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THE FEASIBILITY OF DETECTING A BURNER-CAN BURN-THROUGH BY MEANS OF CO, CO_2, PRESSURE, AND AIR TEMPERATURE LEVELS IN A JET ENGINE NACELLE

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FINAL REPORT

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16. Abstract

Full-scale tests simulating engine combustion section thermal failure (burn-through) were conducted using a cowled J-57 engine to determine the feasibility of detecting a burn-through by monitoring the carbon monoxide (CO), carbon dioxide (CO_2), a pressure level, or air temperature in the nacelle before, during, and after engine case rupture. Results of the tests indicated that CO, CO_2, pressure, and air temperature in the nacelle cannot be relied upon for early detection of a burn-through. Test results also indicated that containment of a burn-through flame in the nacelle creates extremely high temperatures in the nacelle and can cause extensive structural damage.

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INTRODUCTION

PURPOSE.

The purpose of this activity was to determine the feasibility of reliably detecting a burner-can burn-through by monitoring: (1) the concentrations of carbon monoxide (CO) or carbon dioxide (CO_2) in the engine nacelle; (2) the air pressure in the engine nacelle, and (3) the air temperature in the nacelle.

BACKGROUND.

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

In the past, several burn-throughs have gone undetected until a walkaround inspection was performed and holes in the cowling were found.

Due to the severity of a burn-through flame, quick and reliable detection is necessary to keep damage to a minimum.

Further information regarding the occurrence and severity of a burn-through condition is provided in a report entitled, Investigation of Jet Engine Combustion Chamber Burn-Through Fire, T. Rust, Final Report, No. FAA-RD-70-68, March 1971.

DISCUSSION

PROCEDURE.

All tests were performed using a J-57 engine mounted in the nacelle of a B-57 aircraft (see figure 1). A repeatable burn-through was developed by cutting a hole in the burner-can section of the engine and No. 8 burner-can liner as shown in figure 2. A water-jacketed burn-through orifice (figure 3) was then developed and welded into the opening. The standard size burn-through hole used was 1 1/2 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.

To keep cowling damage to a minimum, an 8-X 8-inch section, over the burn-through hole, was removed and a tapped metal frame was installed. This allowed easy installation and removal of 8-X 8-inch plates of aluminum, titanium, and stainless steel of various thicknesses representing different types of cowling material.

