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JET ENGINE BURN-THROUGH FLAME CHARACTERISTICS

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FINAL REPORT

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16. Abstract

Tests were run to determine the effect of the angle and radius of curvature of a firewall, with respect to a burn-through flame, on burn-through time. No difference was noted in burn-through time for angles of zero-, 10-, or 20-degrees. A slight increase was noted at 30 degrees, and at 40 degrees no burn-through occurred. No great difference in burn-through time was noted with a change in the curvature of the firewall. Centerline flatplate impingement pressures and temperatures were measured and graphed for burn-throughs having pressure ratios of 11:1, 9:1, 6:1, and 4:1, and hole sizes of 1, 1.5, and 2 inches. The exit velocity, density, and mass-flow rate were also calculated for those flames. The radial flatplate impingement profile was mapped for an 11:1 pressure ratio flame from a 1.5-inch hole. Flame characteristics of 16:1, 20:1, and 25:1 pressure ratio burn-throughs were estimated. Three appendixes are included in this report: (1) The Design of a Standard Burn-Through Simulator; (2) Determination of a Standard Burn-Through Hole Size; and (3) A Summary of Burn-Through Work at NAFEC From January 1, 1972, to December 31, 1973, including Results and Conclusions.

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INTRODUCTION

PURPOSE.

The purpose of this activity was to define the characteristics and severity of a jet engine burn-through flame having a pressure ratio up to 11:1.

BACKGROUND.

A burner can burn-through is a high-temperature, high-velocity flame exiting from a rupture in a jet engine (usually the diffuser case) caused by uncontrolled combustion in a location within an engine not designed for combustion.

Reference 1 gives further information on burn-throughs regarding severity and occurrences. A chart showing the number of burn-throughs reported in commercial aviation from 1962 through 1969 is included in this reference.

An updating of this summary is depicted in table 1, showing burn-through occurrences reported from 1970 through August of 1973. It should be noted that the number of burn-throughs over the past 4 years has remained at virtually a constant rate of approximately eight occurrences a year for commercial aircraft operations.

TABLE 1. STATISTICAL SUMMARY OF BURNER CAN BURN THROUGHS, 1970 THRU AUGUST 1973

Aircraft	Powerplant	1970	1971	1972	1973 (Till Sept. 1)
FH-227	R.R. Dart-532	1	-	-	3
CV-600	R.R. Dart-542	-	2	-	1
CV-640	R.R. Dart-542	-	-	1	-
YS-11A	R.R. Dart-10/1	1	1	-	-
B707	JT3D	1	-	1	-
B720	JT3C	2	1	-	-
B727	JT8D	-	-	1	1
DC-8	JT3D	2	1	-	3
DC-9	JT8D	1	4	3	-
CV880	CJ805	-	-	1	-
		8	9	7	8

DISCUSSION AND RESULTS

TEST EQUIPMENT AND CONFIGURATION.

Two Pratt and Whitney J57/P37 turbojet engines mounted on a B57 aircraft were used to produce the burn-through flame for all tests. The right J57 engine was modified with an external burner can burn-through simulator (figure 1). This was done by removing the No. 8 burner can and fuel nozzle cluster, running the primary and secondary fuel lines from the No. 7 burner can, external of the diffuser case, to two solenoid-operated shutoff valves. These valves were controlled from a blockhouse and were used to supply fuel to the external burner can. Airflow for the external can was supplied by a 10-inch diameter duct. The duct was inserted in the engine in place of the No. 8 burner can and carried air from the diffuser case to the external burn-through simulator. The external burner can consisted of a diffuser with a 10-inch diameter inlet and a 12-inch diameter outlet, which was blocked by a 0.5-inch-thick steel plate containing a burn-through hole. Fuel was supplied from the primary and secondary fuel lines through the solenoid shutoff valves, and was injected into the burner can through two swirl-type nozzles. An igniter was located just downstream of the fuel nozzles. Total pressure in the external burner can was monitored by a pressure probe on the steel faceplate, 2 inches above the burn-through hole (appendix A describes a design of a burn-through simulator independent of a jet engine). A 1.5-inch diameter burn-through hole was used as a standard (see appendix B for the determination of the size of a standard burn-through hole), although tests were also run using a hole size of 1 and 2 inches.

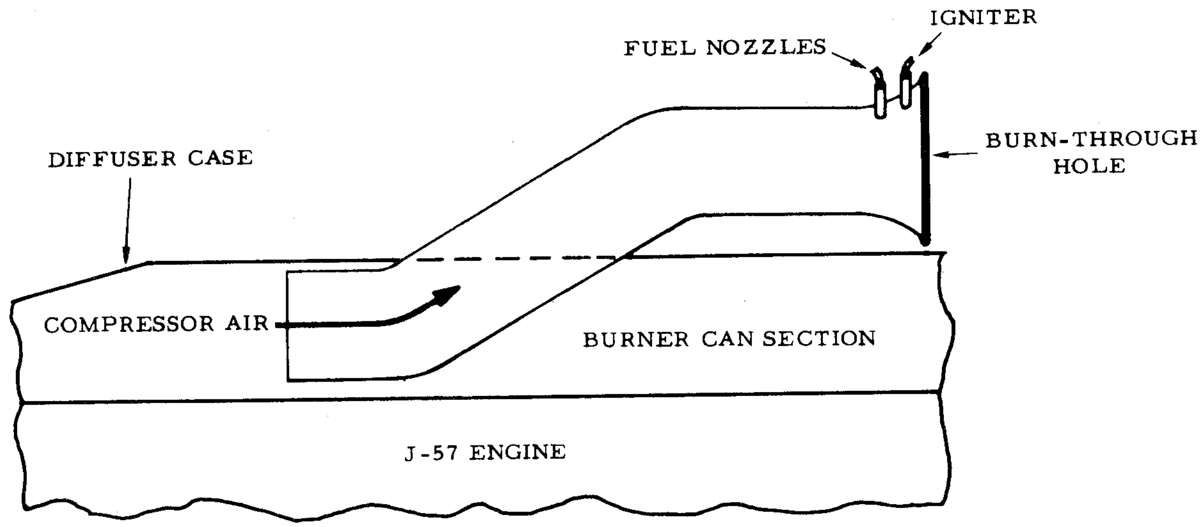


FIGURE 1. BURN-THROUGH SIMULATOR

Although various other methods of creating burn-throughs were developed and used during the testing period, a repeatable burn-through was developed, using the left J57 engine, by cutting a hole in the burner can section of the engine and No. 8 burner can liner. A water-jacketed burn-through orifice (figure 2) was then developed and welded into the opening. The standard size burn-through hole used was 1.5-inches in diameter. The fuel lines to the No. 8 burner can were severed and shutoff valves were placed in the lines. This allowed the burn-through flame to be controlled from the blockhouse.

During the early phases of testing, two other methods of producing a burn-through were used and both methods were discontinued because they caused rapid deterioration of the engine. These methods were:

1. The drilling of a 0.040-inch hole in the primary and secondary fuel manifold, internal to the diffuser case (see reference 2 for details and results).

2. Removal of the locating lug from the No. 8 burner can and tilting it off the fuel nozzles, thus diverting the fuel spray causing it to impinge on the engine case. A 1.5-inch water-jacketed orifice was placed over the No. 8 burner can (figure 3).

MATERIAL GEOMETRY TESTS.

Two series of tests were run to determine the effect of the geometry of a burn-through barrier on its ability to resist a burn-through. The first series of tests were run as shown in table 2, to determine the effect of changing the angle-of-attack of the burn-through flame on the flame barrier. The material used was 0.016-inch stainless steel. It was mounted 5 inches from a 1.5-inch burn-through hole. A 9:1 engine pressure ratio was used. The burn-through flame used was produced by using the internal water-jacket method shown in figure 2. Using this method, most if not all of the burning occurred prior to exit from the burn-through orifice. Also a small percentage of engine internal cooling air may have been mixed with the flame. Therefore, the temperature of the flame produced by this method was lower than the temperature of burn-through flames produced by other methods. This means of producing a flame was not used in determining the flame characteristics, but was used in the material geometry tests since a comparative and not a quantitative relation was wanted. It could be expected that similar burn-through times could be obtained from higher temperature flames by simply increasing the distance of the barrier from the burn-through hole.

The results of the angle-impingement tests (figure 4a) showed that at approximately 30° (that is, the material is 30° from the perpendicular to the burn-through flame), the burn-through time starts to increase and at 40° burn-through does not occur during a 1-minute test. These results compare favorably with those shown in table 3 of reference 1.

