE PRESSURE BLOWDOWN

In order to test the feasibility of the blowdown method of obtaining time delays, a breadboard model of the device was constructed. The test setup was identical to that of the static-test fixture (Fig 3) with the exception that the large supply volume was replaced with a calibrated volume. Approximately 50 test firings were performed in order to size the resonance tube geometry for the proper time delay. It was found that a time delay of about 0.150 seconds could be obtained with a 30 cm^3 bottle charged with helium to a pressure of 925 psig discharging through a 0.036-inch diameter nozzle with a vent area of 0.035 in^2. Once the desired time delay was obtained, a number of test firings were conducted to ascertain the repeatability of the time delay.

The results of the tests are shown in Table III. As can be seen, with the exception of Runs No. 6 and No. 12, the time delays were very repeatable. The calculated mean time delay for these tests was 144.6 milliseconds, with a standard deviation of 7.21 milliseconds. These tests indicated that the time delay goal of 150 milliseconds could be met repeatedly.

Efforts were then directed to utilizing the shorter (S_9) resonance tube (Fig 21) in the prototype FAE igniter due to its reduced size. It was found that a complex relationship exists between the separation distance, vent area, nozzle diameter, and supply volume.

The S_9 tube was laboratory tested in a fixture that provided a known chamber pressure or ambient pressure. With the nozzle and chamber pressures known, the pressure ratio at which resonance heating begins can easily be calculated. Figure 22 presents the results of this testing, and shows the variation in pressure ratio required for resonance heating to commence as a function of the separation distance. This data generally agrees with results previously obtained. Similar data taken with the S_9 tube and an initial pressure of 1,000 psig is presented in Figure 23. It can be seen that an increase in the supply volume of 20 cm^3 produces a corresponding 20-millisecond increase in the igniter time delay. An additional 50- to 100-millisecond increase may be obtained with the 0.047-inch diameter nozzle as shown in Figure 23.

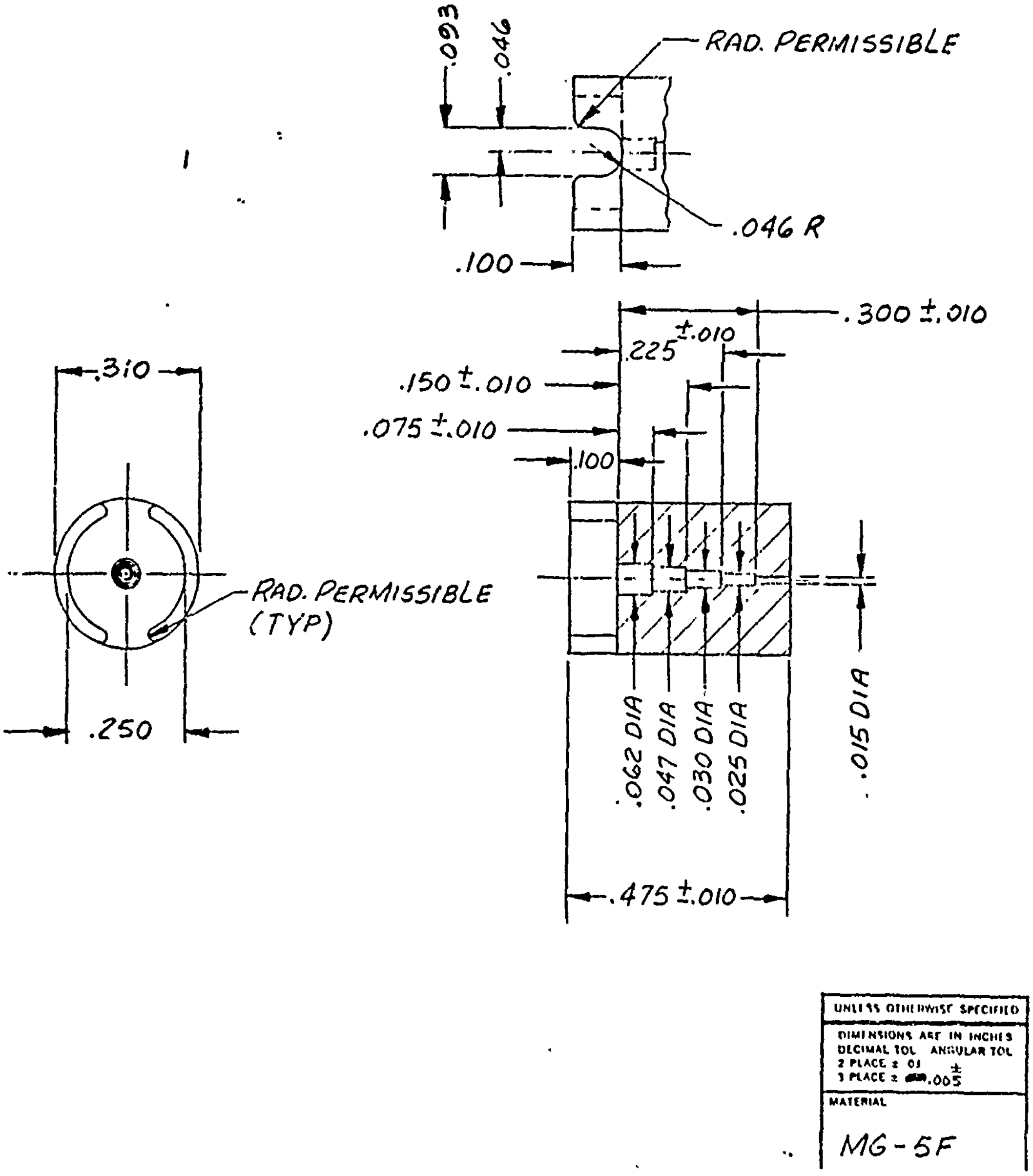


FIGURE 21 RESONANCE TUBE CONFIGURATION

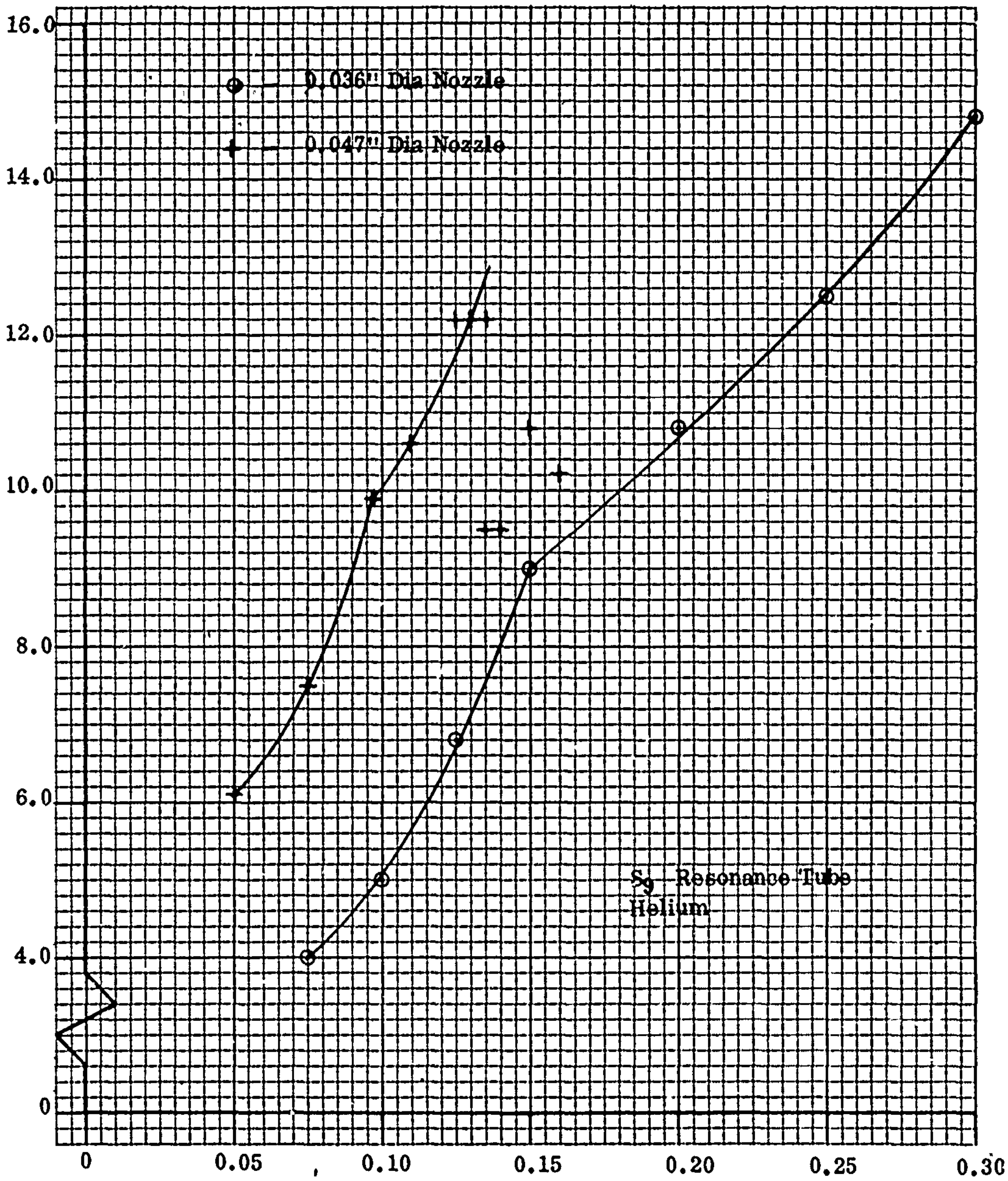


FIGURE 22 PRESSURE RATIO Vs. SEPARATION DISTANCE

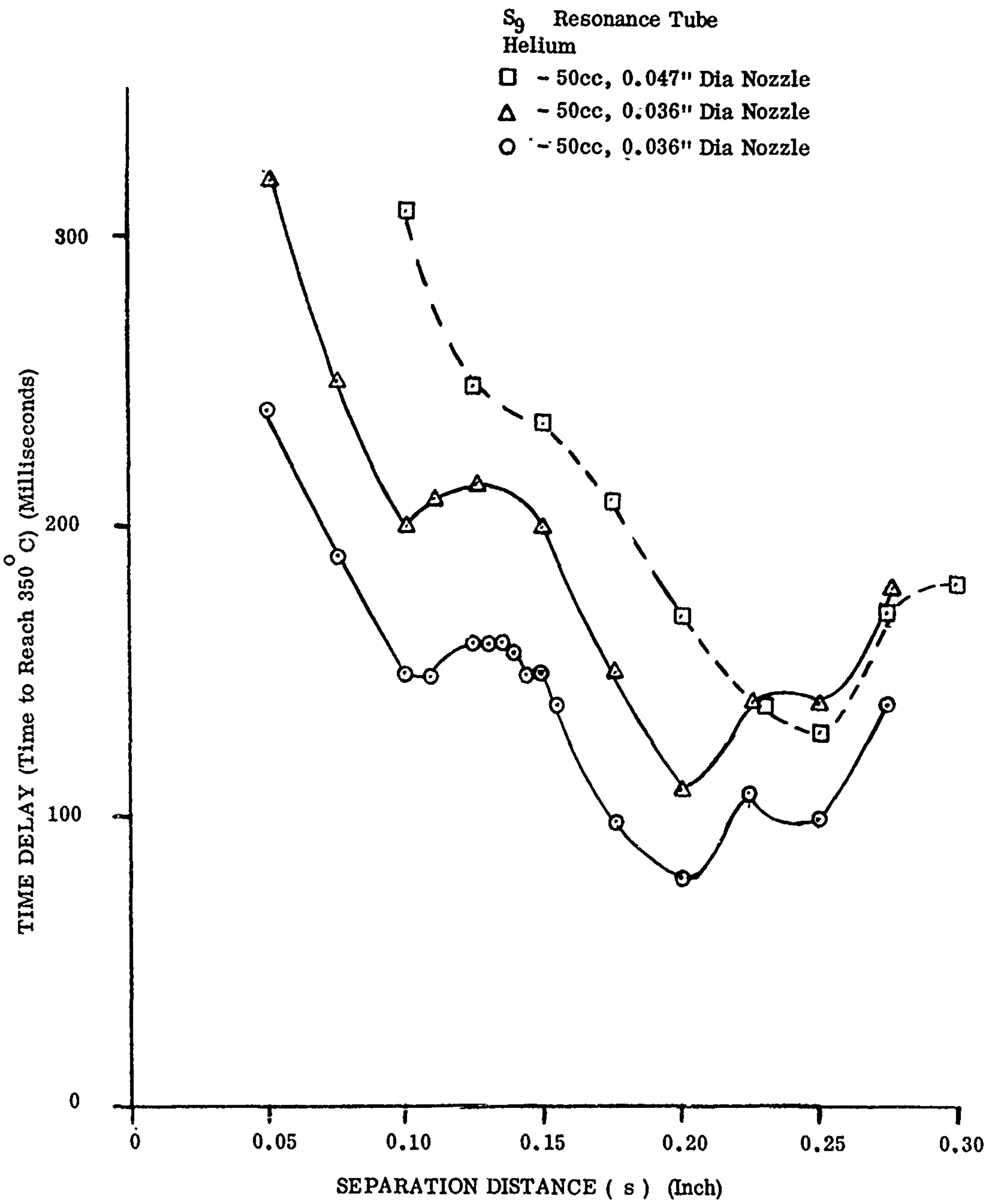


FIGURE 23 TIME DELAY Vs. SEPARATION DISTANCE AND SUPPLY VOLUME

TABLE III

RESULTS OF STATISTICAL TEST FIRINGS

Run No.	Delay	X-Y	Percent Error
1	140 ms	-4.6	-3.2
2	144	-.6	-.4
3	158	13.4	9.3
4	148	3.4	2.4
5	140	-4.6	-3.2
6	138	-6.6	-4.6
7	150	5.4	3.7
8	152	7.4	5.1
9	148	3.4	2.4
10	148	3.4	2.4
11	142	-2.6	1.8
12	128	-16.6	-11.5
13	142	-2.6	-1.8
14	146	1.4	.9

P = 925 psig
0.150-inch diameter vent
0.036-inch diameter nozzle

$\bar{X}$ = 144.6
σ = 7.1

As a result of the analysis and preliminary testing, it was decided to proceed with the design of the operational hardware. The initial hardware was fabricated to allow functional testing of the flueric FAE igniter concept. The hardware consisted of a bottle (Fig 24) and a protective cap (Fig 25), a fill screw (Fig 26), a match housing (Fig 27), and a replaceable 0.036-inch diameter or a 0.047-inch diameter nozzle (Fig 28 and 29). Other ancillary parts included a pressure sleeve (Fig 30) and a chamber (Fig 31). For laboratory static testing, a sleeve (Fig 32), a fill fixture (Fig 33), and a fill screw manipulator (Fig 34) were fabricated. For performance field testing, the hardware was configured as shown in Figure 35. For laboratory testing, the pressure sleeve was used to close off the vents of the igniter prior to functioning (Fig 36).

