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THE INFLUENCE OF ENGINE-DUCTED BY-PASS AIR ON A BURNER-CAN BURN-THROUGH FLAME

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16. Abstract

Tests were run to determine the effect of by-pass air flow on a burner-can burn-through flame. A simulator was developed to produce a burn-through flame external of a J-57 engine. Bleed-air from a J-57 was ducted and used as by-pass air during testing. Temperatures of the outer duct wall were monitored. A large decrease in temperature was noted with air flow through the by-pass duct.

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INTRODUCTION

PURPOSE.

The purpose of this project was to determine the effects of ducted by-pass air on the temperature profile of a burn-through flame and on the ability of the flame to penetrate the inner and outer fan duct walls of a turbofan engine.

BACKGROUND.

Burner-can failures resulting in localized high-velocity flames penetrating the engine case have occurred in the past in both jet and fan jet engines. In some cases a burn-through flame has penetrated both the inner and outer fan duct wall, thus allowing the burn-through flame to impinge upon aircraft structure.

Further information regarding the cause, the occurrence, and the severity of burn-through is provided in references 1 and 2.

DESCRIPTION OF TEST ARTICLE AND EQUIPMENT.

Two Pratt and Whitney J-57/P-37 turbojet engines mounted on a B-57 aircraft (figure 1) were used to produce the burn-through flame and the by-pass air for all tests. The engines were remotely controlled from a blockhouse located approximately 100 feet from the aircraft. The right J-57 engine was modified with an external burner-can burn-through simulator (figures 2 and 3).

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 the blockhouse and were used to supply fuel to the external burner can. Airflow for the external can was supplied by a 12-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 12-inch diameter inlet and a 14-inch diameter outlet, which was blocked by a one-half-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 ignitor 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. A 1 1/2-inch diameter burn-through hole was used during all the tests.

The left J-57 engine was used to supply by-pass air for the simulated fan duct (figure 4). Bleed air was taken off four bleed ports aft of the final stage of the compressor and ducted across to the simulated fan duct section. By-pass air pressure and velocity was measured 3 feet upstream of the burn-through hole (figure 2). A total pressure probe and a static pressure probe were connected to a mecury monometer and true airspeed indicator. Inlet