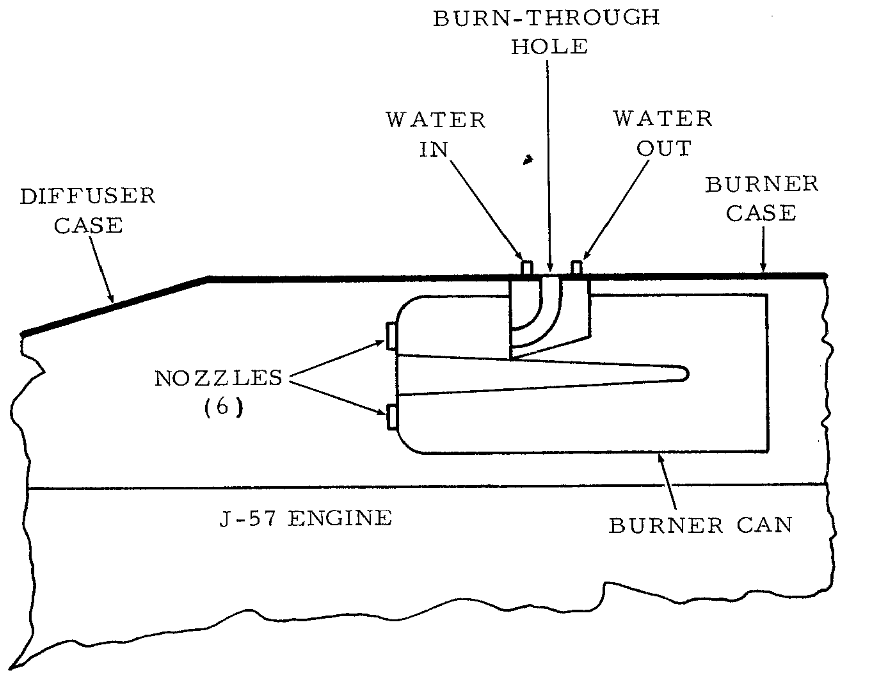


FIGURE 2. INTERNAL WATER JACKET

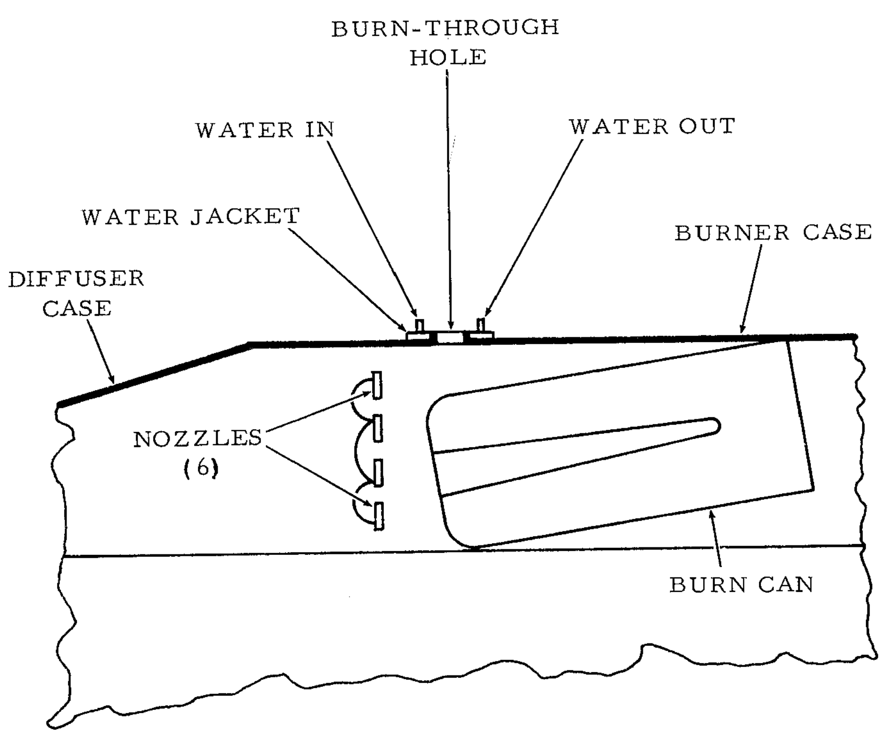


FIGURE 3. BURNER CAN OFFSET FROM NOZZLES

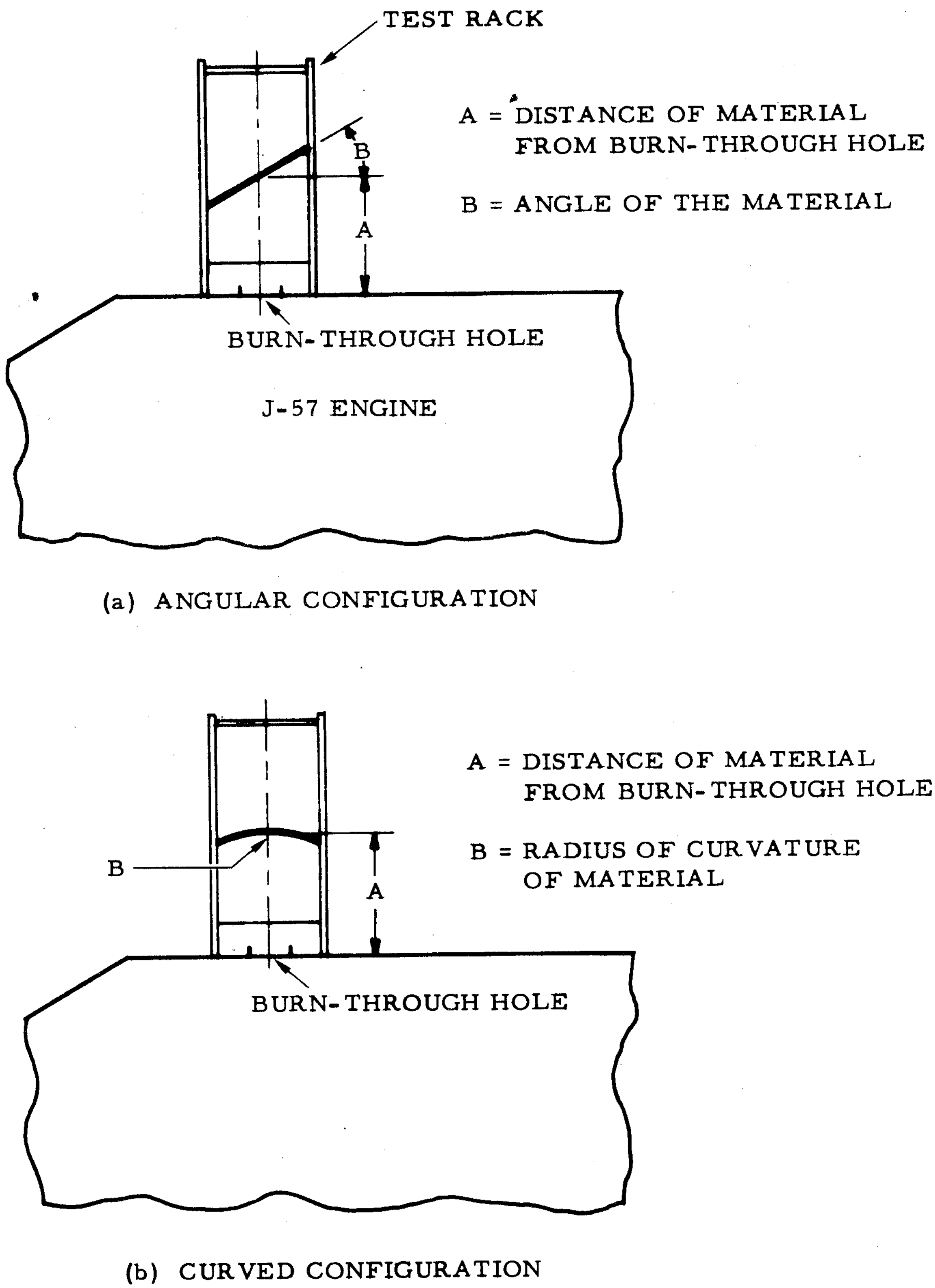


FIGURE 4. CONFIGURATIONS FOR MATERIAL GEOMETRY TESTS

TABLE 2. THE EFFECT OF FLAME IMPINGEMENT ANGLE ON FIREWALL MATERIAL

Angle of Specimen From Normal	Burn-Through Time
(Degrees)	(Seconds)
0	2.0
10	2.0
20	2.0
30	6.0
40	No Burn-Through 60-Second Run

The second series of tests was run to determine the effect of the curvature of the burn-through barrier on resisting a burn-through flame (figure 4b). Table 3 shows the result of these tests using 0.016-inch stainless steel as the test material, mounted 5 inches from a 1.5-inch burn-through hole. An engine pressure ratio of 9:1 was used, and the flame impinged on the concave side. Burn-through times increased as the radius of curvature decreased until the radius equaled 18 inches when the burn-through time began to decrease. The increase or decrease in burn-through time with the radius of curvature was not significant.

TABLE 3. THE EFFECT OF THE CURVATURE OF A FIRE BARRIER ON ITS ABILITY TO RESIST A BURN-THROUGH FLAME

Radius of Curvature of Flame Barrier	Burn-Through Time
(Inches)	(Seconds)
∞ (Flat Sheet)	3.2
36	4.8
30	5.0
24	6.6
18	5.1
12	3.2

BURN-THROUGH FLAME CHARACTERISTICS.

The first step in determining the burn-through flame characteristics was to establish a standard flame to be used, since all the methods of producing a suitable burn-through flame from inside the engine caused some form of internal damage. Therefore, the external burn-through simulator shown in figure 1 was developed. A visual comparison was made between the flames produced in this manner and those produced by a hole in the fuel manifold and a misaligned burner can. It was found that at an engine pressure ratio of 11:1 large amounts of black smoke was experienced which was due to a rich fuel-air mixture. This was corrected in later tests by the introduction of a fuel-metering valve in the fuel supply for the simulator. Figure 5 shows how the nozzle size, or fuel-metering valve opening, was selected for a 1-inch burn-through hole while figure 6 shows the large amount of black smoke experienced. Various fuel-metering valve openings were tested at an engine pressure ratio of 11:1 and 9:1. The centerline temperature of the flame impinging on a flatplate was measured for each valve opening, and pressure ratio. The valve setting giving the highest temperature reading was selected.

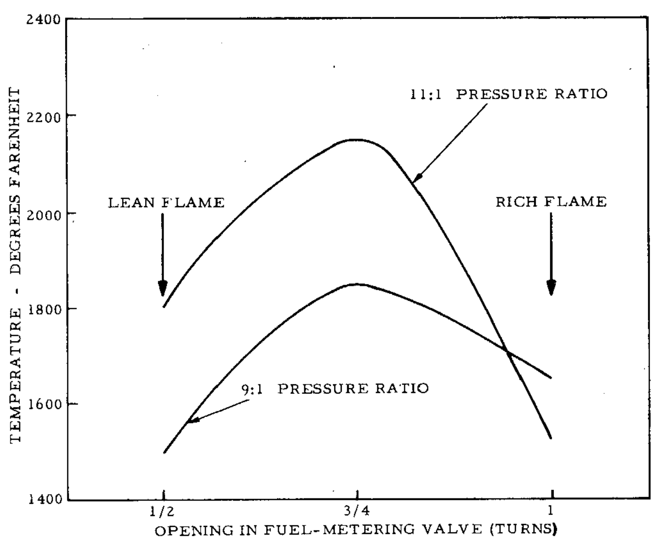
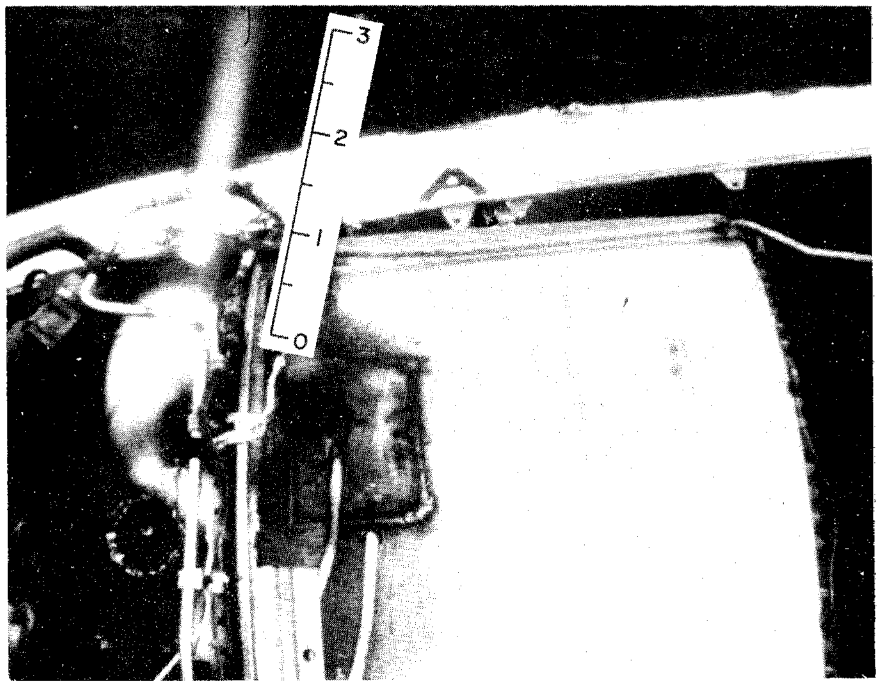