Four tapped vent holes, 0.161-inch in diameter, were provided in the prototype hardware for venting purposes. Various size set screws could then be inserted into the holes to change the vent area. Two sets of set screws with vent holes drilled through them were fabricated. The two sets had holes of either 0.081-inch or 0.101-inch diameter and allowed the vent area to be varied between 0.005 inch^2 and 0.081 inch^2. Figure 37 presents data which illustrates how the vent-area-to-nozzle-throat-area (Av/An) ratio affects the temperature/time performance of the three FAE igniter configurations. In general, for area ratios on the order of 18 to 25, high temperatures were obtained but with very short time delays. For area ratios on the order of 30 or higher, time delay operation was obtained with somewhat lower temperatures. The best results occurred with area ratios between 25 and 30. Static test firings with this hardware configuration were conducted, utilizing plastic explosive cups loaded with 50 mg of KDNBF consolidated at 30,000 psi and incorporating a layer of pyrotechnic mix SI-143 on top of the KDNBF. This was utilized to provide a better mix for photographic data documentation. Laboratory tests were then conducted, utilizing prototype FAE igniter hardware. To perform the tests, the resonance tube end wall temperature was measured with a chromal-alumel thermocouple, utilizing the test apparatus shown in Figure 37. Gas was supplied through the pressure tap on the fill fixture with the fill screw backed out of the bottle. As the pressure in the bottle increases the pressure on the burst diaphragm also increases. When the diaphragm breaks (1 to 4 thicknesses of 5 mil aluminum foil tape), a vent hole 0.25 inch in diameter allows the gas to escape and the resonance heating to initiate. A pressure tap on the static test fixture was used to determine the pressure/