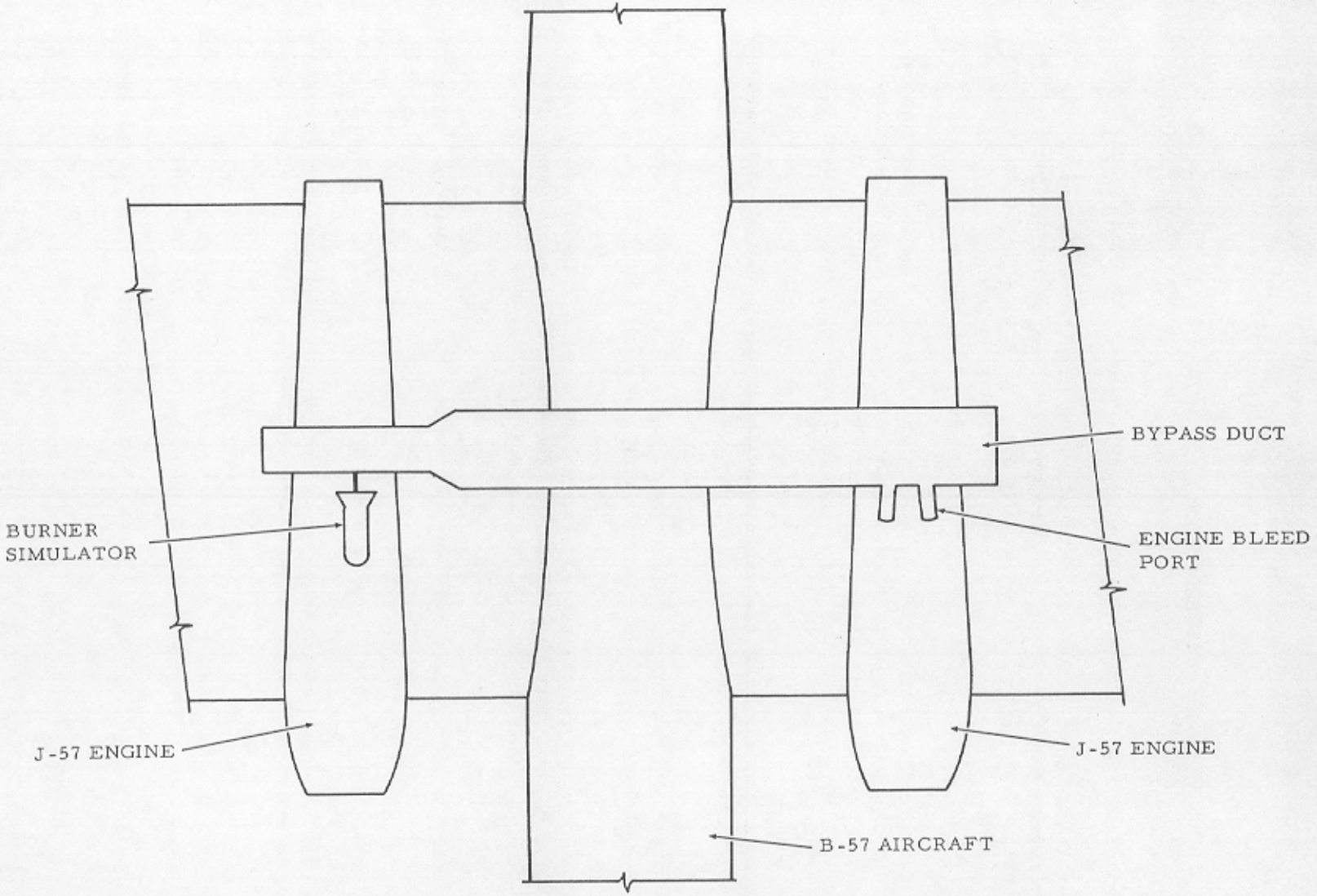


FIGURE 1. BURN-THROUGH TEST SETUP

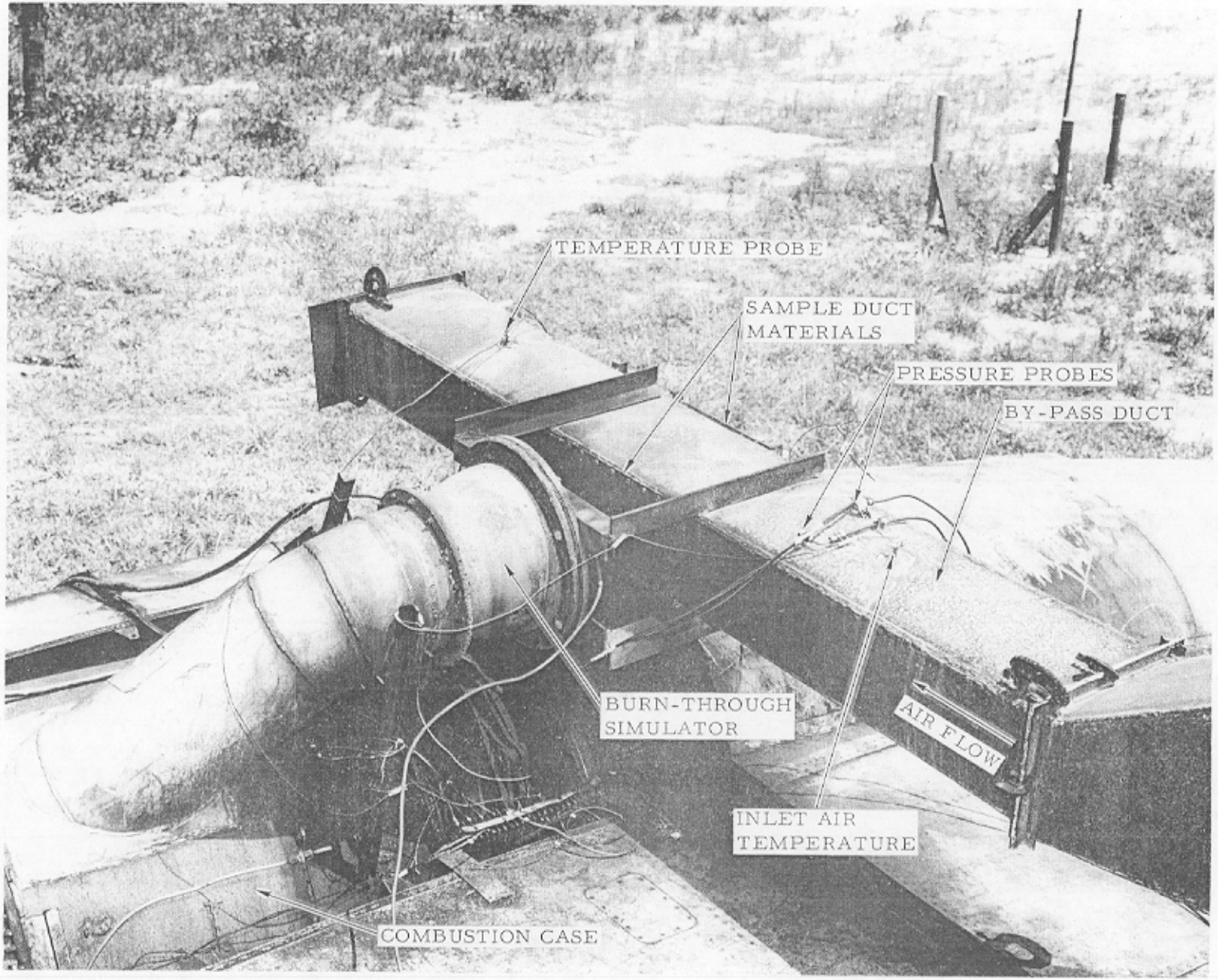


FIGURE 2. BURN-THROUGH SIMULATOR AND BY-PASS DUCT (INBOARD SIDE)

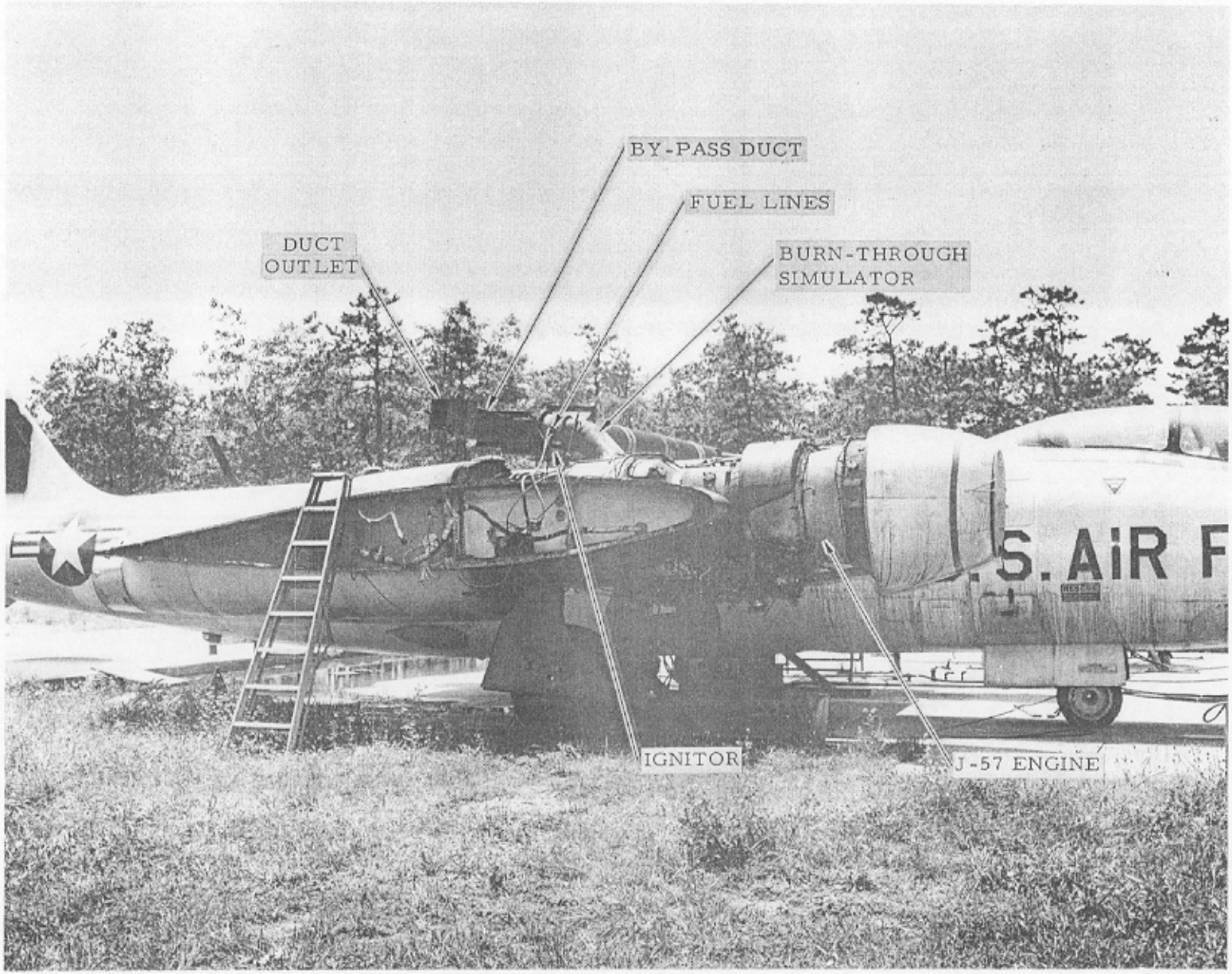


FIGURE 3. BURN-THROUGH SIMULATOR AND BY-PASS DUCT (OUTBOARD SIDE)

FIGURE 4. BY-PASS AIR DUCTING FROM J-57 ENGINE

by-pass air temperature was also monitored using a Chromel-Alumel total temperature probe located 3 feet upstream of the burn through. By-pass duct air outlet temperature was also monitored by a Chromel-Alumel thermocouple in the airstream of the outlet of the simulated by-pass duct. The simulated by-pass duct was constructed such that an 8 by 12-inch panel could be bolted to the inner and outer walls of the duct in the area of the burn through and be used as sample duct material during the tests. The inner wall was located 8 inches from the burn-through hole and, from the outer wall, 20 inches.

In the final test a one-half-inch thick steel plate, 8 by 20 inches, was welded into place as the outer duct wall. Eight Chromel-Alumel thermocouples and two platinum/rhodium thermocouples were used to measure the burn-through flame temperature impinging on the outer duct wall with various by-pass airflows (figure 5). All temperatures were monitored and recorded on a strip chart recorder in the control room.

DISCUSSION

STANDARD MATERIAL TESTS.

In order to determine the effect of by-pass airflow on the destructiveness of the burn-through flame, a series of tests was performed using 0.022 stainless steel (Type-321) as the inner and outer duct wall material. The results of the tests can be seen in table 1:

TABLE 1. TEST RESULTS USING 0.022 STAINLESS STEEL WITH AN 11:1 PRESSURE RATIO BURN-THROUGH FLAME

By-Pass Airflow (Knots)	Inner Duct Result	Outer Duct Result
0	Burn Through 2 sec.	Burn Through 3.6 sec.
150	Burn Through 2 sec.	No Burn Through 270 sec.
120	Burn Through 2 sec.	No Burn Through 270 sec.
90	Burn Through 2 sec.	No Burn Through 270 sec.

As can be seen from table 1, there was no apparent effect on the burn-through rate of the inner duct wall from the by-pass air. The burn-through rate on the outer duct wall, however, was drastically affected by the by-pass air. As little as a 90-knot airflow protected the sample from burn through (figure 6).

A second series of tests was run using 0.063 aluminum (Type-6061-T4) as the outer duct wall. Results of that series of tests can be seen in table 2.