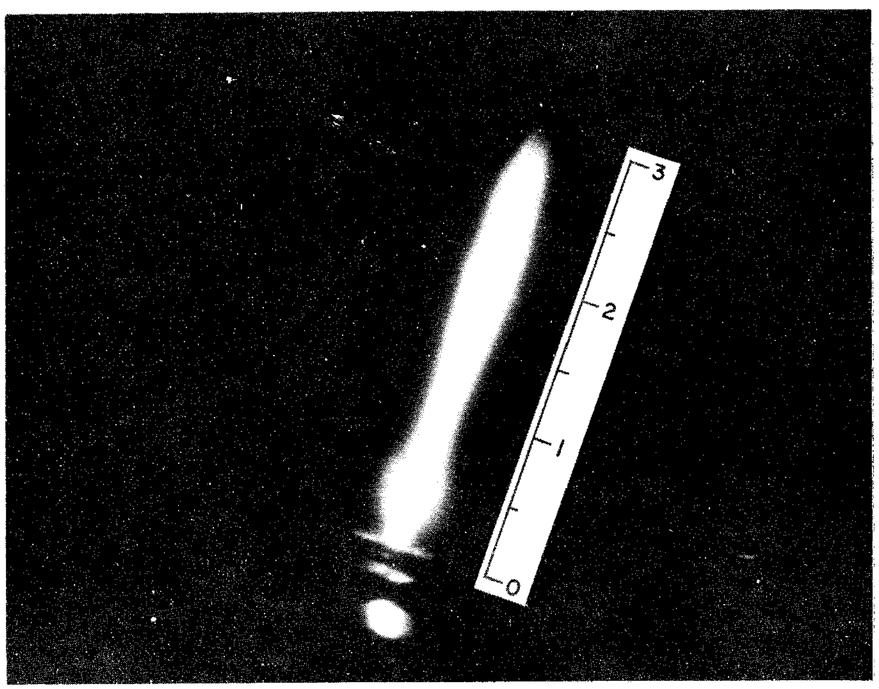
FIGURE 5. A COMPARISON OF CENTERLINE IMPINGEMENT TEMPERATURES FOR DIFFERENT FUEL-AIR RATIOS

Figure 7a is the flame produced from a fuel leak in the internal manifold. Figure 7b represents the flame produced by a misaligned burner can (this photograph was taken at night, hence, the flame looks much brighter). As can be seen from the photographs, all three flames were approximately the same size and shape. The effects of fuel-air ratio on the burn-through flame can be seen in figures 8a and b. Figure 8a is a lean mixture and figure 8b is a rich mixture (note the difference between the two flames). The lean flame is much brighter in the first 12 to 16 inches, indicating possible higher temperatures, but the rich flame is much longer.

FIGURE 6. FLAME EXITING FROM BURN-THROUGH SIMULATOR (PRESSURE RATIO 11:1, EXIT 1.5 INCH)

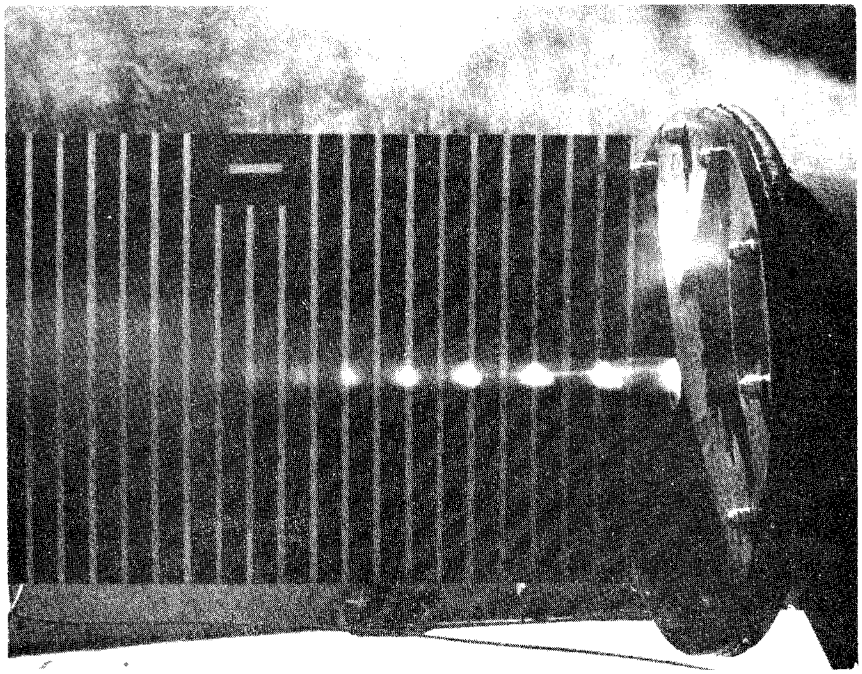


(a) RUPTURED FUEL LINE

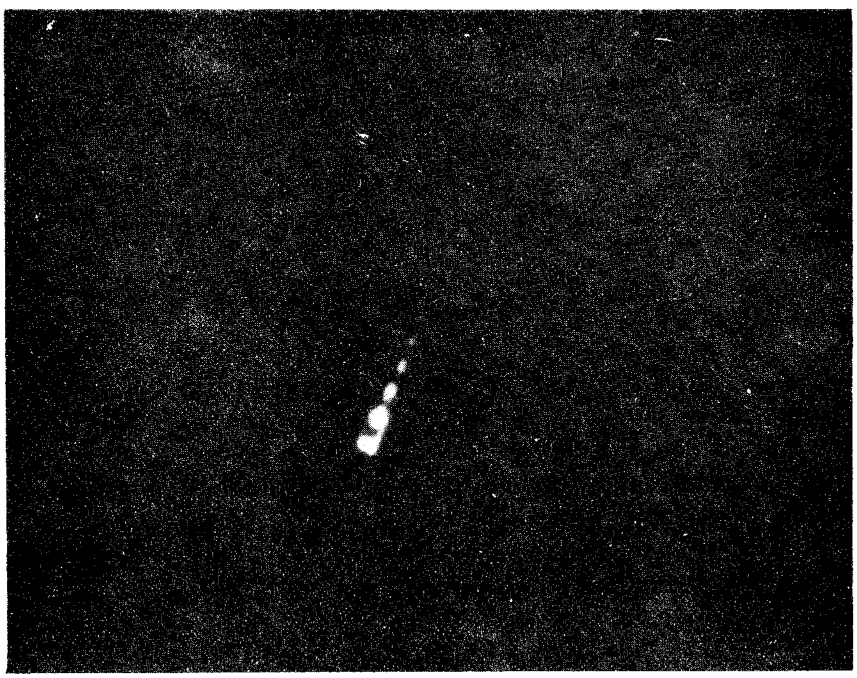


(b) OFFSET BURNER CAN

FIGURE 7. A COMPARISON OF BURN-THROUGH FLAMES AT 11:1 PRESSURE RATIO



(a) SIMULATOR METHOD



(b) OFFSET CAN METHOD

FIGURE 8. A COMPARISON OF BURN-THROUGH FLAMES AT 4:1 PRESSURE RATIO

A few preliminary tests were run to determine the most severe fuel-air mixture at various pressure ratios and hole sizes. The fuel nozzle size giving the most severe overall centerline temperatures, was selected for each hole size: 1 inch, 1.5 inches, and 2 inches. These nozzle sizes remained constant for each pressure ratio using the same size burn-through hole.

Figure 9a and 9b show a comparison of the simulator flame and a flame produced using the misaligned can method at an engine pressure ratio of 4:1. The flame produced by these methods at a 4:1 pressure ratio are very similar. It was decided that the burn-through simulator was a suitable method for producing a flame that would be comparable in temperature, and pressure to an actual burn-through.

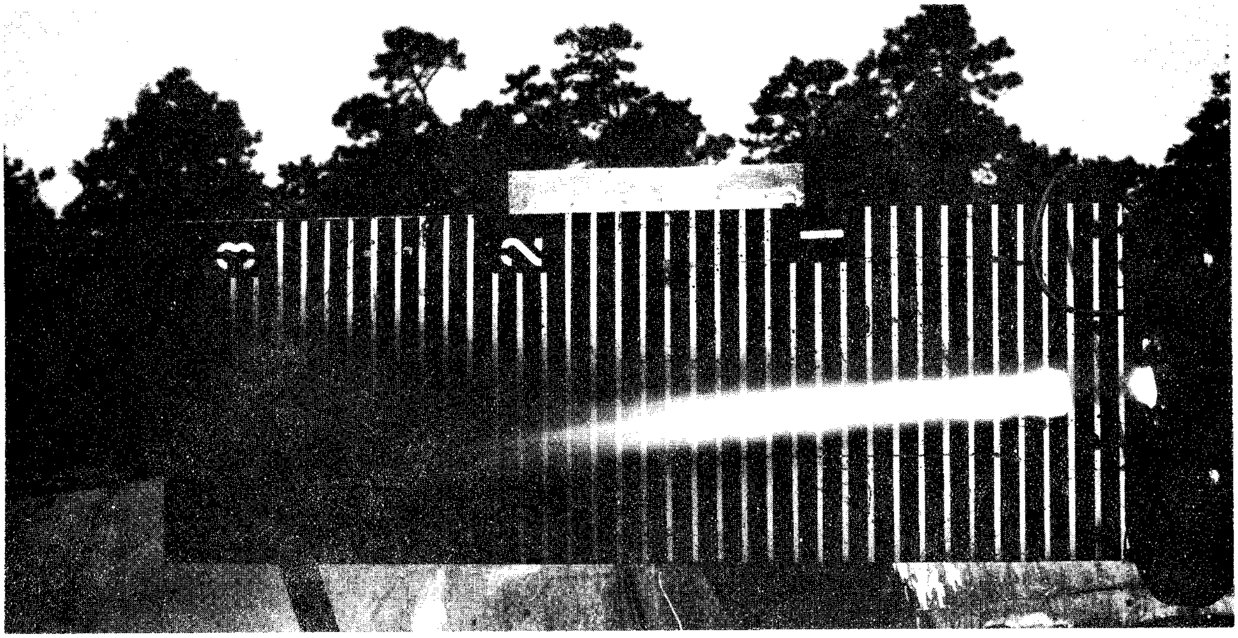
PRESSURE MEASUREMENTS.