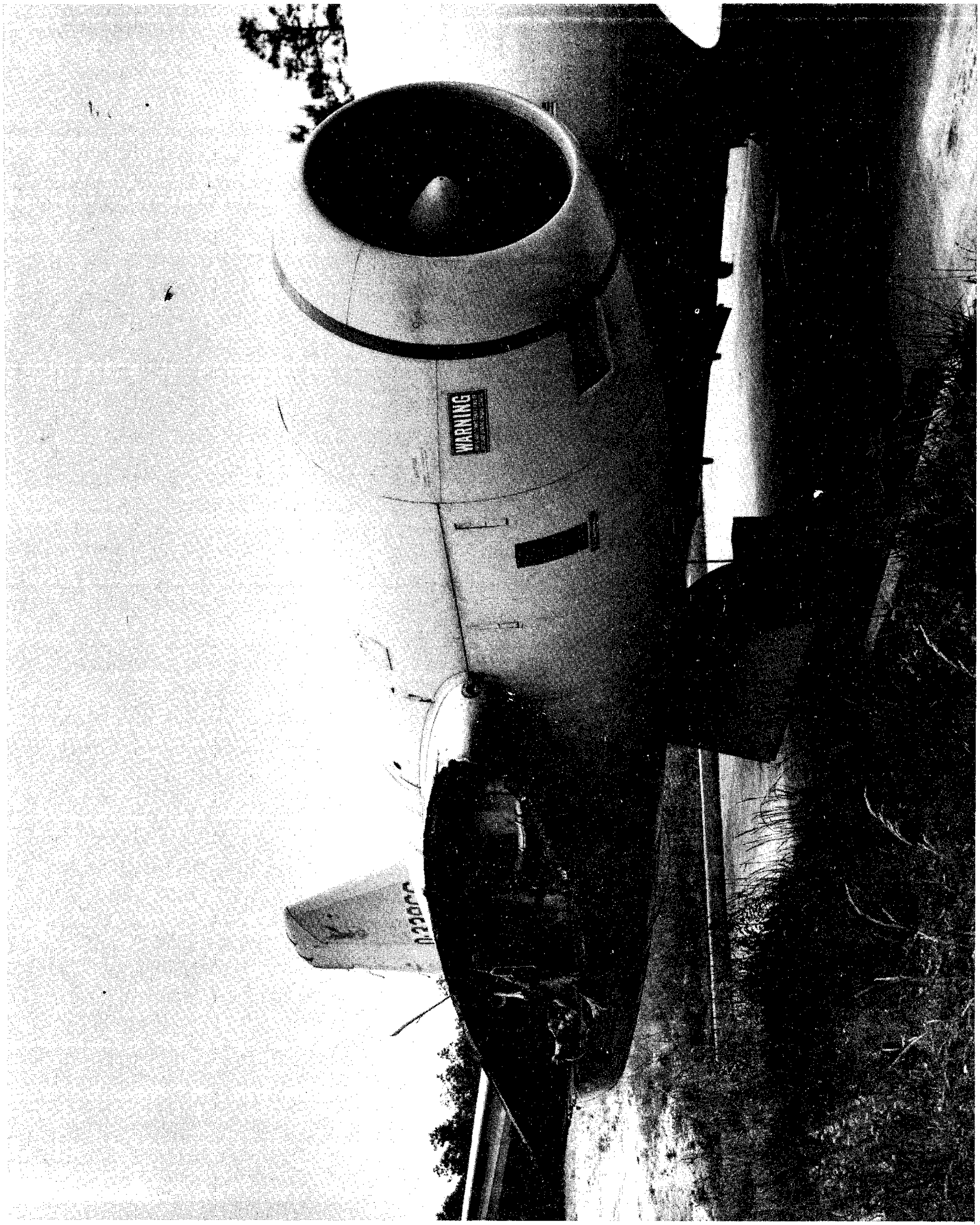

FIGURE 1. J-57 TEST ENGINE AND NACELLE

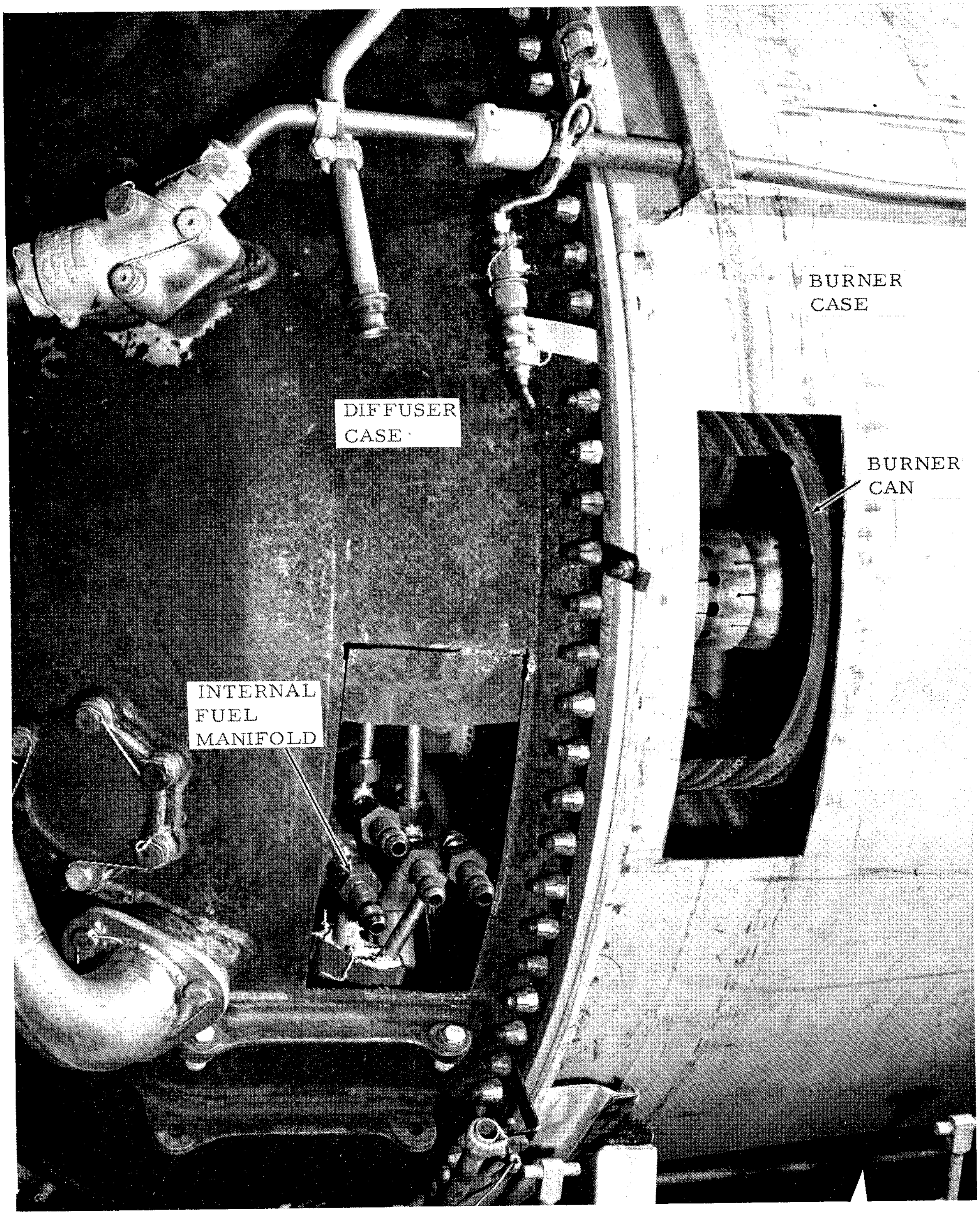

FIGURE 2. TEST ENGINE MODIFICATIONS

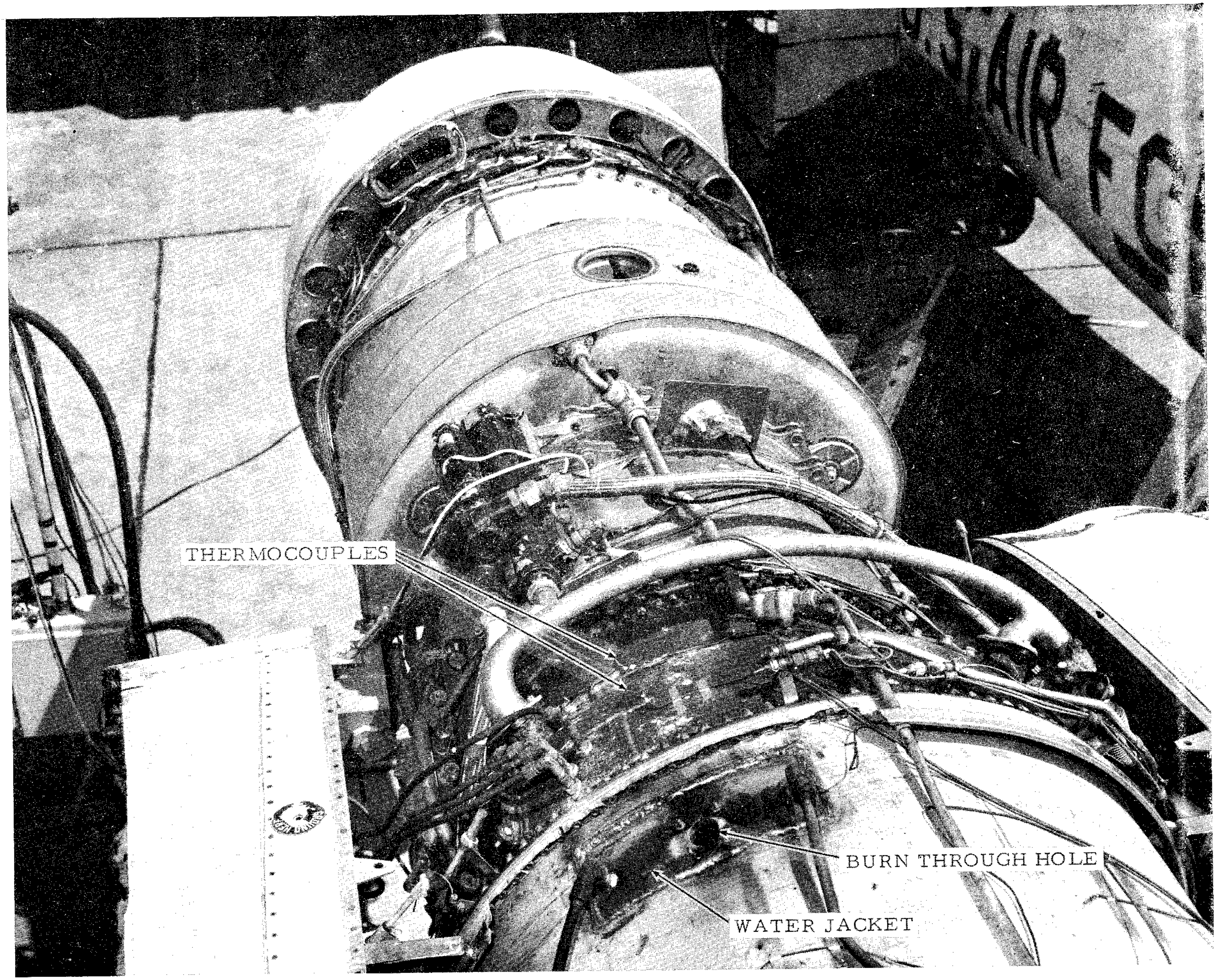

FIGURE 3. J-57 ENGINE WITH WATER-JACKETED BURN-THROUGH HOLE

A 2-X 2-inch, 1/8-inch thick aluminum plate was then bolted over the burn-through hole, thus sealing the engine prior to burn-through. The engine was run up to the desired power, fuel was turned on to the No. 8 burner-can, the aluminum plate was weakened and blown away, and the burn-through flame impinged on the cowling.

During the ongoing tests, a reverse airflow in the nacelle was present, due to its design (see figure 4). At low airspeeds, air is drawn into the nacelle through various openings by the compressor to help cool the engine.

Tests were run using 0.50-inch aluminum, 0.032-inch titanium, and 0.016-inch stainless steel as cowling material and the following parameters were measured:

1. Carbon monoxide was sampled at points on the outboard nacelle firewall, forward and aft of the firewall separating the diffuser case and the burner section, at the 9 o'clock position (figure 5). The gas was analyzed by a Lira Model 300 infrared analyzer with a range of zero to 1.5 percent.

2. Carbon dioxide was sampled at points adjacent to the CO lines (figure 5). The gas was analyzed by a Lira Model 300 infrared analyzer with a range of zero to 10 percent.

3. Two pressure transducers, one with a range of zero to 5 pound-force per square inch (lbf/in^2) differential and the other zero to .1 lbf/in^2 differential were located on the outboard firewall just aft of the difuser case, at the 9 o'clock position (figure 5).

4. Ten No. 36 chromel-alumel thermocouples were used to measure the air in the engine nacelle. The location of the thermocouples is shown in figures 5 and 6.

A final test was run in which only temperatures of the nacelle airstream were monitored. This test utilized as cowling material a composite of titanium and stainless steel 1/4-inch thick. Thermocouple locations were the same as those in the previous tests.

All test results were recorded on strip chart recorders located in the control room. A video record of ongoing tests was kept.