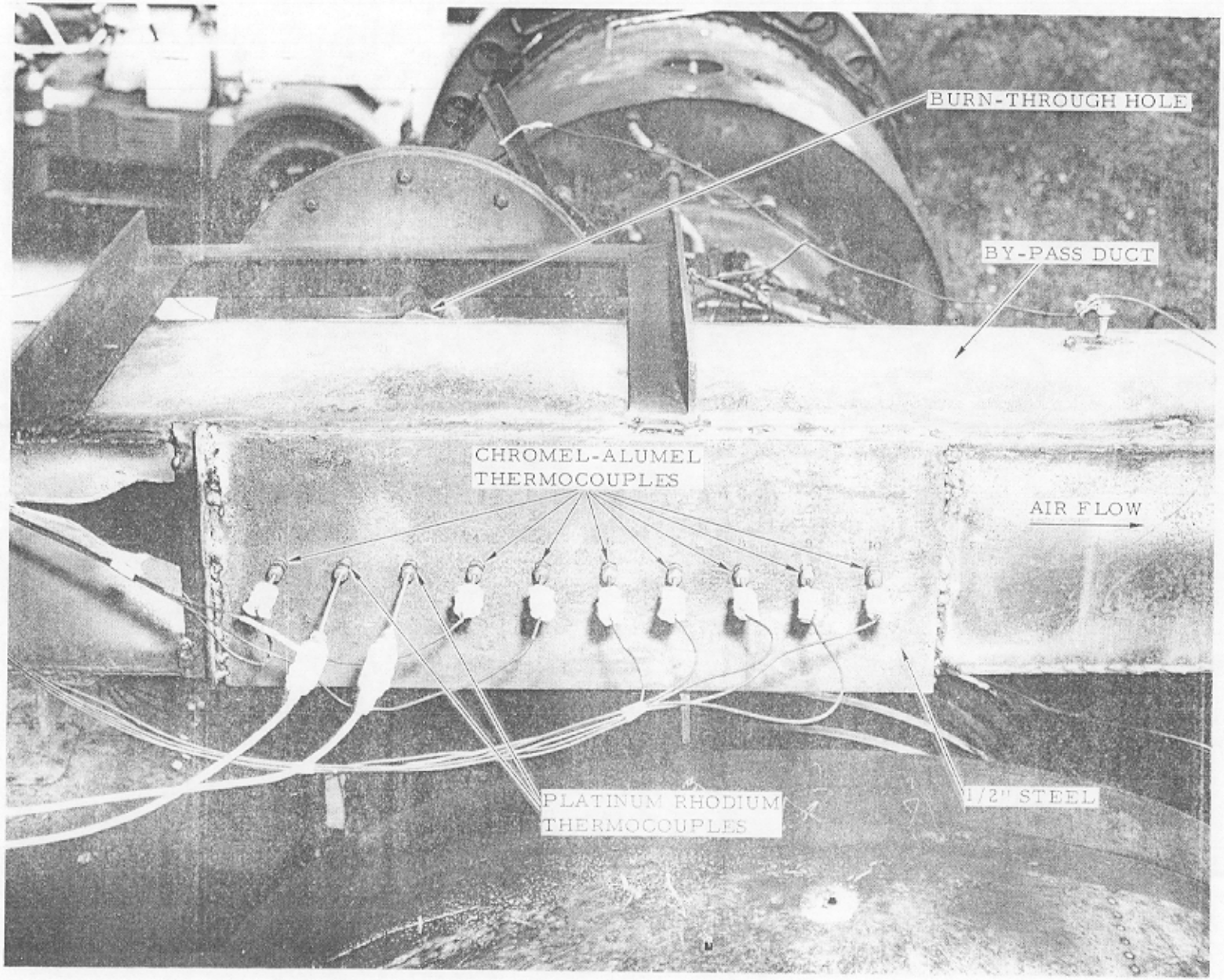
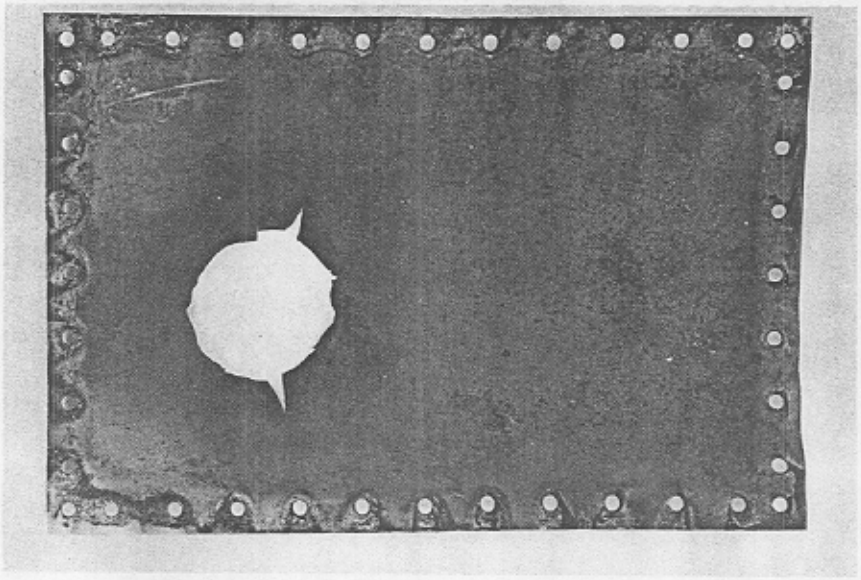
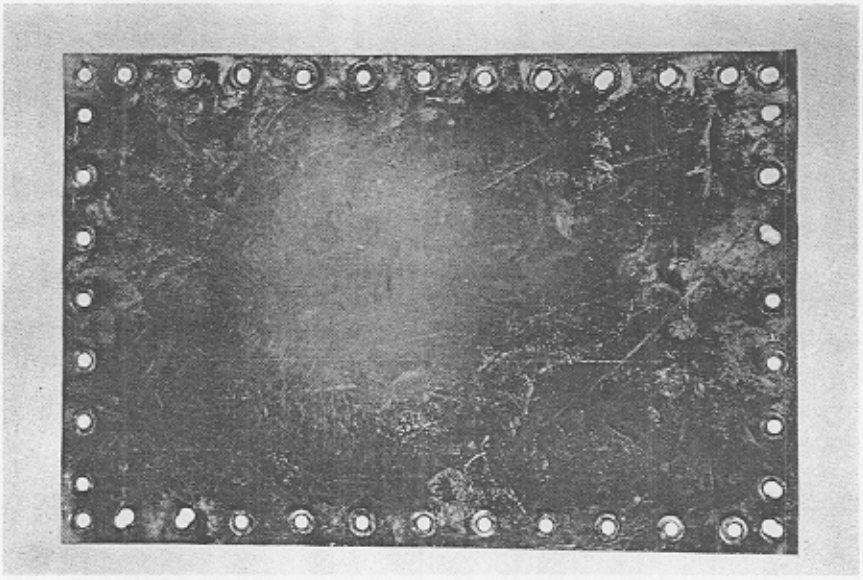


FIGURE 5. PLATE FOR MEASURING TEMPERATURE PROFILE



(a) BURN-THROUGH PRESSURE RATIO-11:1
BY-PASS AIR FLOW - ZERO KNOTS
TEST DURATION - 3.6 SECONDS



(b) BURN-THROUGH PRESSURE RATIO-11:1
BY-PASS AIR FLOW - 90 KNOTS
TEST DURATION - 3 MINUTES

FIGURE 6. OUTER DUCT WALL STAINLESS STEEL SAMPLES AFTER 11:1 PRESSURE RATIO TEST

TABLE 2. TEST RESULTS USING 0.063 ALUMINUM WITH AN 11:1 PRESSURE RATIO BURN-THROUGH FLAME

By-Pass Airflow (Knots)	Results
0	Burn Through 1 sec.
150	No Burn Through 300 sec.
150	No Burn Through 300 sec.
100	No Burn Through 300 sec.