The burn-through flame centerline pressure impinging on a flatplate was measured at various distances for a 1-, 1.5-, and 2-inch hole. This was done by placing a flatplate, figure 10, with two pressure pickups, in the path of the flame, such that the centerline of the flame impinged on one of the pickups. The pressure pickups used were simply 1/8-inch holes in the 0.5-inch-thick plate. Fittings on the reverse side of the plate connected the pickups to the tubing which ducted the pressure to a pressure gauge in the control room. Gauge readings were visually observed and recorded.

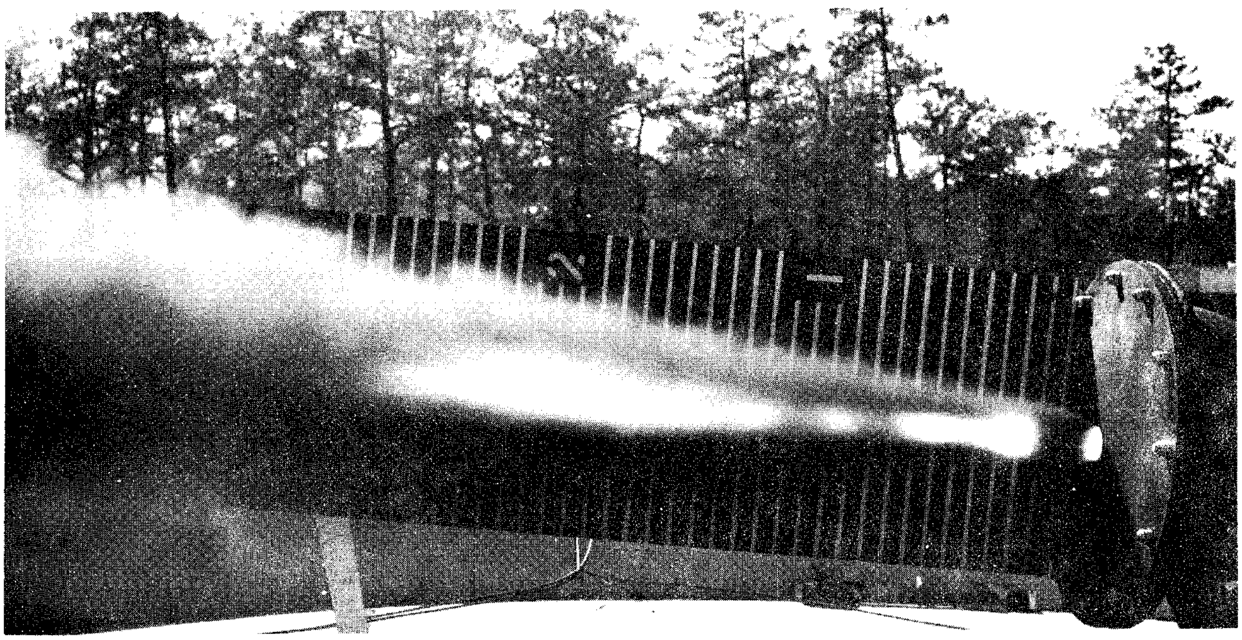
Figures 11 through 13 show the centerline pressure impinging on a flatplate for various pressure ratios. Figure 11 represents a 1-inch hole size. As the pressure ratio increases so does the centerline impingement pressure. Figures 12 and 13 representing a 1.5- and 2-inch hole show that a drop occurred in the flame pressure shortly after exiting from the burn-through hole. The amount of drop depends on the pressure ratio, the larger the pressure ratio, the greater the drop. If measurements were taken closer to the hole on the 1-inch tests, this same phenomena would have been expected. This drop in pressure is caused by formation of a normal shock which increases in size as the pressure ratio is increased; stagnation pressure directly behind the shock is then greatly reduced. The pressure in the portion of flow not containing the normal shock is only slightly affected by an oblique shock. The centerline pressure is gradually raised by the higher pressure surrounding it until it equals that pressure. Reference 3 goes into great detail on the subject.

Figure 14 shows the difference in centerline impingement pressure due to hole size. It should be noted that the larger the hole, the lower the peak centerline impingement pressure.

Figure 15 shows the centerline impingement pressure for a burn-through flame having a pressure ratio of 11:1 (flame on) and a jet of the same pressure ratio (flame off) having an initial temperature of approximately 500°F. Although the initial pressure ratio of the jets was the same, the burn-through flame had a