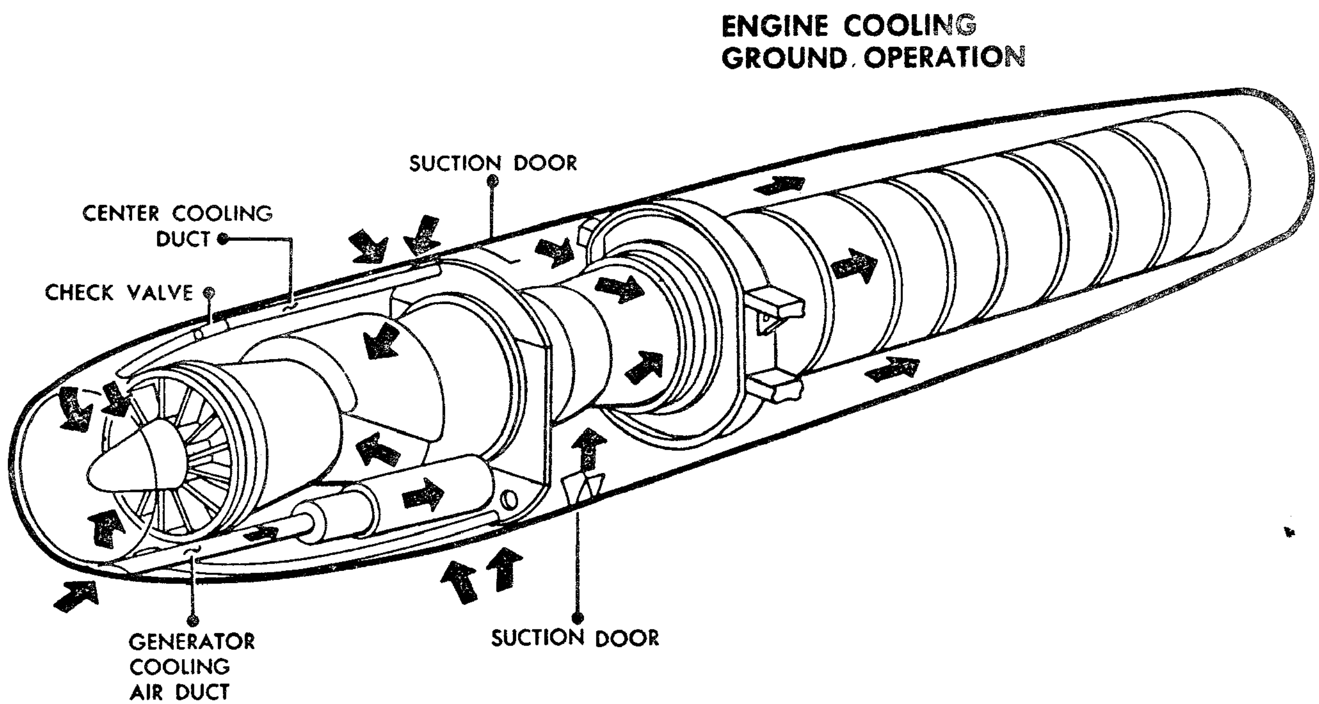

FIGURE 4. COOLING AIRFLOW FOR J-57 TEST ENGINE AND NACELLE

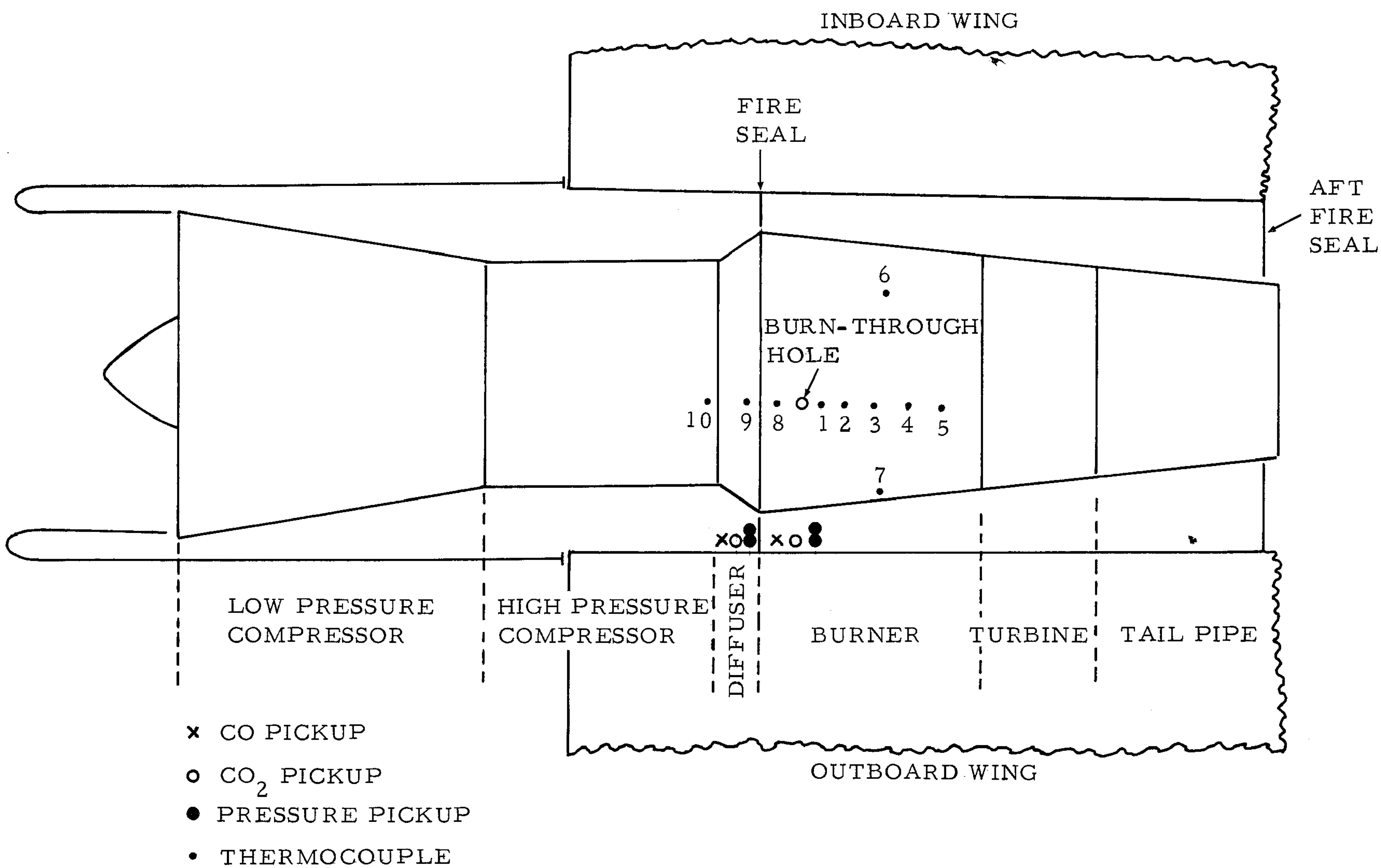

FIGURE 5. LOCATION OF TEST PROBE IN NACELLE

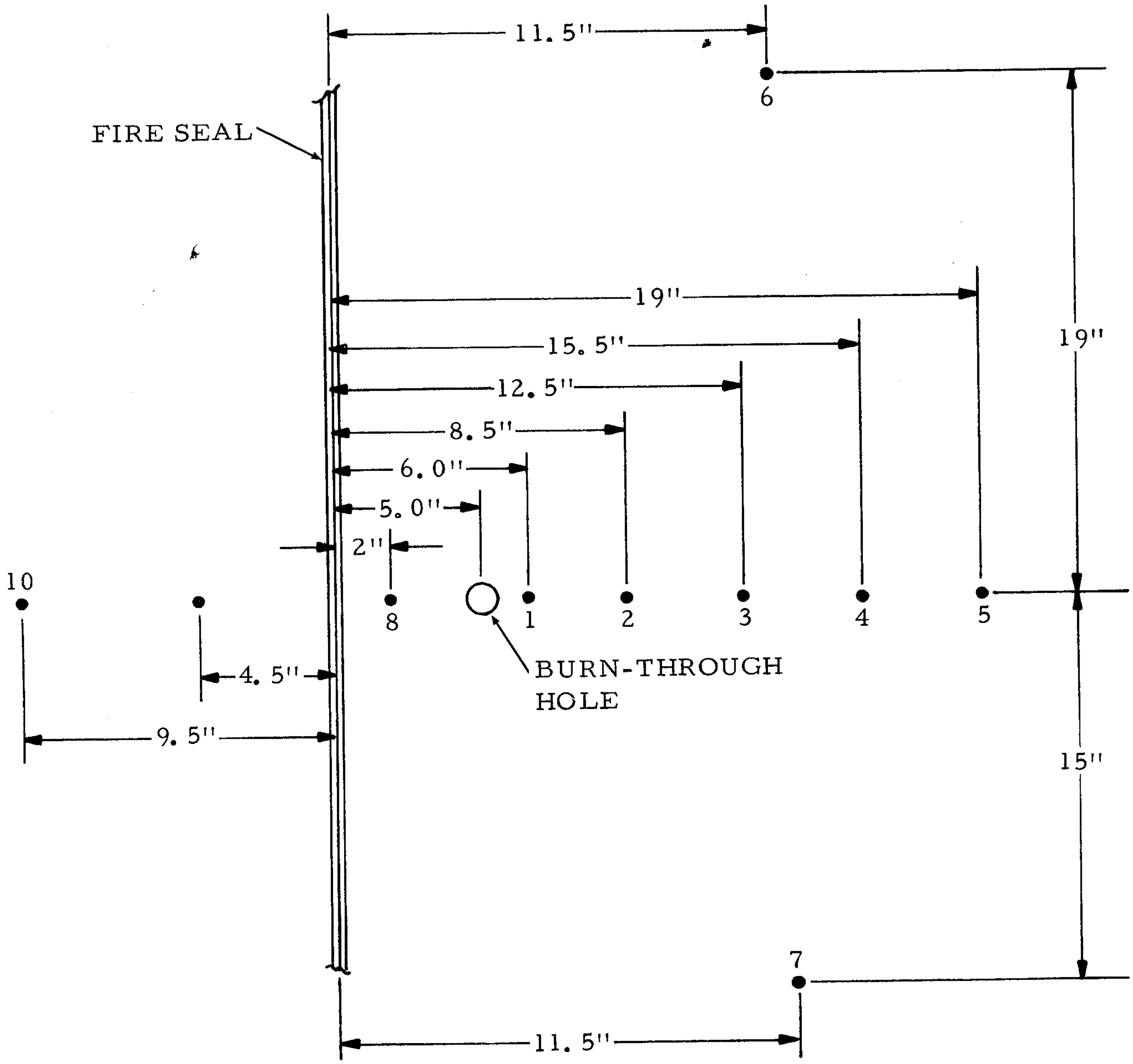

FIGURE 6. LOCATION OF THERMOCOUPLES

RESULTS

The levels of CO, and CO_2 in the engine nacelle before, during, and after a burn-through are shown in figures 7 and 8. The concentration of CO in the nacelle continually fluctuated and in some cases a rise in CO level was less than the normal fluctuation of CO level in the nacelle. Therefore, this method was very unreliable.

The burn-throughs were detected by monitoring the CO_2 level in the nacelle. A sharp increase occurred at the time of burn-through and rose to its highest level of less than 1 percent. The level dropped after fire penetrated the cowling, until 15 seconds after the burn-through occurred, at which time the CO_2 level was back to normal. Due to the low concentration level and the short duration after cowling penetration, the monitoring of CO_2 was not determined feasible as a burn-through detection method.