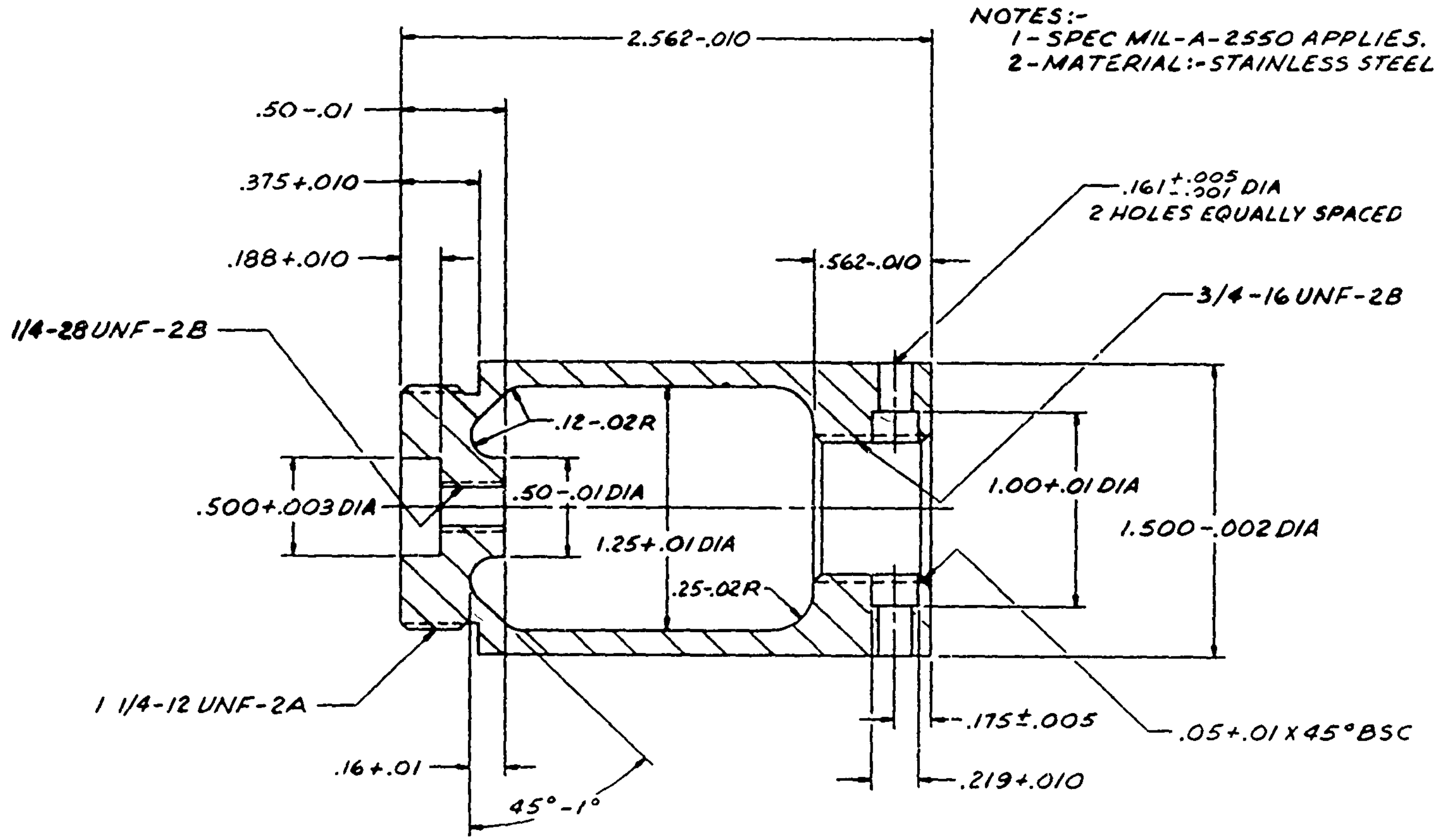


FIGURE 24 BOTTLE

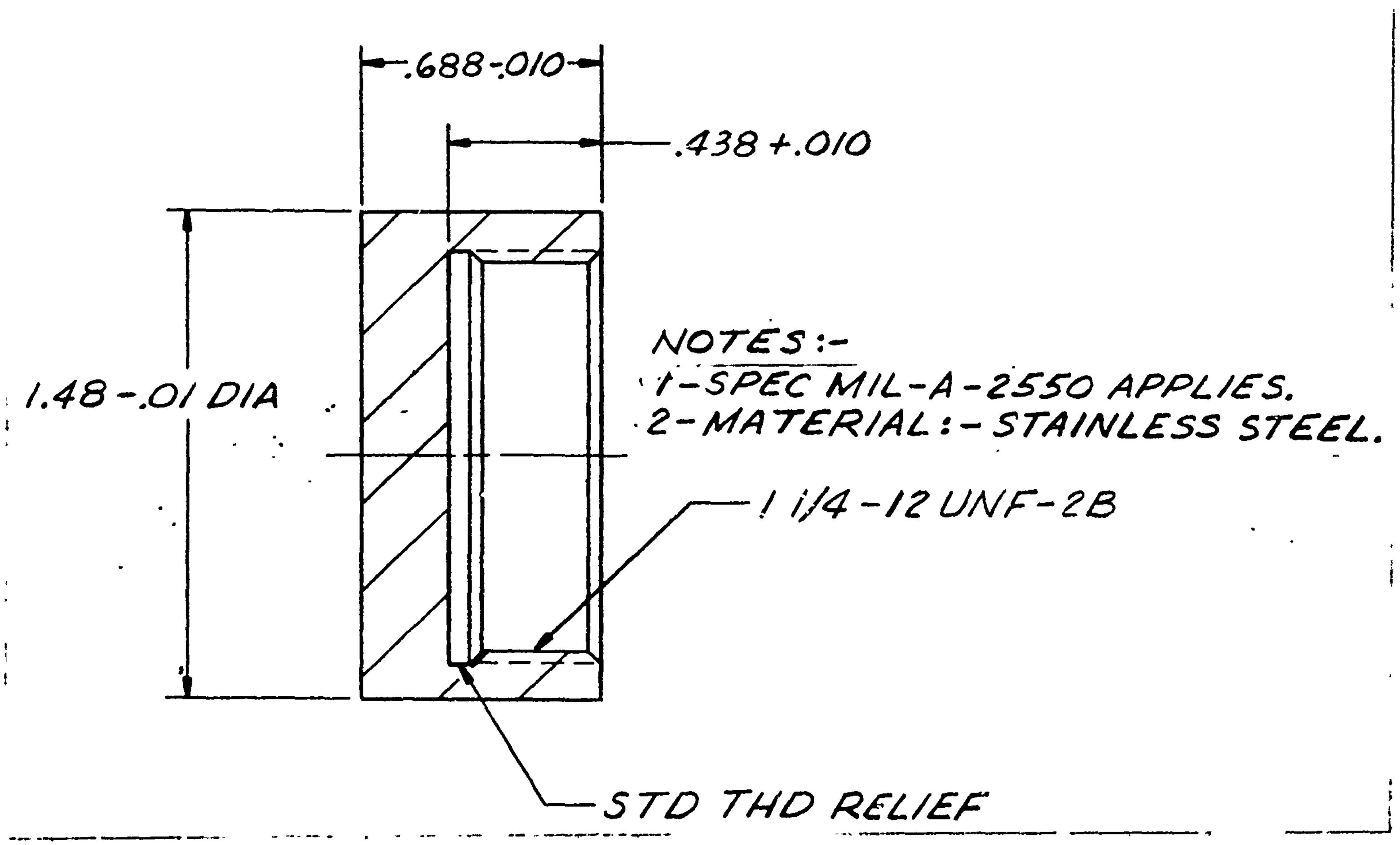


FIGURE 25 PROTECTIVE CAP

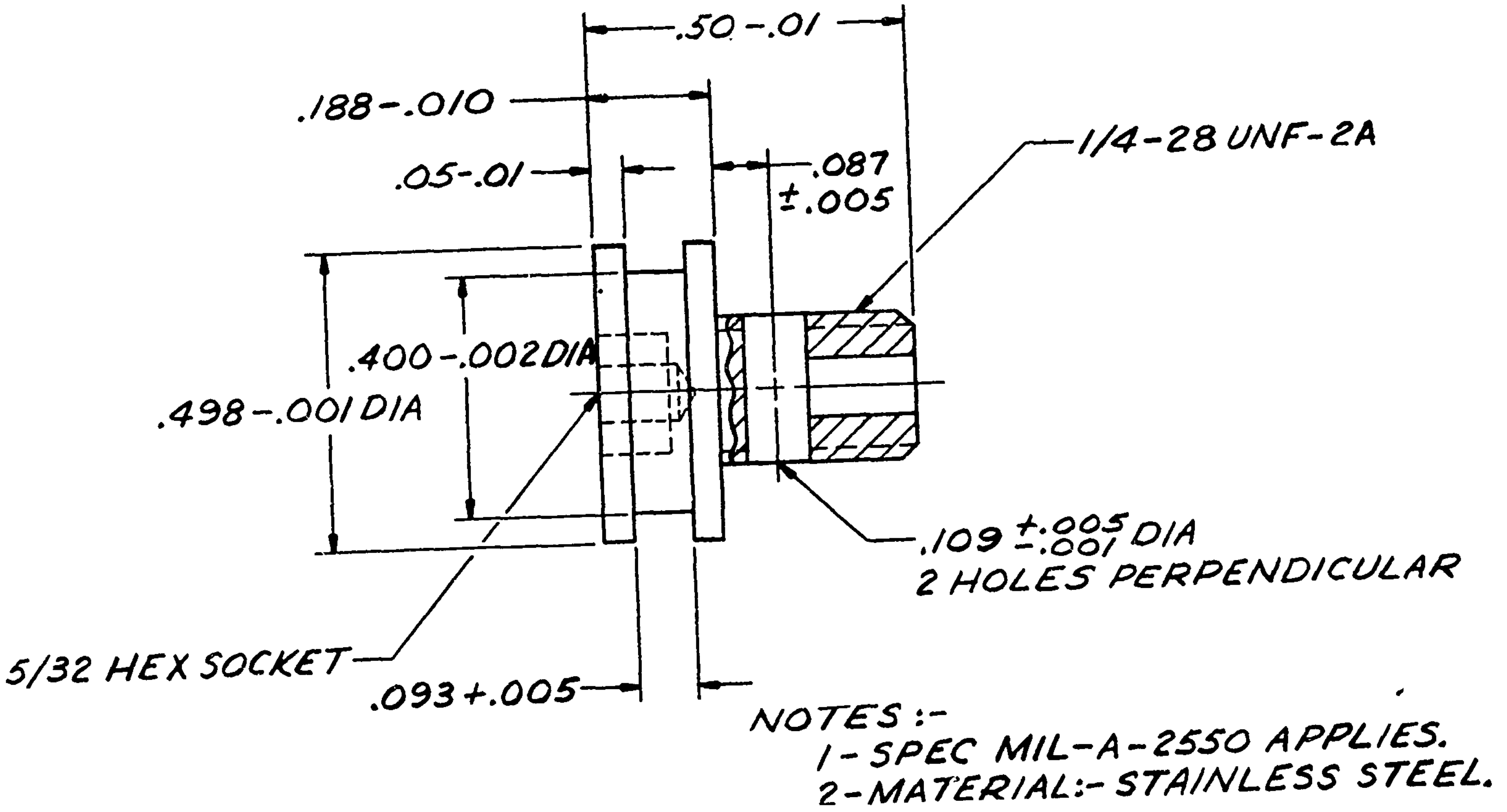


FIGURE 26 FILL SCREW

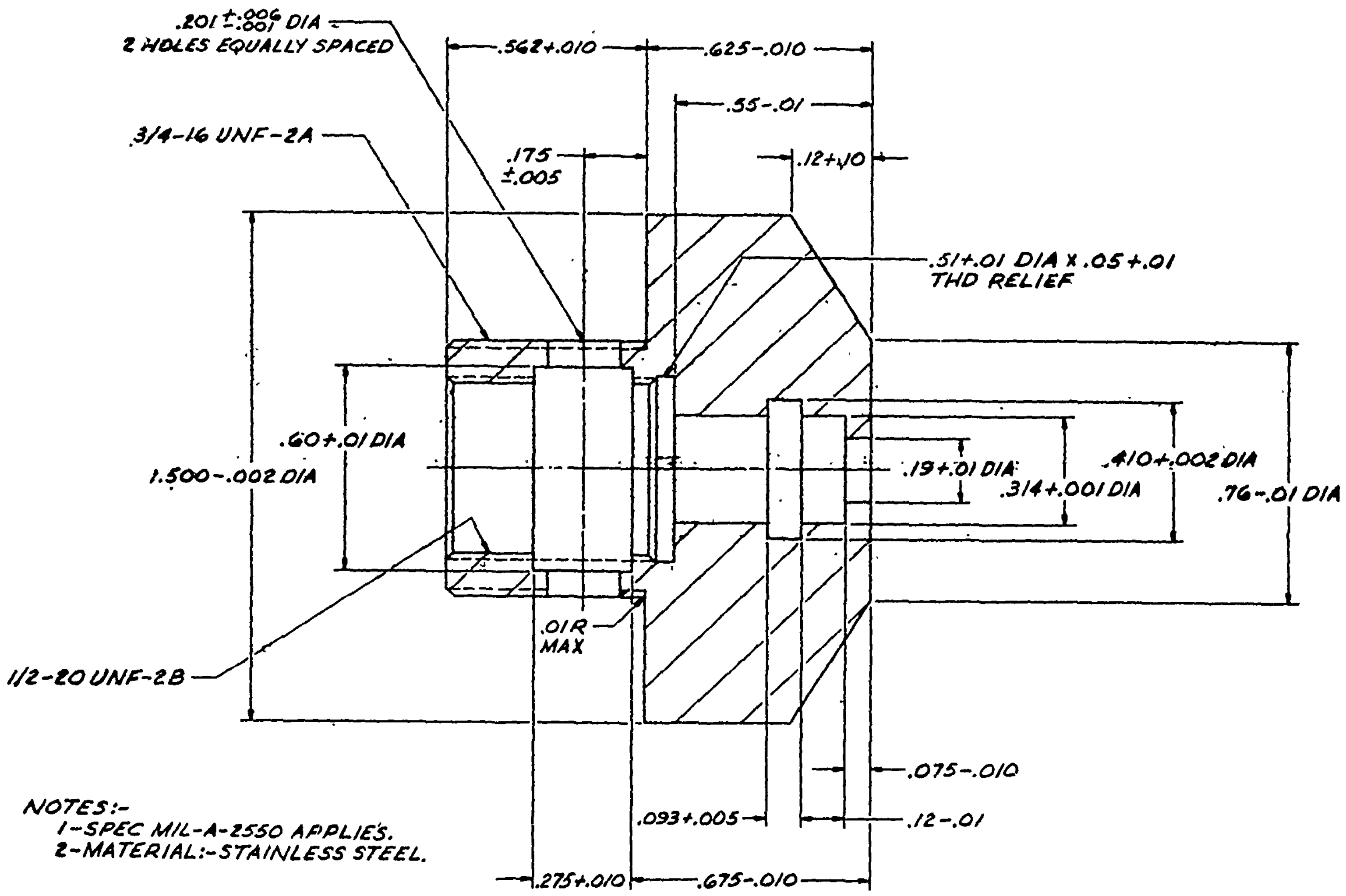


FIGURE 27 MATCH HOUSING

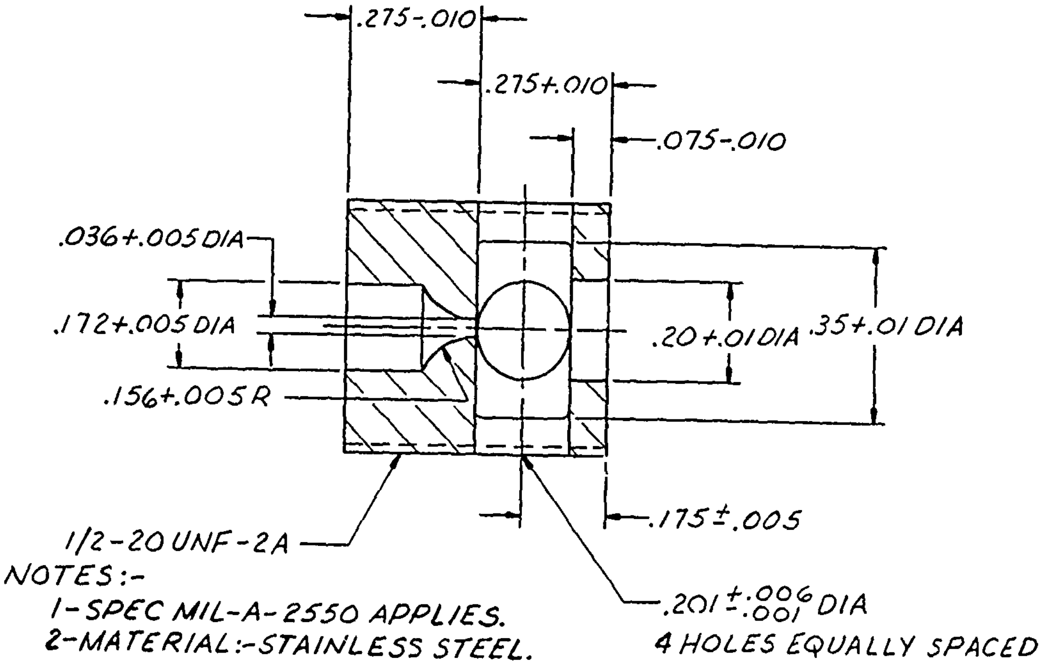