(a) LEAN FUEL MIXTURE



(b) RICH FUEL MIXTURE

FIGURE 9. A COMPARISON OF FUEL-AIR RATIO ON 11:1 PRESSURE RATIO FLAME FROM THE BURN-THROUGH SIMULATOR

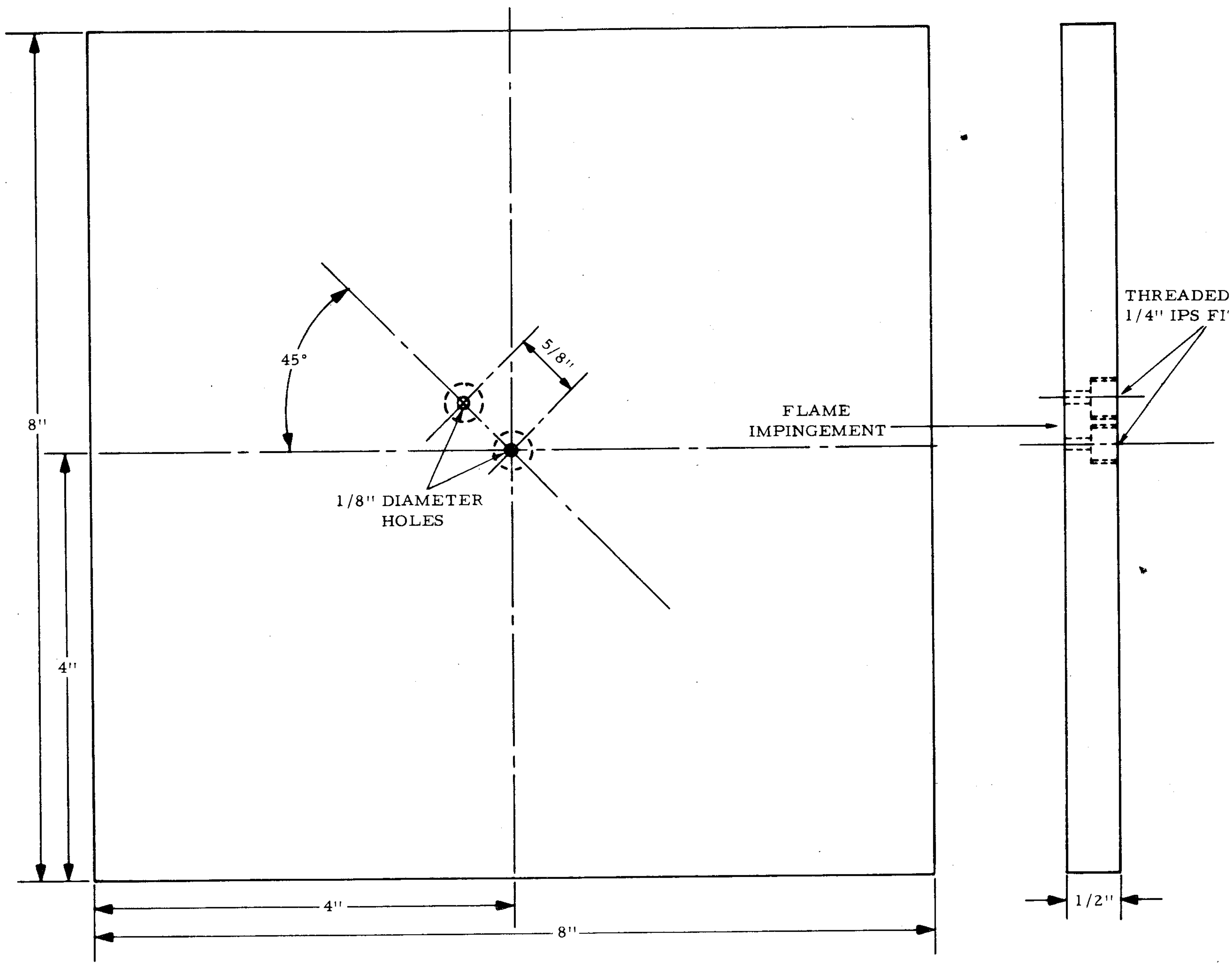


FIGURE 10. FLATPLATE USED IN IMPINGEMENT TESTS

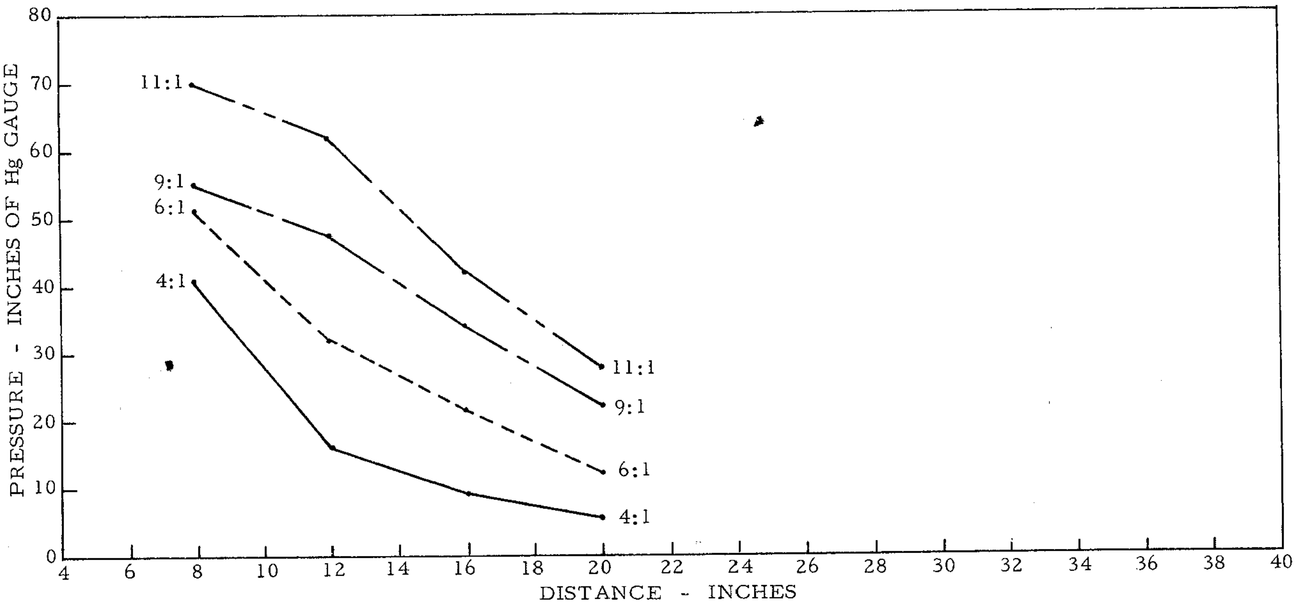


FIGURE 11. IMPINGEMENT PRESSURES FOR 1-INCH BURN-THROUGH HOLE

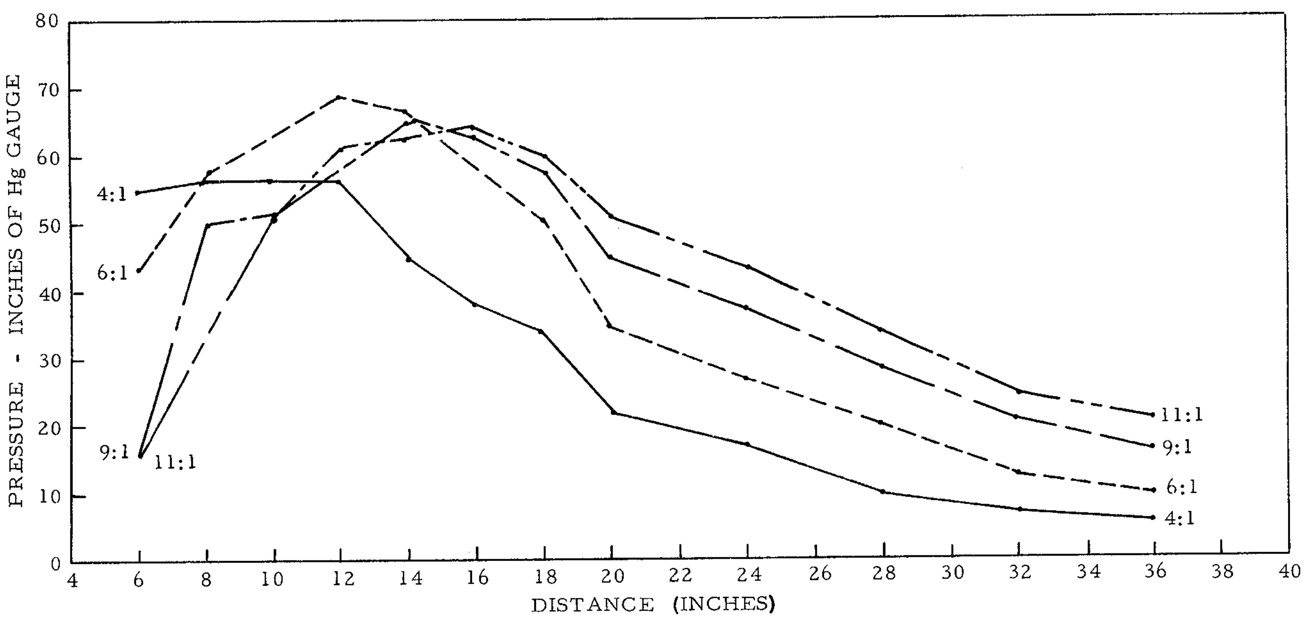


FIGURE 12. IMPINGEMENT PRESSURES FOR 1.5-INCH BURN-THROUGH HOLE

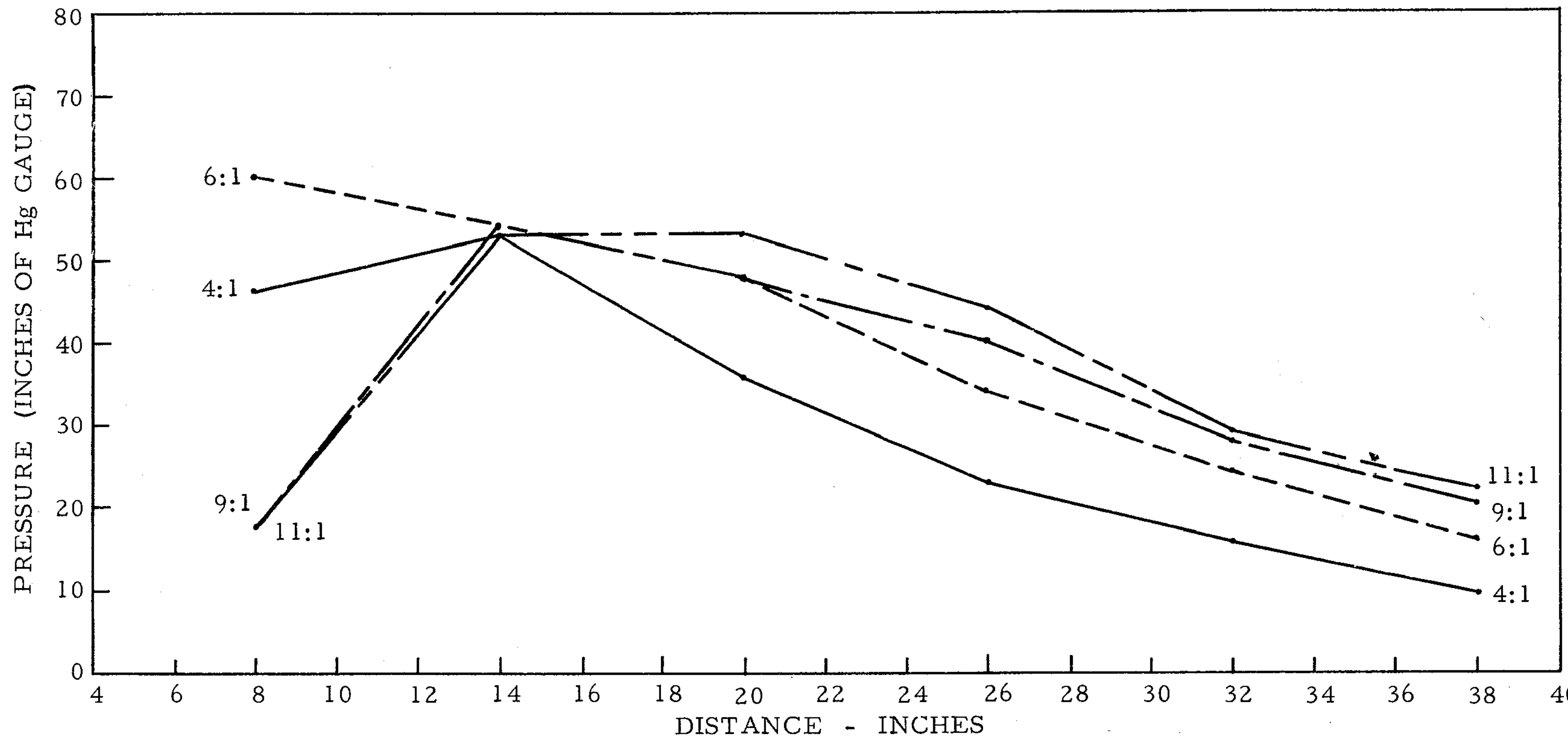


FIGURE 13. IMPINGEMENT PRESSURES FOR 2-INCH BURN-THROUGH HOLE

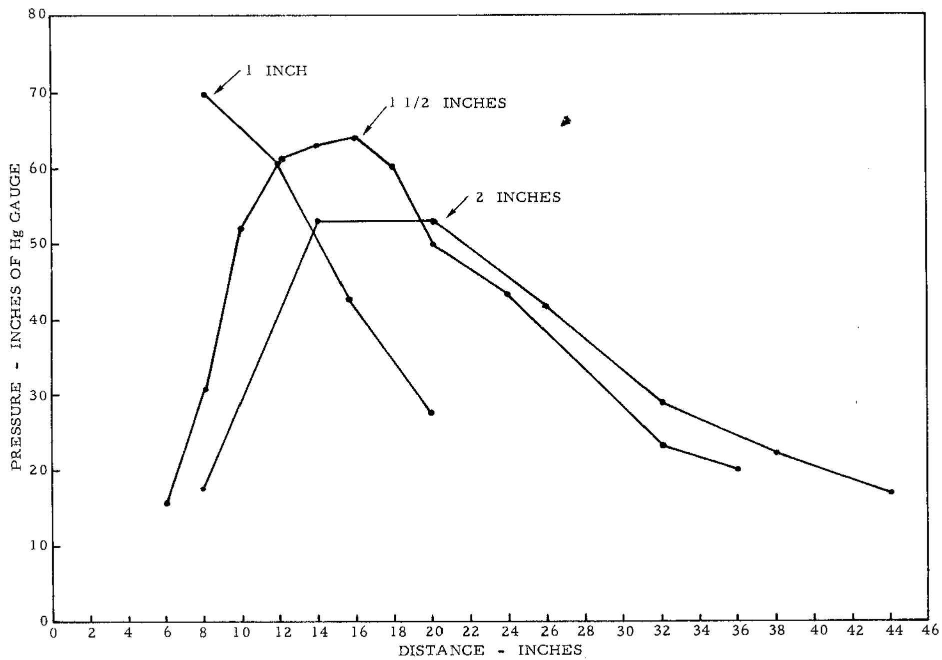


FIGURE 14. BURN-THROUGH FLAME IMPINGEMENT PRESSURES FOR VARIOUS HOLE SIZES AT 11:1 PRESSURE RATIO

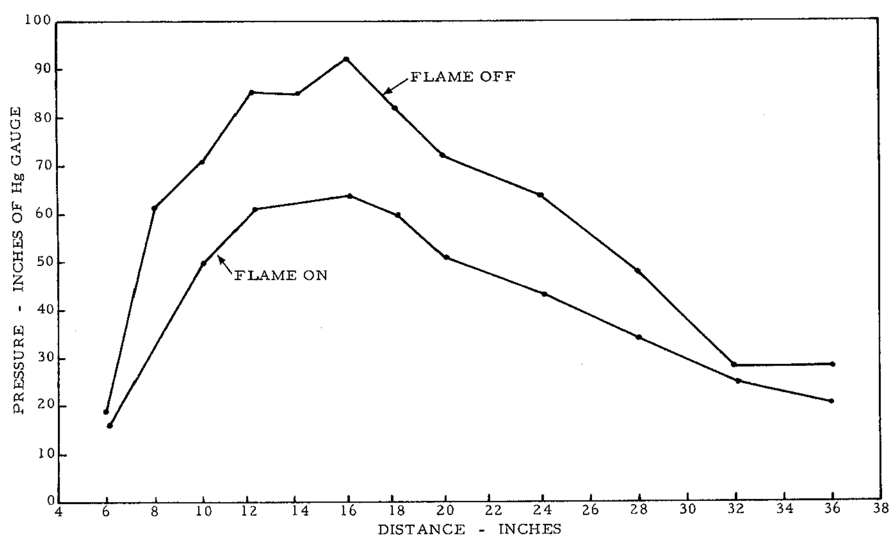


FIGURE 15. HOT JET VERSUS COOL JET CENTERLINE IMPINGEMENT PRESSURES

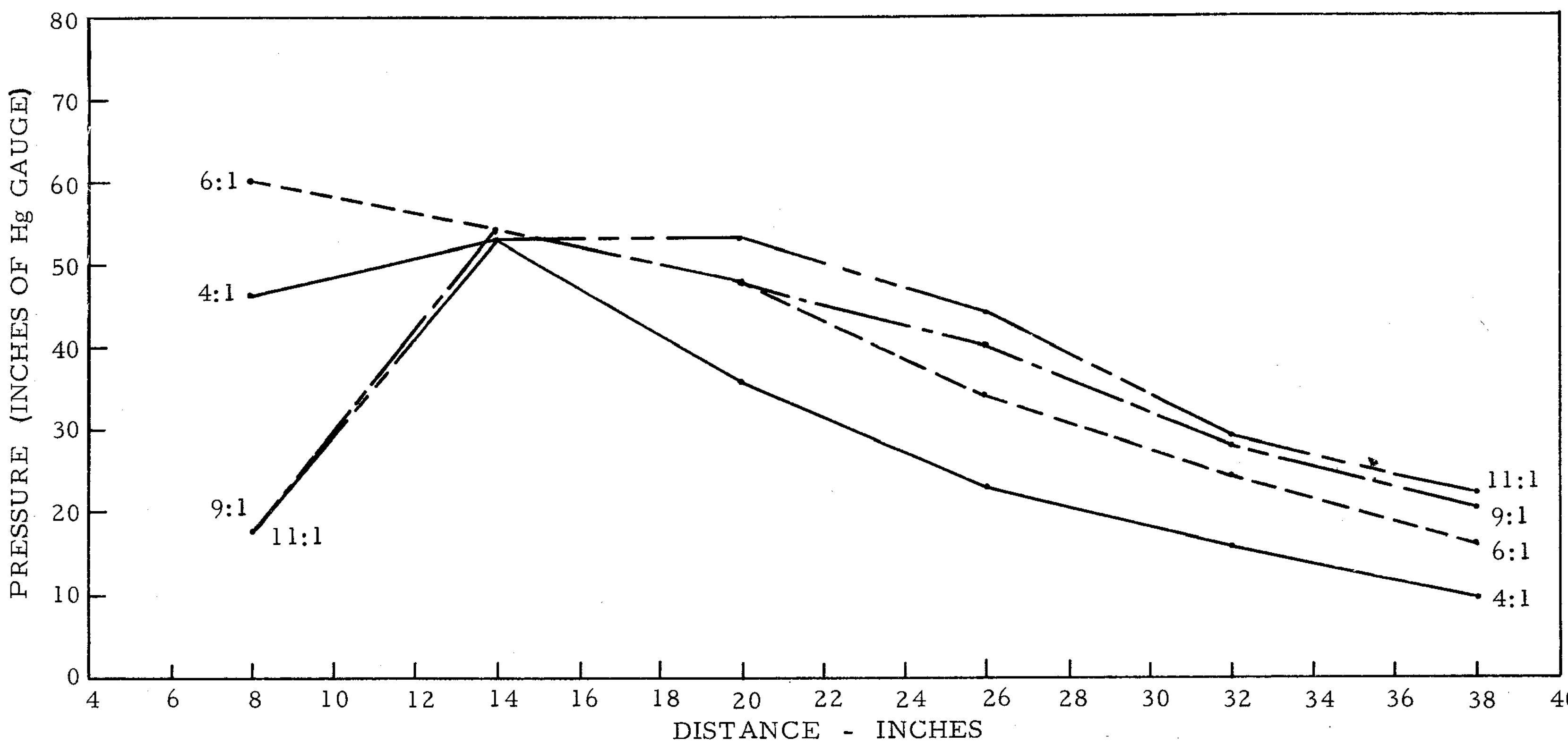


FIGURE 13. IMPINGEMENT PRESSURES FOR 2-INCH BURN-THROUGH HOLE

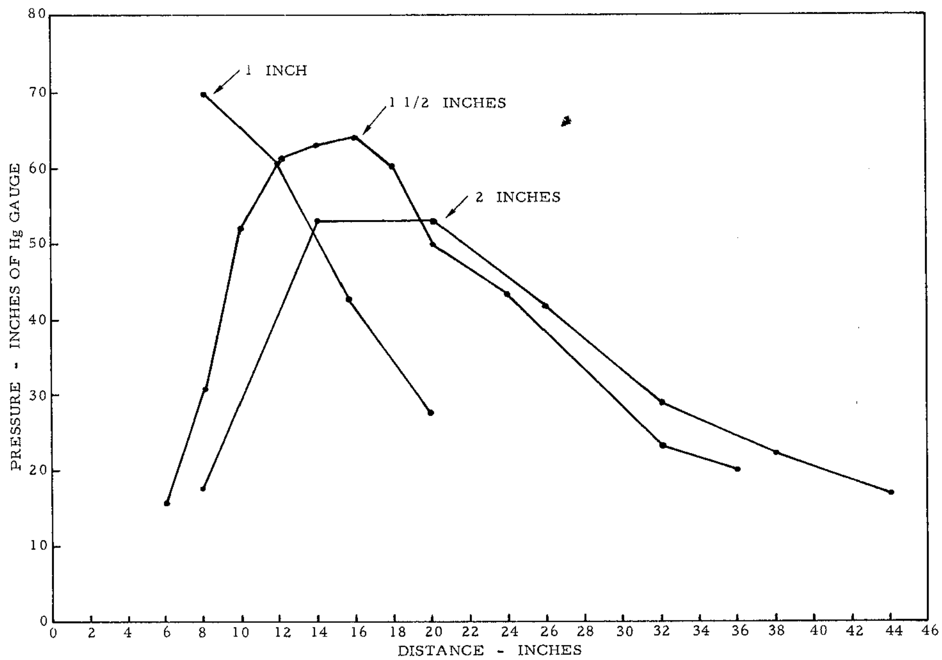


FIGURE 14. BURN-THROUGH FLAME IMPINGEMENT PRESSURES FOR VARIOUS HOLE SIZES AT 11:1 PRESSURE RATIO

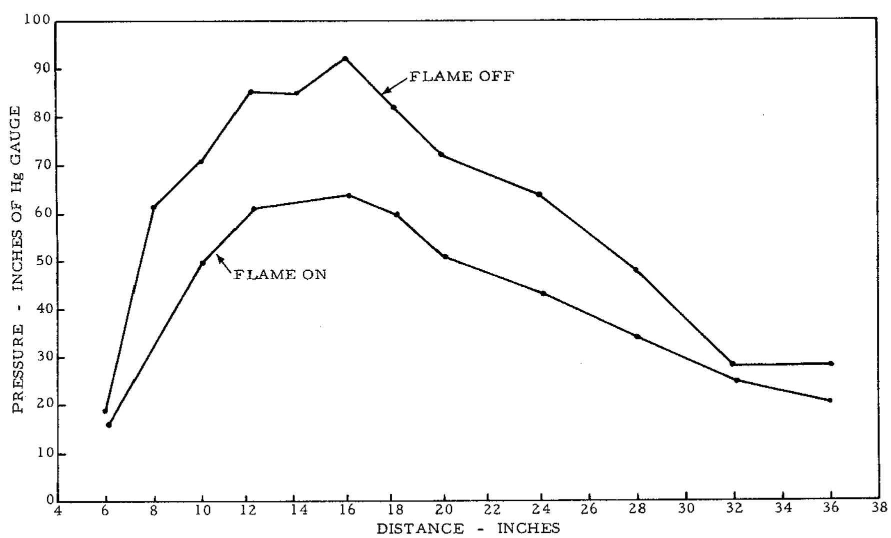


FIGURE 15. HOT JET VERSUS COOL JET CENTERLINE IMPINGEMENT PRESSURES

lower impingement pressure over its entire length than the cooler jet. This is due to the higher temperature creating a higher velocity, thus, a larger area of normal shock. Hence, the recovery time will be longer and the peak pressure lower with the larger normal shock.

TEMPERATURE MEASUREMENTS.

The burn-through flame flatplate impingement temperatures were measured along the centerline of the flame. This was done by using a flatplate (figure 10) where two inconel-sheathed ceramic-insulated thermocouples were mounted 0.016 inches above the front face of the plate. The 24-gauge thermocouple wire junction was kept as small as possible. For centerline impingement temperatures of less than 3,000°F, platinum - 13 percent rhodium vs. platinum thermocouples were used. For above 3,000°F a tungsten - 5 percent rhenium vs. tungsten - 26 percent rhenium thermocouples were used. All noncenterline temperatures were measured using chromel vs. alumel thermocouples having a 2,500°F capability. All temperature measurements were recorded on strip chart recorders in the control room. Noncenterline flame temperatures were monitored in the same manner as the centerline temperature, only the thermocouples were positioned the desired distance off the centerline of the flame.