A typical nacelle pressure profile, before, during, and after a burn-through is shown in figure 9. Just as in the case of CO_2 a sharp increase is noted when the burn-through occurs, and a return to normal after cowling penetration. The magnitude and duration of the pressure rise is not considered large enough for reliable detection of a burn-through.

The monitoring of the nacelle air temperature showed the same pattern as that of the CO_2 and pressure tests, that is, the sharp rise as the burn-through occurs and a return to normal after cowling penetration. Figure 10 shows the temperatures monitored 1 inch from the burn-through hole (thermocouple No. 1) and figure 11 shows the temperature monitored 14 inches from the hole (thermocouple No. 5). Figure 12 represents the temperatures before, during, and after a burn-through versus distance from the burn-through hole.

Although the magnitude of temperature rise of the nacelle airstream was considered to be sufficient for detection of a burn-through, the duration of that elevated temperature (using standard cowling materials (or better) of 0.050-inch aluminum, 0.015-inch stainless steel, and 0.032-inch titanium) was considered far too short for reliable detection. Continued detection after cowling penetration (as with CO, CO_2, and pressure monitoring) was not considered feasible due to the negligible difference from normal nacelle conditions.

In all of the prior tests the penetration of the cowling occurred in a very short time after the burn-through occurred (within approximately 2 seconds). The results of a test using a 1/4-inch burn-through barrier for the flame to impinge upon can be seen in the sequence photographs shown in figures 13 through 19. Burn-through time for this 1/4-inch barrier was 15 seconds. No temperature recordings were obtained due to the intense heat generated which melted the thermocouple wire and terminal strip as well as much of the engine wiring. This containment of heat from the burn-through caused extensive destruction to the engine case and to the cowling as well as igniting fuel in the area of the dump valve causing a fire in the accessory section of the nacelle. A comparison of damage from this test and prior tests using materials comparable to present cowls shows the adverse effect of containing a burn-through flame. Figure 20 shows the results of a test where the engine was run for 1 minute after burn-through using 0.050-inch aluminum as cowling material. The only damage was the burn-through hole itself, and a 3-X 4-inch hole in the aluminum cowling.