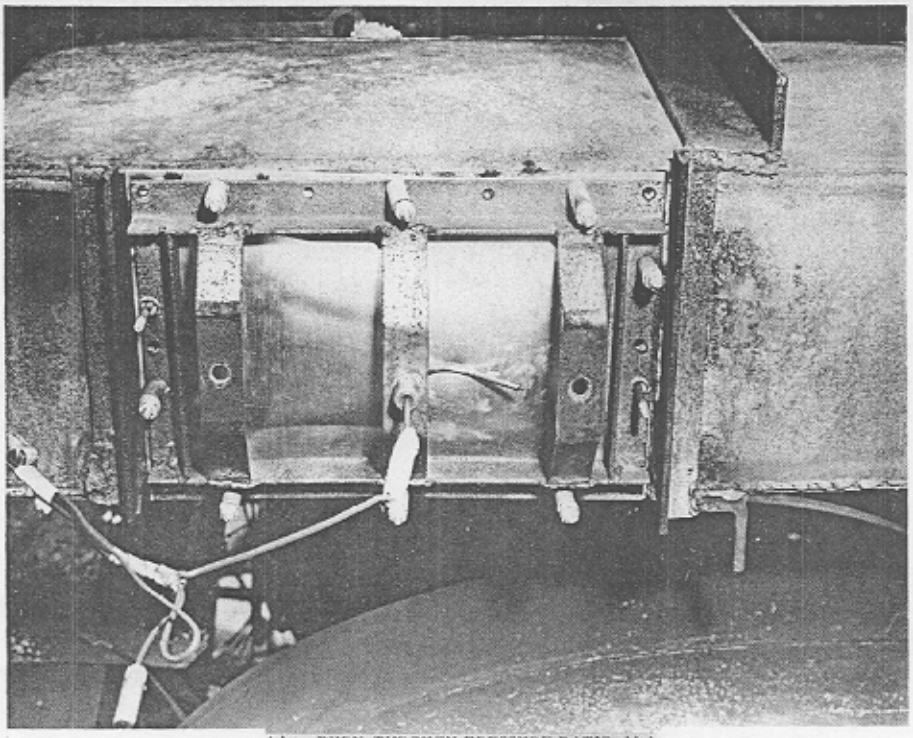
At the completion of each of the tests, using by-pass air, and the aluminum test sample, the sample was bent out considerably but no penetration occurred (figure 7).

ACOUSTIC MATERIAL TESTS.

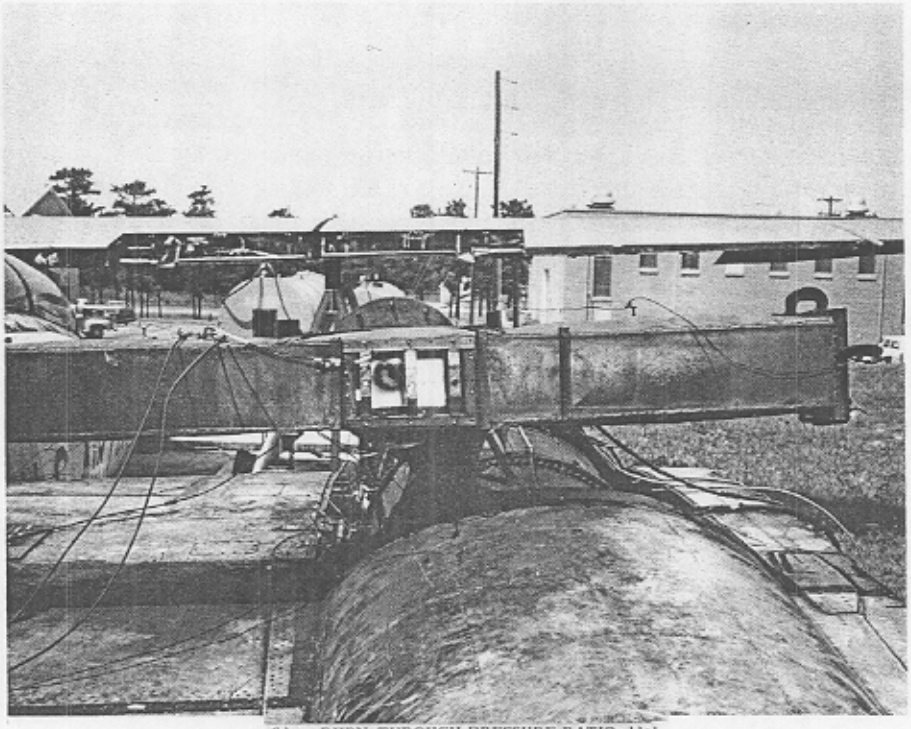
Four composite material designs for use as by-pass ducts for reducing jet engine noise were tested as outer duct wall material using the 12-inch by-pass duct 8 inches from the burn-through hole (figure 8). The materials were 1-inch thick composite of polyimide, aluminum, and combination of polyimide and aluminum. The first three tests were run using a burn-through pressure ratio of 11:1 and by-pass airflow of 150 knots. Burn-through times ranged from 5.8 to 28.6 seconds. The fourth test was run using a burner pressure ratio of 5:1 and by-pass airflow of 150 knots. At those conditions, the temperature of the air impinging on the outer wall was approximately 1,000°F. During that test the material lasted 6 minutes 13 seconds before burning through. Refer to table 3.

TABLE 3. TESTS USING POLYIMIDE ALUMINUM

Material (Refer to Fig.8)	Burn-Through Pressure	By-Pass Airflow (Knots)	Burn-Through Time	Results of Tests Shown in Figures
8-A	11:1	150	19.7 sec.	Figure 9
8-C	11:1	150	5.8 sec.	Figure 10
8-D	11:1	150	28.6 sec.	Figure 11
8-B	5:1	150	6 min. 13 sec.	Figure 12