Since there is a negligible loss in stagnation temperature across a normal shock, the sharp drop that occurs in the pressure does not occur in the temperature.

Figures 16 through 18 show the centerline flatplate impingement temperatures for 11:1, 9:1, 6:1, and 4:1 pressure ratio flames exiting from burn-through holes of 1-, 1.5-, and 2-inch diameters. Generally speaking, as the pressure ratio increases, the peak temperature and the length of the flame increases. In figures 16 and 18, representing a 1- and 2-inch burn-through, respectively, as the distance from the exit increases, the temperatures continually decrease, which is expected. However, as shown in figure 17 for a 1.5-inch burn-through, the impingement temperature increased on a few occasions. It is assumed that this rise is due to combustion in the flame from a rich fuel-air mixture.

Figure 19 shows the relationship of three burn-through flames of the same pressure ratio (11:1) exiting from different size holes, 1, 1.5, and 2 inches. The larger the hole the longer the flame.

All temperatures are those recorded from the thermocouples and no attempt was made to compensate for radiation or convection losses. Such losses were considered to be minimal when other variables are taken into consideration.

Figure 20 shows the results of the cross sectional flame impingement tests for a 1.5-inch flame having a pressure ratio of 11:1. At 20 inches from the exit hole the measured centerline temperature was 3,100°F and within 3 inches of either side of the centerline the temperature was over 2,500°F. Although the centerline temperature at 24 inches from the exit remained close to 3,000°F, the temperature of the flame dropped quickly in the radial direction and was well below 1,500°F, 1 inch off the centerline. At 28 inches a rapid decay in the centerline temperature began.