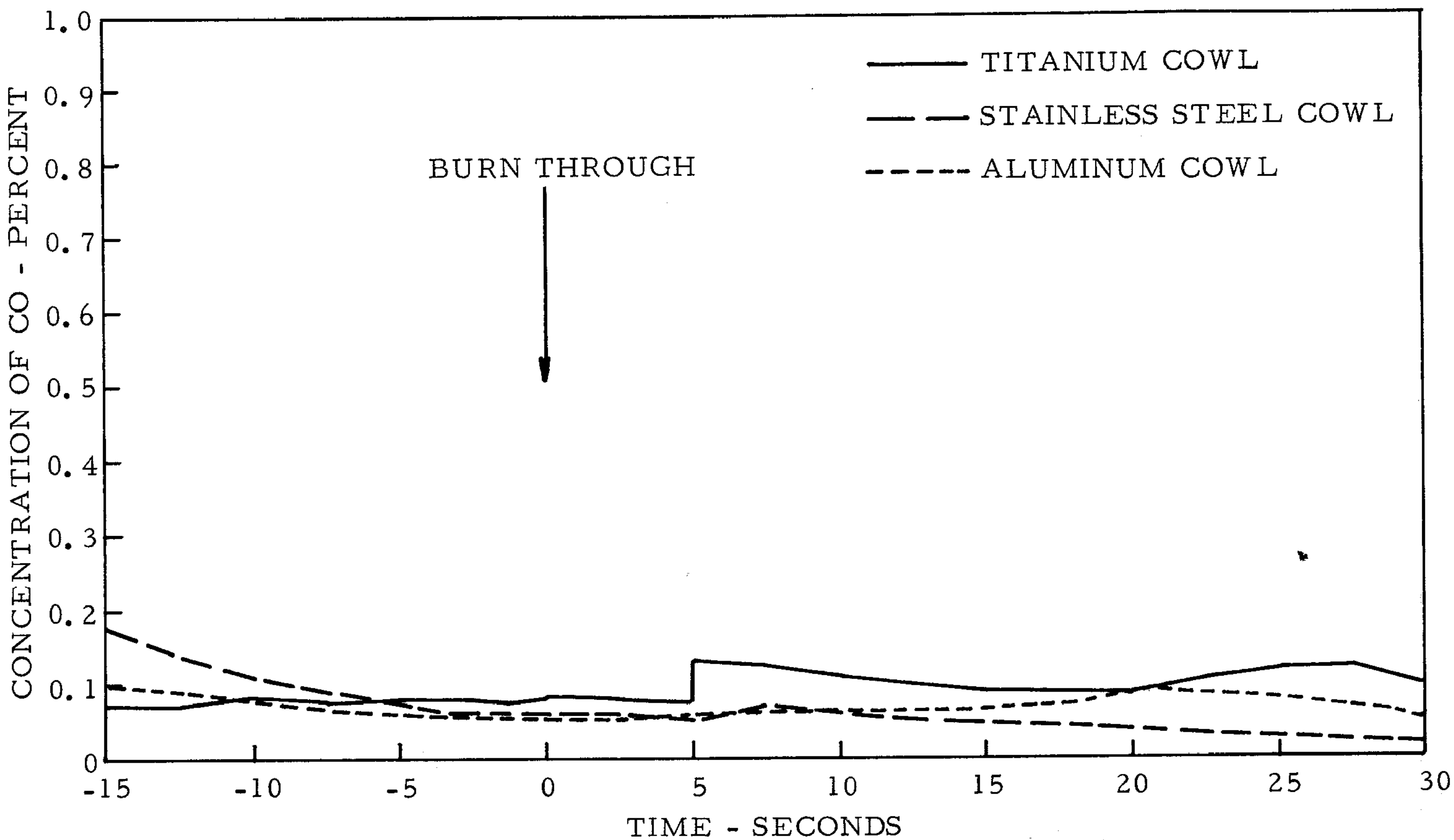

FIGURE 7. CONCENTRATIONS OF CARBON MONOXIDE IN NACELLE DURING BURN-THROUGH TEST USING THREE TYPES OF ENGINE COWLING

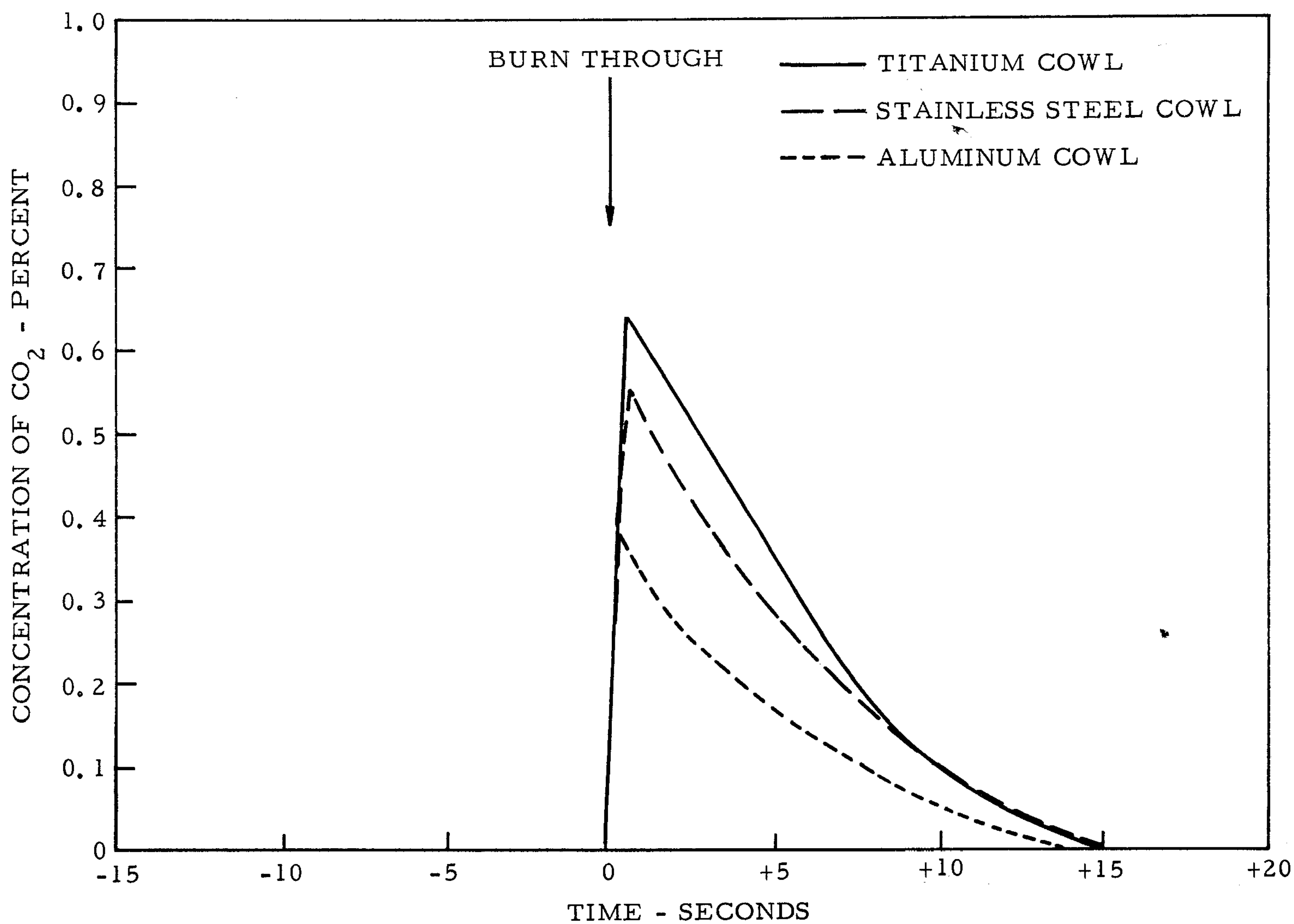

FIGURE 8. CONCENTRATIONS OF CARBON DIOXIDE IN NACELLE DURING BURN-THROUGH TEST USING THREE TYPES OF ENGINE COWLING

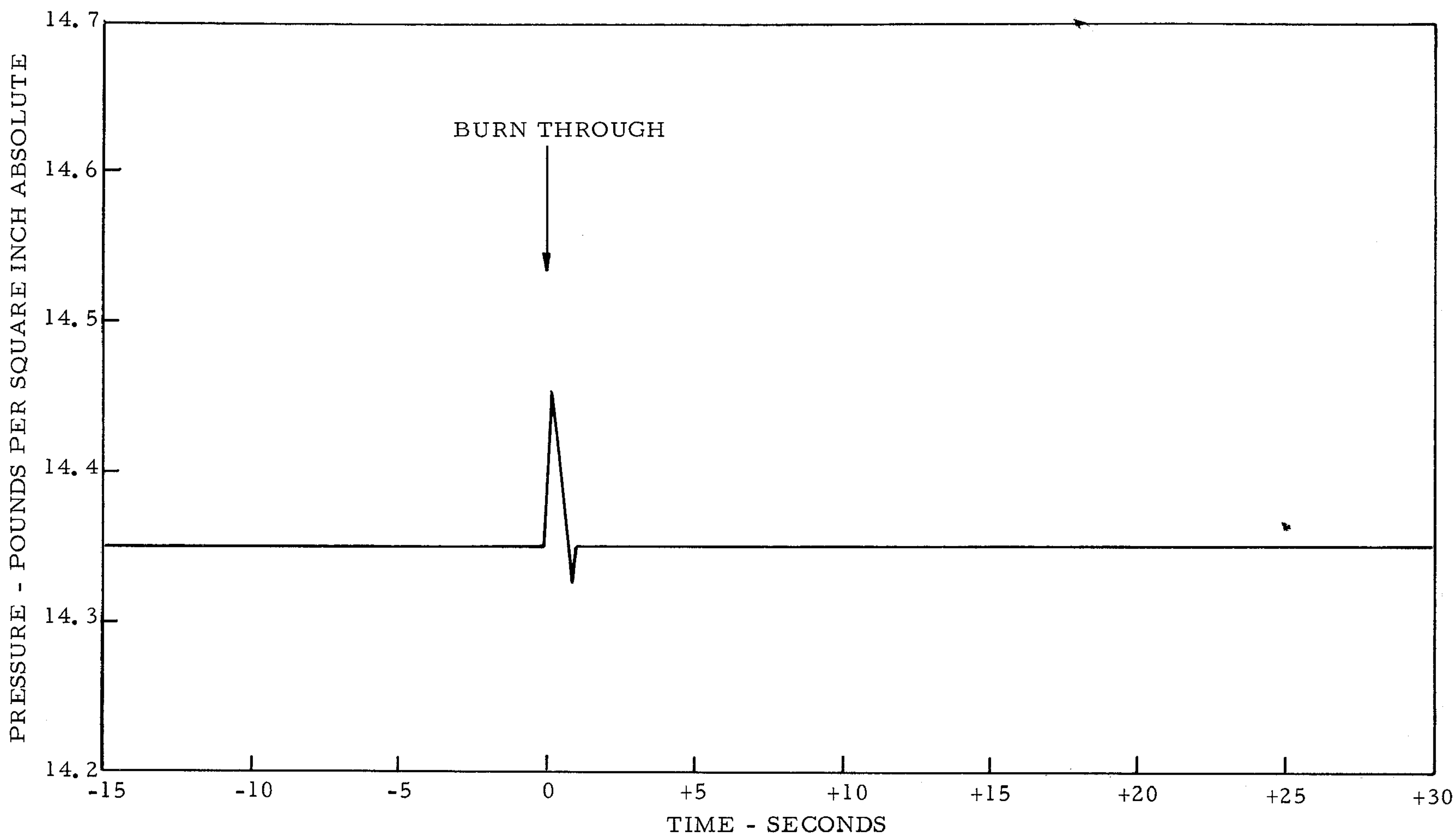

FIGURE 9. PRESSURE LEVEL IN NACELLE DURING TYPICAL BURN-THROUGH TEST

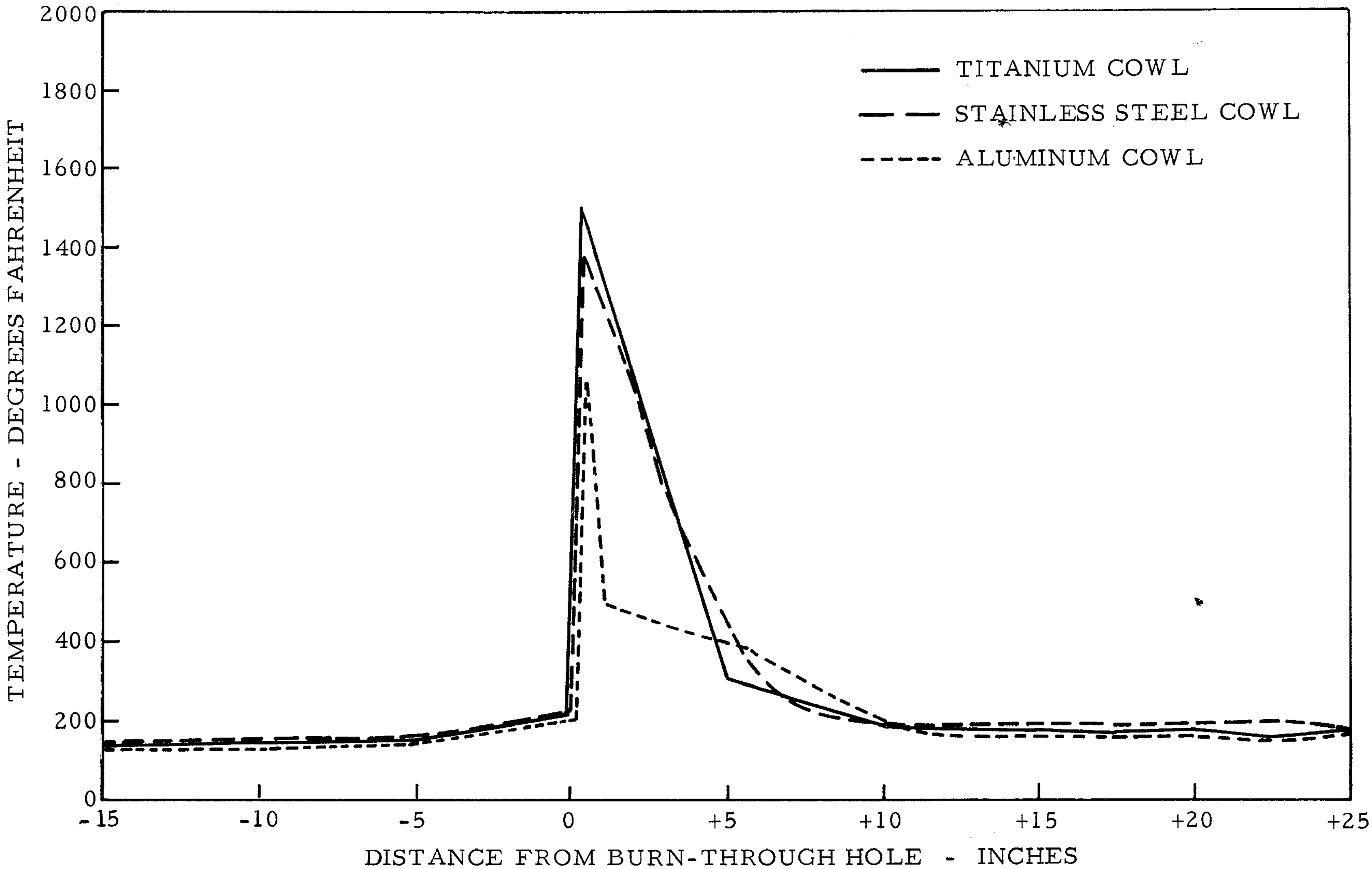

FIGURE 10. AIR TEMPERATURE IN NACELLE 1 INCH FROM BURN-THROUGH HOLE DURING TEST

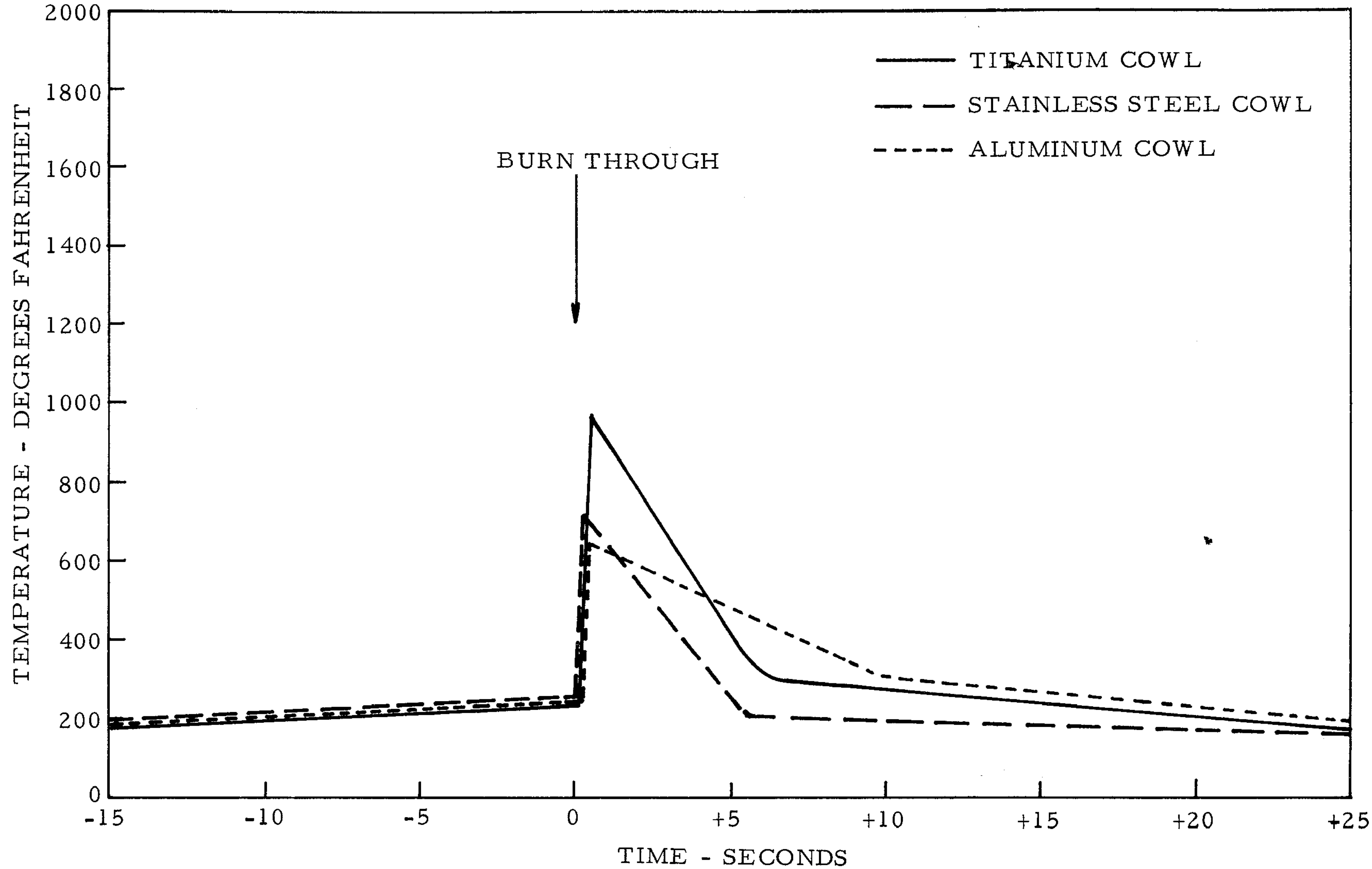