FIGURE 28 0.036 INCH DIA NOZZLE CONFIGURATION

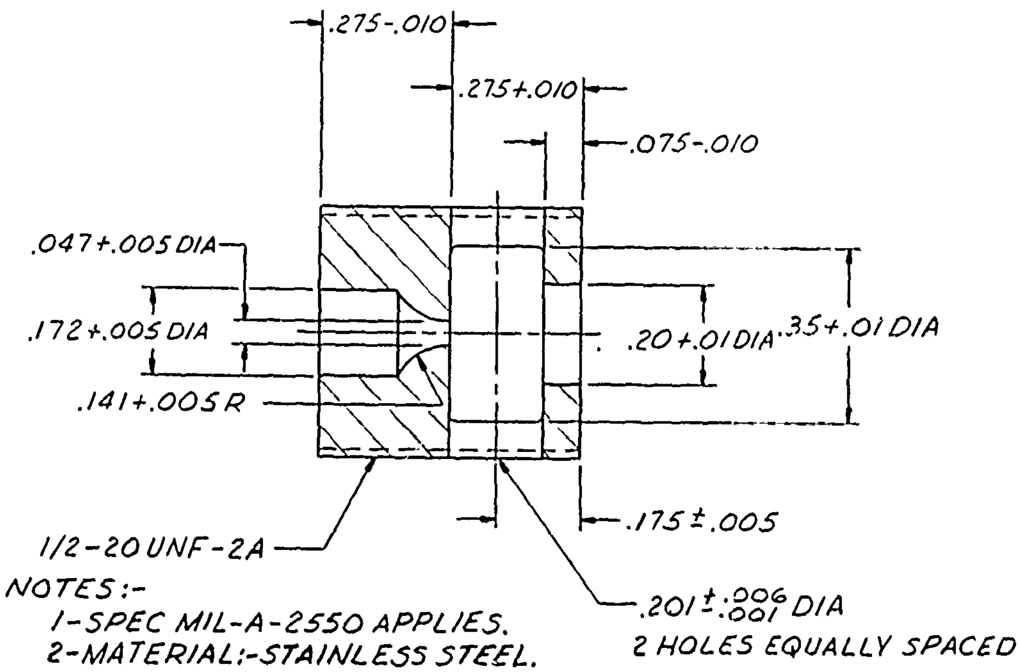


FIGURE 29 0.047 INCH DIA NOZZLE CONFIGURATION

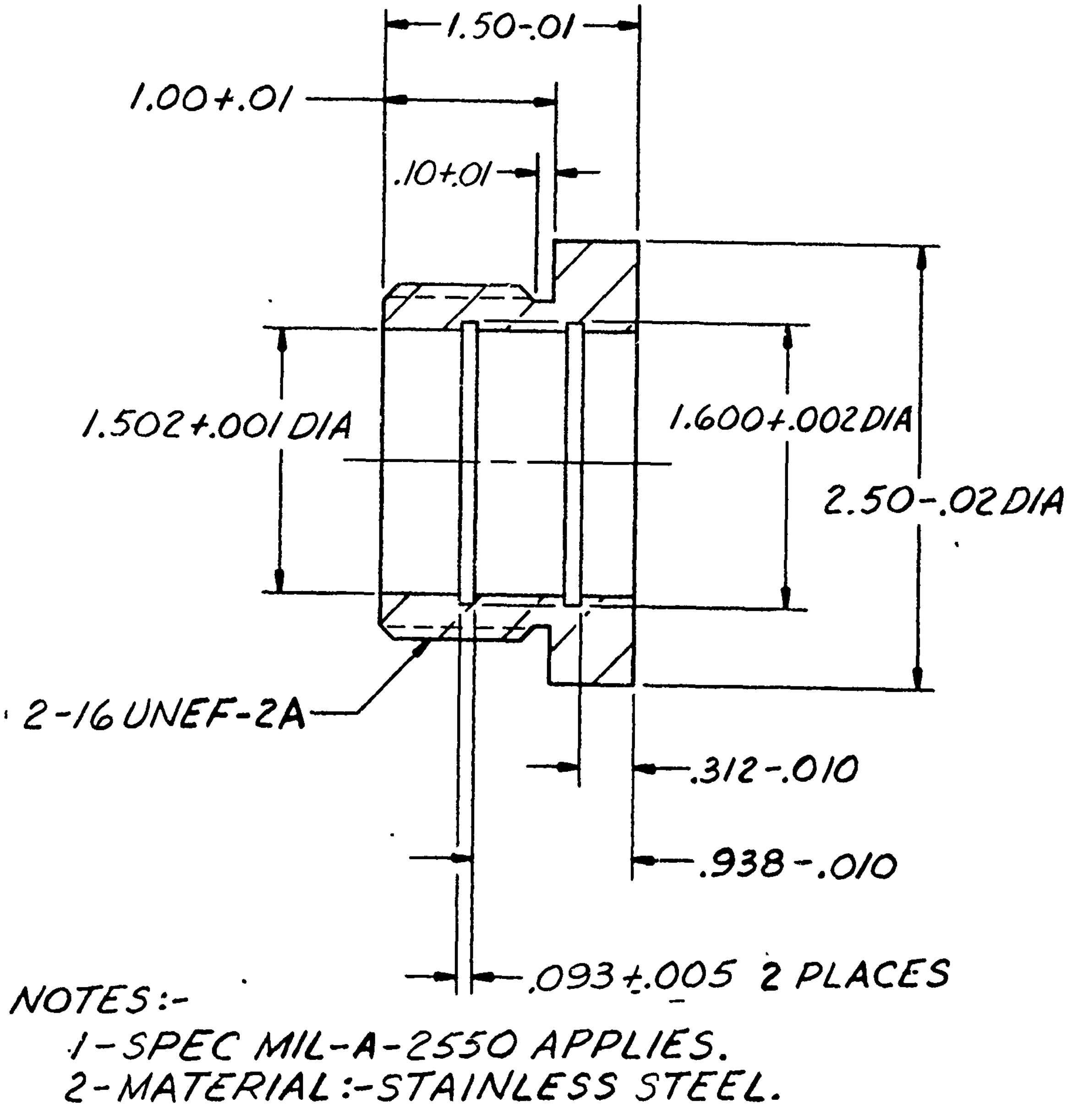
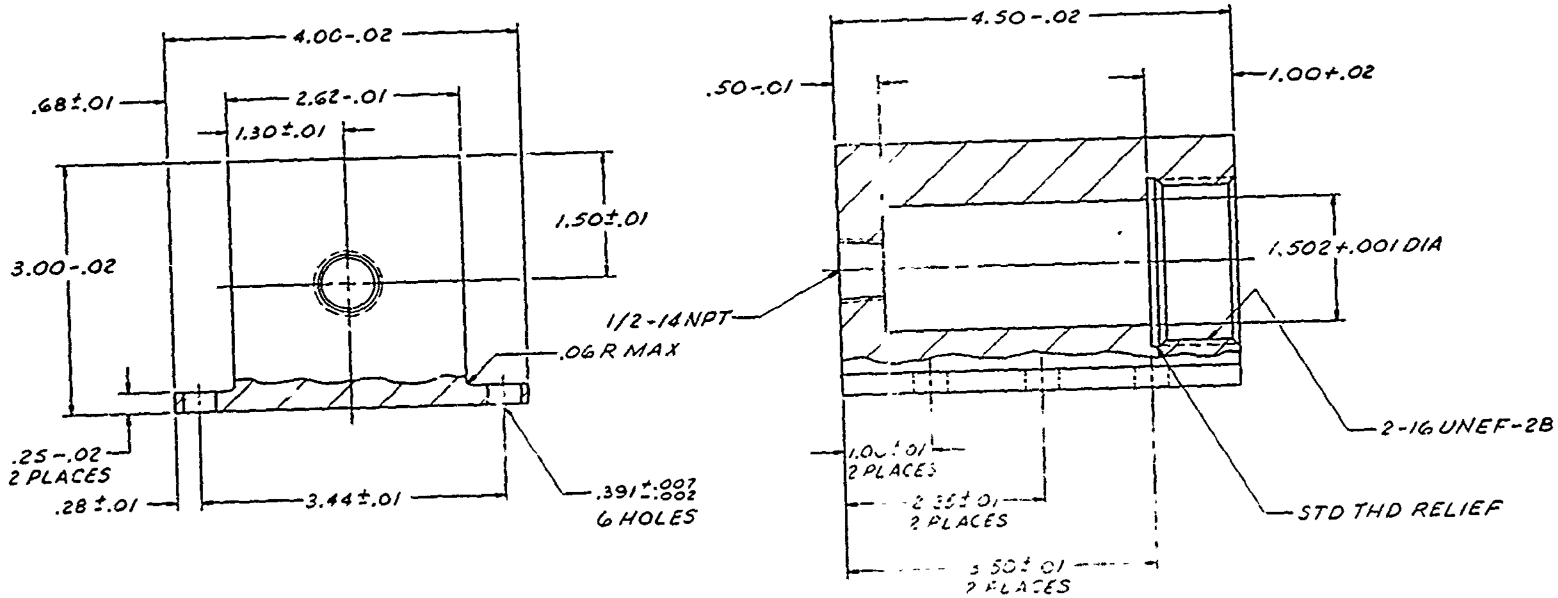


FIGURE 30 PRESSURE SLEEVE



NOTES:-
1-SPEC MIL-A-2550 APPLIES.