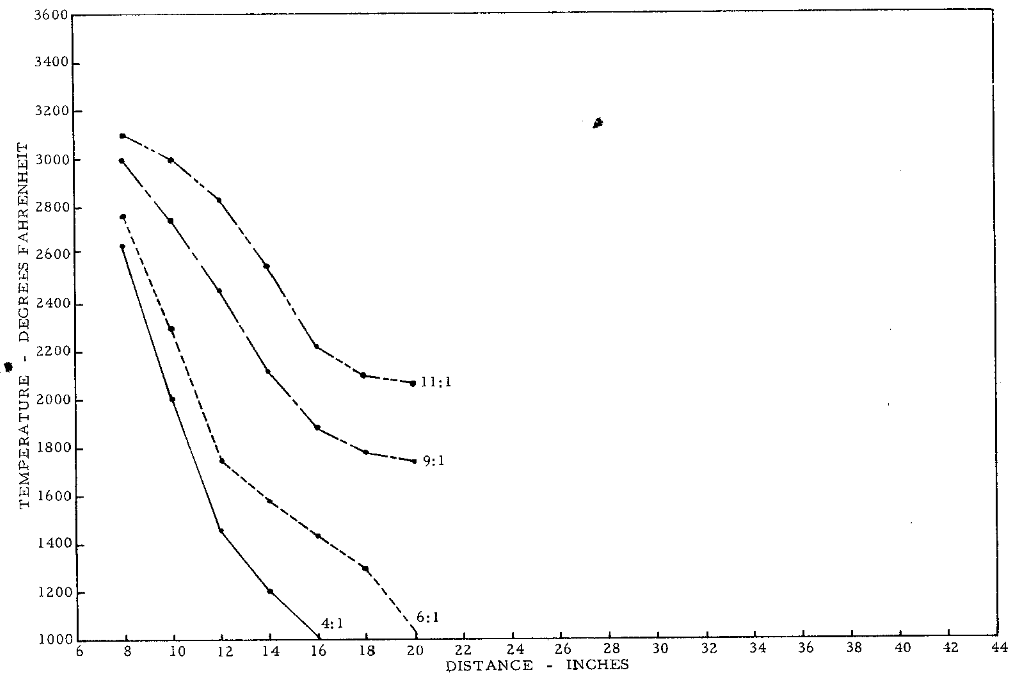


FIGURE 16. CENTERLINE IMPINGEMENT TEMPERATURES FOR A 1-INCH BURN-THROUGH HOLE

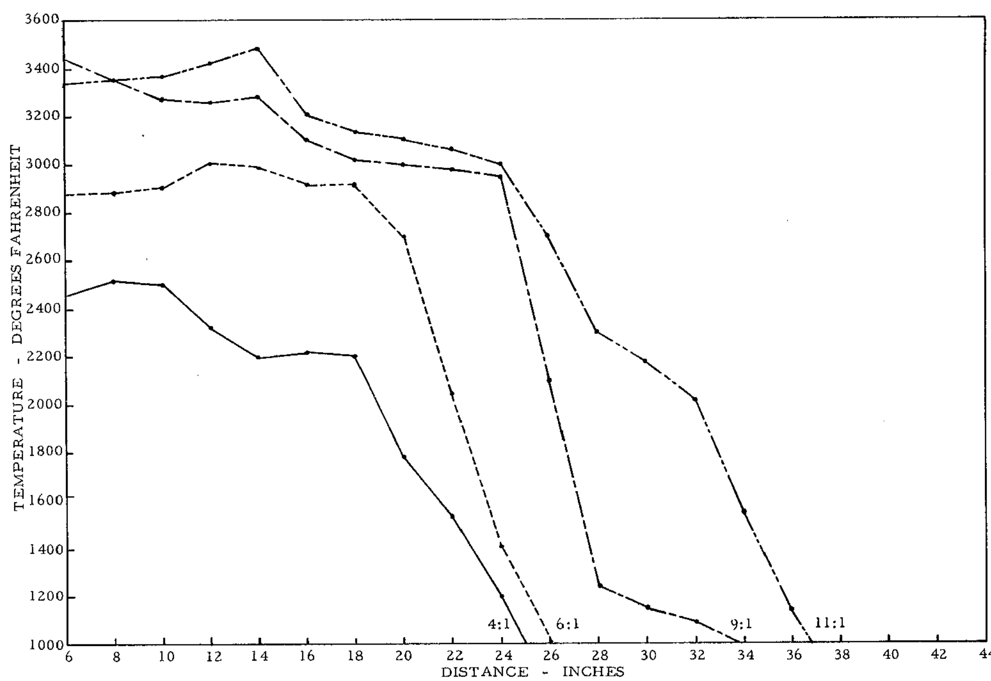


FIGURE 17. CENTERLINE IMPINGEMENT TEMPERATURES FOR A 1.5-INCH BURN-THROUGH HOLE

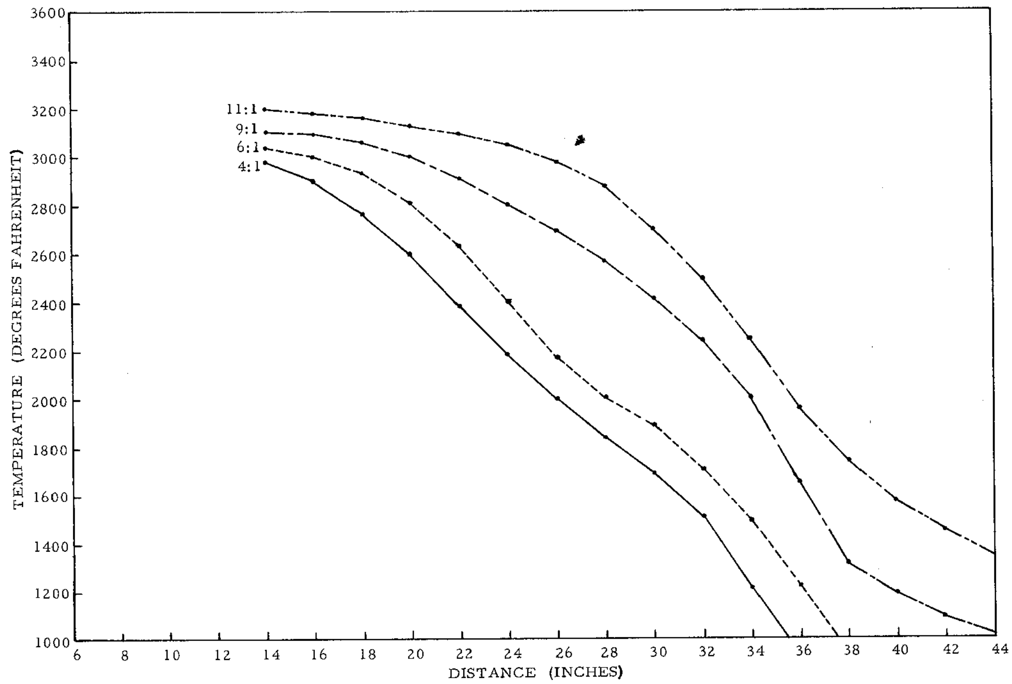


FIGURE 18. CENTERLINE IMPINGEMENT TEMPERATURES FOR A 2-INCH BURN-THROUGH HOLE

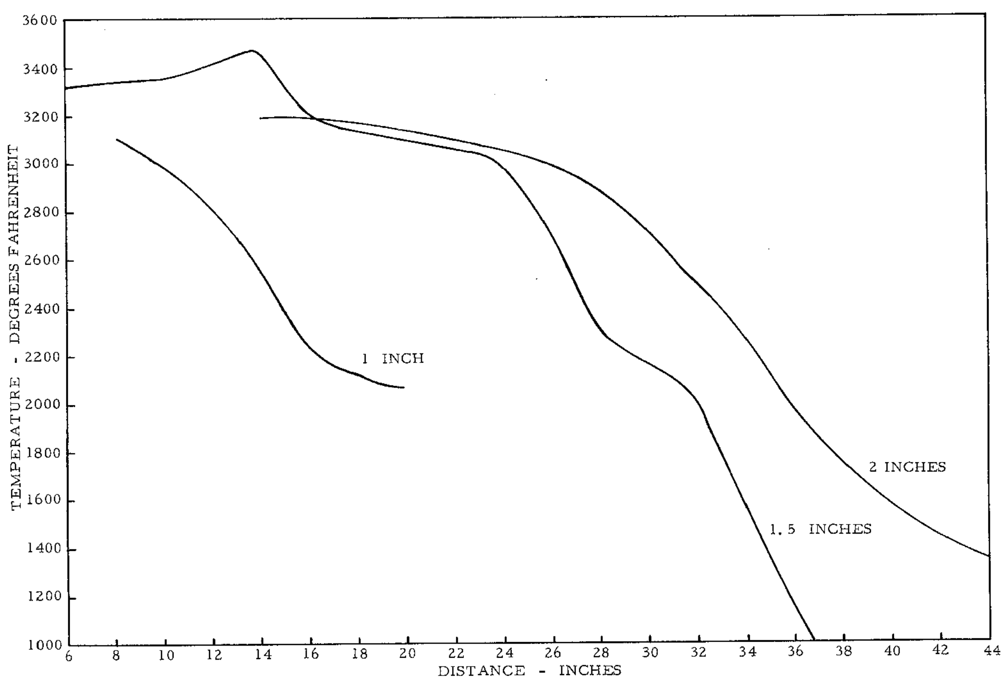


FIGURE 19. BURN-THROUGH FLAME IMPINGEMENT TEMPERATURES FOR VARIOUS HOLE SIZES AT 11:1 PRESSURE RATIO

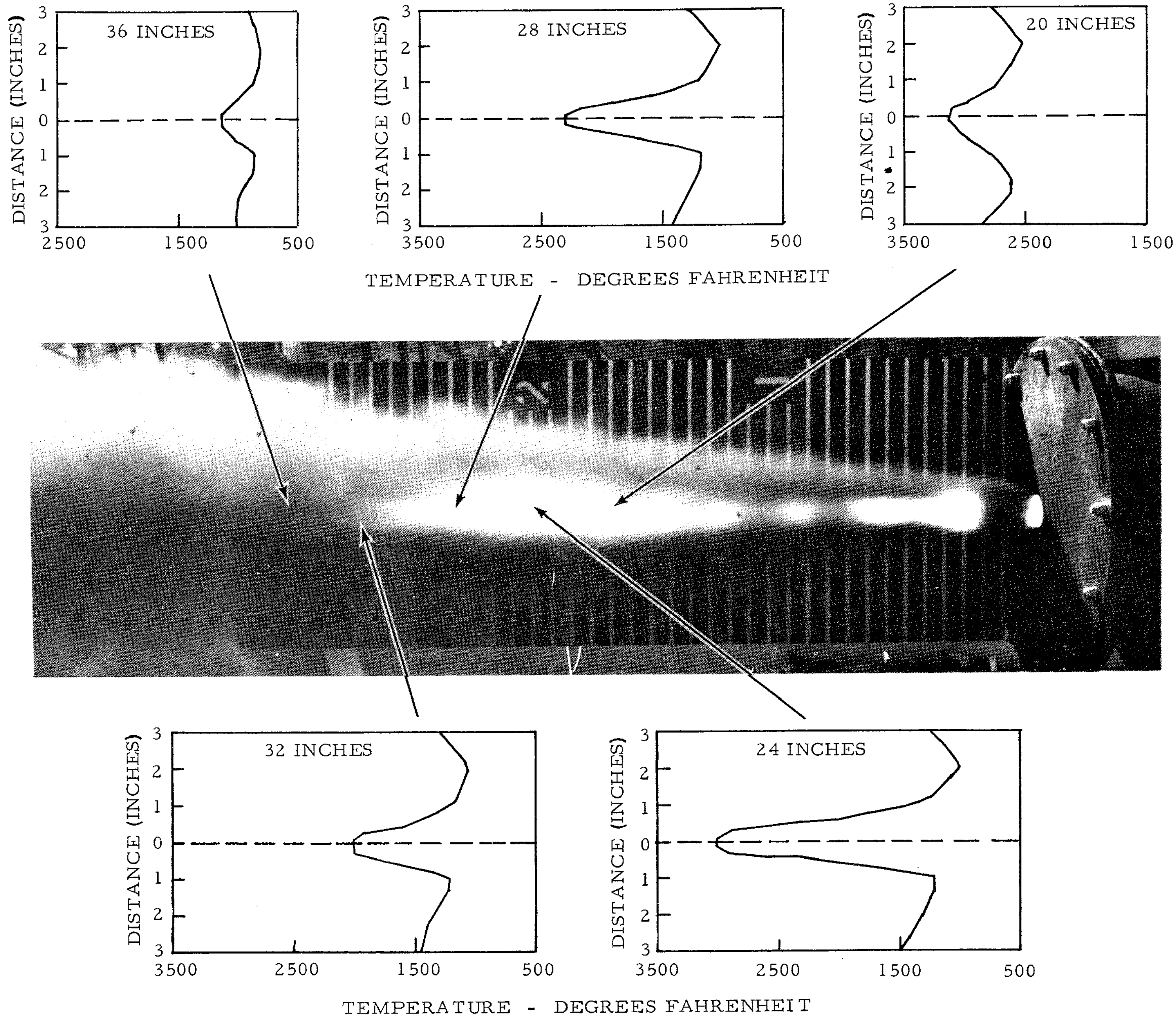


FIGURE 20. RADIAL IMPINGEMENT TEMPERATURE PROFILE FOR 11:1 PRESSURE RATIO FLAME EXITING A 1.5-INCH HOLE

FLAME DENSITY AND MASS FLOW.

To better define a burn-through flame, the flame density at exit (ρe) and mass flow rate at exit (W_e) were calculated as follows:

$$\rho e = \frac{P_e}{(R)(T_e)}$$

where P_e = Pressure at exit

T_e = Temperature at exit

R = Gas constant

Sample Calculation:

ρe for 11:1 flame

$P_e = 14.7 \text{ lbf/in}^2 \; 9110 = 161.7 \text{ lbf/in}^2 \; (144 \text{ lbf/ft}^2/\text{lbf/in}^2) = 23{,}200 \text{ lbf/ft}^2$

$R = 53.34 \dfrac{\text{ft lbf}}{\text{oR lbm}}$

$T_e = 4{,}100°R$ estimated from flame temperature curve.

$$\rho e = \frac{23{,}200 \text{ lb/ft}^2}{53.34 \dfrac{\text{ft lbf}}{\text{oRlbm}} (4100°R)} = 0.107 \text{ lbm/ft}^3$$

$W_e = \rho e \; V_e \; A_e$ Where V_e = Velocity at exit

A_e = Area of exit

Sample Calculation:

W_e for 11:1 flame - 1.5-inch hole

$\rho_e = 0.107 \text{ lbm/ft}^3$

$$V_e = \sqrt{(K)(G_c)(R)(T_e)}$$

Where K = Specific heat ratio (1.3)

G_c = Constant (32.17) lbm/ft/sec^2)

R = Gas constant (53.34 $\frac{\text{ft lbf}}{\text{lbm°R}}$)

T_e = Exit temperature (4,100°R)

$$V_e = \sqrt{1.3 \quad 32.17 \text{ lbm/ft/sec}^2 \quad (53.34 \frac{\text{ft lbf}}{\text{lbm°R}}) \ (4{,}100\text{°R})}$$

$$V_e = 3{,}040 \text{ ft/sec}$$

$$W_e = (0.107 \text{ lbm/ft}^3) \ (3{,}040 \text{ ft/sec}) \ (0.0097 \text{ ft}^2) = 3.15 \text{ lbm/sec}$$

MATERIAL BURN-THROUGH TESTS.

Time for burn-through of a standard firewall material (0.016 stainless steel) was determined at various distances using an 11:1 pressure ratio flame and a 1.5-inch hole. With the material located 20 inches or closer, burn-through time was 2 seconds or less. At 24 inches the time for burn-through increased to between 3 and 5 seconds. At 28 inches no burn-through occurred.

HIGHER PRESSURE RATIO FLAMES.

From the data on burn-through flames, up to 11:1 pressure ratios, an extrapolation to higher pressure ratio flames cannot be accurately made, although some rough estimates of the flames can. (NOTE: The definition of estimate as used in this report is an opinion or judgment. All estimates of flame characteristics of burn-through flame having a pressure ratio higher than 11:1 are the opinion or judgment of the author based on his experience with burn-through flame and the overall general trend of data for lower pressure ratio flames shown in this report.) Table 4 shows calculated flame velocity and density at exit, flame mass flow rate, and estimated flame temperature at exit, for flames with pressure ratios of 16:1, 20:1, and 25:1 exiting from a 1.5-inch hole.

The following is a rough estimate of flame temperature for 16:1, 20:1, 25:1 pressure-ratio flames, exiting a 1.5-inch hole.

As the pressure ratio rises above 11:1 the length of the flame would continue to increase. At 16:1 pressure ratio, a centerline temperature of 3,000°F would be maintained out to about 30 inches, for 20:1 to about 38 inches and to approximately 4 feet for a 25:1 pressure-ratio flame. Table 5 shows estimated distances for flames having a pressure ratio of 16:1, 20:1, and 25:1, at which the centerline impingement temperature drops to 2,500°F and 2,000°F.