FIGURE 11. AIR TEMPERATURE IN NACELLE 14 INCHES FROM BURN-THROUGH HOLE DURING TEST

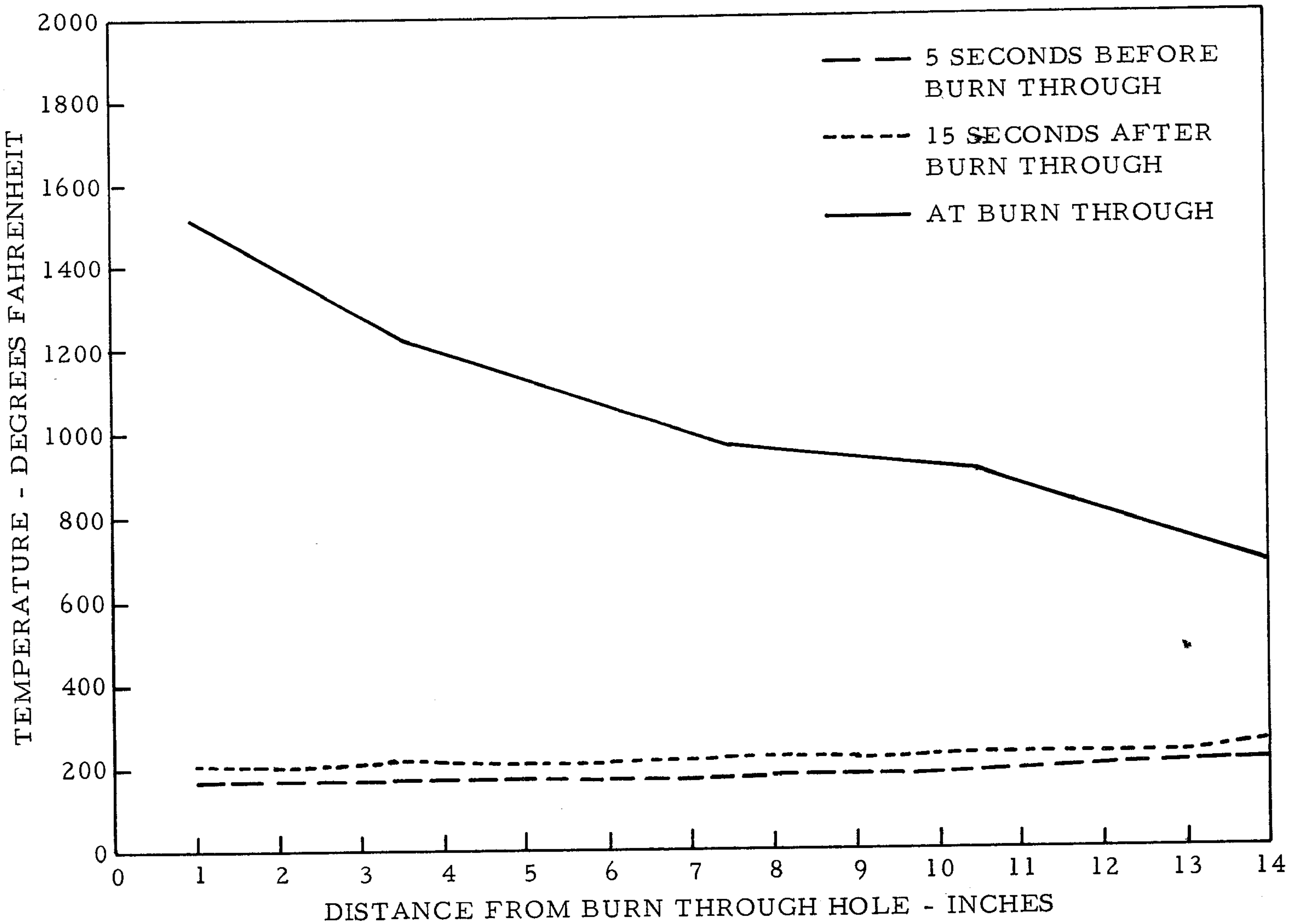

FIGURE 12. AIR TEMPERATURE VERSUS DISTANCE FROM BURN-THROUGH HOLE DURING TYPICAL TEST

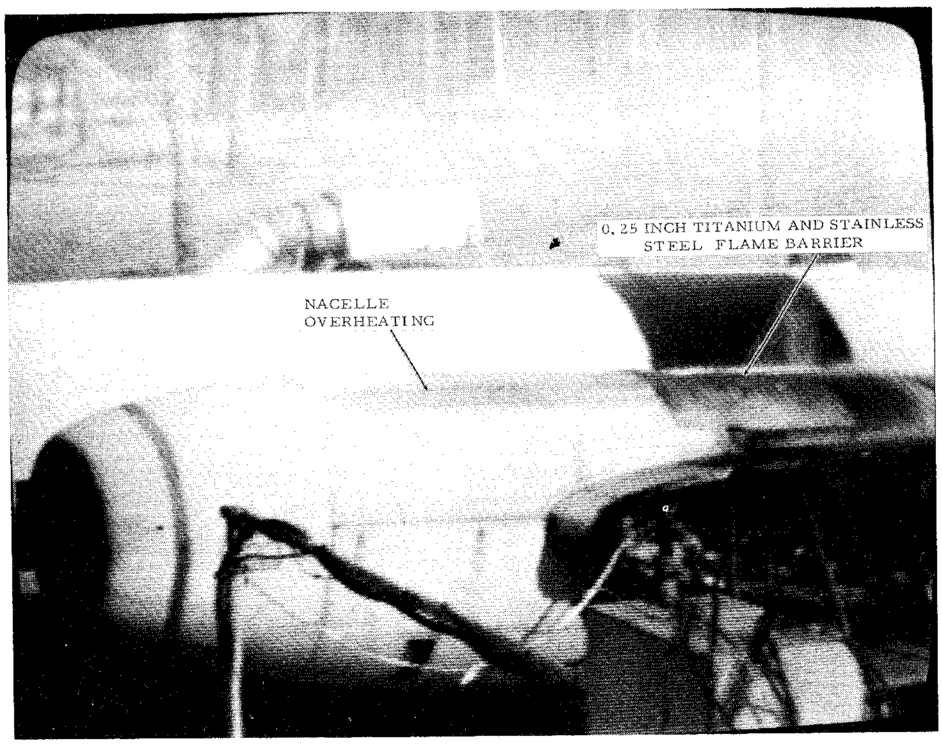

FIGURE 13. NACELLE FLAME BARRIER BURN-THROUGH TEST 12 SECONDS AFTER ENGINE BURN-THROUGH

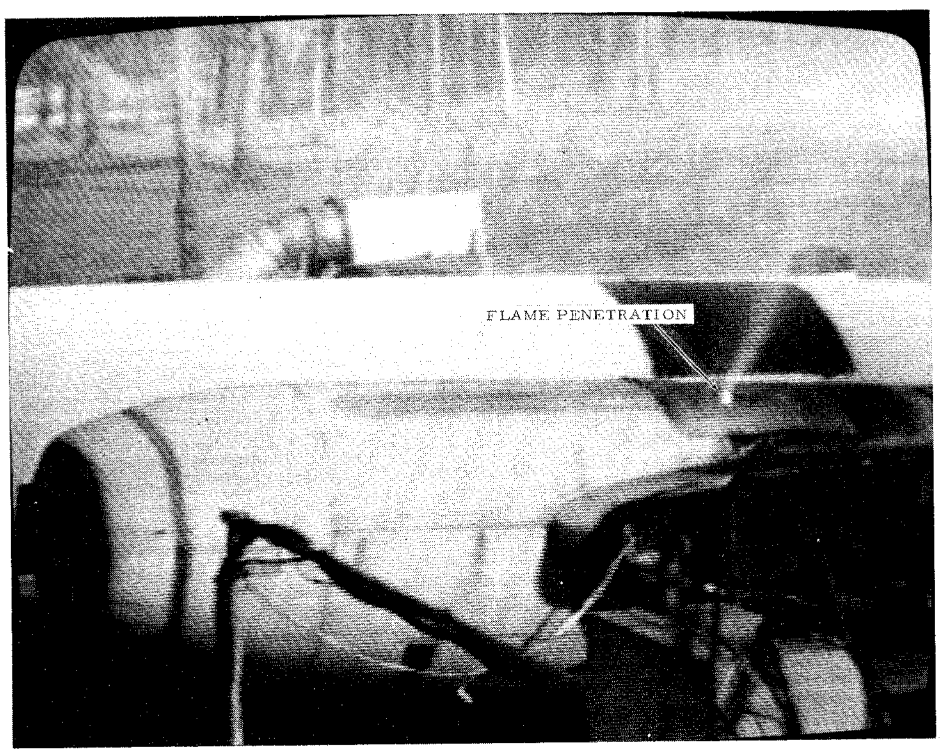

FIGURE 14. NACELLE FLAME BARRIER BURN-THROUGH TEST 15 SECONDS AFTER ENGINE BURN-THROUGH

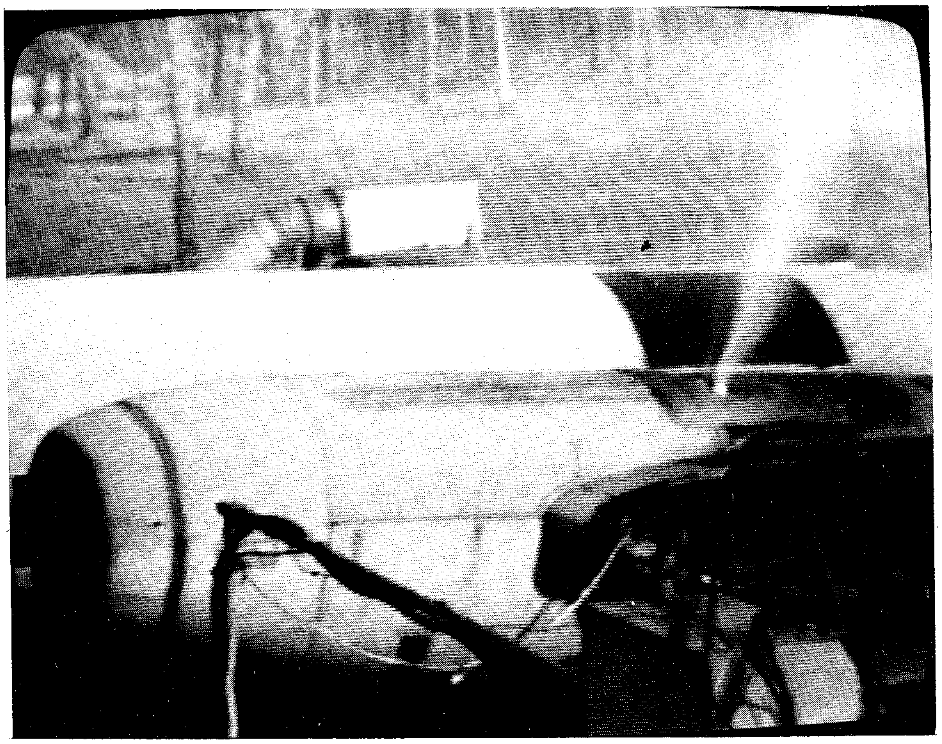

FIGURE 15. NACELLE FLAME BARRIER BURN-THROUGH TEST 16 SECONDS AFTER ENGINE BURN-THROUGH