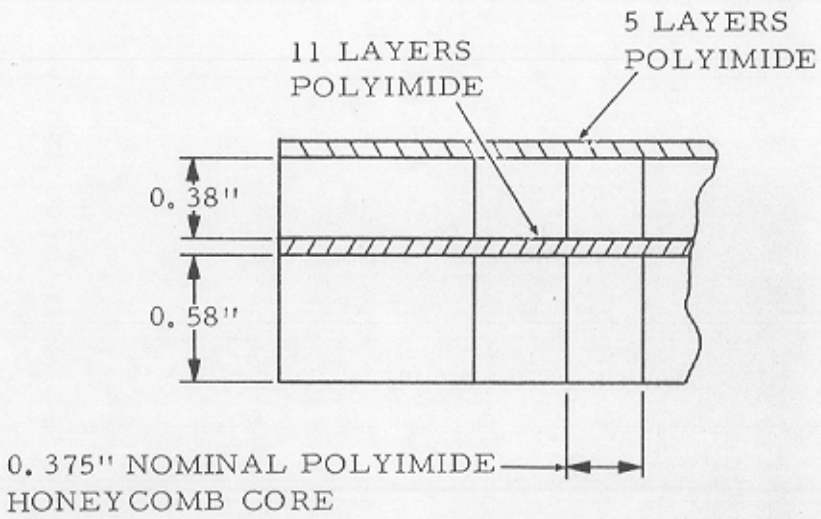


(a) BURN-THROUGH PRESSURE RATIO-11:1
BY-PASS AIR FLOW - 150 KNOTS
TEST DURATION - 6 MINUTES

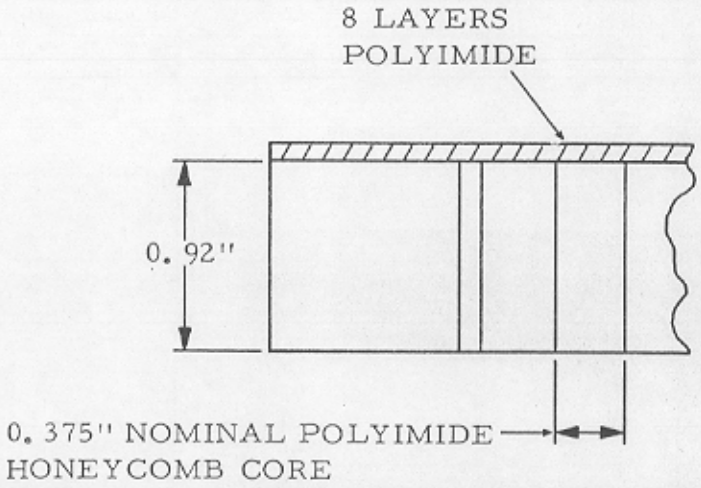


(b) BURN-THROUGH PRESSURE RATIO-11:1
BY-PASS AIR FLOW - ZERO KNOTS
TEST DURATION - ≈1 SECOND

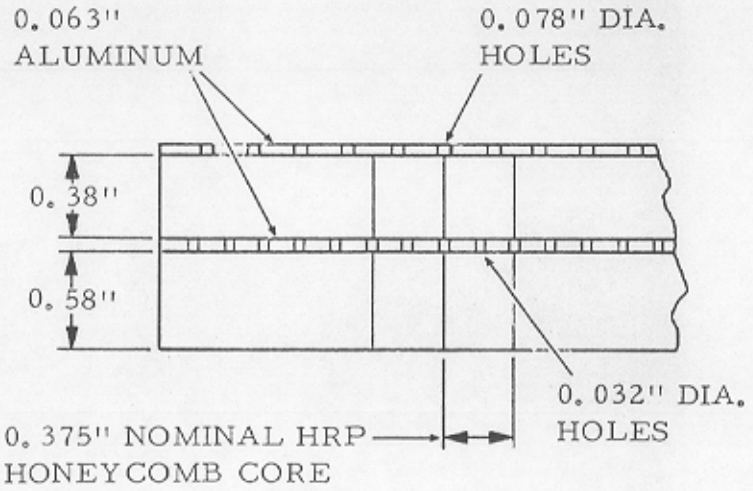
FIGURE 7. OUTER DUCT WALL ALUMINUM SAMPLES AFTER 11:1 PRESSURE RATIO TEST



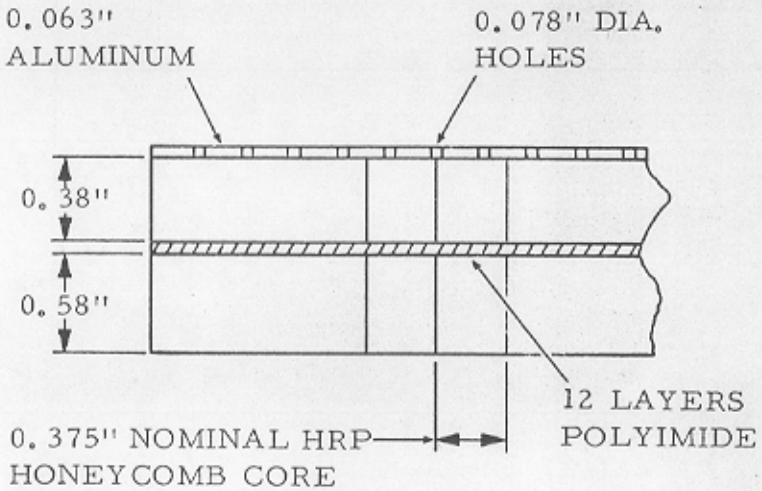
(a)



(b)

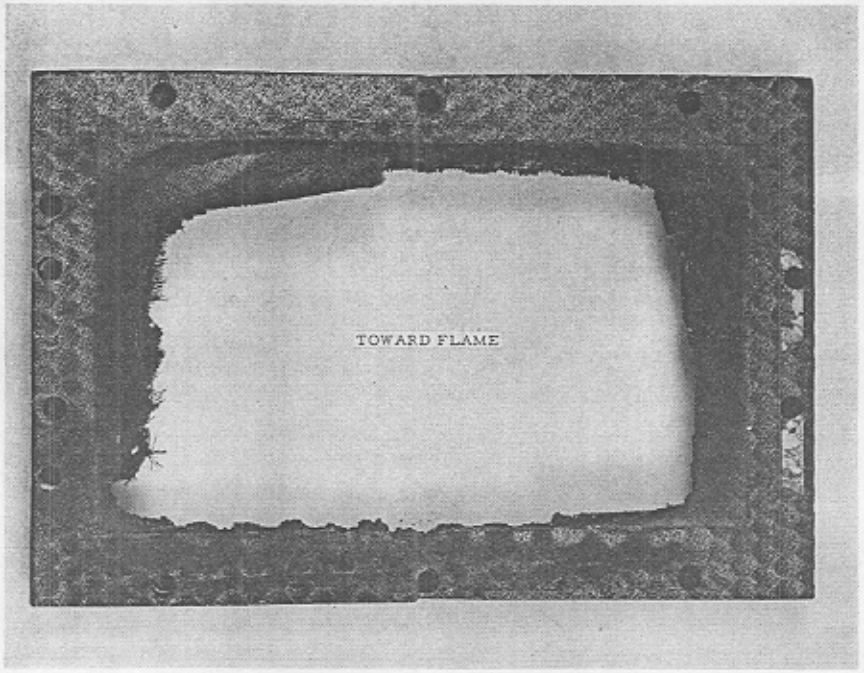


(c)

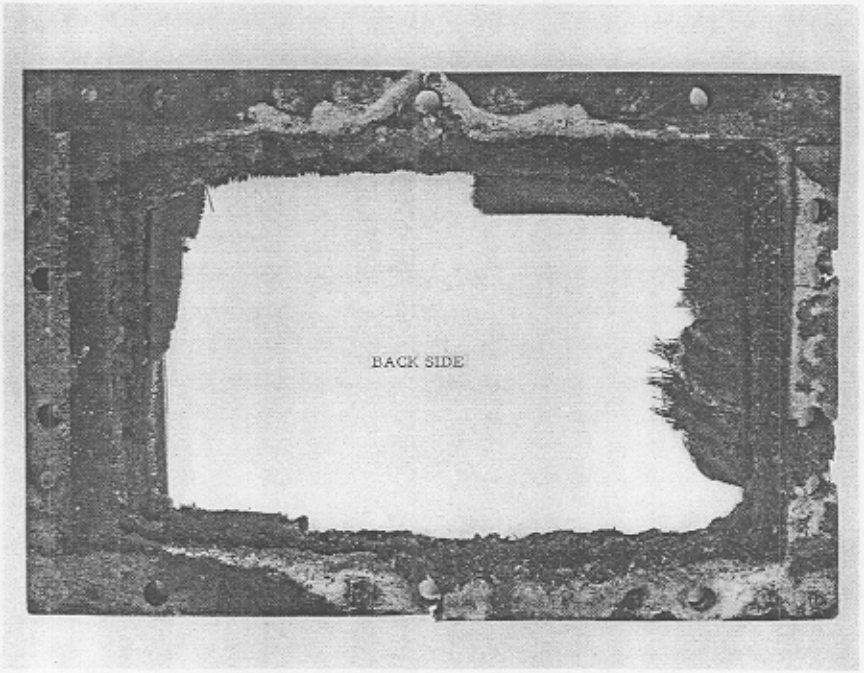


(d)