FIGURE 31 EJECTOR CHAMBER

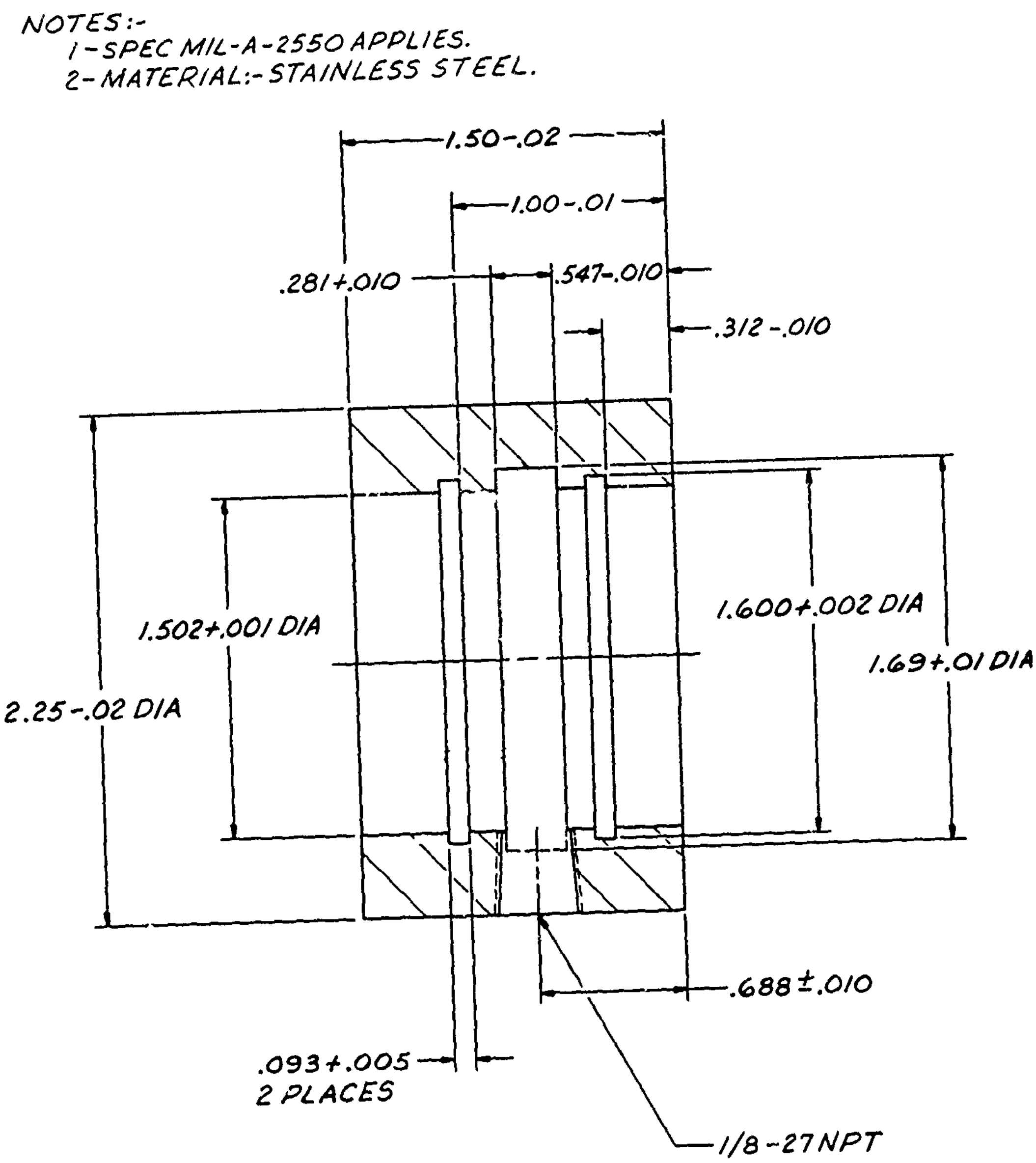


FIGURE 32 SLEEVE

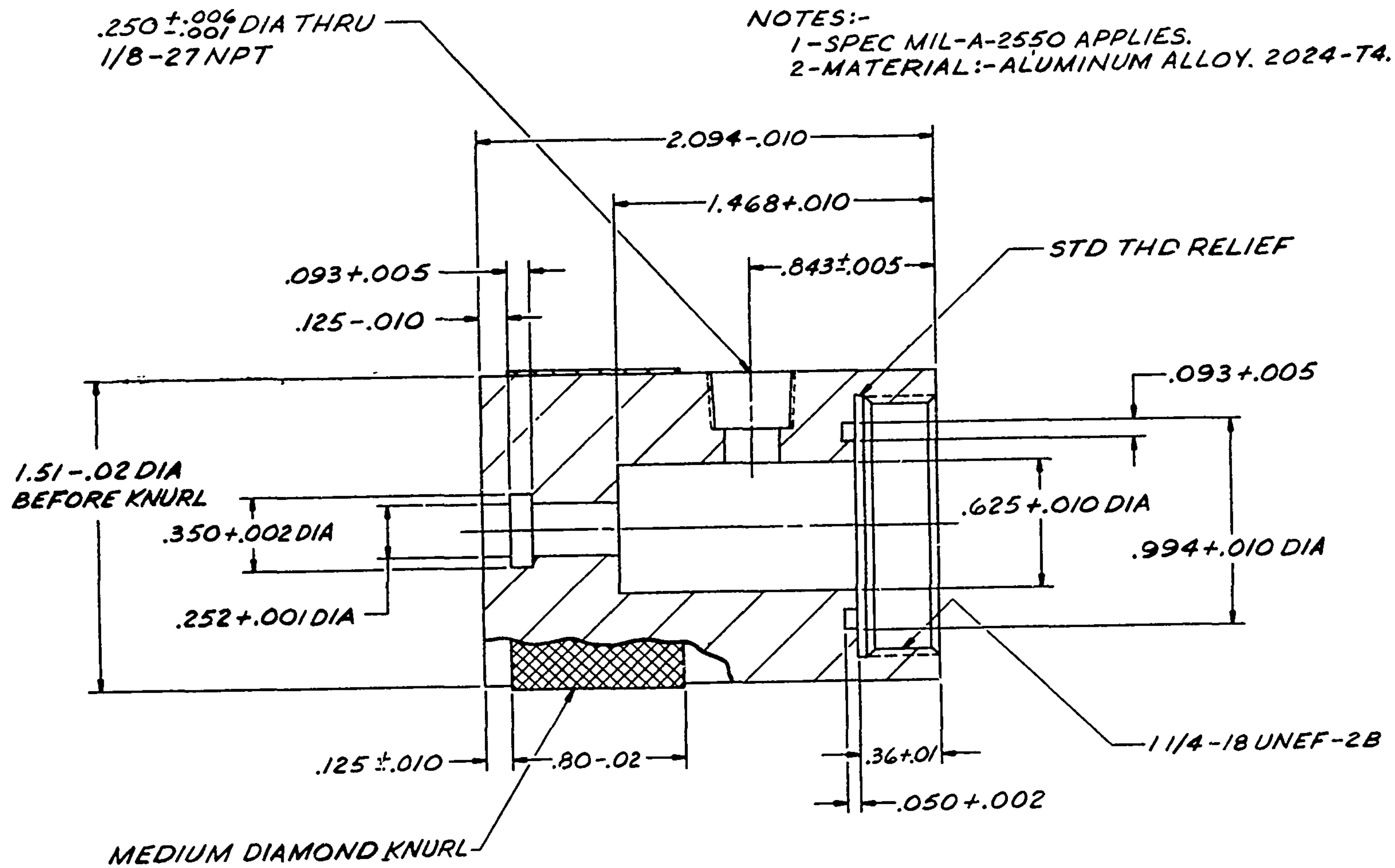


FIGURE 33 FILL FIXTURE

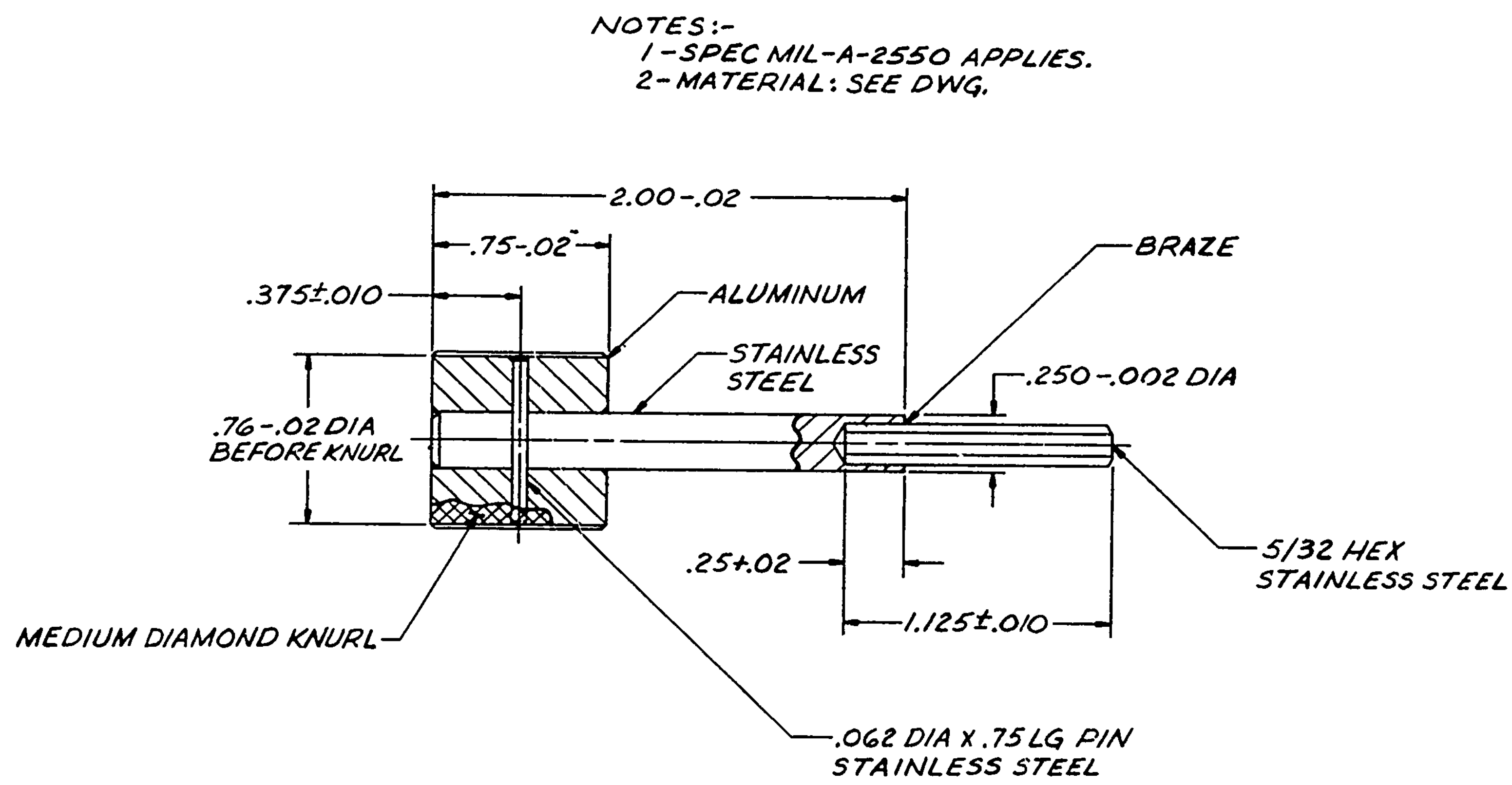


FIGURE 34 FILL SCREW MANIPULATOR

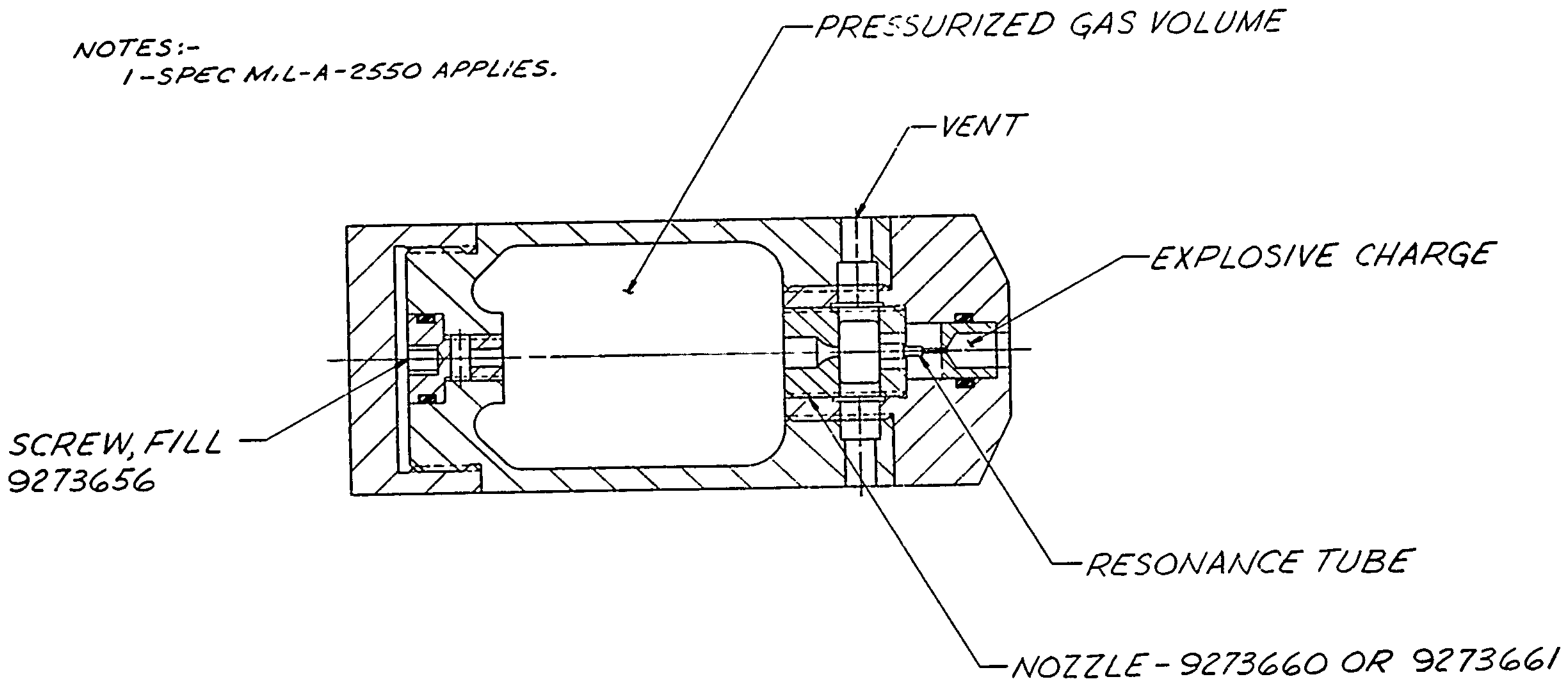


FIGURE 35 FAE DEMONSTRATION IGNITOR

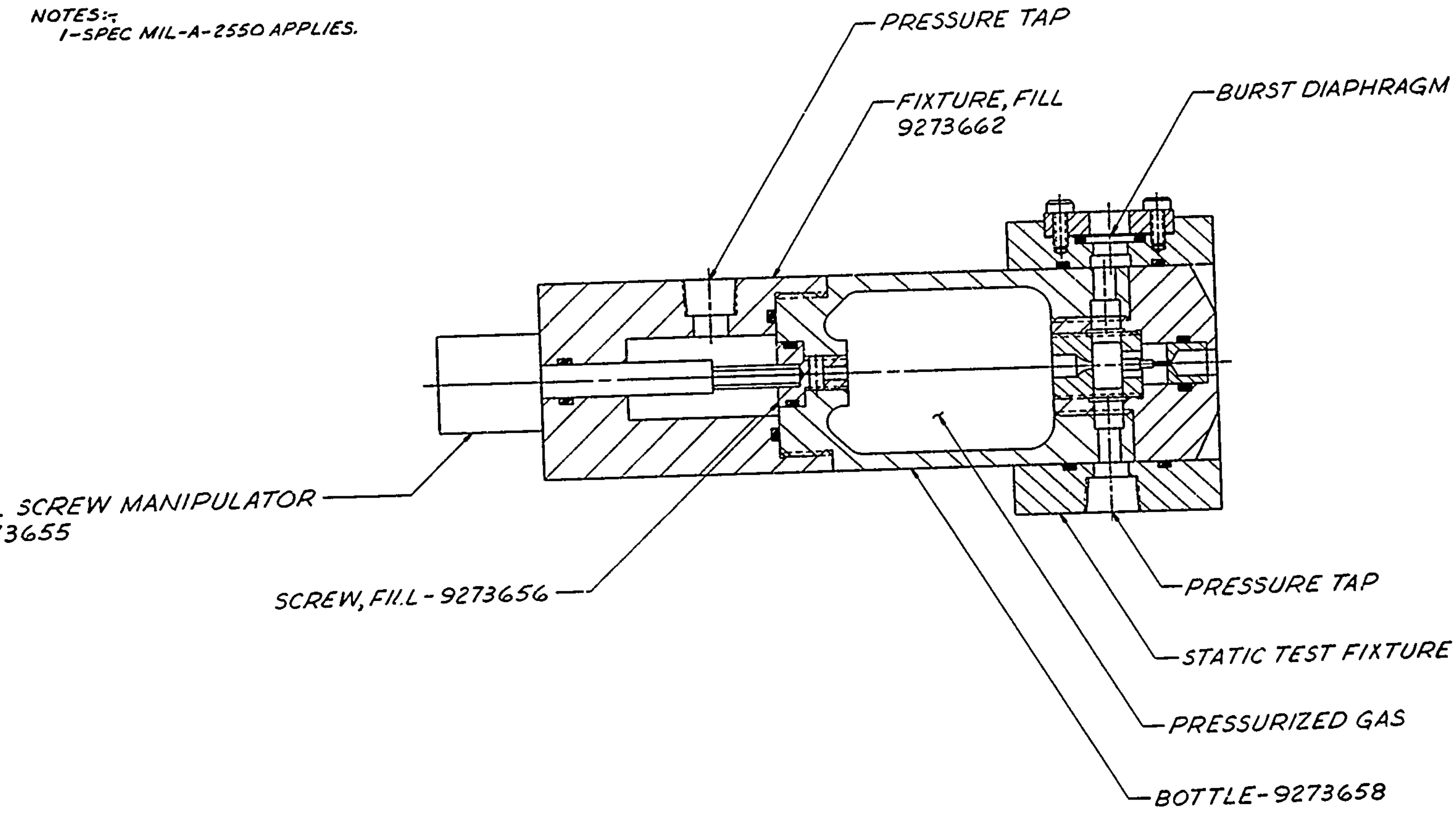


FIGURE 36 FAE DEMONSTRATION IGNITOR TEST APPARATUS

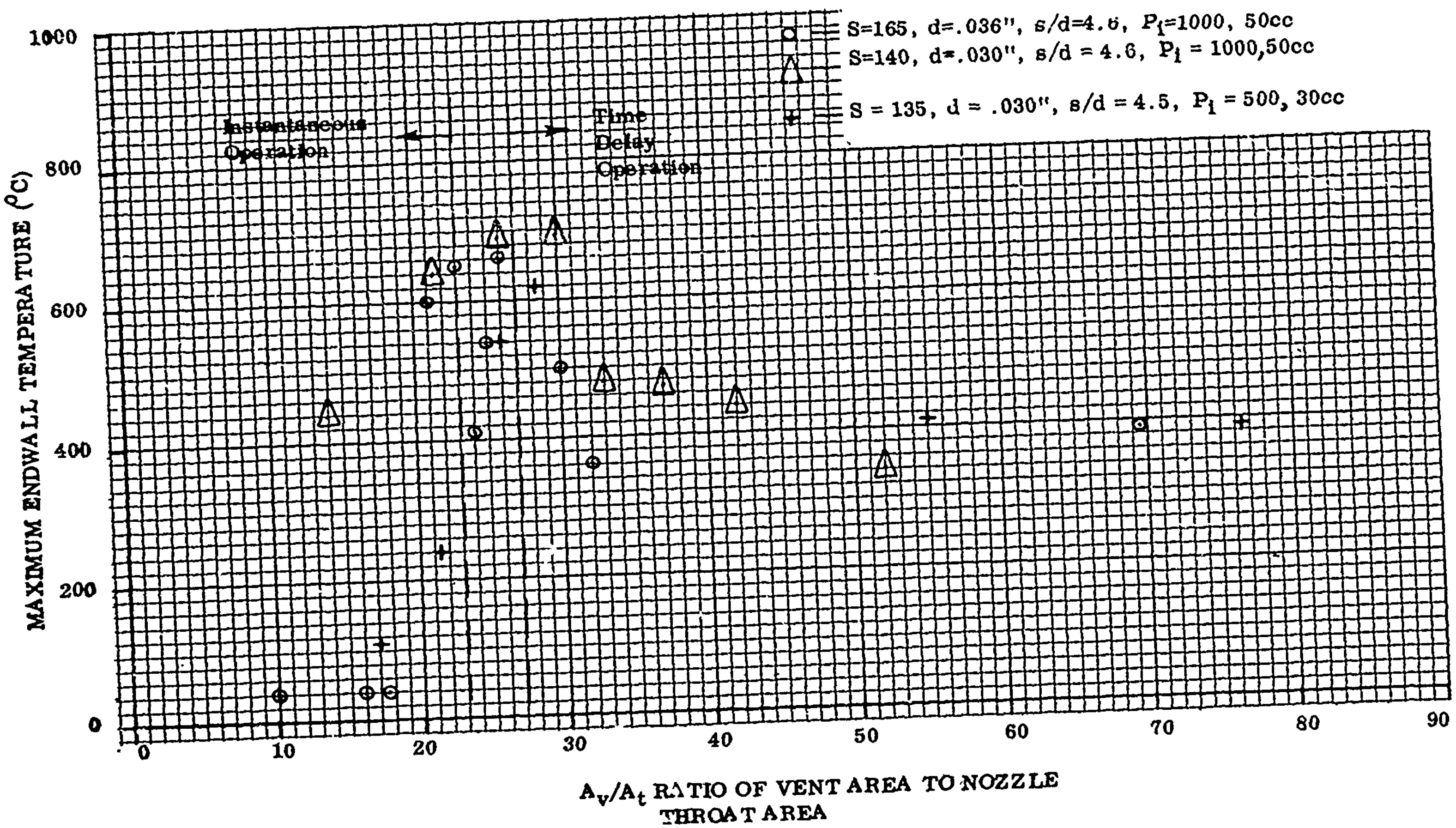


FIGURE 37 AREA RATIO Vs TEMPERATURE

time profile in the vent chamber; however, test apparatus did not allow an accurate means of determining the pressure/time profile of the supply bottle pressure. This series of test data was used to determine the vent size commensurate with proper operation.

An alternate test procedure was developed to provide a measurement of the pressure ratio across the nozzle. The bottle was filled through the pressure tap on the static test fixture through a small orifice. With the fill fixture in place and the fill screw backed out slightly, the bottle pressure could be measured at the pressure tap of the fill fixture. An extension bottle (Fig 38) was fabricated to bring the volume of the FAE bottle to 50 cm^3. The total weight of the igniter with 50 cm^3 capacity is 667 gm. With this volume and the 0.047-inch diameter nozzle, temperature/time data indicated that the vent area was not sufficient to produce a time delay. This is shown in Figure 39, which plots the pressure ratio across the nozzle (P_0/P_c) as a function of time. The pressure ratio for the small vent configuration (solid line) remains almost constant at between 11 and 12. Corresponding data taken with a similar 0.030-inch diameter nozzle in a V-block arrangement produced a time delay of about 230 ms.

The test apparatus after ejection (Fig 40) includes the ejecter block with its low pressure air supply, the modified test fixture with its high pressure helium supply and pressure gauge, the FAE igniter, and a resilient support to stop the forward motion of the igniter after the vents have cleared the fixture. With this apparatus it was possible to conduct both temperature/time tests shown and actual ignition tests. These tests accurately simulate most firing conditions.

Photographic (FASTAX) records made of the dynamic tests were of very poor quality with the result that a quantitative determination of the ignition time or ejection velocity could not be made.

Previous efforts during the pneumatic match development indicated that a 0.024-inch diameter nozzle did not produce a jet large enough to drive a 0.062-inch diameter tube into resonance. The smallest nozzle size which would produce significant resonance heating had not been determined. A nozzle with a 0.030-inch diameter throat (0.0007-$inch^2$ throat area) was fabricated (Fig 41). This nozzle was tested with various separation distances and vent areas and was found to be able to drive the S_9 tube into resonance. Since this nozzle had a throat area