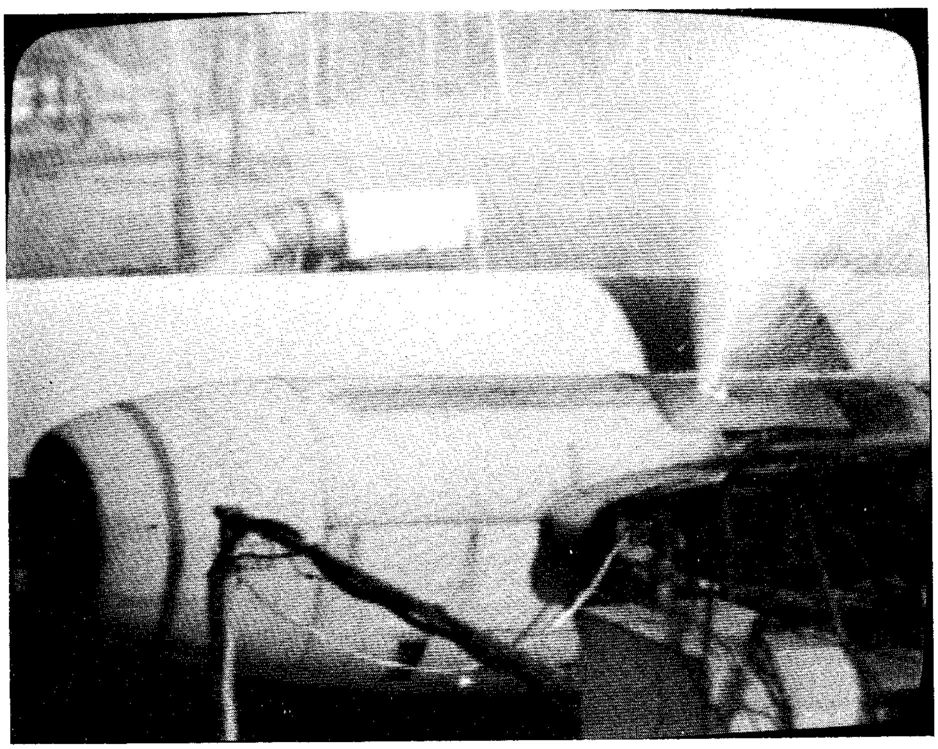

FIGURE 16. NACELLE FLAME BARRIER BURN-THROUGH TEST 17 SECONDS AFTER ENGINE BURN-THROUGH

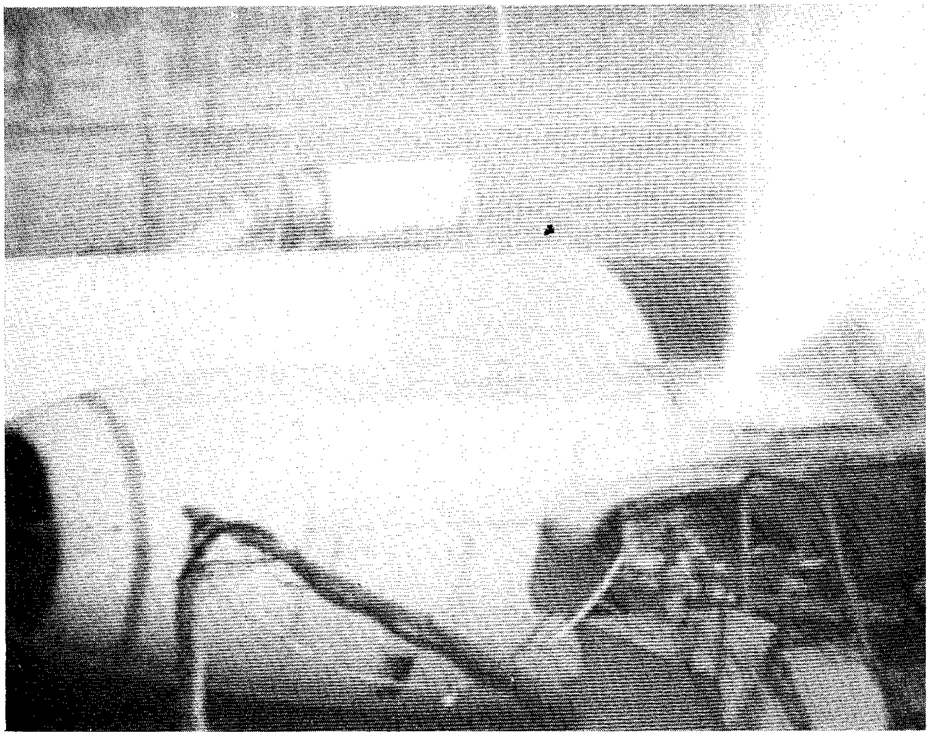

FIGURE 17. NACELLE FLAME BARRIER BURN-THROUGH TEST 18 SECONDS AFTER ENGINE BURN-THROUGH

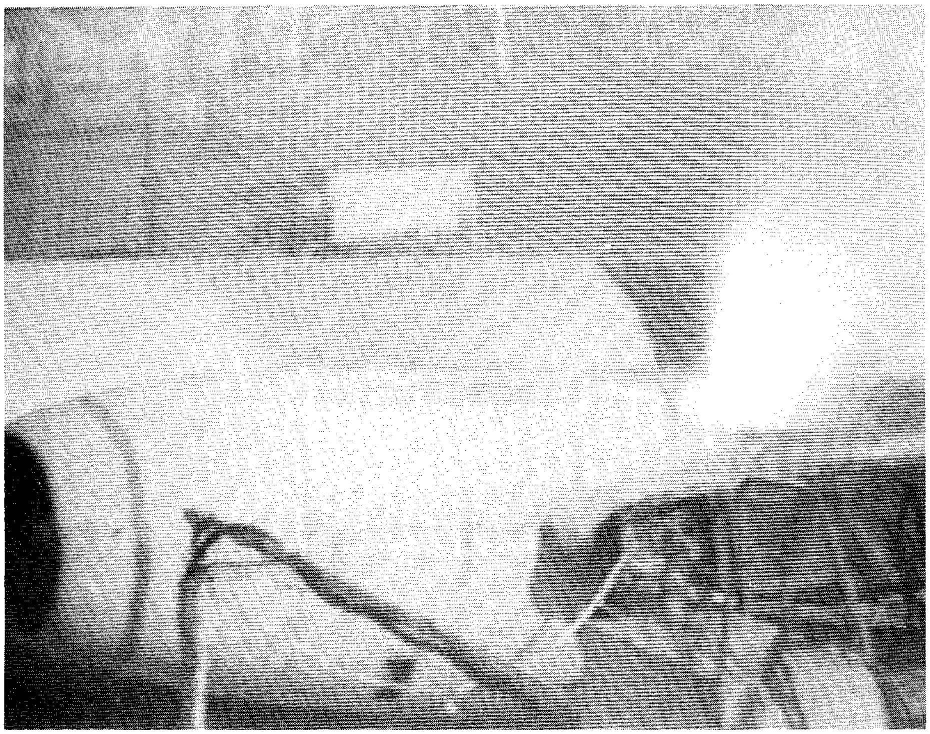

FIGURE 18. NACELLE FLAME BARRIER BURN-THROUGH TEST 19 SECONDS AFTER ENGINE BURN-THROUGH

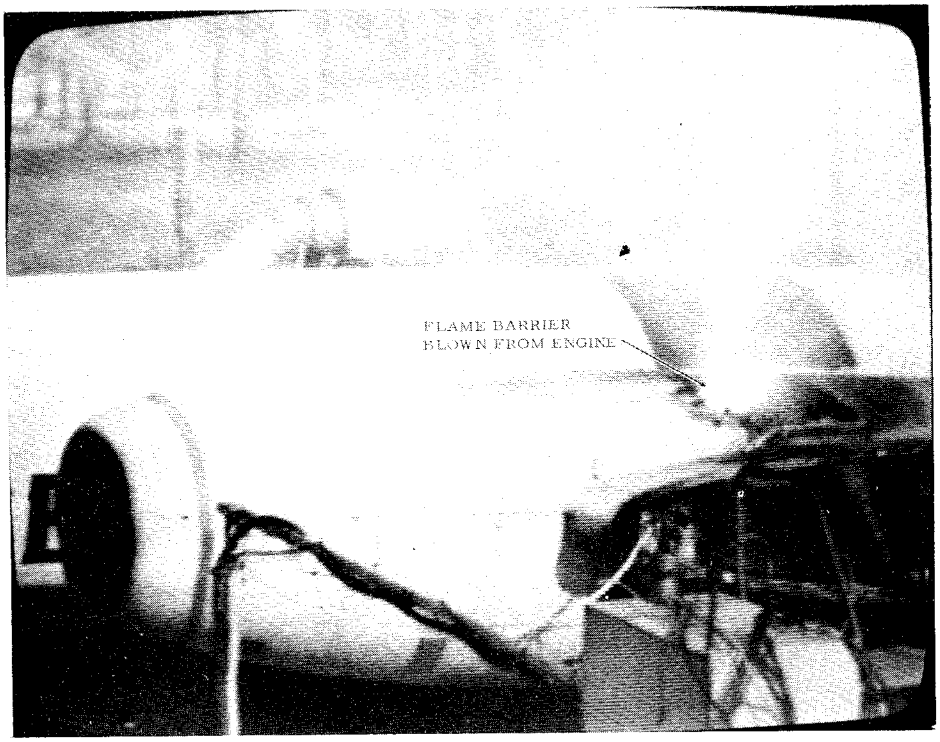

FIGURE 19. NACELLE FLAME BARRIER BURN-THROUGH TEST 20 SECONDS AFTER ENGINE BURN-THROUGH

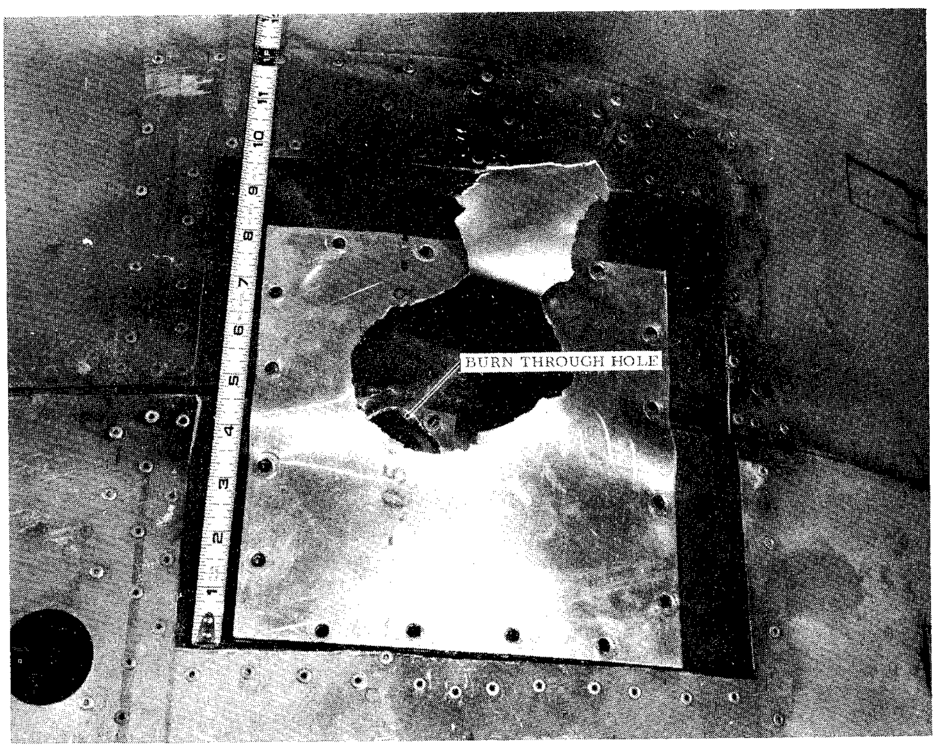

FIGURE 20. DAMAGE AFTER BURN-THROUGH TEST USING ALUMINUM COWLING

CONCLUSIONS

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

1. It is not feasible to detect a burn-through by monitoring either the CO or CO_2 levels in the engine nacelle.

2. Detection of a burn-through by monitoring the nacelle pressure is not feasible.

3. Detection of a burn-through by nacelle air temperature measurement is reliable only when the burn-through flame is contained in the nacelle and enough heat diffused.

4. Containment of a burn-through flame in the nacelle creates extremely high temperatures in the nacelle and can cause extensive structural damage.