FIGURE 8. BY-PASS DUCT ACOUSTIC MATERIAL

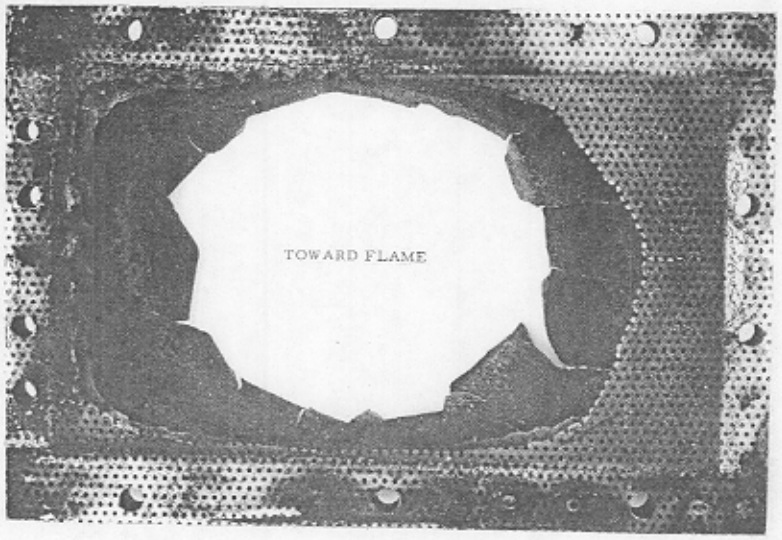


(a) BURN-THROUGH PRESSURE RATIO - 11:1
BY-PASS AIR FLOW - 150 KNOTS
TEST DURATION - 19.7 SECONDS

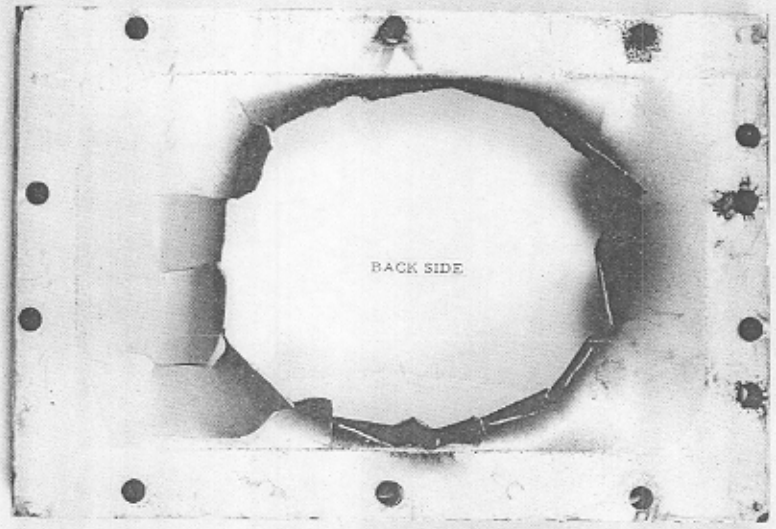


(b) BURN-THROUGH PRESSURE RATIO - 11:1
BY-PASS AIR FLOW - 150 KNOTS
TEST DURATION - 19.7 SECONDS

FIGURE 9. ACOUSTIC DUCT MATERIAL (8A) AFTER BURN-THROUGH TEST

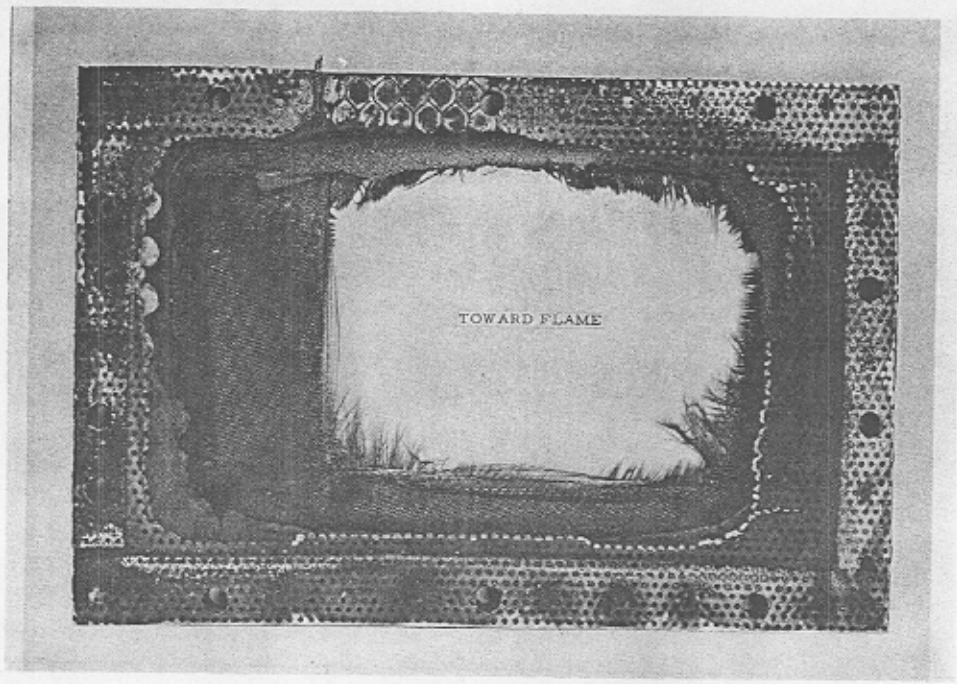


(a) BURN-THROUGH PRESSURE RATIO - 11:1
BY-PASS AIR FLOW - 150 KNOTS
DURATION OF TEST - 5.8 SECONDS

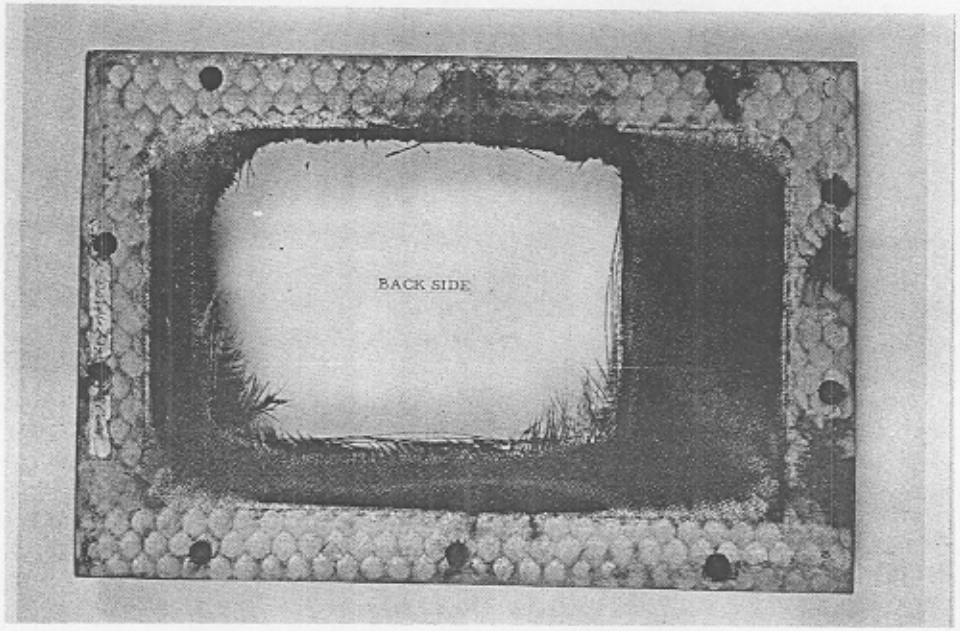


(b) BURN-THROUGH PRESSURE RATIO - 11:1
BY-PASS AIR FLOW - 150 KNOTS
DURATION OF TEST - 5.8 SECONDS

FIGURE 10. ACOUSTIC DUCT MATERIAL (8G) AFTER BURN-THROUGH TEST

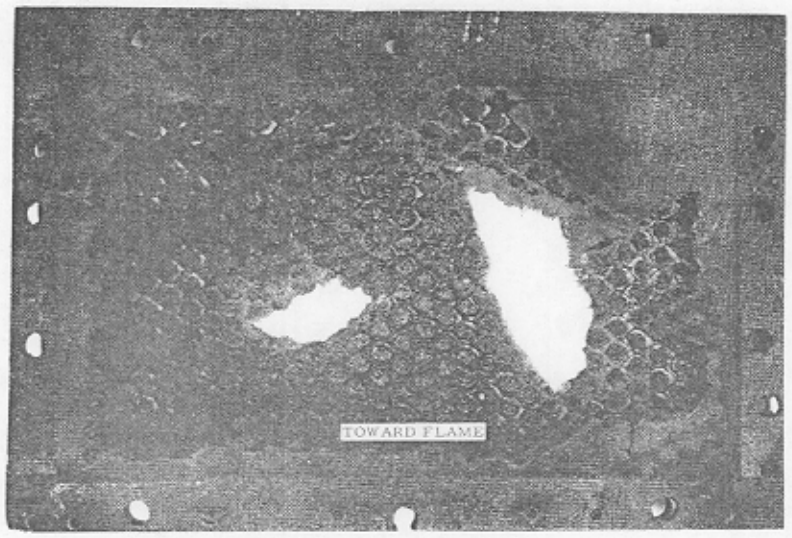


(a) BURN-THROUGH PRESSURE RATIO - 11:1
BY-PASS AIR FLOW - 150 KNOTS
TEST DURATION - 28.6 SECONDS

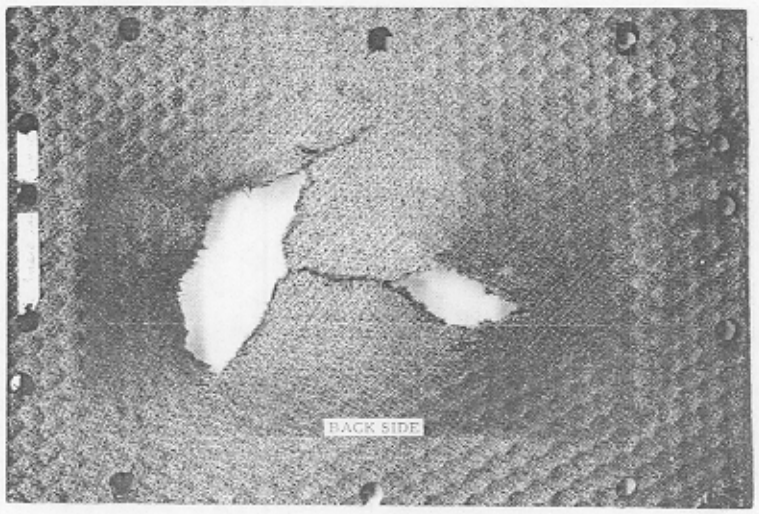


(b) BURN-THROUGH PRESSURE RATIO - 11:1
BY-PASS AIR FLOW - 150 KNOTS
TEST DURATION - 28.6 SECONDS

FIGURE 11. ACOUSTIC DUCT MATERIAL (8D) AFTER BURN-THROUGH TEST



(a) BURN-THROUGH PRESSURE RATIO - 5:1
BY-PASS AIR FLOW - 150 KNOTS
TEST DURATION - 6 MINUTES - 13 SECONDS



(b) BURN-THROUGH PRESSURE RATIO - 5:1
BY-PASS AIR FLOW - 150 KNOTS
TEST DURATION - 6 MINUTES - 13 SECONDS

FIGURE 12. ACOUSTIC DUCT MATERIAL (8B) AFTER BURN-THROUGH TEST

TEMPERATURE PROFILE TESTS.

In the final test the temperature distribution along the horizontal centerline of the outer fan duct wall was measured for burn-through flame pressure ratios of 11:1, 9:1 and 6:1. The results of these tests are shown in figures 13, 14, and 15. A rather large drop in the burn-through flame temperature occurred with airflow in the duct. The higher the rate of airflow the lower the peak temperature. Also the higher the rate of airflow the further downstream the burn-through flame was bent.

It should be noted that in this test, as in all previous by-pass air tests, the inlet air was of a much higher temperature than normal fan air due to its source. Table 4 gives inlet air temperatures for various airflow conditions:

TABLE 4. INLET AIR TEMPERATURES

By-Pass Airflow (Knots)	Inlet Air Temperature (°F)
90	240
120	330
150	430

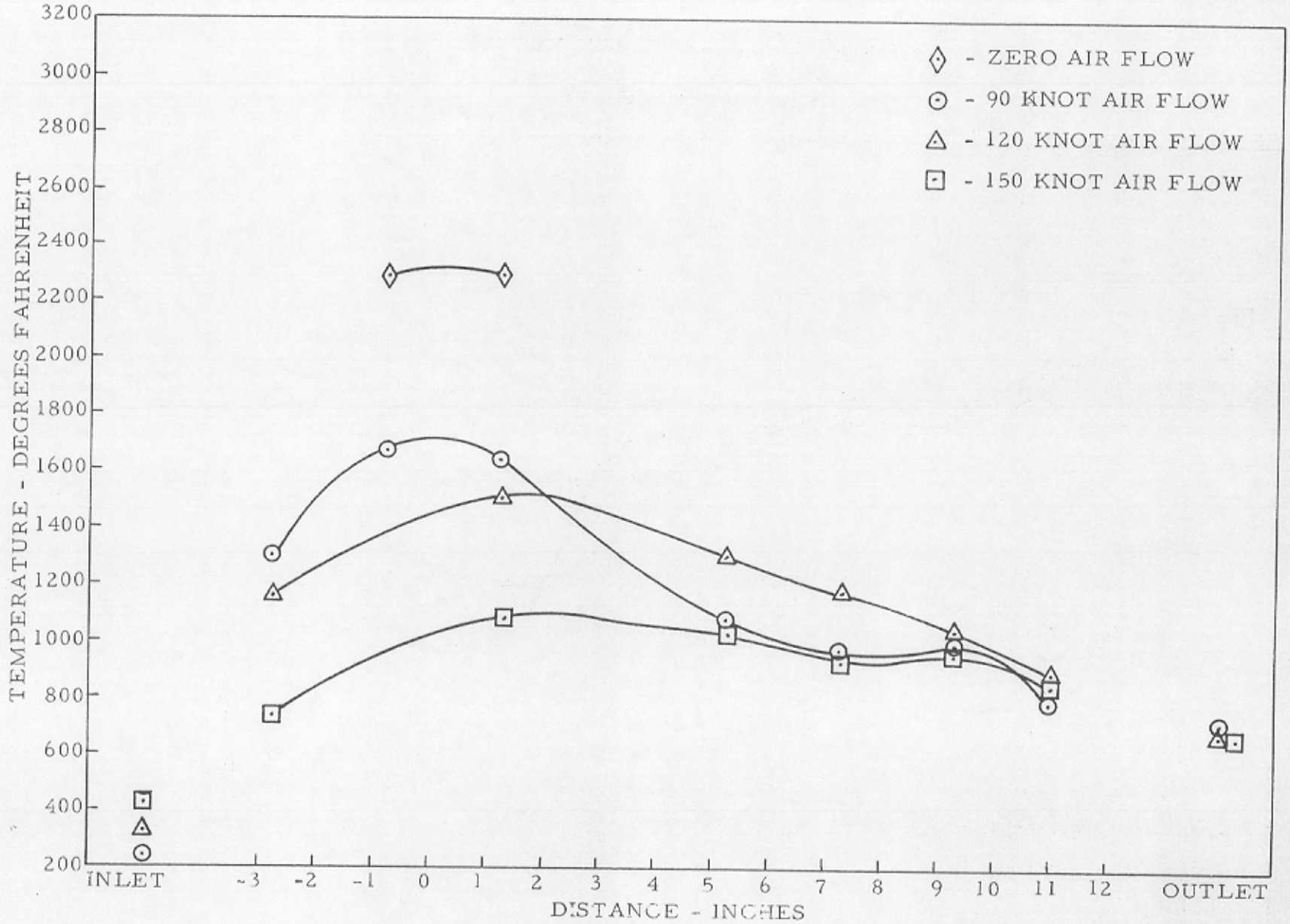


FIGURE 13. OUTER DUCT IMPINGEMENT PROFILE FOR 6:1 PRESSURE RATIO BURN-THROUGH FLAME

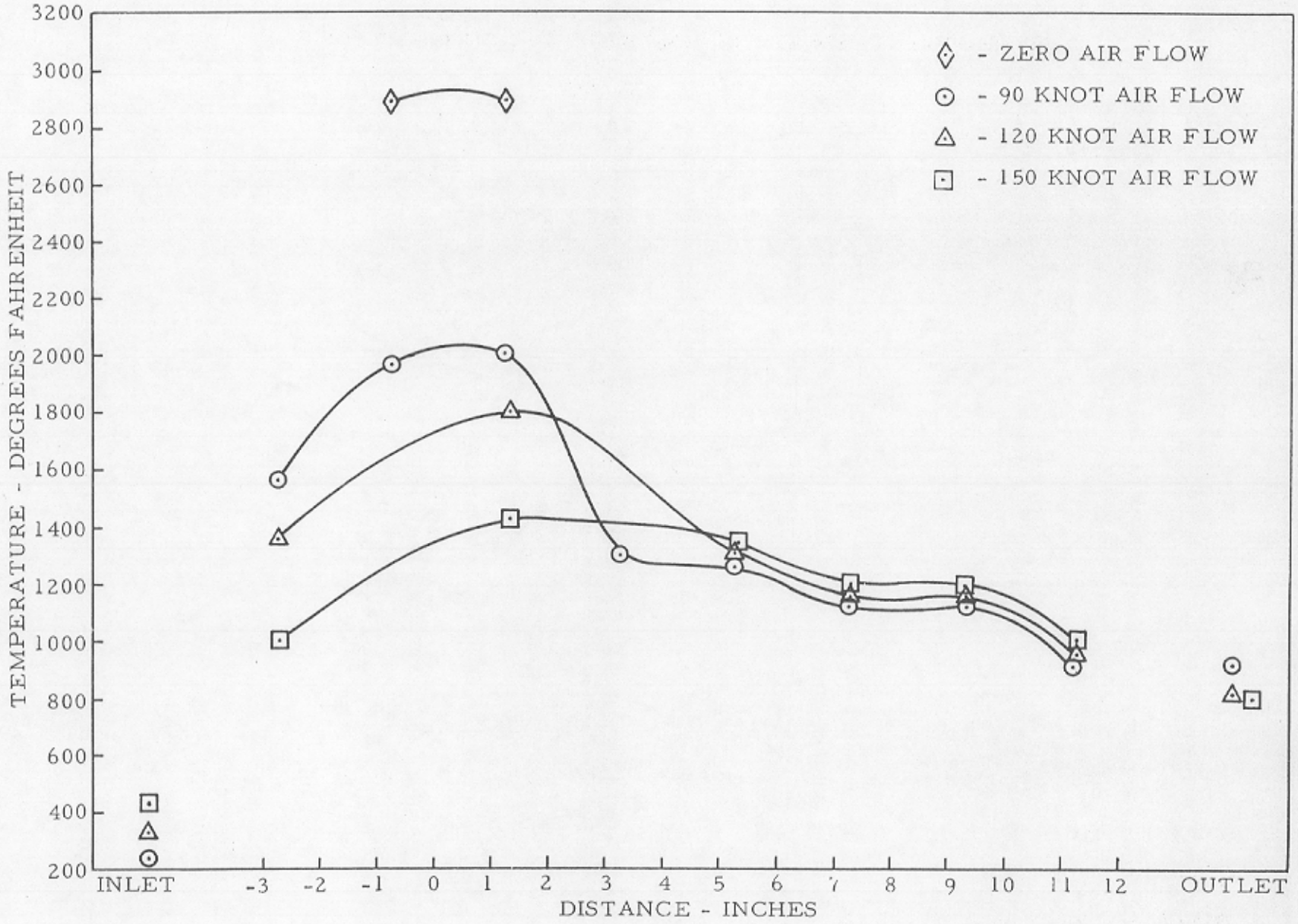


FIGURE 14. OUTER DUCT IMPINGEMENT PROFILE FOR 9:1 PRESSURE RATIO BURN-THROUGH FLAME

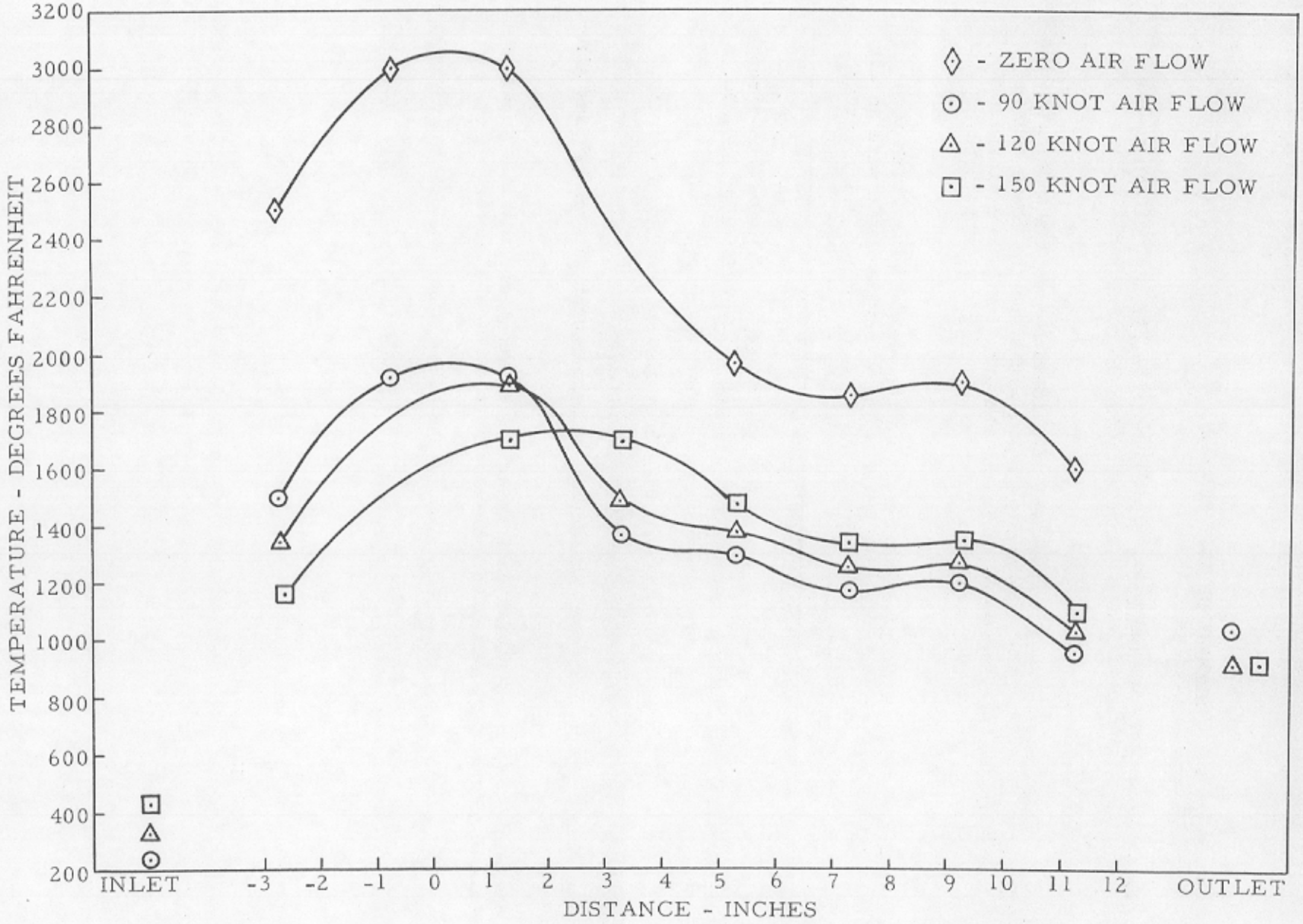


FIGURE 15. OUTER DUCT IMPINGEMENT PROFILE FOR 11:1 PRESSURE RATIO BURN-THROUGH FLAME

SUMMARY OF TEST RESULTS

1. By-pass airflow up to 150 knots had very little, if any, effect on the burn-through rate of the inner duct wall of a fan duct located 8 inches from the burn-through hole.

2. The 0.022 stainless steel outer wall of a 12-inch wide fan duct, with the duct located 8 inches from a burn-through hole, withstood the flame from a burn through with an 11:1 pressure ratio for the duration of a 3-minute test, with an airflow as low as 90 knots, and with a zero airflow burn-through time of 3.6 seconds.

3. An 0.063 aluminum (6061-T4) outer wall on the same fan duct withstood the 11:1 pressure ratio flame for the duration of a 3-minute test with an airflow of 100 knots and 6 minutes at 150 knots. With no airflow, burn-through time was approximately 1 second.

4. Results of temperature profile tests were graphed and show the temperature distribution along the inside of the outer fan duct wall for burn-through pressure ratios of 11:1, 9:1, and 6:1 and by-pass airflows of 150, 120, 90, and zero knots.

5. The peak temperature impinging on the outer fan duct wall was greatly reduced by by-pass airflow.

6. The burn-through flame was deflected, to some extent, by the by-pass airflow.

7. Tests on acoustic-type fan duct materials showed their inablity to withstand the burn-through flame with a by-pass airflow of 150 knots.

CONCLUSIONS

Based on the results of the tests conducted, it is concluded that:

1. The burn-through rate of an inner duct wall is not affected to a great extent by the by-pass airflow in the duct.

2. The burn-through time of the outer duct wall is greatly increased, or burn through is eliminated, by airflow in the fan duct.

3. The higher the airflow in the by-pass duct the greater the deflection of the burn-through flame and the lower the peak temperatures.

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2. Rust, T., Investigation of Jet Engine Combustion Chamber Burn-Through Fire, Final Report, Report No. FAA-RD-70-68, March 1971.