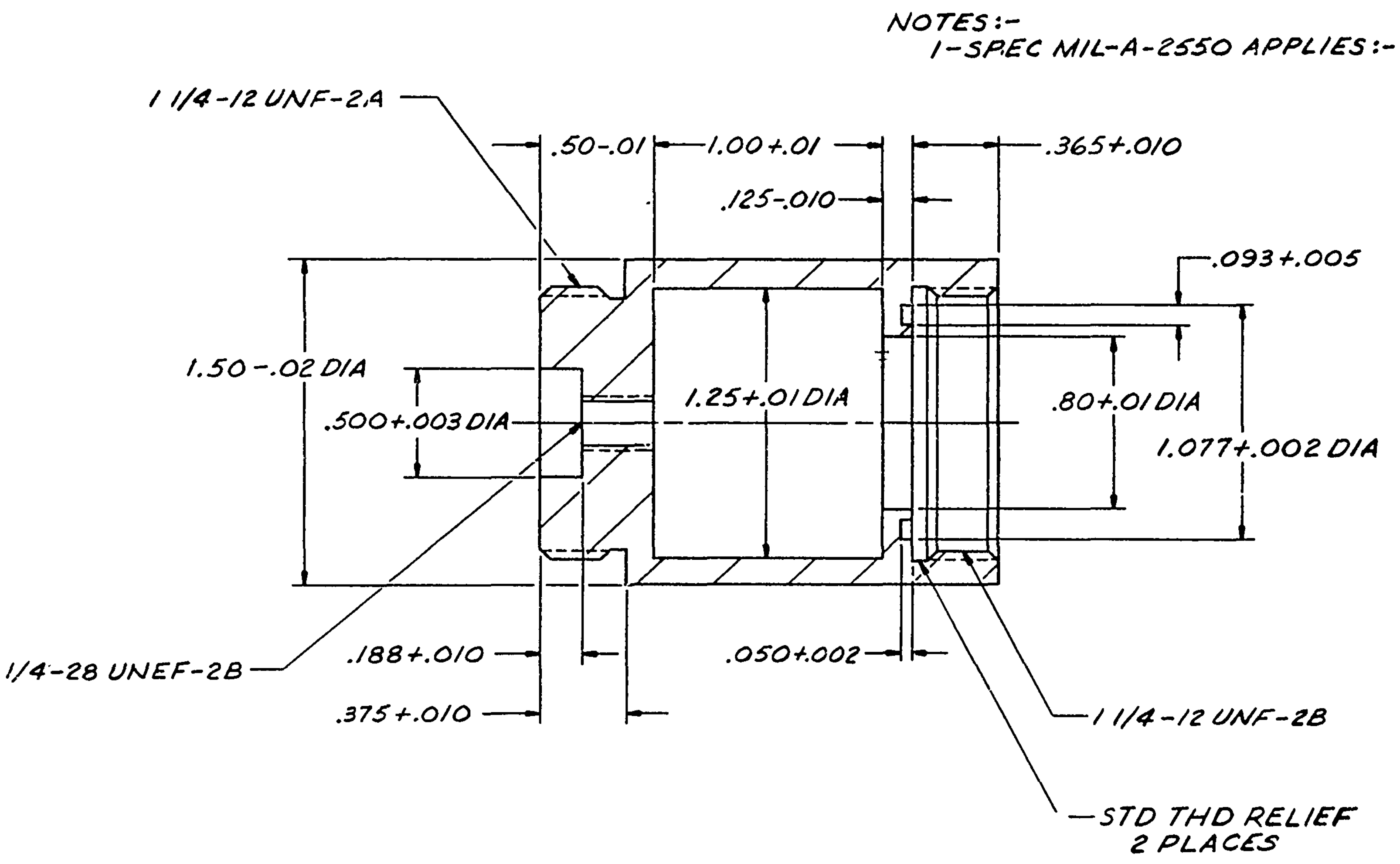


FIGURE 38 EXTENSION BOTTLE

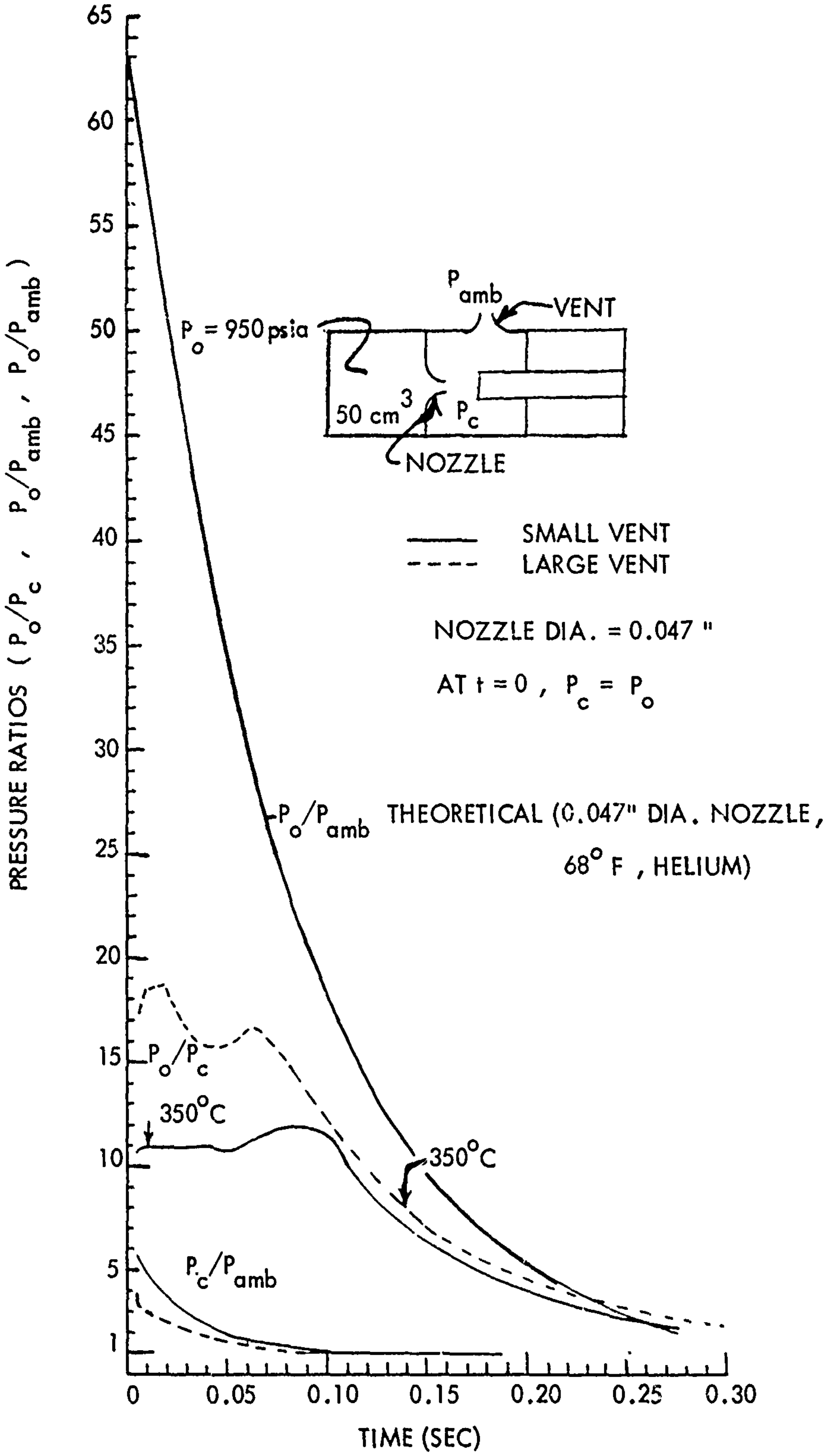


FIGURE 39 PRESSURE RATIO/TIME PROFILES

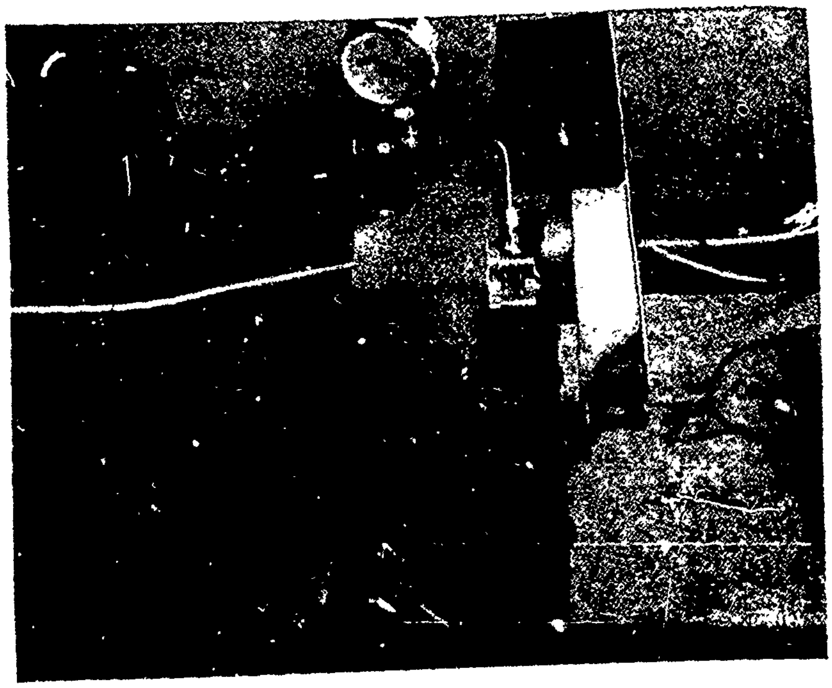


FIGURE 40 LABORATORY TESTING FIXTURE

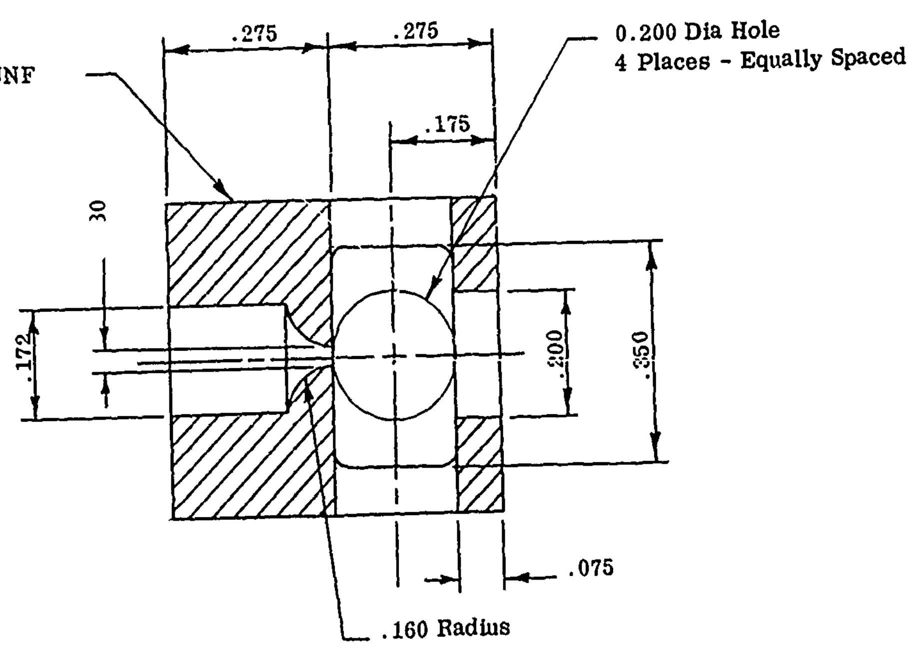
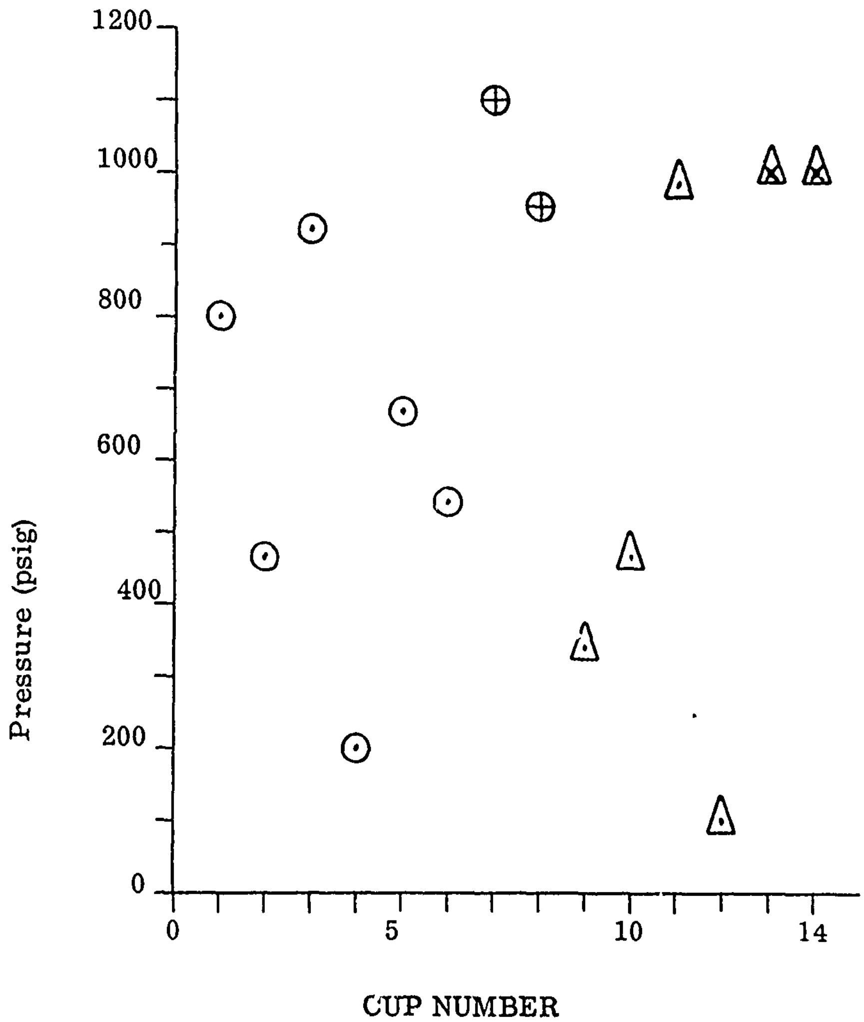


FIGURE 41 0.030 INCH DIAMETER NOZZLE CONFIGURATION totaling 69 percent of the smallest previously tested nozzle, longer time delays (300 ms) were possible when this nozzle was coupled with the 30 cm^3 supply volume. Previously, only nominal performance had been obtained with the 30 cm^3 volume. Although the 0.030-inch nozzle produced a slower supply pressure decay, the pressure/time data did not agree with the calculated values.

Another difficulty encountered with this test apparatus was that it required the use of the plastic explosive cups. These cups were designed during the previous FEI development, primarily from the standpoint of ease of fabrication, and no effort was directed toward achieving any specific structural properties. During static testing the cups were never subjected to pressures greater than 20 psig (due to the fact that the vents were normally open when the solenoid valve opened to start operation). In the FAE igniter hardware, however, the cups were subjected to a differential pressure of up to 1,000 psig. It was found that the majority of the plastic cups loaded with 25 mg of KDNBF could not withstand this pressure without developing leaks around the closure disk. Several cups were tested to determine the pressure at which the gas leak occurred. As shown in Figure 42, unloaded cups showed wide variations (200 to 900 psig). It was found that a teflon washer placed between the resonance tube and the cup would provide some improvement. This washer had a 0.300-inch OD with a 0.020-inch ID and 3-mil thickness. In fact, one unloaded cup failed only after 30 minutes at 1,100 psig. The majority of cups did not, in general, perform as well.

It was felt that the thin wall section around the closure disk in the cup was the main cause of the failures and that damage incurred in the cups during the loading process was a probable secondary failure causative. Since the hardware had been fabricated before the difficulty was encountered, and since there would be a finite delay in the testing program until new hardware was fabricated, it was decided that modification of the cup might allow a continuation of the testing program.



Plastic Cup Configuration

○ — Unloaded

⊕ — Unloaded with 3 mil teflon washer between tube and cup

△ — Loaded (25 mg KDNBF)

△ — Loaded, epoxy filled with 3 mil teflon washer between tube and cup

FIGURE 42 RESULTS OF PRESSURE TESTING PLASTIC EXPLOSIVE CUPS

The plastic explosive cups were modified by placing an aluminum closure disk on top of the explosive in the cup and then using an epoxy adhesive to fix the disk in place in such a manner as to leave the center of the disk free of epoxy (Fig 43). Many cups modified in this manner successfully withstood the pressures associated with the FAE hardware tests; however, the failure rate was still unacceptably high, and an alternative explosive cup was desired. A standard production explosive cup (designated M17 by the Army) was chosen for evaluation.

M17 cups with 0.0022-inch thick aluminum closure disk ultrasonically welded in place were tested to determine if they offered any improvement in performance over the plastic cups. Unloaded cups were used for these tests and the average burst pressure was found to be 520 psig with a range from 460 to 600 psig. It was found that these nonstandard M17 cups with 0.001-inch thick stainless steel closure disks laquered in place would withstand 1,000 psig pressure, if they were modified as were the plastic cups (i.e., an M17 cup loaded with KDNBF with a stainless steel disc epoxied in place (Fig 44). M17 cups fabricated in this way were successfully detonated and successfully ignited a pyrotechnic material packed on the epoxied disk. They also exhibited a lower failure rate than that for the plastic cups.

A long-time delay FAE fixture was designed at this time with the following goals:

a. Eliminate the leakage paths
b. Use standard M17 detonator cups
c. Provide a holder for large quantities of explosives
d. Allow for variable separation distances
e. Allow for quick change of supply volumes
f. Use standard gas bottles as supply volumes
g. Incorporate variable vent area
h. Compatible with ejector

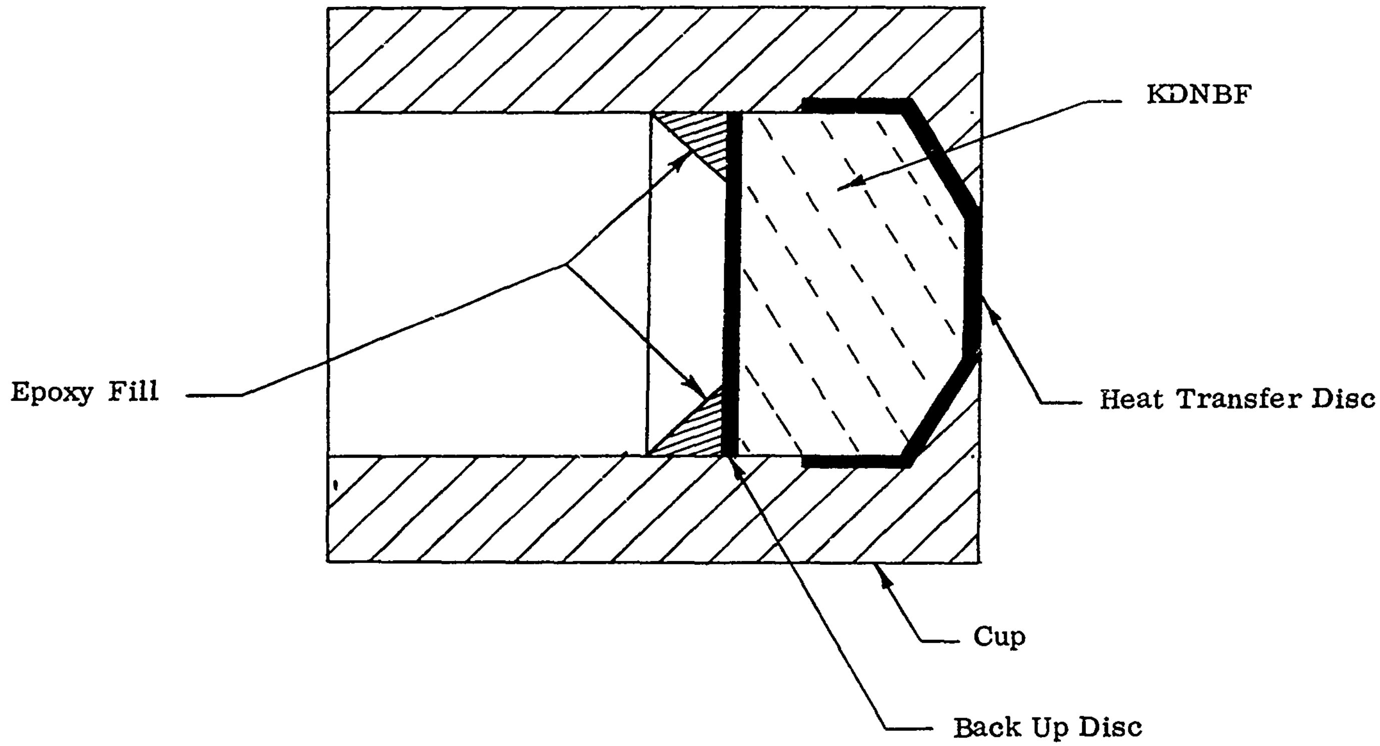


FIGURE 43 MODIFIED PLASTIC CUP

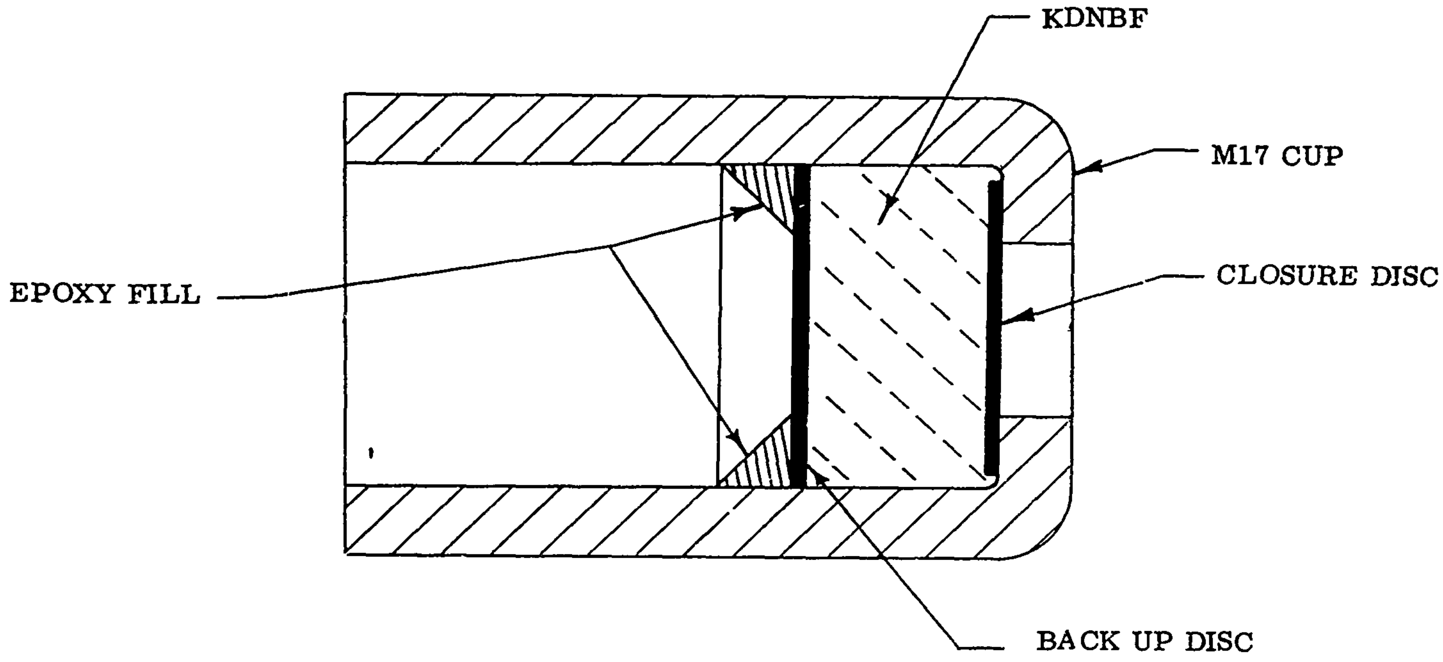


FIGURE 44 MODIFIED M17 CUP

This FAE fixture is shown in Figure 45. It consists of an igniter housing which provides a seal around the nozzle and the explosive cup, a gas supply bottle, and a support flange to hold the igniter assembly. Three nozzles which were utilized in this fixture had diameters of 0.047 inch, 0.030 inch, and 0.025 inch. Testing of this long-delay FAE configuration was accomplished by inserting a nozzle and a resonance tube as shown in Figure 45. A thermocouple was attached for initial testing. An M17 cup was affixed to the resonance tube with epoxy to effect a seal. The separation distance was determined by the amount of the cutback in the resonance tube. With zero cutback, the separation distance is maximized at 0.200 inch.