Table 6 lists the flame velocity and density at exit, estimated flame temperature, and calculated flame mass flow rate at exit, for burn-through flames having a pressure ratio of 11:1, 9:1, 6:1, 4:1, and hole sizes of 1, 1.5, and 2 inches.

TABLE 4. CALCULATED PROPERTIES OF BURN-THROUGH FLAMES WITH PRESSURE RATIOS HIGHER THAN 11:1

Pressure Ratio	Hole Size Diameter (inches)	Flame Velocity at Exit (ft/s)	Flame Density at Exit (lb/ft^3)	Flame Estimated Temperature at Exit (°R)	Flame Mass Flow Rate at Exit (lb/s)
16:1	1.5	3060	0.152	4200	4.5
20:1	1.5	3090	0.185	4300	5.55
25:1	1.5	3130	0.226	4400	6.86

TABLE 5. ESTIMATED BURN-THROUGH FLAME LENGTH AT PRESSURE RATIOS OF 16:1, 20:1, AND 25:1

Pressure Ratio	Distance (inches) 2,500°F	Distance (inches) 2,000°F
16:1	36-40	42-46
20:1	44-50	53-59
25:1	56-62	68-74

TABLE 6. PROPERTIES OF THE FLAME EXITING THE BURN-THROUGH HOLE

Pressure Ratio	Hole Size Diameter (inches)	Flame Velocity at Exit (ft/s)	Flame Density at Exit (lb/ft^3)	Estimated Flame Temperature at Exit (°R)	Flame Mass Flow Rate at Exit (lb/s)
11:1	1	3040	0.107	4100	1.77
11:1	1.5	3040	0.107	4100	3.15
11:1	2	3040	0.107	4100	7.06
9:1	1	3000	0.089	4000	1.45
9:1	1.5	3000	0.089	4000	2.59
9:1	2	3000	0.089	4000	5.80
6:1	1	2930	0.063	3800	1.01
6:1	1.5	2930	0.063	3800	1.79
6:1	2	2930	0.063	3800	4.02
4:1	1	2890	0.0433	3700	0.68
4:1	1.5	2890	0.0433	3700	1.24
4:1	2	2890	0.0433	3700	2.72

SUMMARY OF TEST RESULTS

1. The following methods for creating a burn-through flame were developed:

- Holes placed in internal fuel manifold -
  Caused major damage to engine -
  Burn-through flame uncontrolled.

- Offset burner can from fuel nozzles -
  Caused major damage to engine -
  Burn-through flame controlled.

- Inserted water jacket in burner can -
  Little engine damage -
  Weak burn-through flame.

- Burner simulator -
  Little engine damage -
  Good controlled flame.

2. Burn-through time for 0.016-inch stainless steel 5 inches from a 1.5-inch hole and a pressure ratio of 9:1 was 2 seconds when the material was placed perpendicular to the flame. When at 30° to the flame the burn-through time increased to 6 seconds, and at 40° no burn-through occurred during a 60-second test.

3. The effects of the radius of curvature of a fire barrier on burn-through time was investigated. Using a 0.016-inch stainless steel the radius of curvature was varied from ∞ (flat) to 12 inches. The shortest times occurred for the ∞ and 12-inch radius at 3.2 seconds, and the longest at 24-inch radius, 6.6 seconds.

4. Burn-through centerline impingement pressures were measured for pressure ratios of 11:1, 9:1, 6:1, and 4:1, and hole sizes of 1, 1.5 and 2 inches. It was noted that a normal shock just downstream of the exit greatly reduced the centerline pressure. The higher the pressure ratio the greater the loss across the normal shock.

5. Burn-through centerline impingement temperatures were measured for pressure ratios of 11:1, 9:1, 6:1, and 4:1, and hole sizes of 1, 1.5, and 2 inches. Higher temperatures were noted further downstream as the pressure ratio or hole size was increased. Fuel-air mixture also had a great effect on flame temperature.

CONCLUSIONS

1. A simple burn-through simulator can be made utilizing jet engine compressor air.

2. If a burn-through impinges on a material at 40° angle or greater, the time for burn-through of the material is greatly increased.

3. The radius of curvature of a fire barrier does not greatly affect its burn-through rate.

4. The characteristics of a burn-through flame depends not only on the engine pressure ratio, but on hole size, and fuel-air ratio.

5. As the pressure ratio of a burn-through increases, the length of the flame peak temperature, exit velocity, exit mass flow rate, and exit density increase.

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