A sleeve holder was fabricated to allow the mounting of the filling sleeve to a base plate. This test apparatus, incorporating an air cylinder for actuation, is shown in Figure 46. The igniter with a 40 cm^3 gas supply bottle is shown in Figure 47.

Operationally, the igniter housing is sealed within the filling sleeve and the supply bottle is filled through the vents. When filled, the valve on the fill line is closed, leaving the pressure indicator to monitor the gas supply pressure until actuation. Actuation is accomplished by pushing or pulling the igniter housing past the seals in the filling sleeve, thereby opening the vents to ambient pressure.

Temperature/time data for a static test utilizing this hardware, a 0.030-inch diameter nozzle, and a supply volume of 100 cm^3 are shown in Figure 48. This configuration appeared very promising and was subjected to further dynamic testing. The dynamic tests conducted at Picatinny Arsenal resulted in achieving time delays on the order of 850 milliseconds. One such dynamic test produced a time delay of over 1,000 milliseconds. These time delays were determined from FASTAX film records.

Testing was accomplished with this hardware under two environmental conditions - under water and in a sonic flow field. The test setup for the underwater tests (Fig 49) consisted of mounting the long-time delay test setup vertically in a water tank so that water completely covered the filling sleeve vents. Several tests were conducted with the hardware in this configuration. Resonance heating was observed in every test; however, the amount of heating was degraded due to the hardware/instrumentation effects while operating in this adverse environment (Fig 50).

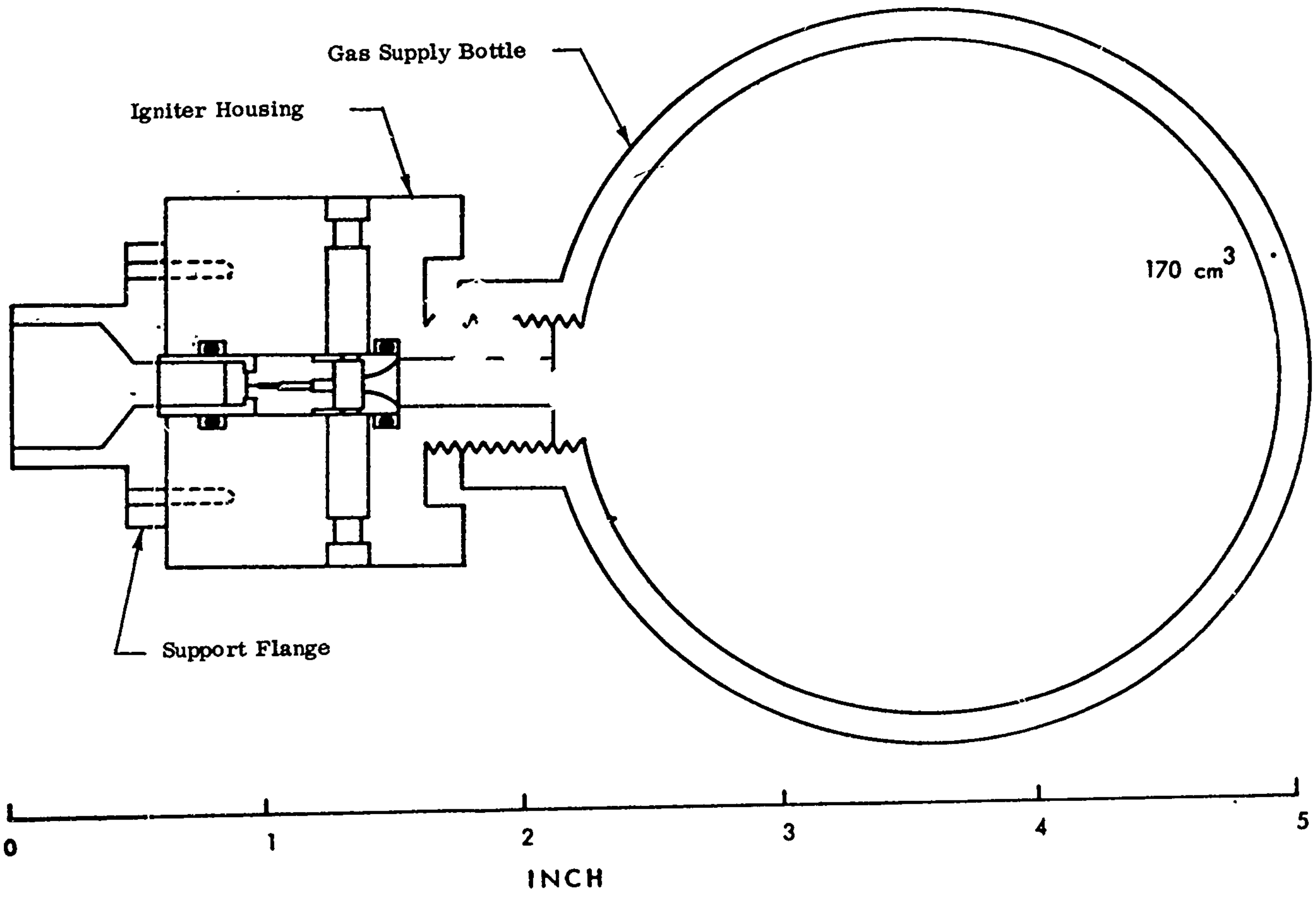


FIGURE 45 LONG TIME DELAY HARDWARE (LTDH)

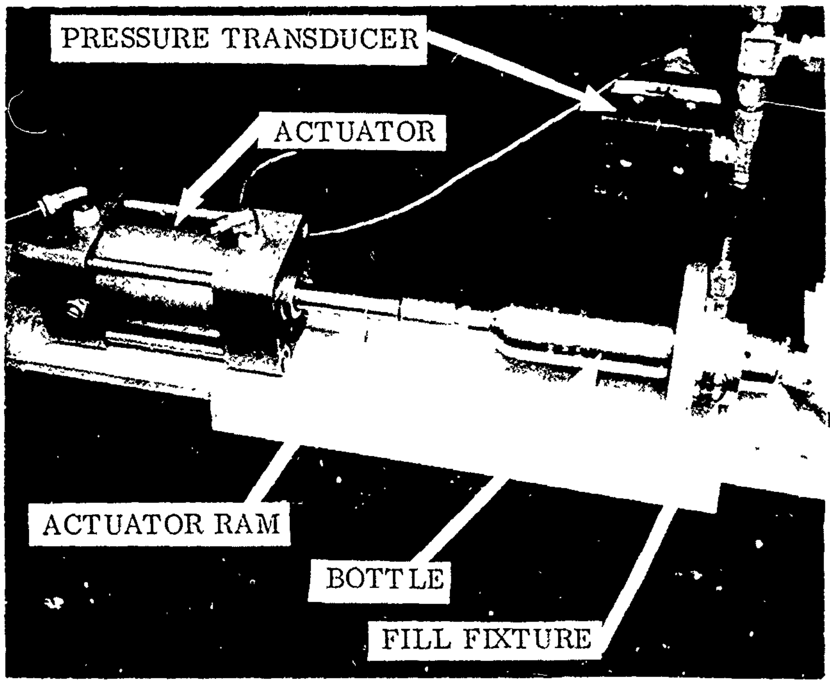


FIGURE 46 LONG TIME DELAY HARDWARE AND ACTUATOR

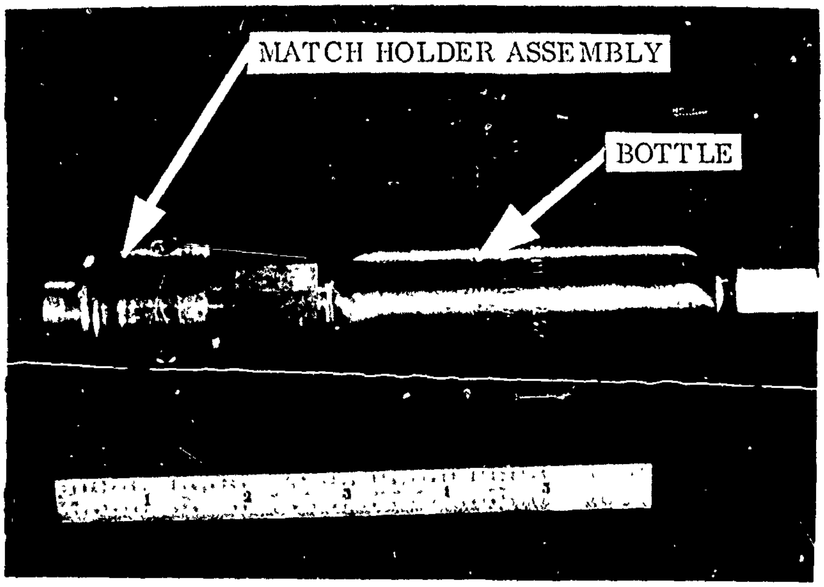


FIGURE 47 LONG TIME DELAY HARDWARE WITH 40 CM^3 BOTTLE

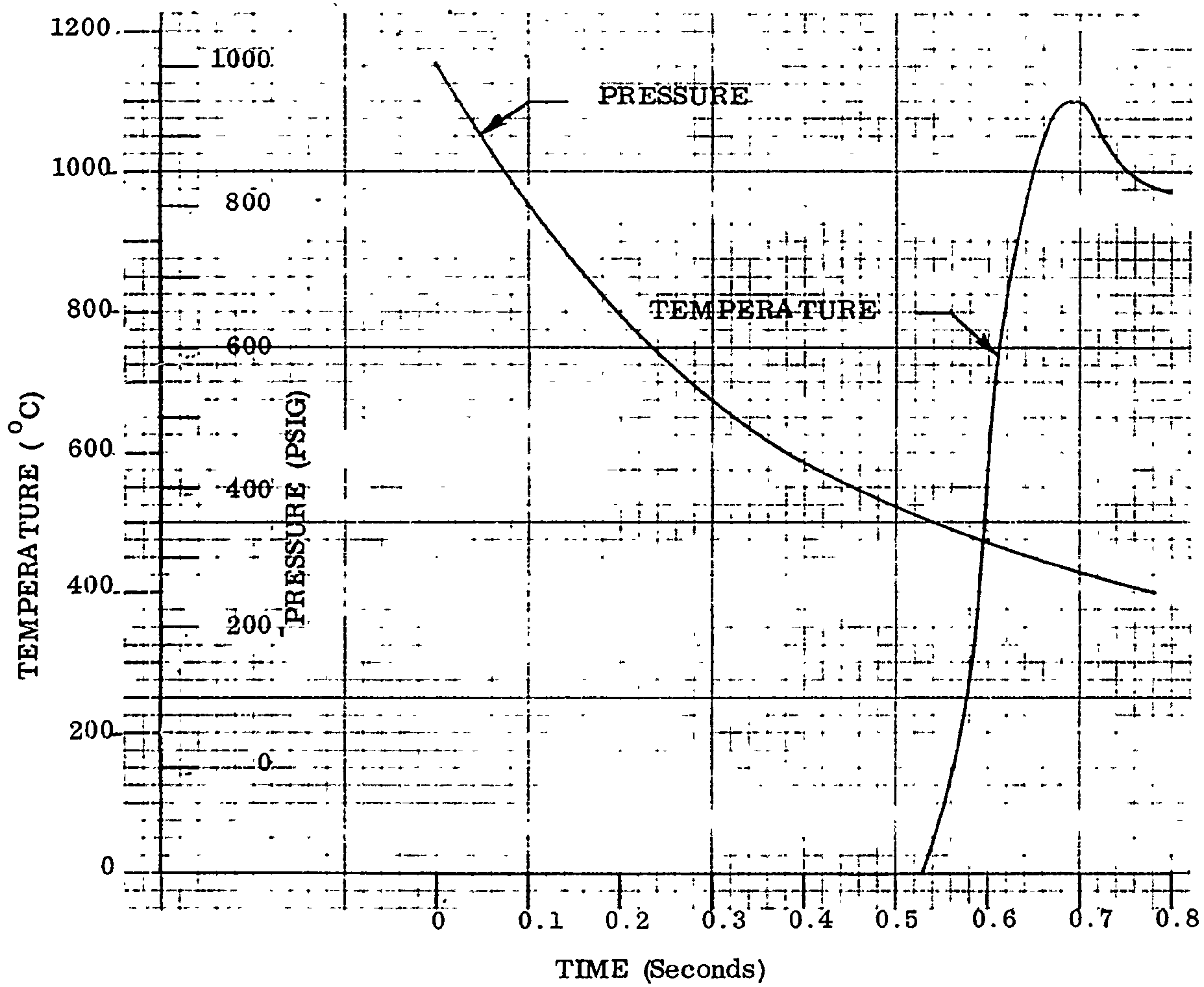


FIGURE 48 TEMPERATURE/TIME PROFILE AND SUPPLY PRESSURE PROFILE FOR 100cc VOLUME, 0.030" DIA. NOZZLE, 1000 PSIG HELIUM

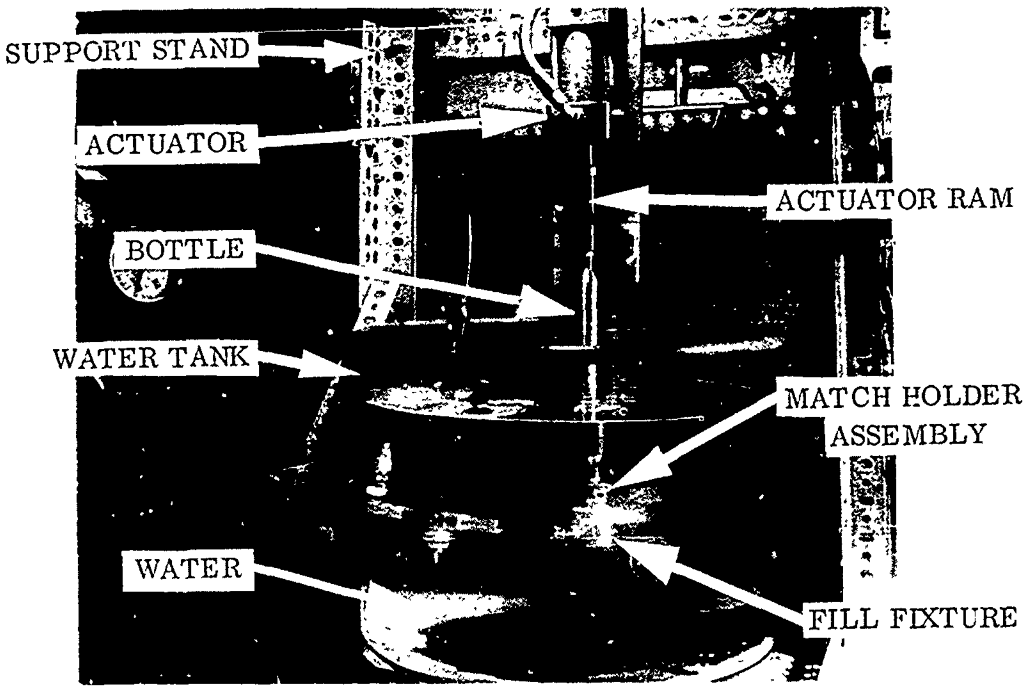


FIGURE 49 WATER TEST EQUIPMENT ARRANGEMENT

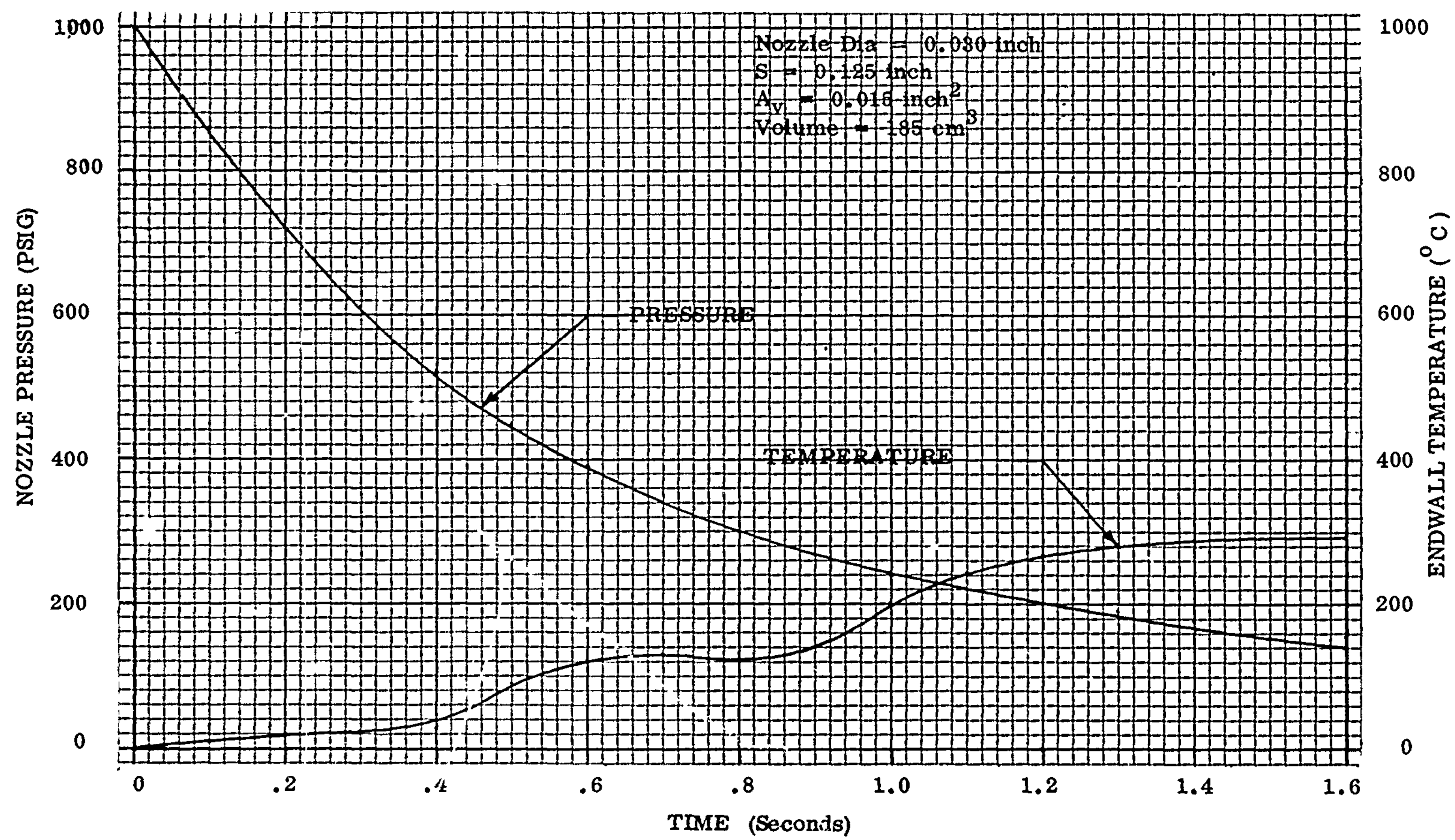


FIGURE 50 UNDERWATER ENVIRONMENTAL TEST RESULTS

Since resonance heating was observed, it was concluded that operation under water is feasible; however, further effort must be expended to determine the actual performance in this environment.

For testing in a sonic flow field, air was supplied through a 1-inch ID pipe and directed into one of the four vents of the igniter housing, this being determined as representing the worst operating condition. The hardware configuration of this test is shown in Fig. 51 & 52 The results of the testing indicated that, although the shape of the temperature/time curve of the device changed appreciably, the maximum temperature attained did not change when compared to similar test data conducted under still air conditions (Fig 53). It was therefore concluded that a high velocity flow field would have little or no effect upon the operation of the device.

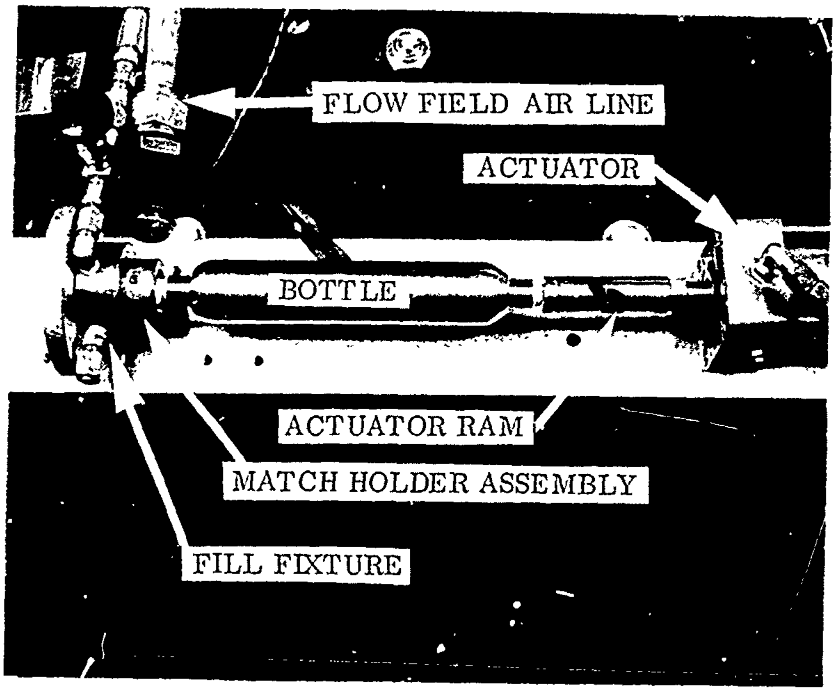


FIGURE 51 SONIC FLOW FIELD TEST EQUIPMENT

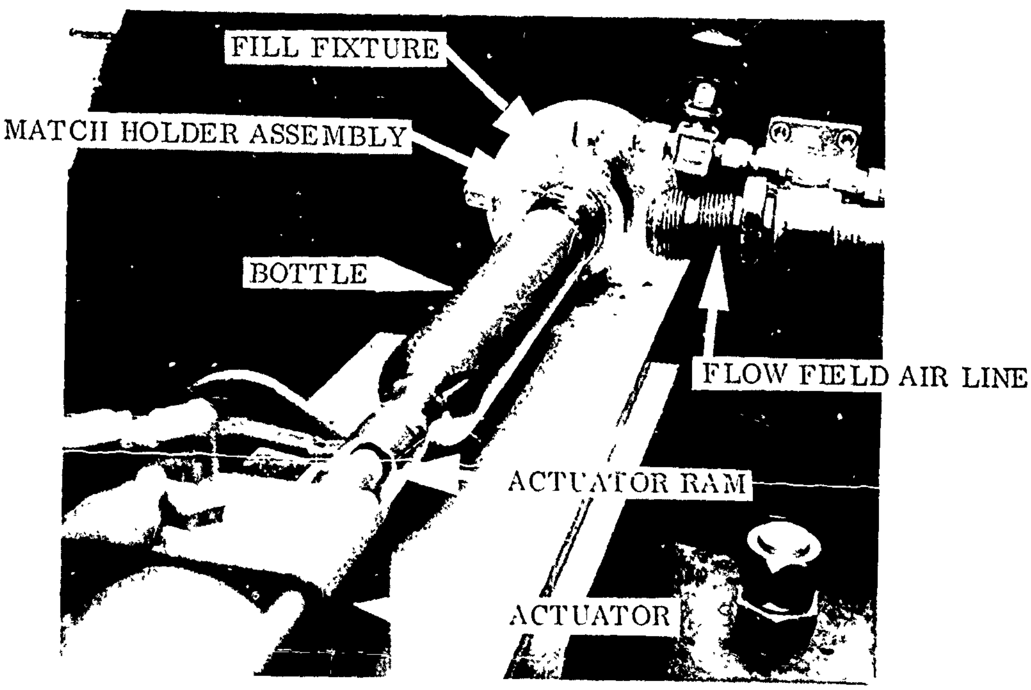


FIGURE 52 SONIC FLOW FIELD TEST EQUIPMENT

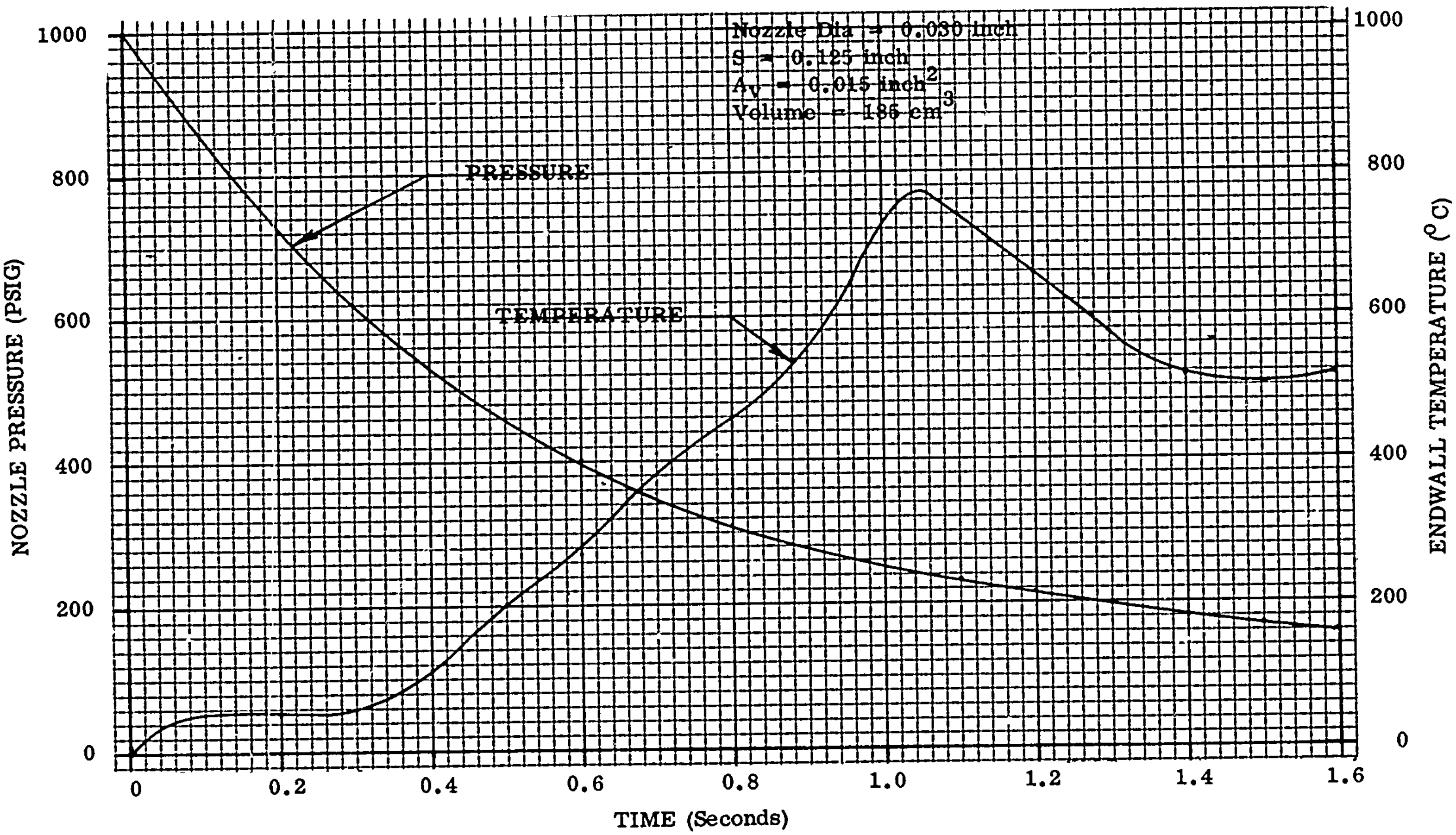


FIGURE 53 SONIC FLOW FIELD ENVIRONMENTAL TEST DATA

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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5 AUTHOR(S) *(First name, middle initial, last name)*

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11. SUPPLEMENTARY NOTES Available in DDC	12. SPONSORING MILITARY ACTIVITY Air Force Armament Laboratory Air Force Systems Command Eglin Air Force Base, Florida 32542

13 ABSTRACT

A flueric second event initiator for Fuel Air Explosives has been designed and tested. It consists of an ignitor incorporating a gas supply bottle and a modified Flueric Explosive Initiator which ignites an explosive through resonance heating. The main feature of the initiator is that it is capable of achieving repeatable time delays of 10 to 1000ms with no moving parts. Time delay mechanization is accomplished by preventing resonance heating at high gas supply pressures and allowing the gas supply pressure to bleed down to the operating point of the ignitor. The characteristic time delay of the discharging supply bottle is therefore the time delay of the ignitor. It was shown how the characteristic time delay of the supply bottle could be made insensitive to the ambient temperature of the gas. Time delay ignitions of KDNBF explosive of 1000ms were obtained with a 170cm^3 gas supply bottle initially charged to 1000 psig.

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fuel-Air Explosives						
Pneumatic Match						
Resonance Tube						
Flueric Initiator						
FAE Igniter						
Explosive Cup						